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PREFACE

After the four successful International Symposiums on Agricultural Engineering – ISAE, that were held in Belgrade at the Faculty of Agriculture, thanks to our colleagues we are organizing The Fifth International Symposium on Agricultural Engineering – ISAE 2021. Together with the University of Basilicata, School for Agricultural, Forestry, Food and Environmental, Sciences (Potenza, Italy), University of Sarajevo, Faculty of Agricultural and Food Sciences (Sarajevo, Bosnia and Herzegovina), Aristotle University of Thessaloniki Faculty of Agriculture, Thessaloniki (Greece), University of Belgrade, Faculty of Mechanical Engineering, Department of Agricultural Engineering, Belgrade (Serbia), Vinča Institute for Nuclear Science, Belgrade, Serbia, and thanks to the Ministry of Education, Science and Technological Development, Republic of Serbia, support of the AMAPSEEC, RebResNet and BENA, and sponsor and donors, we have managed to organize the presentations of the 29 papers that were submitted to the Scientific Committee of the ISAE 2021 Symposium. We have arranged them in to four sections and categorized them as Original scientific papers, Scientific review papers, Firs (short) communications, Case studies, Professional (Expert paper) and Popular papers. All papers within the Proceedings of the ISAE 2021 were reviewed by the members of the Scientific Committee and kind assistance of some members of other Conference bodies.

The Proceedings of the ISAE 2021 International Symposium is organized in four thematic sections. Section I – Sustainable agriculture and biosystems engineering; Section II – Soil tillage and agroecosystems protection; Section III – Energy and energy efficiency in agriculture and Section IV – Economics in agricultural engineering.

We wish to thank to all the authors for their contribution to the ISAE 2021 Symposium and to the all the Institutions, Associations, Universities, Sponsors and Donors for the contribution in ISAE 2021 Symposium organization.

ISAE-2021 Proceedings

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Section I: Sustainable Agriculture and Biosystems Engineering

Section II: Soil tillage and agroecosystem protection

Section III: Energy and energy efficiency in agriculture

Section IV: Economics in Agricultural Engineering

TMA EXPLOITATION INDICATORS FOR MECHANIZED DRILLING OF PITS FOR PLANTING FRUIT

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Abstract: *Performing works with the land where a lot of mechanical work is engaged, such as making pits for planting fruit, needs to be mechanized. This replaces human labour with a tractor-machine aggregate with an increase in productivity and thus makes the process cheaper. For the proper selection of individual means of mechanization, it is important to determine the optimal agrotechnical parameters of their application. Proper selection and use of mechanization tools for planting have a decisive influence on the intensity and progress in cultivation technology. Defining energy and exploitation parameters of tractor-machine aggregates during mechanized construction of pits is the subject of this research. The pits are intended for individual planting of fruit seedlings as well as the installation of trellis poles. The test results of the tractor-machine aggregate show that the lowest driving force engaged for drilling was achieved in the field and was 6.36 kW for the excavated pit with the depth of 885 mm and with a diameter of 520 mm, the number of revolutions of the drill was 93 rpm and drilling was achieved in 27 s. The highest driving force for drilling was engaged in field III, which was 30.8 kW for the excavated pit 780 mm deep with a diameter of 490 mm, the number of revolutions of the drill bit was 111 rpm and drilling was realized in 30 s. The results obtained in these tests show that the consumption of motor power largely depends on the type of soil, the quality of previous soil preparations and the number of revolutions of the tractor PTO shaft. The time required to move the aggregate from one to the next drilling site is crucially influenced by the terrain configuration, the state of soil preparation and the skill of the tractor driver and auxiliary worker.*

Keywords: *tractor-machine aggregate, hole drill, spiral drill, aggregate productivity, exploitation parameters*

1. INTRODUCTION

Establishing good-quality perennial crop plants also implies rational engagement of human labor and machinery means. Soil preparation and the very process of raising plants is a complex and elaborated work that requires a great deal of mechanical work. When raising perennial crop plants, digging holes, as a basic operation, includes the greatest part of the human and machinery work. Mechanization of this process is most often achieved with a tractor unit, consisting of a tractor equipped with a connecting machine whose element is in the form of one or more helical drills. For machines with one helical drill that is aggregated with light tractors of up to 24 kW, the unit can be operated by only one worker [16]. Labor costs for this operation depend on the quality of soil preparation during pre-tillage. Great mechanical and human work is engaged to perform these works [5]. In areas of arid climate where irrigation is not present, the plantings or the planting should be performed in autumn in order to achieve the best possible effect of receiving planting material. For these fruit growing conditions, it is necessary to perform quality basic and additional tillage [15] in order to sufficiently accumulate and rationally consume soil moisture.

The process of excavating holes for planting represents the cultivation of the soil at greater depths, due to which over two thirds of the total energy consumed during planting is spent on drilling holes [16]. Pre-tillage has the greatest influence on the use of machine work as well as on the total engagement of energy when drilling holes [14]. In addition, it has a great influence on the use of machinery [13] in the formation and exploitation of land and infrastructure.Modernization of the fruit growing technology is primarily related to the implementation of new techniques and machinery in the production process, regardless of the fruit species [11].

The use of appropriate technical means in raising crop plants enables cost reduction and ecological preservation of land [2]. The development of agricultural techniques, and especially information and communication technologies, have significantly improved agricultural machinery [9]. The transition from conventional to new technological procedures in primary production should be achieved gradually [6], using scientific and professional knowledge. By choosing technological procedures and adequate machinery, it is possible to achieve greater economic and energy efficiency [8], while preserving the environment and land.

The obtained results in specific production conditions [9], indicate the possibility of energy savings and increase the productivity of aggregates in works with the soil.

The transition from conventional tillage to reduced tillage [7] imposes the need for better quality in deeper planting in order to achieve the best possible rooting and development of plants. And especially with the introduction of zero tillage, in order to reduce soil degradation in productive soils [3] and [4], it imposes the need to achieve quality shaking of the soil in the zone of the root system by making holes. Some experience in practice shows [1] that when drilling holes, the speed of the drill should be 60-70rpm, where one hole takes 30-40 seconds, which is 90-120 holes per hour, which multiplies productivity. The development of technology [10], and especially information and communication technologies, have significantly improved agricultural mechanization.

2. MATERIAL AND METHODS

Testing of the tractor drill, product of the company "Lemind Proleter" Leskovac, was performed according to the methodology of the Institute for Mechanization of the Faculty of Agriculture - Zemun, using laboratory-field and operational tests, whereby the functionality, properties and quality of this machine were determined throughout the all test phases. Field tests were performed on the test field "Radmilovac" of the Faculty of Agriculture on undulating terrain, at an altitude of about 71m. The geographical position of the crop plants was determined by the moderate continental climate, and the dominant type of soil was the brown soil [13] with certain varieties and the occasional appearance of degraded chernozem. Soil moisture was very low, as the test was performed during the dry season. The drill was tested in a unit with an IMR 65 tractor.

Technical characteristics of the drill

Mode of aggregation with the tractor...................................... in three points

Maximum drilling depth.. 1100mm

Working tools.. spiral drill

Maximum drill diameter.. 800mm

Worm gearbox with gear ratio... i = 1 : 6,3

Mass... 132kg

Basic technical characteristics of the Rakvica 65 tractor important for the operation of the drill:

Nominal power (at 2300 min^{-1} of the motor)........................ 47kW

Minimum specific fuel consumption.................................... 234g/kWh

Maximum engine torque (at 1350 min^{-1})............................... 217,5 Nm

Mass without ballast... 2600kg

Length with weights on the front axle.................................. 3420mm

Width.. 1900mm

Height up to top of the muffler... 2300mm

Distance between front and rear axles.................................. 2050mm

Torque on PTO shaft... Nm

During the operational tests under certain working conditions, indicators were taken such as: chronography of working hours, time required for drilling one hole, time for transition of the unit from one to another drilling position at intervals of 6x6m, depth, diameter, hole filling, fuel consumption, performance or number of holes drilled in 1 hour of gross, net and actual working time. The determination of the engaged tractor engine speed was performed according to the formula:

$$N = \frac{M_O \cdot n_p}{1323{,}8} \ [kW]$$

where: M_o - torque measured on the PTO shaft; n_p- PTO's number of revolutions.

In addition to all this, during the testing, observations were made about the suitability of the drill for handling, adaptation to various field conditions, the strength of the structure itself, safety at work, etc.

In the laboratory-field tests, in addition to other parameters, the motor power consumption of the tractor for drilling holes on 4 differently treated terrains and at different number of revolutions of the tractor PTO shaft was determined.

Fig. 1 test preparation unit

Fig. 2 Position "Torque and speed sensor" DMN 10 in the unit

Fig. 3 Unit of measure with display

Fig. 3 The drilling process

Table 1. Type of terrain depending on the method of cultivation

Terrain code	Pre-tillage	Soil moisture up to [%]	Terrain configuration
a. In laboratory-field tests			
I	Plowing to a depth of 28 cm. Additional tillage performed well	7,1	Not expressed
II	Not performed (wasteland)	8,2	-
III	Plowing to a depth of 28 cm. Additional tillage not performed	9,1	Micro relief expressed as a consequence of poor tillage
IV	Not performed (wasteland)	8,3	-
b. In exploitation tests			
I	Deep plowing at depths up to 600cm. Additional tillage performed	12,3	Not expressed
II	Deep plowing at depths up to 60 cm. Additional tillage is not performed well	10,5	Micro relief expressed as a consequence of poor tillage
III	Plowing to a depth of 30 cm. Incomplete additional tillage	11,8	Micro relief uneven
IV	Plowing twice at 20 and 30cm depth. Additional tillage performed well	12,5	Microrelief partially expressed
V	Not done (plot with uncut stumps)	13,8	-

To measure the resistance and number of revolutions of the drill, the "Torque and RPM sensor" DMN 10 was used, which was mounted directly on the tractor shaft and on which a cardan shaft was mounted to drive the drill. The value of the torque expressed in Nm and the number of revolutions in rpm are read directly on the display of the unit. Registration of the tractor PTO speed of the readings on the "tracometer" of the control panel. Duration time in the experiments was measured using a stopwatch.

3. RESULTS AND DISCUSSION

3.1. Technological process of drill operation

The practical procedure of the work with the drill is as follows:

- positioning the tractor in such a position that the tip of the drill comes exactly above the marked place for drilling,

- moving the drill backwards by 3 to 5^{o} from the vertical position, which best ensures vertical drilling of holes,

- activating the coupling of the tractor’s PTO shaft and putting the drill into operation,

- easy movement of the hydraulic lift lever of the tractor and lowering the drill to the working position.

By lowering the drill put into operation, it begins to penetrate the soil, during which the cutter blades cut off the layers of soil and the spiral accepts them and throws them to the surface of the soil around the hole.

There are two ways to drill holes: single-phase and multi-phase. In the multi-phase mode, when the drill reaches half the depth of the hole, by acting on the handle of the hydraulic lift lever of the tractor, the drill rises and throws around the hole all the soil that was caught by the spiral. After that, by lowering the hydraulic lift lever, the drill is lowered into the hole again. In the field conditions of compact soils, this way of working is recommended, but it requires a more experienced and trained tractor driver. In the single-phase mode, which is recommended for lighter terrains and lands, the work is done in one go. As soon as the drill reaches a certain depth, by acting on the handle of the hydraulic lift lever of the tractor, it rises and spirals out the rest

3.2. Results of the laboratory-field tests

- *3.2.1. Motor power input for drill operation*

The results obtained in these tests are shown in Table 2. The required motor power largely depends on the type of soil, the quality of pre-tillage and the number of revolutions of the tractor’s PTO shaft.

Tests in the field have shown that the engine power consumption of the tractor ranges from 5,08 to 8,94kW. In this field, the tractor engine was running at 1000, 1500 and 1800rpm. In experiments on the fields II, III, and IV, the measurement of engine power consumption was performed at 1890rpm of the PTO shaft.

The results presented in Table 1, show that the power consumption of tractors on field II ranges from 21,12 to 22,58 kW, on field III from 23.65 to 25,59kW, on field IV from 21,98 to 23,05 kW, where also an overload of the tractor engine occurred. Based on that, it can be stated that a tractor with an engine power over 30kW is needed to work on drilling the holes in insufficiently cultivated or uncultivated terrain. For medium and easily arable and well-prepared soils, the IMT-533 tractor or the Fe-35 tractor, which belong to the category of light tractors, can be used reliably.

In this way, the quality of drill operation in these conditions is the best. When the drilling of one hole is final, the coupling of the tractor drive shaft is disconnected and it is moved to the next drilling site.

Table 2. Test results of tractor aggregate In laboratory-field tests

No.	Drilling time per hole [s]	Hole depth [cm]	Hole diameter [cm]	Number of revolutions on the tractor's PTO shaft [o/min]	Drill speed [o/min]	PTO torque [Nm]	Power required to drive the drill. [kW]
Ground I							
1	22	85,6	51,0	716	113	16,53	8,94
2	24	76,9	51,2	716	113	13,77	7,45
3	24	81,9	50,0	540	86	16,20	6,61
4	19	76,5	52,0	540	86	16,00	6,53
5	28	90,1	51,7	360	57	20,63	5,61
6	27	88,4	52,0	360	57	18,68	5,08
Ground II							
1	47	85,6	48,5	716	113	40,52	21,92
2	44	78,8	49,5	716	113	39,05	21,12
3	59	77,5	49,6	590	93	50,66	22,58
Ground III							
1	30	78,0	49,0	700	111	48,39	25,59
2	29	75,0	49,8	719	114	43,54	23,65
Ground IV							
1	33	80,0	48,8	625	115	46,55	21,98
2	57	82,0	50,0	565	89	53,37	22,78
3	63	90,0	50,0	575	91	53,07	23,05

- *3.2.2. Quality of drilled holes*

Analyzing the basic criteria, a tractor drill gives a satisfactory quality of drilled holes. They are vertically well oriented in the soil, are usually circular in shape and relatively clean, which in this case corresponds to agro-technical requirements. In Table 1, the basic parameters are given, which show that the depths of the holes are in the range from 75 to 92cm, the diameters from 48.5 to 52.0cm, soil scattering is relatively small and ranges from 6.6 to 36.2%. There was a higher degree of soil scattering somewhere, primarily due to the unsuitable number of revolutions of the drill, then due to poor pre-tillage, insufficient cleaning of the veins, the degree of humidity, terrain configuration, training of the tractor driver, etc.

The number of revolutions of the drill is crucial when drilling holes. On filed I at 113rpm the soil scattering is only 8.8%, and at 86rpm the soil scattering suddenly increases and climbs to 22.0%, while at 57rpm the soil scattering increases even more and amounts to 36.2%. This is explained by the fact that at a higher number of revolutions, due to the action of centrifugal force, its spiral completely throws the soil from the hole and better scatters it around at the surface, as well as by the fact that the drill drills the holes more compactly. Poor pre-tillage of the land and insufficient clearing of veins, caused in some fields the soil scattering problem which ranged from 14 to 36%. On well-prepared and cleared soils, and at higher humidity (from 17 to 20%), soil scattering is the lowest in percentage.

Table 3. Quality and chronography of aggregate operation during machine drilling of pits

Quality of excavated holes			Unit performance during operation with 6x6m hole arrangement					
Soil scattering		Raised land above the hole cm	hour of gross work		hour of actual work		hour of actual work	
Depth cm	From the depth of %		Pieces	ha	Pieces	ha	Pieces	ha
16,4	13,7	15,8	69,9	0,25	90,0	0,32	156,0	0,56
37,2	32,7	21,7	35,7	0,13	60,0	0,21	100,0	0,35
21,5	19,7	19,9	55,4	0,20	74,5	0,26	130,0	0,46
12,9	12,9	23,9	43,6	0,15	56,7	0,20	82,1	0,29
16,0	19,7	24,0	40,8	0,14	49,8	0,18	75,8	0,27
11,0	11,1	22,6	56,5	0,20	80,2	0,28	135,1	0,48

3.3. Operational tests

These tests were performed under the conditions set out in Table 1. The drill in the unit with the IMR-65 tractor worked for 5 days, of which 2 days with a drill 130cm long and 3 days with a drill 110cm long. During these tests, in addition to the tractor driver, an auxiliary worker also joined the test, and his task was, in cases of drill congestion, to eliminate the delay as soon as possible.

At the time of these tests, the tractor engine was running at 1500 to 1900rpm, at which mode the best quality of holes was obtained. The results achieved in these operational tests are presented in Table 3.

- *3.3.1. The effect of the unit at work*

Determining the performance and thus the productivity of units on individual terrains was obtained on the basis of performed chronographies that had the time structures shown through the examples in Tables 4 and 5. From the results shown in Table 3, it can be seen that the average time required to drill a hole in different terrains is from 23.0 to 47.9s. The least time spent on this was in field I, and the biggest in field IV. The lowest amount of time was achieved on the deep plowed soil at a depth of up to 60 cm, and the highest on the ground that was plowed at a depth of 30 cm. After this depth of 30cm, the drill found a very hard layer of earth, which is why the time spent on drilling holes was higher. The highest work performance was achieved in field I, and the lowest in fields II and IV. The work performance ranged on average from 35.7 to 69.6 holes for 1 hour of gross working time, 49.8 to 90.0 of net and 75,8 to 115.0 for 1 hour of actual work.

On field III, due to soil scattering, they resorted to removing the "plug", i.e., raising the drill at the moment when it reaches the desired depth with its tip, during which the stuck mass of soil is taken out together with the drill bit, so that it remains clean and with compact walls.

The time required to move the unit from one to the next drilling site is also a significant factor in achieving the effect of the machine drilling of holes. This time ranges from 16.6 to 24.7s with a spacing of 6x6m of planting. This was influenced by: the configuration of the terrain, the state of soil after the pre-tillage and the competence of the tractor driver and auxiliary worker.

According to all the above, the machine drilling of holes for seedlings is economically completely justified and should therefore be applied in practice wherever there are conditions for it.

Table 4. Time structure when drilling holes with a tractor drill in the field

Elements of working time	Utilization of working time			
	In total *[min]*	Share *[%]*	Average machine work per hole *[min]*	Average human labor per hole *[min]*
1. Production	**389**	**81,0**	**0,81**	**1,62**
1.1. Productive drilling	143	29,8	0,35	0,70
1.2. Non-productive				
a) Moving the unit	227	47,3	0,42	0,84
b) Turning the unit in furrows	19	3,9	0,04	0,08
2. Non-productive	**65**	**13,5**	**0,13**	**0,26**
2.1. Preparations	35	7,3	0,07	0,14
2.2. Rest	30	6,2	0,06	0,12
Losses	**26**	**5,4**	**0,05**	**0,10**
3.1. Delay for improper installation of the drill	14	2,5	0,02	0,04
3. 2. Defect on the unit	12	2,9	0,03	0,03
In total	**480**	**100**	**0,99**	**1,98**

- *3.3.2. Tractor fuel consumption in the unit*

The basic parameters that affect fuel consumption are the condition of the terrain, which is defined by the type of soil on which the specific resistances depend and their impact on the value of torque that should be overcome by the drill during operation. The value of resistance is crucial for the intensity of mechanical tillage of the soil, the presence of stumps, veins and other foreign bodies in the soil. Fuel consumption per unit time also depends on the performance of the unit, i.e. the active time during which drilling is performed, which is influenced by the speed of revolutions of the PTO shaft, which is reflected through defined engagement of drilling power. When defining fuel consumption per excavated hole, the direct effect has the performance that depends, in addition to the mentioned conditions, on the terrain relief, the speed of moving the unit, the training of the operator, the reliability of the unit, etc. In the performed experiments, the fuel consumption also changed in accordance with the mentioned parameters, because it was the lowest in field I and amounted to 8.76kg/ha and the highest was in field IV, where the consumption went up to 17.26kg/ha. The almost double fuel consumption per unit of working time, when drilling holes in field IV, is explained by the fact that the land is a wasteland or uncultivated.

Table 5. Time structure when drilling holes with a tractor drill in the field II

Elements of working time	Utilization of working time			
	In total *[min]*	Share *[%]*	Average machine work per hole *[min]*	Average human labor per hole *[min]*
1. Production	**389**	**81,1**	**1,6**	**2,82**
1.1. Productive drilling	168	35,0	0,94	1,70
1.2. Non-productive				
a) Moving the unit	203	42,2	0,52	0,94
b) Turning the unit in furrows	19	3,9	0,14	0,18
2. Non-productive	**65**	**13,4**	**0,13**	**0,26**
2.1. Preparations	35	7,3	0,07	0,14
2.2. Rest	30	6,2	0,06	0,12
Losses	**26**	**5,5**	**0,07**	**0,10**
3.1. Delay for improper installation of the drill	14	2,9	0,04	0,06
3. 2. Defect on the unit	12	2,6	0,03	0,04
In total	**480**	**100**	**1,8**	**3,18**

4. CONCLUSIONS

Using the established facts based on the performed tests, the following conclusions can be made:

- The manual work in the process of making holes for planting perennial crop plants as well as setting the trellis pillars should be completely replaced by machinery work:
- The quality achieved by mechanized drilling of holes satisfies agro-technical requirements and is therefore better in relation to manual work, especially when it comes to holes of greater depth.
- The productivity of mechanized drilling is 15 to 20 times higher than manual excavation.

- From an economic point of view, this way of drilling holes is multi-faceted, because in addition to better quality, it brings savings of 11.5 to 41.8 per hole.
- Handling and working with this drill is much simpler and does not require greater technical knowledge, but only a little more training and competence of the tractor driver.
- As a drive unit, tractors with simple equipment can be used, where the presence of a shaft is required, as well as tractors of lower power

In addition to the above, in order to achieve the highest possible quality of drilled holes, which is reflected in the lowest possible soil scattering during drilling in heavy and poorly prepared soils, a multi-phase method should be applied with more frequent removing and lowering of the drill into the soil.

Acknowledgement: *The work is granted by the Ministry of Education, Science and Technological Development of the Republic of Serbia - project number TR 31051: "Improvement of biological processes in the function of rational use of energy, increase of productivity and quality of agricultural products", within the framework of the contract for the realization and financing of scientific research work in 2021 between the Faculty of Agriculture in Belgrade and the Ministry, contract registration number: 451-03-9/2021-14/200116. Present study has not received any additional specific grant from funding agencies in the public, commercial, or not-for-profit sectors.*

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INFLUENCE OF VEHICLE CENTER OF GRAVITY CHANGE ON DYNAMIC CHARACTERISTICS

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Abstract: *The position of the vehicle's center of gravity is one of the most important vehicle parameters, which has a significant role in the dynamic bahavior of the vehicle (roll, pitch, yaw and load transfer). When the vehicle body moves, the weight of the vehicle is redistributed, which affects grip and stability. The aim of this work is to prove experimentally the influence of the change in the height of the center of gravity on the vehicle dynamic characteristics by adjusting the suspension system. Changes in the angles of the vehicle body in the longitudinal and transverse planes were observed.*

The experiment was performed on a vehicle that has a mechanically adjusted support of the spring wich changes suspension system parameters and the height of the center of gravity. The test was performed using the Moose Test, defined in ISO 3888-2, with roll, pitch and yaw (angle, rate and acceleration) and longitudinal speed and acceleration being measured by equipment installed in the vehicle. With this experiment we have quantified how the height of the center of gravity affects the dynamic characteristics and showed how much the dynamics of the vehicle is disturbed by ≈55 mm change in the height of the center of gravity.

Keywords: *center of gravity, stability, suspension, Moose test.*

1. INTRODUCTION

Vehicle Dynamics is the engineering subject about vehicle motion in relevant user operations. It encompasses the interaction of vehicles, drivers and the environment, and contributes to the improvement of handling, stability, active safety and driving comfort. The development of vehicle dynamics is based on the fields of mechanics (statics, kinematics, dynamics) and research of engineers in vehicle development.

The movements of the vehicles can be curvilinear, rectilinear with constant or variable speed. Dynamic movements on the vehicle occur under the influence of forces that are imposed on the vehicle as well as the influence of gravity, aerodynamics and forces that occur in the contact of the tire and the ground. The vehicle and its components are studied to determine what forces of these sources will produce when the vehicle is moving, and how it will affect the movement of the vehicle as a whole.

The vehicle's coordinate system is usually set with a coordinate origin at the center of gravity of the vehicle, but other points may be used, such as the center of the front axle (ground contact or wheel center height), the center of the front bumper, the outer edge of the body in relation to certain obstacles or some arbitrarily placed point on the vehicle. The vehicle coordinate system is defined by the "ISO 8855: 2011" standard [1].

Vehicle dynamics is classified according to the coordinate axes of the vehicle into longitudinal, transverse and vertical dynamics.

In addition to this classification, it can also be as:

• Tire Dynamics,

• Full-vehicle Dynamics.

This division enables the observation of individual vehicle systems separately and the introduction of simplification and the use of simple models for understanding of vehicle dynamics.

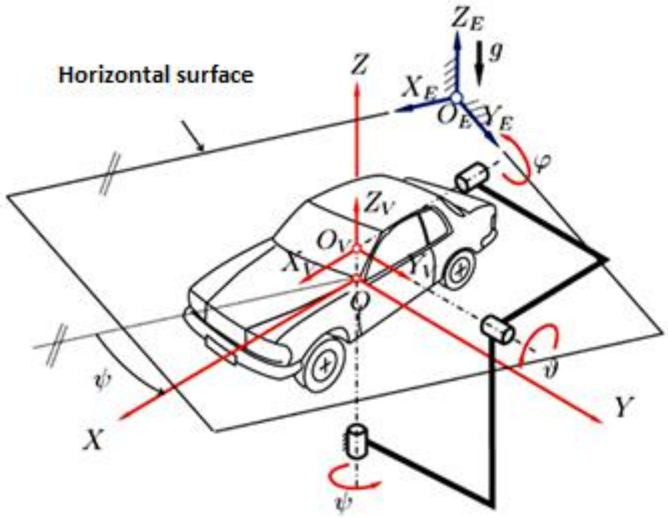


Fig. 1: Vehicle coordinate system *„ISO 8855:2011"* [1]

A Vehicle is a complex system consisting of components arranged within its body with different function, impact and movement. However, for many elementary analyzes that are applied, all components move together. For example, when braking, the vehicle slows down and can be presented as a object with mass at its center of gravity. For acceleration, braking, and most motion analysis, one mass is considered as a whole. To analyze vehicle movement, it is often necessary to observe the wheels as separate masses. In this case, the vehicle body is a "leaning mass", and the wheels are characterized as "unsupported mass". [2].

Knowing the coordinates of the vehicle's center of gravity is one of the necessary conditions for conducting detailed analyzes of a large number of traction and dynamic characteristics of the vehicle. The methods used to determine this characteristic of the vehicle are basically simple. However, in practical works, sometimes, even during tests, certain difficulties are encountered, especially if high accuracy is insisted on. This has led to the definition of certain standard measurements, which are used for all types of vehicles [3].

The position of the vehicle's center of gravity is one of the most important parameters of the vehicle, which have a significant role in the dynamic characteristics of the vehicle, its roll, pitch, yaw and the load transmitted to the wheels [4].

The dynamic characteristic of a road vehicle is a very important aspect of active vehicle safety. Each vehicle, together with the driver and external influences, represents a unique closed loop system. The task of assessing dynamic behavior is therefore very difficult, because the significant driver-vehicle-environment interaction is complex in itself. A complete and accurate description of the behavior of a road vehicle must necessarily include information obtained from several different tests. During the test which is used in this paper, significant movement parameters are measured and then comparative criteria for assessing vehicle dynamics are derived. [5].

Relevant data when performing the VDA obstacle avoidance test are:

• Longitudinal and transverse vehicle speeds

• Steering wheel angle and torque

• Forces and moments acting on the wheels

• Orientation and angle of inclination of the wheels, as well as the travel of the wheels

• Slip angle of the vehicle

• Roll, pitch, yaw

• Longitudinal, transverse and lateral acceleration

2. MATERIAL AND METHODS

Calculating the position of the center of gravity of a motor vehicle is very delicate because it requires knowledge of the position of the center of gravity of each part of the vehicle. Therefore, experimental procedures are very often used.

2.1 Determination of longitudinal coordinates of the center of gravity

Determining the longitudinal coordinates of the center of gravity is the distance of the center of gravity from the front and rear axles, can be determined by measuring the weight of the whole vehicle G, and then the reaction of the soil to the weights loaded on the front G_p and rear axle G_Z. By setting up equations.

$$G_Z \cdot 1 - G_T(l - l_Z) = 0 => l_Z = \frac{l(G_T - G_Z)}{G_T} \tag{0.1}$$

the distances of the center of gravity in relation to the front and rear axles are obtained, where the wheelbase $l = l_p + l_Z$. This method of determining the longitudinal and transverse coordinates of the center of gravity can be used both in case the front and rear wheels are the same, and when these wheels are of different dimensions, such as in a tractor (Fig. 2). [6].

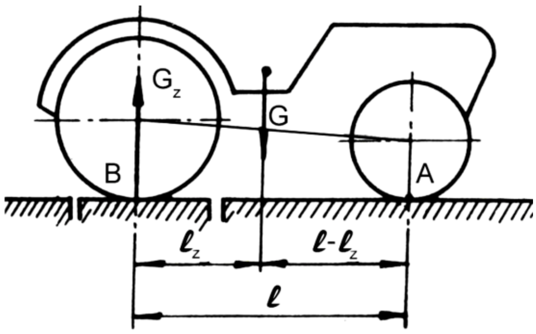


Fig. 2: Sketch for determining the longitudinal coordinates of the center of gravity [6].

2.2 Determining the height of the center of gravity

Determining the position of the height of the center of gravity from the ground is similar as previous experiments, with one of the axles (front or rear) being raised to a height H (it schould be as high as possible).[6].

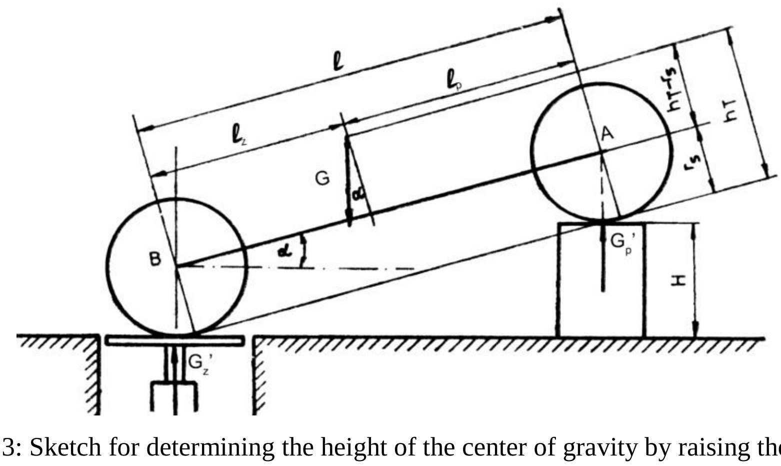


Fig. 3: Sketch for determining the height of the center of gravity by raising the front (rear) wheels when the diameters of the front and rear wheels are the same [6].

From the moment equation in relation to the point of support of the front wheels it follows:

$$G \cdot l_P \cdot cosa + G(h_T - r_s) \cdot sina - G_z' \cdot l \cdot cosa = 0 \qquad (0.1)$$

Where:

- $a -$ the angle of inclination of the vehicle in relation to the horizontal plane
- $h_T -$ height of the center of gravity
- $r_s -$ static radius of a point
- $G, G_Z -$vehicle weight or soil reaction to the weight of the rear axle (this value is measured on the balance when the vehicle is in a horizontal position)
- $G_Z' -$ weight on the rear axle, when the vehicle is raised (this value is measured on a scale with the front wheels raised)
- $H -$ height to which the vehicle is raised

From the above equilibrium equation follows the height of the center of gravity h_T:

$$h_T = r_s + \frac{l}{G} \cdot \frac{G_Z' - G_Z}{tga} \qquad (0.2)$$

Where:

$$tga = \frac{H}{X} \qquad (0.3)$$

$$X = \sqrt{l^2 - H^2} \qquad (0.4)$$

$$tga = \frac{H}{l} \qquad (0.5)$$

The height of the vehicle's center of gravity was measured using a device that enables the lifting of passenger vehicles. The device is schematically shown in **Fig.** 4.

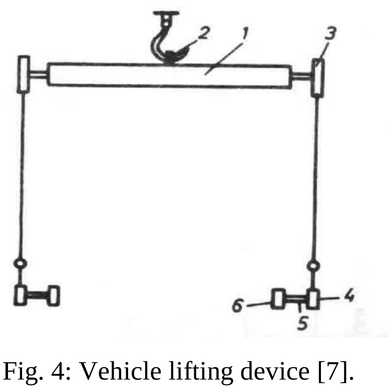


Fig. 4: Vehicle lifting device [7].

The bracket (1) is placed on the crane hook by means of the eye (2). The sliders (3) are placed symmetrically on the openings on the support (1), and their distance is determined by the width of the vehicle. For the sliders (3), extensions (4) are connected via bearings with coils (5), on the inner sides of which there are flanges (6). They are used to connect the device to the wheel hubs, by means of wheel bolts, without dismantling the wheels themselves. [7].

2.3 Suspension system with mechanical vehicle height adjustment

The height adjustment of the vehicle is done mechanically using a thread located on the elements of the suspension system. The height of the front of the vehicle is adjusted using a threaded spindle located on the damping element under the spring. The height of the rear of the vehicle using an additional element located above the spring, which also has a thread for height adjustment (Fig. 5).

By regulating the position of the parts on which the spring is mounted, the height of the vehicle is regulated, ie the complete vehicle body is moved by a certain value, and that affects the position of the height of the vehicle's center of gravity.

Fig. 5: Adjustable suspension system [8]

2.4 Moose test (VDA test)

The VDA test (Verband der deutschen Automobilindustrie) defines the criteria for the lane change test to ensure that the results are reproducible, visible and also understandable to consumers. The test is designed to provide a criterion for proving vehicle stability in the areas of maneuverability, vehicle control and rolling tendency. [9].

The VDA test procedure is officialized as ISO 3888-2 and it defines the dimensions of the test track, the lane change maneuver that simulates the avoidance of obstacles to the subjective determination of performance, vehicle dynamics and the ability to stay on the road. It is applicable to passenger vehicles as defined in ISO 3833 and light commercial vehicles up to a gross weight of 3.5 tonnes [5].

The obstacle avoidance maneuver track must be set up as shown in Fig. 6, and the dimensions are given in Table 1. The length of the track sections is fixed, while the track width, b, is a function of vehicle width. The total length of the trail must be 61 m.

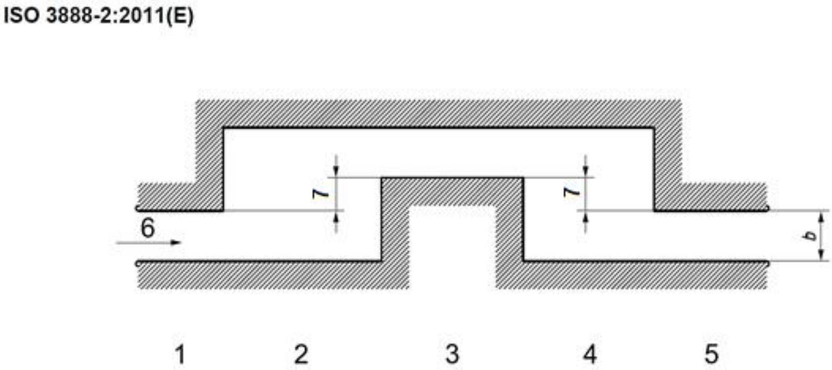


Fig. 6: Display of the test track

Table 1 Maneuver track dimensions

Section	Length	The space between Lane	Width b
1	12	-	1,1× vehicle width +0,25 m
2	13,5	-	-
3	11	1	vehicle width + 1 m
4	12,5	-	-
5	12	-	1.3× vehicle width +0,25 m, but not wider than 3 m

Note: Vehicle width indicates the overall width of the vehicle, but does not include mirrors.

The obstacle avoidance path must be marked with conical cones with a minimum height of 500 mm (Fig. 7). The cones are placed at the points shown in Fig. 8.

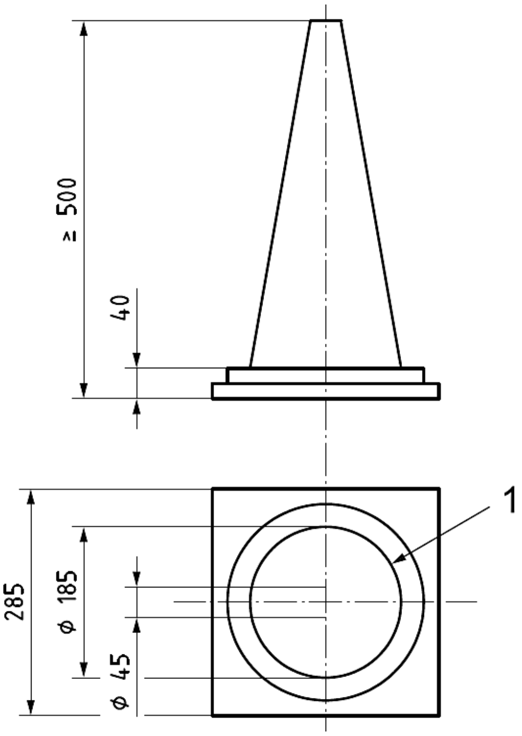


Fig. 7: Appearance and dimensions of cones (dimensions shown in millimeters)

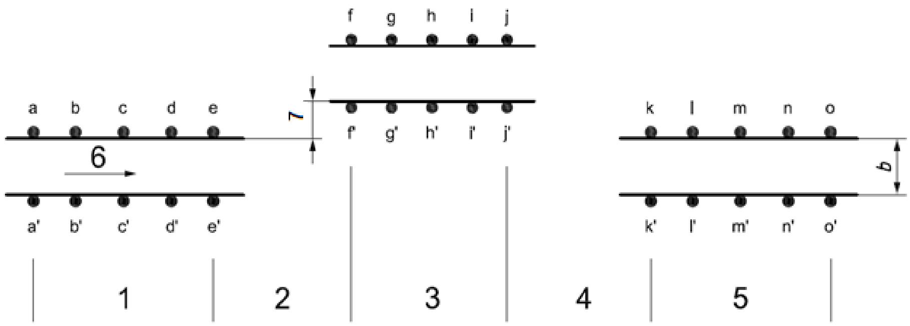


Fig. 8: Placement of conical cones for marking polygons

Obstacle avoidance maneuver is a dynamic process that involves driving the vehicle from the starting lane to the second lane parallel to the first and returning to the starting lane, without exceeding the limits. The goal is for the vehicle to achieve a certain range of alternating, lateral accelerations so that vehicle dynamics can be assessed. The passage is considered satisfactory when none of the cones placed in accordance with Fig. 8 is moved.

- *2.4.1 Test procedure*

a) Vehicle entry into section 1 should be achieved with the highest gear guaranteeing a minimum engine speed of 2000 rpm.

b) Two meters after entering section 1 (Fig. 9), the accelerator pedal is released and the remaining part of the polygon is conducted with the accelerator pedal released so that the vehicle moves through the track in deceleration mode.

There must be no contact with the cones during the test. Otherwise the vehicle did not pass the test.

To allow the test procedure to be repeated, the initial vehicle speed is measured at the end of section 1 and stated in the test report.

The speed at which the test is performed is measured (7) at the entrance to section 1 where the accelerator pedal is released (6) and then maneuvered. The test is repeated, and the speed of the test is increased step by step, starting from 60 km / h until the vehicle completes the test, until there is contact with the cones or turning the vehicle. This usually happens at speeds of around 70-80 km / h (45-50 mph) at best. Tests are performed with and without ESP system (Electronic Stability Program). ESP is used to avoid sudden excessive vehicle reactions (drift).

Because of the influence of the driver (driving strategy) in this test, there is no possibility of achieving objective measurements of vehicle dynamics data; only a subjective assessment is recommended. Different paths conducted in different tests lead to significant scattering of the measured data. Due to these limitations, this part of ISO 3888 defines only the dimensions of the test track for the subjective assessment of vehicle dynamics. [5].

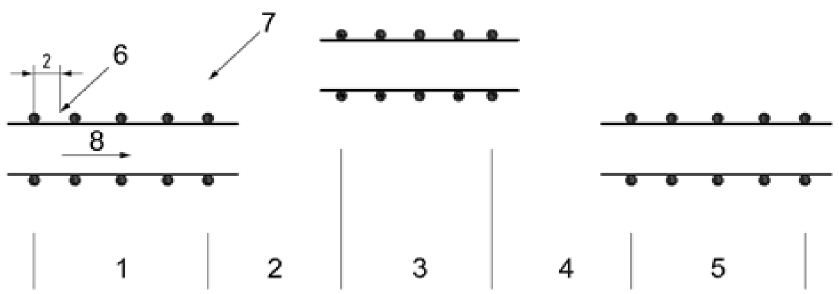


Fig. 9: Test track scheme

2.5 Equipment used in testing

- *2.5.1. Kistler tans*

A navigation sensor that combines a three-way MEMS gyroscope with a three-way accelerometer in one compact housing [10]. It is used for measuring speed in three axes, correction of slip angle, detection of position and movement.

- *2.5.2. Racelogic GPS VBSS05*

Based on a 5 Hz high-precision GPS system, the VBSS05 speed sensor is used for non-contact speed reading. Analog and digital signals enable integration with data acquisition acquisitions and test applications. Using the analog output, a result can be obtained on vehicle speed, lateral acceleration as well as longitudinal acceleration of the vehicle [11].

- *2.5.3. QuantumX*

QuantumX is an acquisition unit for data collection that is used as a tool for testing and measurement purposes [12].

- *2.5.4. Catman Easy*

Catman software for data collection during measurement, visualization and analysis

3. RESULTS AND DISCUSSION

The first part of the experimental test was to measure the center of gravity of the vehicle. Vehicle measurement and center of gravity determination were performed without a driver.

The height of the vehicle's center of gravity was measured in two vehicle states, when the suspension system was set to be raised to the extreme upper position and lowered to the extreme lower position.

Fig. 10: Determining the height of the center of gravity

Based on three measurements and calculations for different vehicle adjustment, the following results of the vehicle height were obtained:

Table 3 Results of center of gravity measurement

	Suspension system set to the extreme upper position	Suspension system set to the extreme lowered position
h_{T_1}	$493{,}0\ mm$	$437{,}2\ mm$
h_{T_2}	$486{,}5\ mm$	$431{,}7\ mm$
h_{T_3}	$491{,}4\ mm$	$436{,}1\ mm$

On 23.08.2020. at the location Batajnički drum - Zemun (Belgrade), a test of the dynamic characteristics of the vehicle was performed. Based on the calculation and measurement of the vehicle center of gravity position, the navigation sensor is placed approximately in the vehicle center of gravity position so that the results are accurate.

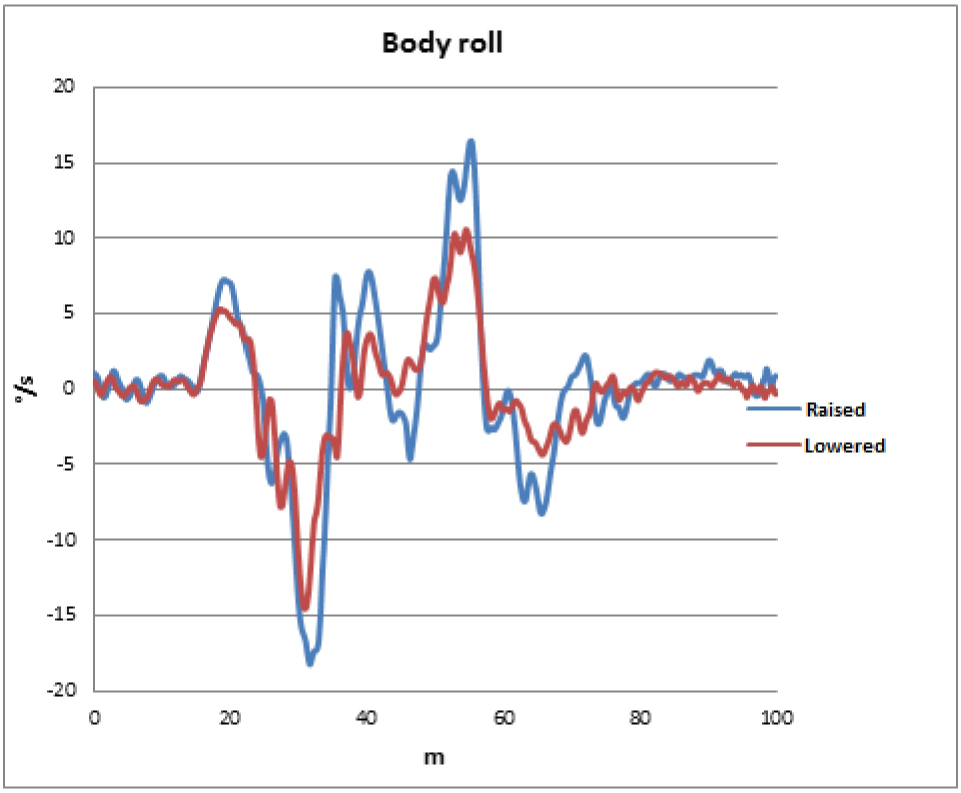
Fig. 11: View of the marked polygon for the test

By gradually passing the marked polygons, increasing the speed with each passage, it has been established that the safe speed for the test is $65\ km/h$. The test was performed with the driver and front passenger. After several times the vehicle passed through the polygon, the suspension system was adjusted and the position of the center of gravity was lowered. Based on the measurement of the height of the center of gravity, and the table shown, we notice that by adjusting the elements of the suspension system, the height of the center of gravity is lowered by $\approx 55\ mm$.

Fig. 12: Kistler tans position and software interface

Fig. 13: Power supply, acquisition and GPS sensor located in the trunk of the vehicle

By using the mentioned measuring equipment and passing through the polygon, we come to the test results. In order to obtain the most relevant results, the test was repeated six times for a vehicle with a higher and lower center of gravity, after which the results were compared. The following graphs show the obtained values of angles for Roll, Pitch and Yaw of vehicles from three selected vehicle passages.



Graph 1: Mean values of the change in the Roll angle of the vehicle obtained on the basis of three passes in the VDA test for the raised or lowered vehicle

During a vehicle passing through the polygon, the largest change in the value observed on roll of the vehicle, what we can see in Fig. 14. By comparing the graphs and observing the maximum values, it can be noticed that the changes in the roll angle of vehicles with lower center of gravity are smaller compared to vehicles with higher center of gravity by ≈3 °/s. We conclude that a vehicle with a lower center of gravity roll less when performing the test, which results in less redistribution of vehicle weight from one side to the other, and therefore less chance of loss of traction when wheels become unloaded.

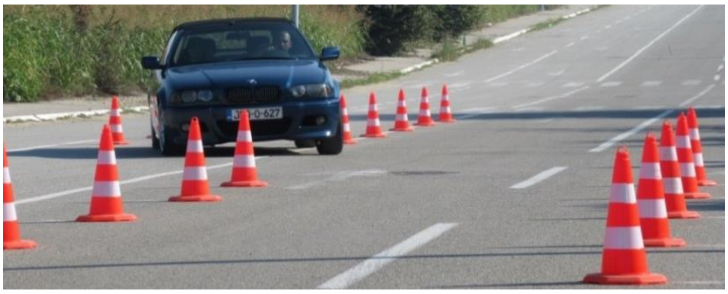
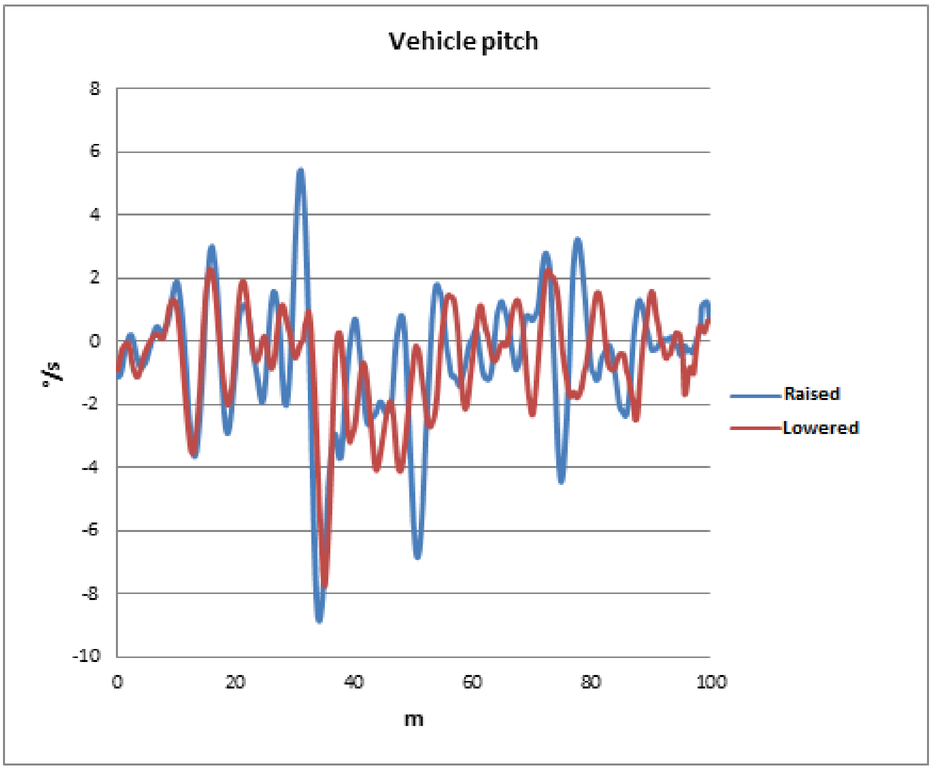
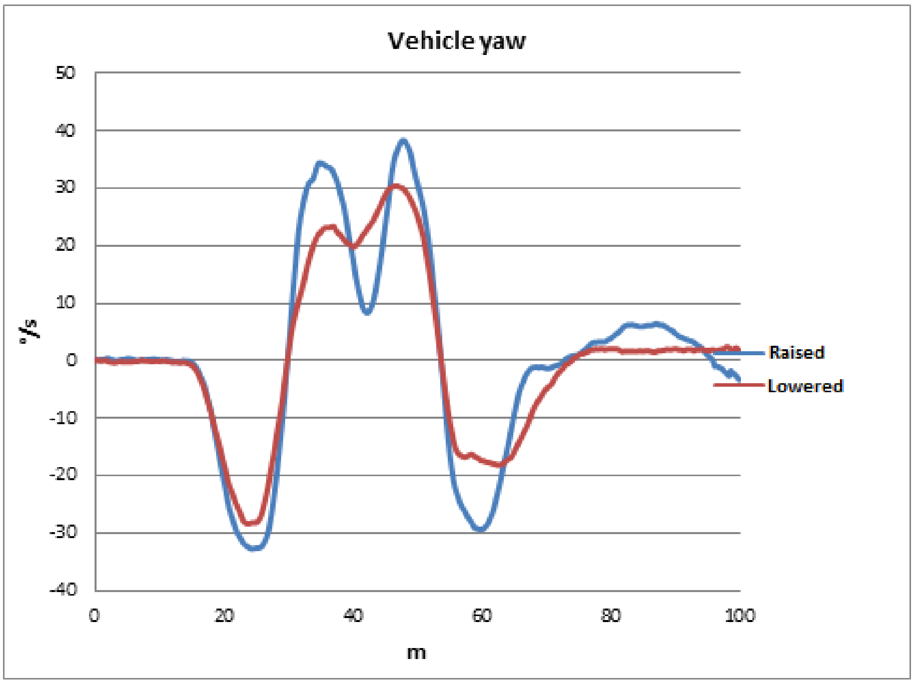


Fig. 14: Passage of the vehicle through the polygon



Graph 2: Mean values of the change in the pitch angle of the vehicle obtained on the basis of three passes in the VDA test for the raised or lowered vehicle

The change in the angle of the vehicle in the longitudinal plane (Pitch) during the performance of this test was not significantly observed. The values for a vehicle with a lower center of gravity position are higher in some passages than in a vehicle with a higher center of gravity position, and in some passages the situation is opposite. We conclude that when changing direction, the values of angle changes in the longitudinal plane do not change significantly in vehicles with a raised center of gravity position compared to a vehicle with a lower center of gravity position.



Graph 3: Mean values of the change in the angle of yaw of the vehicle obtained on the three passes in the VDA test for the raised or lowered vehicle

According to the obtained results, we conclude that passing a vehicle with a center of gravity in a higher position, have greater loss of vehicle control and vehicle yaw, which of course is not desirable. Since the test was prescribed to be performed with vehicle stability control, and for safety reasons, this also contributed to the result. For a vehicle with a raised center of gravity, the difference in yaw angles when passing through the first curve is ≈ 10%, and then increases when passing through the track. When passing through the second curve the difference between the yaw angles $\approx 10\,°\ /\,s$. It can be noticed that through other sections of the track, the difference between the angles yaw is $\approx 10\,°\ /\,s$, which is on average ≈30%. On the graphs, we notice more uneven results, ie the trajectory of the vehicle for a vehicle with a higher center of gravity compared to a vehicle with a lower center of gravity. The graphics look more continuous with smaller oscillations from which it can be concluded that the handling of the vehicle is better.

4. CONCLUSION

Based on the theory and the results of the experiment, we conclude that the height of the vehicle's center of gravity affects its dynamic characteristics and the roll of the vehicle, where the lower the center of gravity the lower the vehicle's roll, which contributes to less mass redistribution and better vehicle stability. This is shown by the results of vehicle yaw during the test, where the results show that the position of the vehicle's center of gravity affects the stability of the vehicle, its handling, which contributes to less vehicle drift, and loss of control over the vehicle while avoiding obstacles, which is simulated by the test. In addition, the height of the center of gravity position also affects the pitch of the vehicle when turning, whereby the changes in the angles of pitch of the vehicle are smaller for a vehicle with a lower center of gravity position. The mentioned angles when moving the vehicle represent the values that affect the final result, ie the stability of the vehicle when overcoming various obstacles and achieving better performance.

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CIAH Laboratory for motor vehicles at the Faculty of Mechanical Engineering - University of Belgrade that support with equipment to use and helped during the test.

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ANALYSIS OF THE LOAD DISTRIBUTION IN A ROLLING BEARING - WITH AND WITHOUT DAMAGE

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Abstract. *Due to action of an external radial load on the bearing assembly, the load is transferred through the rolling elements from one bearing ring to another. However, not all rolling elements are equally involved in the load transfer from the shaft to the housing. This directly reflects on the non-uniformly load distribution on the rolling elements, which depends on the internal geometry of the bearing and the intensity of the external load. The main character of load distribution on the rolling elements of a single-row rolling bearing with radial contact with and without damage on the rolling race was analyzed in this paper. The Finite Element Analysis for a particular ball bearing type is developed for these purposes. The influence of damage dimensions variation, as well as external load intensity on the load distribution within the bearing is considered. The obtained results show that when damage dimensions increase, the load transmitted by rolling elements located just below central plane increases, while the loading on the rolling elements whose center is in the direction of external load decreases. However, with the increasing of the external load, and in the case of damage appearance on the rolling race, load distribution between rolling elements become very similar to the load distribution for the case of the bearing without damage.*

Key words: *rolling bearings, load distribution, damage, Finite Element Analysis*

1. INTRODUCTION

Rolling bearings are widely used in mechanical engineering as the standardized machine elements that have a role in load transfer and provide the required accuracy of parts in relative motion. They are used in the motor vehicle industry, aircraft industry, agricultural machinery industry, small home appliances. There is almost no machine that does not contain one or more rolling bearings.

Bearing parts damage, regardless of whether they are rolling raceway, rolling elements or a cage can cause a significant increase in vibration level. Failures caused by bearing parts damage led to unplanned downtime of the entire plant where they are installed, followed by significant material losses.

Because of that, the analysis and prediction of rolling bearings conditions have particular importance for continuous and productive work of bearings and the entire plant where they are installed.

During operation, due to the action of an external radial load on the bearing assembly, the load is transferred through the rolling elements from one bearing ring to another. However, not all rolling elements are equally involved in the load transfer from the shaft to the housing. That directly reflects on the unequal load distribution on the rolling elements, which depends on the internal geometry of the bearing and the intensity of the external load.

Therefore, besides contact stress and deformation and clearance, one of the most important parameters affecting the behaviour and operation of rolling bearings is considered to be load distribution between rolling elements [1]. Accordingly, the character of load distribution on rolling elements of a single-row rolling bearing with radial contact with and without damage on the rolling race was analyzed in this paper.

2. USE OF THE FINITE ELEMENT METHOD (FEM) IN THE DETERMINATION OF LOAD DISTRIBUTION ON ROLLING ELEMENTS OF BALL BEARING 6206

As part of the numerical modelling process, a geometric model of ball bearing 6206 without damage was developed in the Ansys APDL software, [2, 3]. The characteristics of materials and contact elements were defined as input parameters for numerical calculation. The model is placed in the position that the external load has direction in the radial direction, at the coordinate origin of a global coordinate system of the bearing model and varies in the range of 500 - 7000 [N].

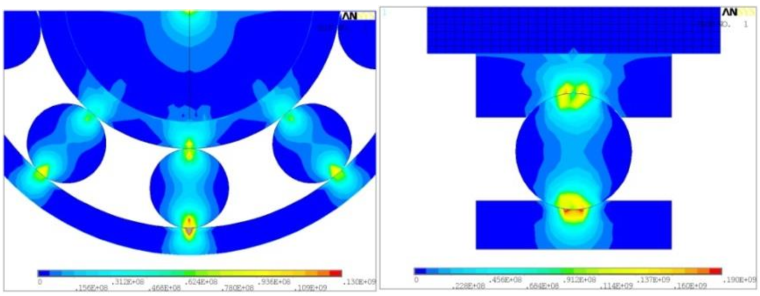


Fig. 1 Numerical results of equivalent VonMisses stress for SKF6206 ball bearing [N/m^2] for the external load of 1000 [N]

Based on numerical simulation, the load distribution on rolling elements for the case of the external bearing load of 1000 [N] is shown - Figure 1. As expected, the rolling element, which has a position in the load direction, carries most of the load, while the rolling elements, which are beside him, are less burdened. The same case of load distribution was obtained for other analyzed external loads.

Developed 3D numerical model of rolling bearing for monitoring of stress and deformation states of the bearing elements without damage on rolling race has been verified by results of experimental tests presented in the available published literature [4]. After verification, a new model was defined to determine the influence of damage geometry on rolling bearings parameters.

For a detailed analysis of the impact of damage on load distribution on rolling bearings elements, a three-dimensional model of ball bearing SKF6206 with cone-shaped damage on the rolling raceway of the inner bearing ring was developed. Within this work, damage in cone form was simulated, where cone-base diameter and cone-high are equal, and they are 0.65 [mm], 1.3 [mm] and 2 [mm] - Figure 2.

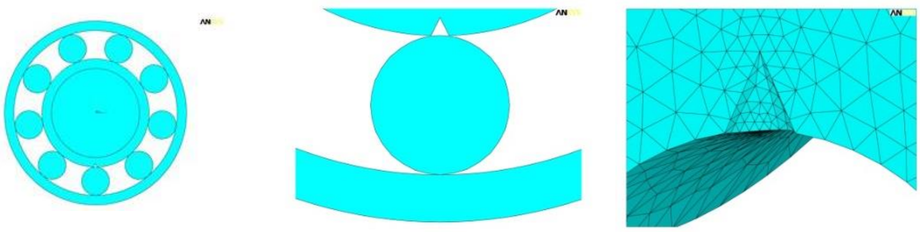


Fig. 2 A local defect in the shape of a cone on the inner ring raceway of the 3D solid finite element model of SKF6206 ball bearing

Although the ball bearing SKF6206 in real constructions is not used mainly for loads over 2000 [N], for a more precise analysis of the dependence of damage dimension and given external radial load on stress and deformation state, intensity of external radial load in range from 500 to 7000 [N] was analyzed, and diameter of the cone-shaped damage on rolling race of inner ring was from 0.65 [mm] to 2 [mm].

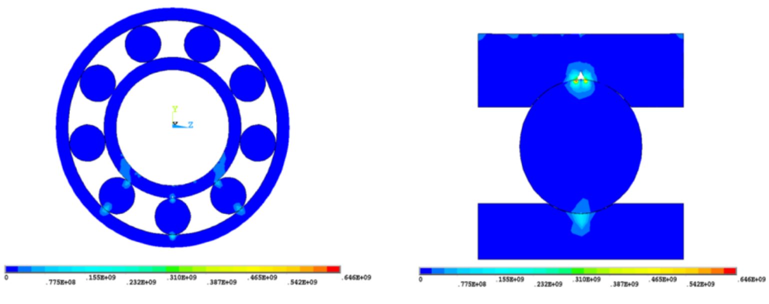
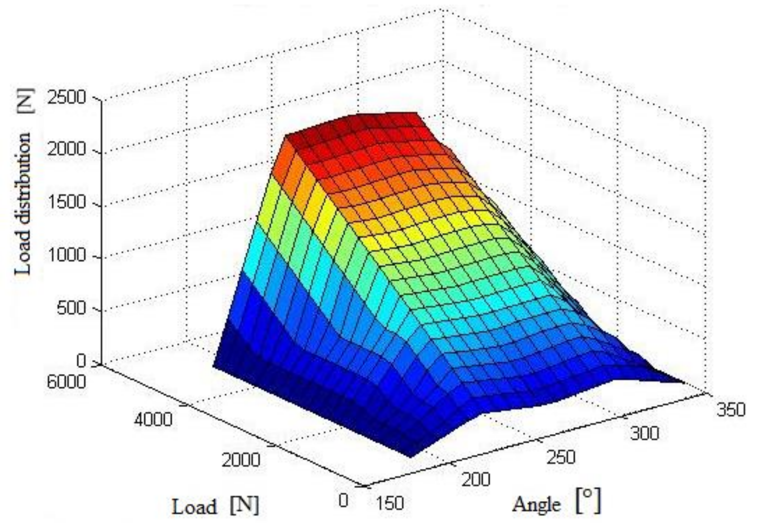


Fig. 3 Numerical results of load distribution on SKF6206 ball bearing with a defect in

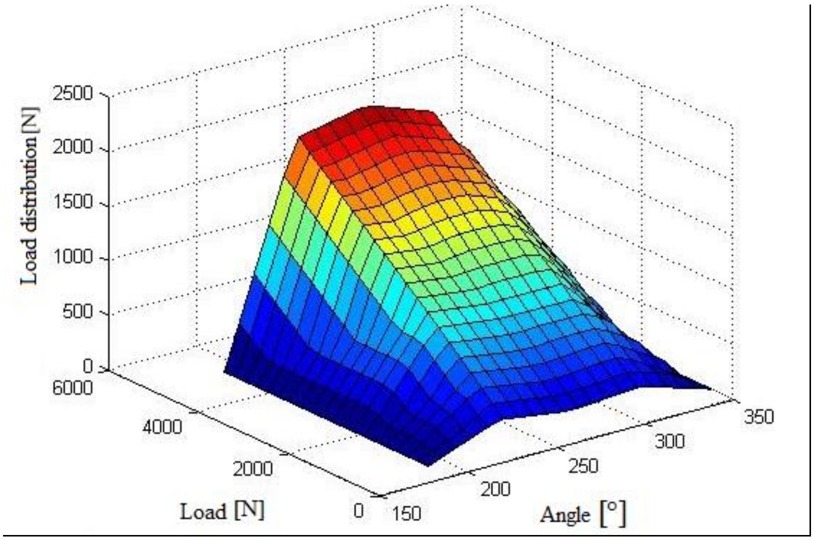
the shape of the cone, for the case of the external radial load of 500 [N] and defect diameter of 0,65 [mm] – full bearing cross-section and detail of the most loaded rolling element of SKF6206 ball bearing

3. RESULTS OF LOAD DISTRIBUTION ON ROLLING BEARINGS ELEMENTS WITHOUT DAMAGE AND WITH DAMAGE ON THE ROLLING RACE

Regarding the load distribution on the rolling elements of the ball bearing SKF6206, as numerical calculation provides a clear visual overview of results, it can be concluded that the increase of damage dimensions increases the load of rolling elements located just below the meridian plane. Figure 4 shows three-dimensional diagrams of load distribution between rolling elements of ball bearing 6206 depending on external load for different defect dimensions.



a)



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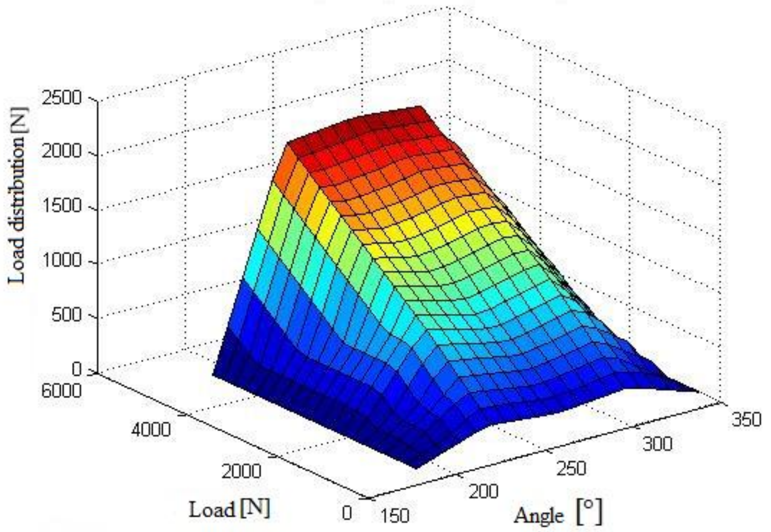

c)

Fig. 4 Three-dimensional diagram of load distribution between rolling elements of SKF6206 ball bearing for different intensity of external load and different defect: a) 0,65 [mm], b) 1,3 [mm] and c) 2 [mm], [5] Based on obtained load distribution results for different external loads, the continuous diagrams shown in Figure 5 were obtained by the interpolation procedure. Thus, the load distribution can be predicted for an arbitrary load from diagrams.

For a complete analysis, the level of external radial load and defect dimensions on the raceway were varied in different ranges. Fields with different levels of load distribution were clearly distinguished in the diagram. These fields were shown in different colors in the diagrams. The rolling element located in the direction of the external radial load on the diagrams was marked with the number 3. The rolling elements which were located left and right of it were marked with numbers 2 and 4, while the rolling elements located just below the meridian plane were marked with numbers 1 and 5.

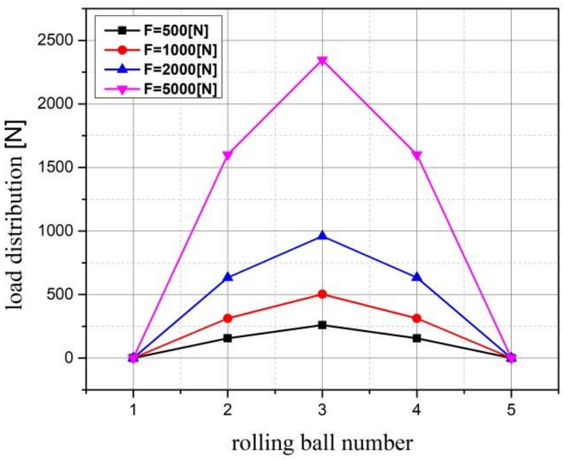

Fig. 5 Load distribution between rolling elements of SKF6206 ball bearing without defect depending on external load, in case of bearing without defect

In the case of bearing without defect, it can be seen from Figure 5 that the inequality of load distribution between rolling elements of ball bearing increases with the increase of the external radial load of bearing. The most loaded rolling element is located in the direction of load and carries most of the load. The furthest rolling elements from the most loaded rolling element-just below the meridian plane- transfer a very small part of the external load.

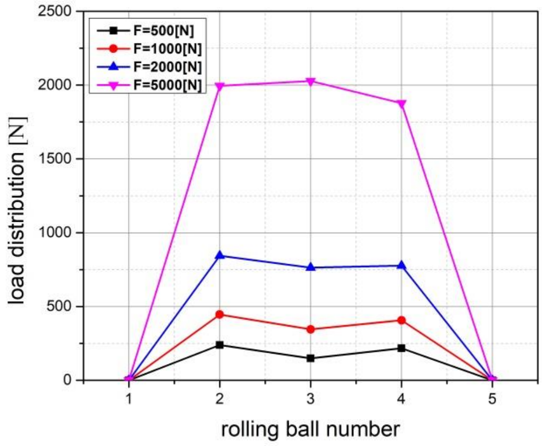

Fig. 6 Load distribution between rolling elements of SKF6206 ball bearing depending on external load, in case of bearing with defect diameter of 0.65 [mm]

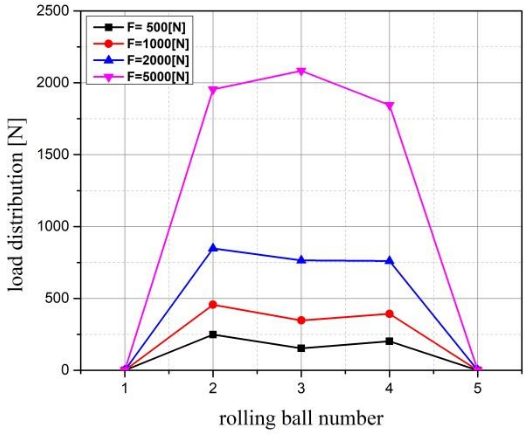

Fig. 7 Load distribution between rolling elements of SKF6206 ball bearing depending on external load, in case of bearing with defect diameter of 1.3 [mm]

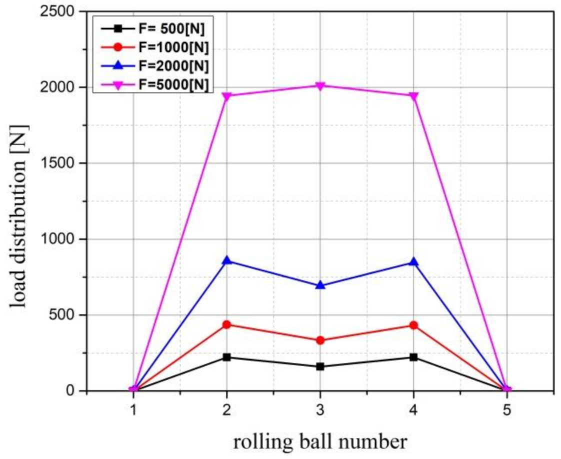

Fig. 8 Load distribution between rolling elements of SKF6206 ball bearing depending on external load, in case of bearing with defect diameter of 2 [mm]

The character of load distribution inside the bearing changes with the change of defect dimensions at bearing rolling raceway. The diagrams clearly show that with the increase of the defect dimension, the load of rolling elements located just below the meridian plane, while by increasing the defect dimension, the load of the rolling element is located in the direction of direction external load decreases. Due to that, the load of other rolling elements increases. However, it can be concluded that with the increase of external load and in the presence of a defect on the rolling raceway, the load distribution between rolling elements gets close to the load distribution for the case of the bearing without defect.

The diagrams of load distribution dependence on the intensity of external load, for different defect dimensions, are presented in Figures 6-8 to facilitate the understanding of the boundaries of individual load distribution fields of SKF6206 ball bearing.

4. CONCLUSIONS

A model and a procedure developed for monitoring load distribution between rolling balls during radial ball bearings operation was presented. It was shown that the load distribution depends on the intensity of external load and different dimensions of defect on the rolling raceway. The obtained results are important in monitoring the working capacity and other working characteristics of ball bearings. Also, they can be directly used for further development of mathematical models of correlations between different shapes and dimensions of ball bearing defects and their operating characteristics. The analysis of obtained results provides the possibility that in further research, besides defect dimensions, other factors that significantly affect the load distribution also. It is essential to point out that a more precise prediction of the expected service life of ball bearings can be made based on the proposed research - which is extremely important in a design process.

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TECHNICAL RESOURCES FOR SPECTRAL CROP SCOUTING – CURRENT STATE AND PROSPECTS

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INVITED PLENARY LECTURE

Abstract: *From planting to harvest, the primary aim of agricultural producers is associated with monitoring cultivated plant species (arable crops or fruit plantations) in arable field areas during the vegetation period in order to make timely and appropriate decisions regarding the implementation of adequate agricultural measures to provide optimal plant development and to maximize the yield. Information about the current state and recent changes in crop sets over the vegetation period represents an important basis for reaching more precise decisions in the spheres of agronomy, economics, and environmental protection. By analyzing large amounts of interdisciplinary spatial data over longer periods of time, key information becomes available, facilitating monitoring crops in larger land areas, and providing the definite picture of changes in arable plots and ecosystems. Spectrometry is the most widespread method of scouting crops. Indirect analysis of the data obtained this way can help determine nutritional deficiencies of crops, as well as defective states caused by diseases, weeds, or pests. Consequently, it is possible to ensure the distribution and administration of optimal doses of appropriate fertilizers and pesticides subsequent to or concurrent with monitoring within the optimal agricultural frame and/or with changeable dosage norms. This review covers various technological processes for spectral crop scouting contingent on various technical resources and sensors. At the end of the paper, advantages and disadvantages of each resource are given, and the key comparisons are made in terms of the efficacy and precision of these resources.*

Keywords: *crop scouting, spectral sensors, sensor carriers, tractors, unmanned aerial vehicles, satellites*

1. INTRODUCTION

From planting to harvest or picking, the primary aim of agricultural producers is associated with monitoring cultivated plant species in arable field areas during the vegetation period in order to make timely and appropriate decisions regarding the implementation of adequate agricultural measures to provide optimal plant development and to maximize the yield. Information about the current state and recent changes in crop sets over the vegetation period represents an important basis for reaching more precise decisions in the spheres of agronomy, economics, and environmental protection. By analyzing large amounts of interdisciplinary spatial data over longer periods of time, key information becomes available, facilitating monitoring crops in larger land areas, and providing the definite picture of changes in arable plots and ecosystems. Therefore, crop scouting involves an analytical process whose aim is to discover spaciotemporal changes in crops from planting to harvest [1].

Incentives to embrace crop scouting techniques include a possibility of yield increase, better fertilizer utilization, and/or pesticide cost reduction. Field specofocity determines whether location-specific approach is profitable or not. However, field experiments that compare uniform rate application (URA) with variable rate application (VRA) show unstable advantages in yield and profit [2-7], and just a few agricultural producers have so far adopted precision agriculture technologies, such as implementation of variable rate application based on crop scouting sensor readings. It should be borne in mind that the main motive of agricultural producers to accept innovations involving crop scouting sensors is their interest in technology [8-12]. They actively use the collected data, frequently comparing them from one season to the next, discovering variations in the biomass change. Still, this group comprises little more than 5% of agricultural producers in Denmark, for example, one of the most developed countries in Europe.

Four principal problems regarding crop scouting in the aforementioned period include (1) limitations that large acreage to be monitored impose; (2) the necessity of quick, effective, precise, and accurate measuring; (3) chemical instability of nitrogen as the most significant crop nutrient, because of which very dynamic changes in its content levels in the soil and plants occur, which means that for determining optimal nitrogen-based artificial fertilizer doses it is essential to measure the nitrogen levels as close as possible to the time of the fertilizer application; and finally (4) enabling mineral nutrient distribution via variable rate application represents an additional challenge.

Data collected by crop scouting represent a solid basis for geo-agronomic analyses. Nevertheless, different ways of detecting changes in crop state are not equally suitable to every analysis, so digital detection of crop changes is affected by special, atmospheric, spectral, and temporal limitations. To counter these, we have at our disposal numerous techniques for detecting changes, while opting for an appropriate method or algorithm for the desired crop scouting is key to the successful analysis of the obtained data. The diagram in Figure 1 presents the most prevalent ways (methods) and indirect means of using multispectral camera sensors for agricultural purposes in crop scouting.

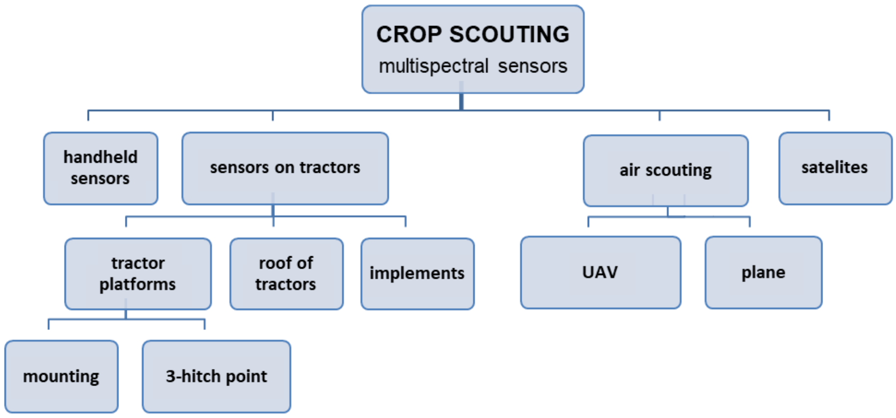

Figure 1. Ways of multispectral crop scouting and multispectral technical systems (platforms) in agriculture [1]

Each of the crop scouting ways mentioned, together with the accompanying multispectral technical system comprising a multispectral camera sensor and an adequate sensor carrier, possesses certain advantages and renders recommendations for use in line with the preferred intentions or actual conditions in crop scouting.

2. SPECTROMETRY DESIGN AND ITS APPLICABILITY IN AGRICULTURE

Remote detection represents a non-invasive method of collecting information using systems that are not in a direct, physical contact with the object or the phenomenon examined (Figure 2). Sensors are main devices in this type of investigation dedicated to discovering, registering, and measuring electromagnetic radiation emitted or reflected by the examined object. Sensors transform the registered electromagnetic energy into electric impulses, and their set-up enables them to cover a narrow or wide spectral range. To monitor fields with adequate remote sensors, of all types of electromagnetic radiation, only those types of radiation whose wavelength corresponds to that of visible light, infrared light, and microwaves are used. Field mapping is mostly done using the so-called optical RGB cameras and spectral sensors, although for agricultural purposes, in crop scouting directed at observing parameters presented in Figure 2, mechanical sensors, thermal imaging cameras, scanners, lasers, radars, and ultrasound sensors are used as well.

Main units of multispectral sensors that measure light reflectance from a certain part of the spectrum are light source, reflected light detector, control unit, and power supply unit. A schematic representation of a sensor thus defined is given in a block diagram in Figure 3.

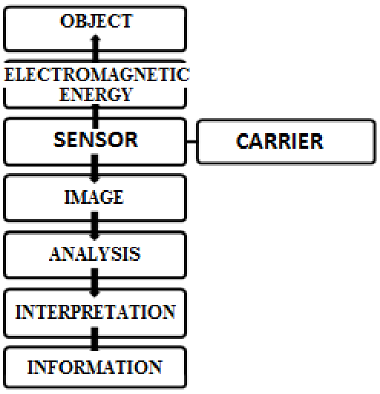

Figure 2. Remote detection principle

Since reflectance is measured in several distinct parts of light spectrum, the source must be such that it can generate light in four portions of the spectrum, that is, in the blue, green, red, and infrared spectra. In this way, calculating several reflectance indices is made possible. One light diode is used as a light source, and its chip incorporates all four light sources necessary for the described sensor function and crop scouting. The light source has the power of 3 W. The reflected light detector can be a PIN photodiode that has the ability to detect light in the range of 400—1100 nm. A PIN photodiode is a semiconductor component which converts an optical signal into a corresponding electrical signal, or charge. This semiconductor component has better dynamic characteristics and sensitivity compared with other types of photodetectors, such as phototransistors or photoresistors.

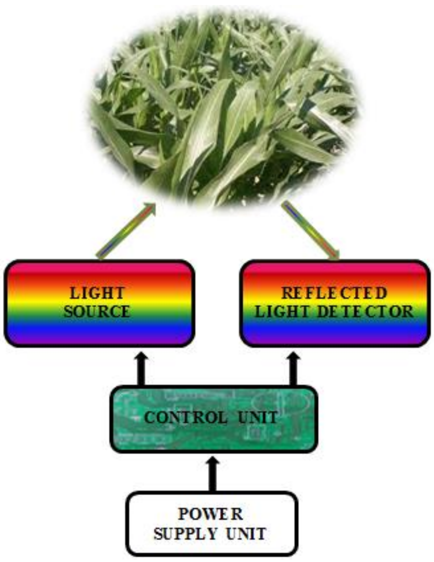

Figure 3. Block diagram of a multispectral sensor

Multispectral analysis is currently the most prevalent and the most comprehensive type of remote detection, or crop scouting in agriculture. Despite various manners, or indirect technical means for implementing multispectral sensor imaging in agriculture, what they all have in common is the multispectral camera sensors that measure plant spectral reflectance and detect the typical vegetation spectral signature.

3. ON-THE-GROUND CROP SCOUTING SYSTEMS

On-the-ground crop scouting is performed using sensors integrated in agricultural machinery, that is, machine-tractor aggregates, and is categorized under the so-called terrestrial photogrammetry. Tractor platforms can be mounted or mounted directly on the tractor by means of a special construction adapted to each tractor model individually or by means of a platform of the coupling type which enables connection to the tractor in three points in the classical way (Figure 4). The number of multispectrometic sensors on the carrier is usually two or four, although any number of sensors can be installed. In addition to special platforms, the sensors can also be mounted on the roof of the tractor or directly on the working machines, e.g. on the wings of mounted and towed sprayers or on the wings of high-clearance self-propelled sprayers. The front tractor platforms for multi-spectrometic sensors, as well as those sensors that are mounted on the roof of the tractor, can be used, although much less frequently, for exclusive crop reconnaissance without simultaneous dosing of any agent per plot and crops. In any case, the common characteristic of all variations of the above-mentioned method of crop reconnaissance is the best possible resolution and possible simultaneous reconnaissance and dosing of fertilizers and pesticides with a variable rate.

Figure 4. Typical tractor platforms for crop scouting

On market, there are comparatively few complete crop scouting tractor platforms, predominantly with a three point hitch system. Their load-bearing structure is robust, they allow hydraulic wing manipulation, and they are equipped with two laterally placed sensors. However, the leading manufacturers of agricultural GPS equipment base their business and development in the domains of sensors and electronics, meaning that they deliver autonomous systems for spectrometric crop scouting in the form of sets comprised of nothing else but electronic sensory equipment with a various number of sensors in accordance with the customers' demands, controlling module, and the accompanying cabling. Customers are completely left to their own devices when it comes to positioning these components on corresponding platforms. Agricultural sprayers have wide wings, enabling sensor installation and positioning to some extent. Still, using sensors simultaneously with fertilizing or solely for crop scouting inevitably requires a separate, specifically designed platform for sensor installation.

4. ADVANTAGES AND DISADVANTAGES OF SCOUTING SYSTEMS

Using hand-held sensors is the least effective method of crop scouting. Thus, scouting boils down to inspecting agricultural plots or fruit plantations visually, above all, and the sensor itself is used for evaluating the state of the crops using the vegetation index measured. Vegetation index measuring is done sporadically, at the discretion of the technicians doing the scouting, and less frequently according to a plan determined in advance. The location can be a *spot*, when the hand-held sensor is activated and held for several seconds above an individual plant, or a *line*, when one walks several dozen meters along a single row with the activated sensor that is directed to the crop. The number of measurements (samplings) depends on the predetermined measuring period of time and the skill of the technicians themselves, and wet or muddy terrain can be a significantly limiting factor for this manner of scouting. In addition to its price, the advantages of these devices include small dimensions and light weight, portability, as well as a very quick computation of the vegetation index (in a couple of seconds) with no need for long imaging procedures and processing. Nevertheless, these devices can most frequently determine only one vegetation index.

On-the-ground crop scouting is done using the sensors integrated in agricultural machinery, or machine-tractor aggregates (MTAs), and is categorized under the so-called terrestrial photogrammetry. This type of scouting is most profitable and most effective when it is done simultaneously with the distribution of mineral nutrients and with the chemical protection of plants. What is more, in that case, the aggregate may include a tractor and two machines. Behind the tractor, an implement/attachment (a fertilizer spreader or a sprayer) is mounted, and in front of the tractor, there is a front tractor multispectral sensor carrier which is used for scouting the crops, or for direct measuring of the reflectance of various light wavelengths from the green parts of the plants, as well as for indirect calculations of one of numerous vegetation indices based on the prior scientific research [13]. Based on this index, the optimal dosage rate is calculated, in line with the adopted recommendations or algorithm, and the obtained data on the variable and location-specific rate are sent to the implement/attachment actuators behind the tractor. The number of multispectral sensors on the carrier is usually two or four, but actually, any number of sensors can be attached. These platforms can be mounted, that is, installed directly onto the tractor with a special construction adjusted to each model of tractor separately, or they can be attached, with a three-point hitch with the tractor in the standard way. The sensors can be attached not only to special platforms – they can be installed onto the tractor roof, or directly onto the implements/attachments: for example, onto the sides of the mounted and trailed high-clearance sprayers. Front multispectral sensor tractor platforms, as well as sensors installed onto the tractor roof can be used, albeit rarely, solely for crop scouting, without simultaneous plot or crop agent dosing. In any case, what all the aforementioned variations of crop scouting have in common is the best possible resolution and a possibility to scout and dose the pesticides and fertilizers with a variable rate.

As carriers of spectrometric sensors, for agricultural purposes unmanned aerial vehicles (UAVs) are also used. They are better known as drones (although drones also include remote-control vehicles that move on land or water). These are low-flying aircraft controlled by navigators or pilots who remotely send signals from the ground or from an autonomous aircraft flying by the memorized data set in advance. A sensor and an aircraft constitute an unmanned aircraft system (UAS) for aerial crop scouting, so this type of scouting belongs to the so-called aerial photogrammetry. With the installation of multispectral sensors for agricultural purposes, it is possible to do the sampling as many times as the client requires, even several times in one day. Scouting is most frequently done by using dedicated software to choose a region to be scouted (a field, for example), then a desired route of the unmanned aerial vehicle is set, as well as the imaging frequency. After that, an unmanned aerial vehicle circles the region by the set route and does the sampling, or imaging. This is how the so-called autonomous mission is achieved. The resolution of the images obtained is of the order of magnitude of several centimeters. For agricultural purposes, fixed wing unmanned aerial vehicles and unmanned aerial vehicles with propellers are used, with the number of propellers typically being four. The former group of aircraft is quicker and more resilient to the wind, which generally presents the biggest obstacle in using drones for crop scouting. Rain is also an extremely unfavorable atmospheric phenomenon during scouting. In terms of spectrometry, these systems are typically equipped with a light sensor, which means they are more independent of daylight than the sensors normally used on agricultural machinery. Of course, in addition to their speed, one of the greatest advantages of drones as spectrometric sensor carriers in comparison with the agricultural machinery is their independence of the state of the soil during scouting, so while scouting muddy terrain or flooded fields drones are employed perforce [14].

Satellite remote sensing is by far the fastest way to monitor fields and crops, but due to a low resolution of sampling ranging from several meters to several dozen meters, the usability of the maps and data they provide is limited. Although a big advantage of determining plant reflectance indices using satellite images is an ability to obtain data for vast regions, there are a number of disadvantages of this method. If the sky is overcast, it is impossible to obtain the data on plant spectral reflectance. Another disadvantage is a low frequency of sampling (depending on the frequency of the satellite flyovers over a certain territory and the time needed for data processing). Depending on the satellites used and the area monitored, the sampling periods range from one day to several weeks. One more disadvantage is that multispectral cameras installed on the satellites do not have fixed filters; that is, it is not possible to alter light spectra in which sampling is performed. All these disadvantages may pose a problem when it is necessary to do crop scouting very frequently (sometimes several times a day), and for this reason monitoring state of the plants using satellite imagery is most frequently used to monitor the effects of climate change on the flora. Satellite imagery is mostly used for the initial detection of the bad state of the soil in terms of the presence of water in the plots, presence of wider areas with crop stress induced by insect invasion, presence of an extreme deficiency of a nutrient, or presence of widespread plant diseases and/or weeds. When a satellite image suggests or identifies any of the alarming states, other available and feasible measures involving more detailed scouting are taken.

5. CONCLUSION

The speed of spectrometric imaging of arable land with crops or orchard plantations with an aim of scouting directly affects the efficiency of the operation itself. The height from which scouting, or imaging is performed, is indirectly related to the precision and detail (resolution) when locationally specific values of vegetation indices are represented. Resolution is manifested by an actual area of a real plot per a corresponding pixel of a digitally mapped image. The expected areas of implementation of all four types of spectrometric crop scouting are depending on the desired speed or scouting precision.

Leading manufacturers of GPS equipment for agricultural machinery focus on the design and functionality of their devices predominantly in the domains of sensors and electronics. Spectrometric crop scouting sensors are delivered in sets including the controlling module and the corresponding cabling. These sets comprise autonomous systems for spectrometric crop scouting. An unanswered question and an unresolved issue that remains is the installation of sensors and their adequate positioning in order to perform optimal crop scouting, to measure the reflected electromagnetic waves, and to do the final calculations of vegetation indices based on which maps of crop nitrogen content are generated.

A specifically designed and manufactured tractor platform for spectrometric crop scouting should have a simple, adjustable construction.

These are the features of a simple construction:

- light weight of a machine
- easy handling and maintenance
- no hydraulic system to operate the wings, as it increases the complexity and the cost of the platform itself

Adjustable construction means

- it is possible to raise the platform wings to the transport position and to lower them to the working position together with the sensors, while there is a quick and simple way to secure the wing position

- it is possible to attach the platform to tractors of all brands and types, considering the types and dimensions of the tractor lift mechanism, as well as how modern the tractors are, meaning how ready they are to support GPS technology
- it is possible to adjust the spacing between the sensors and the crops
- it is possible to adjust the spacing between the sensors, which enables the scouting of the crops with different row spacing
- it is possible to disassemble the platform to its constituent parts easily, to pack them in a small space, and to transport them to distant locations

It is estimated that serial production of these platforms is feasible in all production conditions, and that their availability on the market will encourage and by all means improve crop scouting procedures with autonomous systems for spectrometric crop scouting, motivating indirectly the implementation of the concept of precision agriculture in the regions where the effects of GPS technology on agriculture are still not significant enough. This task above all falls to mechanical and agricultural engineers. Hand-held crop scouting sensors are sufficiently developed in correlation with their usability, while the development of aerial monitoring systems awaits aerospace and electrical engineers.

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ENHANCING AGRICULTURAL INDUSTRY THROUGH INDUSTRY 4.0

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Abstract: *Agricultural industry is essential for humanity. It provides it with food, fibers, fuel and raw materials that are necessary for a normal living. As the technology advance, it is vital to see how the same technology can be implemented in other industries. With the development of Industry 4.0, many industries are trying to implement new technologies. Industry 4.0 represents the current peak of industry development. Today there are demands in various industries for shorter delivery and production time, more efficient, cost efficient and automated processes. The technology of Industry 4.0 can be applied to agricultural industry as well. Improvements of agricultural machineries in terms of electronic, sensors to enhance their current performances. Using electronics, sensors and drones, supports the data collection of agriculture key aspects, such as crops behaviour, weather, animals etc. The main task is how to implement the right methods in order to enhance agricultural industry with the help of Industry 4.0.*

Keywords: *Industry 4.0, agricultural industry, industry, technology.*

1. INTRODUCTION

Industry 4.0 is a revolution in manufacturing, and it brings a whole new perspective to the industry on how manufacturing can collaborate with new technologies to get maximum output with minimum resource utilization [1]. Over the years, worldwide the manufacturing context has been characterized by disrupting breakthroughs leading to radical changes in production and related processes [2]. Industries were and still developing due to so-called industrial revolutions.

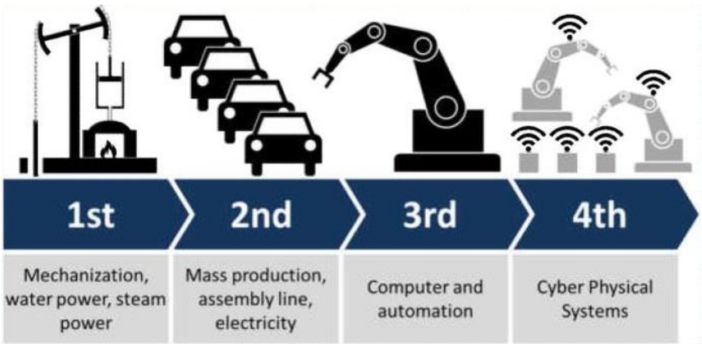

Fig. 1 Industrial revolutions [3]

The first industrial revolution began at the end of the 18th century and was characterized by mechanical production plants based on water and steam power [4]. Industry 2.0, from the end of the 19th century to the 1980s, was the period when industrial products burgeoned both in volume and variety [5]. The third industrial revolution since the 1980s described the use of electronics and information technology (IT) in production automation and generated a widespread digitalization wave. In turn, this digitization wave created a suitable environment for Industry 4.0. [6].

Industry 4.0 involves the use of advanced Information and Communications Technology (ICT) to increase the degree of automation and digitalization of production, manufacturing and industrial processes. Its purpose is to manage the entire value chain process, improving efficiency in the production process and generating quality products and services [7].

Fig. 2 Industry 4.0 [8]

2. MATERIALS AND METHODS

In order to enhance agricultural industry through Industry 4.0, it is vital to define what overall goals are.

Individual operation have to be organized and executed at the right time. It is important to have a good planning, which can be based for example on crop quality, yield, economy and environmental impact. As part of the concept of 4.0 all operations have to be planned as part of full production system [9].

Fig. 3 Industry 4.0 and Agriculture [10]

Agricultural industry is developing in correspondence with Industry 4.0 (Fig. 3). It stands for the combined internal and external interacting of farming operations, offering digital information at all farm sectors and processes. Even in agriculture, as the industrial sector, the 4.0 revolution represents a great opportunity to consider the variability and uncertainties that involve the agri-food production chain. Factories become smarter, more efficient, safer and more environmentally sustainable, due to the combination and integration of production technologies and devices, information and communication systems, data and services in network infrastructures. A farmer with his farm or agricultural companies must be able to adapt and to make changes in order to remain competitive on the market. One of the primary needs to be met is a constant communication between market and production, and within the business itself [11].

Technology has certainly developed in the 21st century. Nowadays we have easy access to it. There are several technologies, which can help farmers or companies and which can be implemented together with Industry 4.0:

- Big Data analytics
- Cloud based ICT systems
- Cheap and improved sensors and actuators

Agricultural machinery (tractors, combine harvesters, etc.) today come with enhanced performance and equipment, which is now standard:

- Many sensors for the operation of the machine and the agronomic process
- Smart control devices (on/board computers)
- Advanced automation capabilities (guidance, seed placement, spraying, etc.) [12]

Agricultural machinery and equipment are now widely used during the entire production process, including land preparation, crop planting, fertilization, harvesting, animal feeding and food processing. Agricultural mechanization significantly reduces manual work and improves productivity, so that fewer farmers can provide more food to meet the global demand for food. The innovation ICT and its integration with agricultural production helps farmers and companies to make a digitalization of farming [13] (Fig. 4).

Fig. 4 Digitalization of farming

Digital farming and in general digital agriculture offers the ability to utilize technology to convert precise data into actionable knowledge to drive and support complex decision-making on-farm and along the value chain. The promise is that, whilst past sources of knowledge were based on general knowledge often derived from research experiments, smart technologies will be able to offer on-farm, local-specific information to farmers. As such, digital agriculture reflects a shift from generalized management of farm resources toward highly optimized, individualized, real-time, hyper-connected and data driven management.

Sensors provide raw data (e.g., weather data), and smart devices (robotic vehicles, drone mounted cameras) will allow sophisticated farm management advice while smart systems have the capability to execute autonomous actions [14]. Large-scale farmland monitoring, crop identification, and yield forecasting are available through remote sensing [15] with GPS technology [16] and UAV [17].

3. RESULTS AND DISCUSSION

In order to implement elements of Industry 4.0 in the agricultural industry, certain tasks must be fulfilled:

- **Farm size**: Usually farmers that have large farms tend to accept new technologies instead of farmer who posseses small size farm due to costs of investment.
- **A need for standards to ensure compatibility of equipment**: The major challenge in Industry 4.0 requires technological standards to ensure the compatibility of equipment and also applicability of equipment in rural areas.
- **Communication infrastructure development in rural location**: An important challenge that faces in rural areas in the IoT adoption for agriculture is communication infrastructures development. Mostly communication network is deployed in urban area specially to capture markets but success of Industry 4.0 in agriculture depends on the ability to exchange and analyses data. Thus, communication networks will have to be established in rural areas.
- **The ability of farmers to modernize from a financial aspect**: The essential challenge of adapting Industry 4.0 in agriculture is farmer’s ability to invest and to revolutionize their production practices. The economic tight situation of farmer leads to limited investment ability in new production tools, agricultural machinery and limited access to credits.

When certain tasks are accomplished, implementing Industry 4.0 in agriculture has its own benefits in terms of improving agriculture:

- **Enhanced product quality and volumes**: Controlling all the agriculture processes and maintaining high standard of, for example, grain quality, which results in increase of productivity.
- **Data collected by smart agriculture sensors**: Data collected by sensors are analyzed and states, for example, crop’s growth, cattle health, weather conditions, soil quality. This data can be used to track the plants and equipment efficiency.
- **Better control over the internal processes and, as a result, lower production risks**: This new technique helps in planning for better product distribution and depends on output prediction by data processing.
- **Increased business efficiency through process automation**: With the utilization of smart automated device in maximum activity in production cycle like irrigation, fertilizing, etc.

4. CONCLUSION

Industry 4.0 is indeed a new revolution in industry. With the implementation of Industry 4.0 in agriculture, it is possible to have shorter production time, better product quality, automated processes, intelligent machinery, etc. The technology is in constant development. It is important that with these above stated reasons farmers and companies can achieve better results in terms of production and quality of the goods. Often are people skeptical to new technology and don't see any benefit from it, especially small farmers. It is desirable that they are provided with knowledge what are the benefits of implementing the Industry 4.0 into their farms. Nowadays there are financial funds that can help farmers and companies to buy or upgrade their agricultural equipments and machines.

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EXPERIMENTAL ANALYSIS ON CONCRETE BLOCKS REINFORCED WITH ARUNDO DONAX FIBERS

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Abstract: *Over the last decade, there has been a growing attention in research and development on non-conventional building materials and technologies, such as vegetable fibers (e.g., flax; hemp; jute; etc.), to be used as eco-friendly materials in a wide range of applications in civil construction. The main reasons of this interest are related to the specific properties, price and sustainability of natural fibers, which can be considered as "green" building materials. In this article, a new kind of fibers, extracted from stem of the Giant Reed Arundo donax L., has been investigated as a potential reinforcement of construction materials. These fibers, which widely grow in Mediterranean areas, but that are diffused all around the world as well, have been extracted from the outer part of plant stem. Then, some experimental concrete bricks, have been prepared with the addition of different weight percentages of vegetal fiber. To assess the mechanical properties of these bricks, tensile tests on single fiber have been performed, as well as compression tests on the whole block. Hence, the differences between concrete bricks without any fiber and those reinforced with different weight percentages of natural fiber have been analyzed, and their potential applications in bio-architecture have been assessed.*

Key words: *bio-architecture, concrete bricks, Arundo donax fiber, mechanical properties, tensile test.*

1. INTRODUCTION

Over the last decades, a growing attention on the use of less polluting materials and technologies [1] and natural fibers instead synthetic ones (*i.e.*, glass, carbon or kevlar fibers) has been focused by both the academic and industrial world [2]. The main reasons of this interest are related to the specific properties, price and low environmental impact of this kind of fibers. A great variety of different natural fibers are actually available as reinforcements of construction materials. The most widely used are flax, hemp, jute, kenaf and sisal, because of their properties and availability while some recent scientific works advance the feasibility to use less common natural fibers [3] such like artichoke [4], okra [5], isora [6], ferula [7], althaea [8], piassava [9], sansevieria [10] and buriti [11]. In this work, a new kind of fibers, extracted from the stem of the giant reed *Arundo donax* L., is investigated as a potential reinforcement in concrete blocks. The giant reed is a perennial rhizomatous grass that grows plenty and naturally in all the temperate areas of Europe (mainly in the countries of the Mediterranean area) and can be easily adapted to different climatic conditions. Thanks to its high growth rate, it represents, in some environmental conditions, an invasive and aggressive species so its disposal is difficult [2]. In Italy, this allochthonous species is invasive in some territorial contexts and in others it is almost completely naturalized. Its field of application is very wide, ranging from the production of reeds in musical woodwind instruments for at least 5000 years to the use as a source of fibers for printing paper [12]. *A. Donax* L. is also used as a diuretic and as a source of biomass for chemical feedstocks and for energy production. Furthermore, this non-wood plant is recently considered in the manufacturing of chipboard panels alternative to those wood-based ones [13].The stem of the giant reed is often used to make fences, trellises, stakes for plants, windbreaks, sun shelters [14]. Owing to their specific mechanical properties (e.g. strength–density ratio), the stems of the giant reed are also employed in agricultural buildings and relevant construction activities.

2. MATERIALS AND METHODS

Some experimental concrete bricks (Fig. 1) – *i.e.*, cubic samples with 15 cm side, and cylindrical samples with 10 cm diameter and 15 cm height - have been prepared in relevant molds, with the addition of different weight percentages of *Arundo donax* vegetal fiber (0.0, 0.2, 0.6 and 1% by weight, respectively).

The concrete samples consist of Pozzolanic cement "CEM IV 325", according to UNI EN 197-1:2011 [15]; sand particles, measuring less than 1,5 mm with a humidity content below 10%, in a percentage of 3.2 of the total volume; quarry gravel, with a characteristic grain size of less than 30 mm, in a percentage of 6.4 of the total volume; and water, in a percentage of 0.96 of the total volume. Regarding fibers, the material used was culms of giant reed. They have been collected along the “Bradano” river basin, in the Basilicata region (Southern Italy), and dried in an oven at 105° until a relative moisture content of less than 10% was reached. The average culm height was 3 m and the average culm diameter was 2 cm. In order to get the most homogenous fibers, samples with different lengths have been cut from culms, avoiding nodes. Only fibers from internodes have been tested. Finally, after vibrating the concrete mix, aimed at improving compactness and adherence of blocks to formworks, the samples have been left for 28 days in a humid environment, so as to promote their curing and hardening.

Fig. 1 Cubic and cylindrical samples for the laboratory tests

To assess the mechanical properties of these bricks, tensile tests on single fiber have been performed, as well as compression and tensile tests on the whole block. All these mechanical tests have been performed at the Laboratories for Testing Materials of the SAFE School of the University of Basilicata (Potenza – Italy) by using a Galdabini PMA10 universal testing machine.

Tensile test on *Arundo donax* fibers

Within the present experimental tests, fibers obtained from the trunk of plant - cut and treated so as to obtain homogeneous shape and size, preferentially between 3-8 cm long - have been examined by tensile test (Fig. 2). The preparation of the fibers to be subjected to tensile tests has been performed according to ISO 22157:2019 [16], respecting the relevant requirements: the cross-section of the samples is almost rectangular, with a width equal to around half the thickness; the span between the anchors is between 50 mm and 100 mm; the anchorage has prevented the samples sliding and crushing.

The tensile tests have been carried out using a maximum 2.5 kN load cell, and is equipped with an internal optical drive that read the displacement. The lower head of the machine is fixed, the upper head is stretching along the axis of the fiber (Figure 2).

Fig. 2 Tensile tests on *Arundo donax* fibers: front view (left) and side view (right)

The sample is fixed to the grips, which exercises a pressure that can be adjusted using a pressure gauge. The tests have been carried out in displacement control, with a loading speed of 2 mm/min (which has been estimated as the right compromise according to the stiffness and size of the sample) and a frame acquisition frequency of approximately 1/700-1/800 ms. All the 10 tested samples – each one having a variable free length of 3-8 cm – have been fixed to the grips of the machine, removing the slack without stretching the sample and making certain that the sample was well aligned and straight within the grips and in the line along the applied load to the fiber, since any misalignment could produce a transverse/torsion movement of the grips, hence introducing errors in the measurement of elongation and contributing to the premature failure of the fiber.

During the tensile tests, failures occurred at the anchorages in some samples. This means that the samples are not subject to a perfectly centred normal deformation but that a certain bending moment component was present. This is essentially due to the low load of these samples and therefore to a lack of sensitivity of the machine to low loads. Most of the samples, on the other hand, have showed a perfectly centred normal deformation with failure in the center or at least away from the anchorages (Fig. 3), so only these samples have been taken in consideration for the experimental analysis.

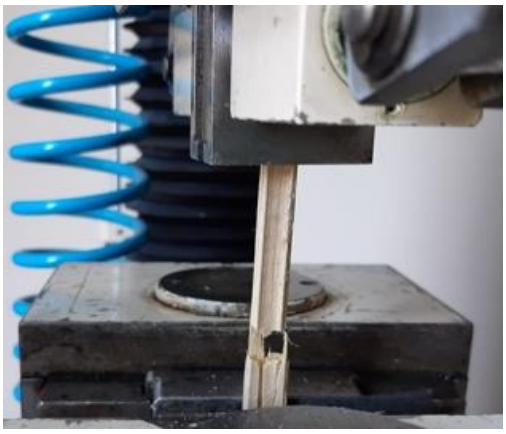

Fig. 3 Tensile test on *Arundo donax* fibers: fibre breaks in the centre

Compression test on cubic samples

After the setting and hardening period (28 days), for each typology of cubic sample, the mechanical behavior of the bricks has been measured by placing them between the rigid steel plates of the testing machine and testing them of unconfined compression strength through displacement controlled uniaxial tests (Fig. 4). This testing machine consists of two columns high stiffness frame, with maximum vertical daylight between platens equal to 185 mm, horizontal daylight between columns of 175 mm, platens diameter equal to 153 mm, ram travel of approximately 45 mm and 2 pressure transducers. The upper frame is fixed, while the lower frame is free to move and compresses the sample.

Fig. 4 Compression test on a concrete brick reinforced with natural fibers

The frames are equipped with a safety device that interrupts the test after breaking the sample, to prevent damage to the accessories used during the tests. A uniform load has been progressively applied without shock, and it has been continuously increased until failure, with the moving head of the testing machine traveling at a rate of 1 mm/min. [17].

Split tensile test on cylindrical samples (Brazilian proof)

A split tensile test - also known as the Brazilian test – has been carried out with the testing machine as well, then involving longitudinal compression along two diametrically opposed generating lines of the cylindrical sample, in accordance with UNI EN123-90-6 [18] (Fig.5).

Fig. 5 Tensile test on a cylindrical concrete brick reinforced with natural fibers

In this case, in the diametrical plane containing the load line, a tension representative of the tensile strength of concrete is generated in the orthogonal direction. The test has been performed on a cylindrical concrete brick by placing the sample with the horizontal axis between plates of a press and compressing them according to two opposite generators, according to UNI EN 123-90-6 [18].

3. RESULTS AND DISCUSSIONS

Tensile test on *Arundo donax* fiber

In Table 1, the tensile properties of *Arundo donax* fibers are reported in terms of average value, with the corresponding 95% confidence interval [16].

Table 1 Tensile strength of the *Arundo donax* fibers experimentally tested

Load (N)	Tension [N mm-²]	Elongation [mm]	Yield Point [N mm-²]	Young Modules [GPa]
2008	133.89±0.33	7.94±0.045	131.76±0.45	2.53±0.0072

In figure 6 the diagram elongation/load for the *Arundo donax* fiber is reported. The mechanical behavior of *Arundo donax* fibers appears to be very interesting, especially because its tensile strength is considerably high before the yield point. Just as a reference, the corresponding value for an ordinary steel used for building, is around 400-700 N mm-²

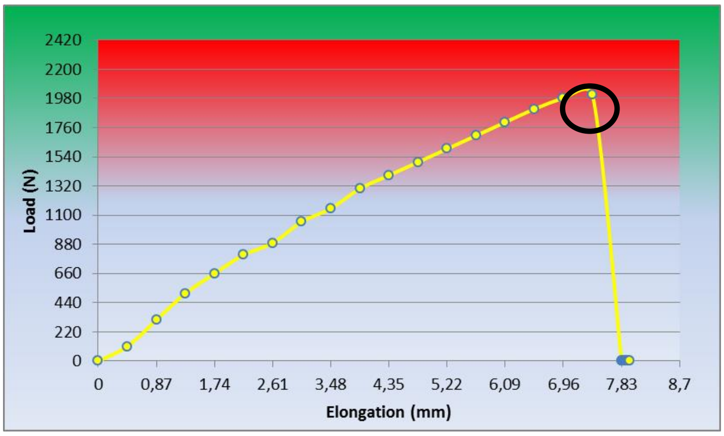

Fig. 6 Elongation/load diagram for the tensile test on *Arundo donax* fiber

This tensile strenght value is more important even if compared with other different natural fibers which have showed, indeed, lower tensile strength and deformation properties as in the case of Spanish broom [19]. In this last case, from the laboratory tests, an experimental mean value of the tensile strength equal to about 41.53 N mm-² (Natural sprig) and 36.62 N mm-² (rope) have been detected, with a high standard deviation depending on the natural variability of the fibers. Indeed, this value difference depends on several factors, such as the fiber origin, the production process, the environment of origin, the part of the fibre considered, *etc*.

Moreover, the value obtained is in line with the value obtained by Spatz et al. [20] who carried out tensile tests on parts of internode of length equal to 150 cm. They calculated the average elastic modulus of the epidermis for internodes extracted in the central part and at the base of the culm of about 10 Gpa. In the case under examination, considering a length of 15 cm, the value obtained has been2.53 GPa.

Compression strength on cubic concrete samples

In table 2 the results of compression tests on the four different types of cubic concrete sample are reported while figure 7 reports a tension/deformation diagram for the samples experimentally tested.

Table 2 Compressive strength of the different concrete bricks experimentally tested

Vegetal fibers	**0 [%]**	**0.2 [%]**	**0.6 [%]**	**1 [%]**
Maximum applied load (N)	554, 000	389, 000	386, 000	369, 000
Deformation	1.87	1.83	2.2	2.85
Maximum compressive strength (Mpa)	55.4	21.9	17.1	16.3
Tension σ (Mpa)	4.10	2.88	2.86	2.73
Elastic modulus E (Mpa)	2.19	1.57	1.3	0.96

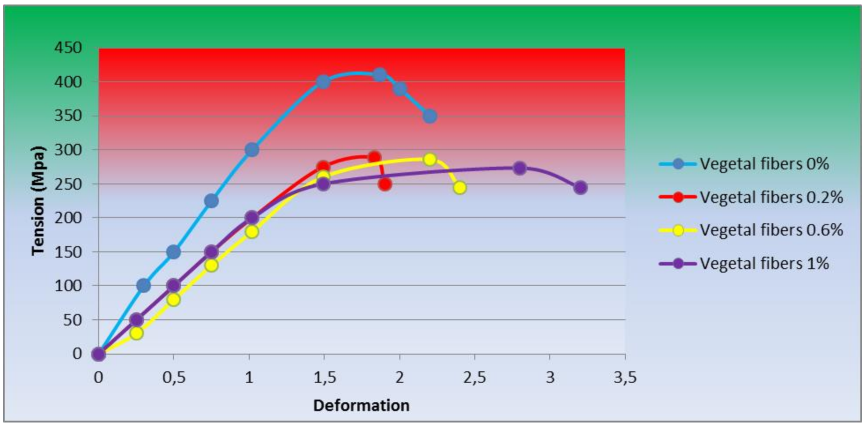

Fig. 7 Tension/deformation diagram for the compression test on cubic samples considered

From the results analysis (Table 2) it can be deduced that the value of the compressive strength of the sample with concrete only, reflects the literature values (typically 30-60 MPa). As we imagined, adding different amounts of fibers (samples 2, 3 and 4) has led the value of compressive strength to decrease so worsening this resistance value.

Directly proportional to the tension is *the "modulus of elasticity"* (or Young's modulus) which represents the stiffness of the material. The lower its value, the lower the stiffness of the sample, then indicating that the material can deform easily.

From figure 7, indeed, it can be noticed that the behavior of this material is almost elastic in the first phase, followed by a very limited plastic phase that quickly precedes the definitive failure of the cubic sample. From the results obtained through the present experimental tests, it can be concluded that further analysis should be performed, aimed to the definition of optimal percentage of natural fibers, also taking into account the length-to-thickness ratio. Indeed, natural fibers, even due to their increased aspect ratio (length/diameter) compared to non-fibrous filler, usually improve the mechanical properties of composite materials [21].

Split tensile test on cylindrical samples (Brazilian proof)

In Table 3 the results of split tensile tests on the four different types of cylindrical concrete sample are reported. The tensile strength values are in line with the values provided by the Technical Standards for Construction, in which the strength of the generic sample is calculated using the (1):

$$\text{Tensile Strength} = (2*F)/(\pi*L*d) \qquad (1)$$

where "F" is the break load, "L" is the sample length, "d" is the diameter of the cylindrical sample.

Table 3 Tensile strength of the different cylindrical samples experimentally tested

Vegetal fibers	**0 [%]**	**0.2 [%]**	**0.6 [%]**	**1 [%]**
Maximum applied load (N)	37,100	20,800	37,500	55,400
Deformation	0.71	0.2	0.69	1.07
Tensile strength (Mpa)	1.6	0.9	1.6	2.04

Figure 8 reports a tensile strength/load applied for the sample 4 (1% of *Arundo donax* fibers), which shows the direct proportionality between the two parameters (elastic phase) before the sample breaks. The analysis of the results reported in table 3 shows the limit from which an increase in tensile strength can be appreciated following the addition of natural fibers: up to a fiber percentage of 0.6% weight (sample 3) there is no improvement in tensile strength, whereas from 1 % onwards (sample 4) the tensile strength also begins to increase in an interesting way, if we consider the narrow range of difference between the various fiber percentages.

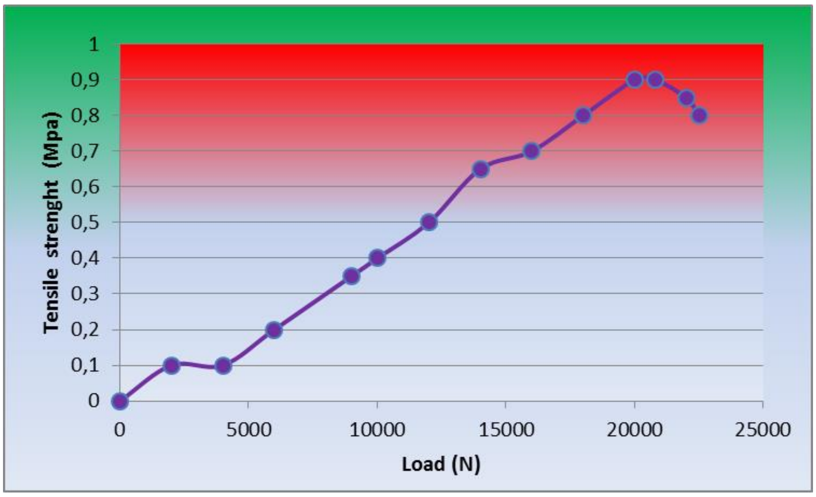

Fig. 8 Tensile strength/load applied diagram for the cylindrical sample number 4.

4. CONCLUSIONS

The experimental tests performed in the present work have confirmed that the compressive strength of the concrete does not benefit from the addition of fiber in any of the three cases. However, some interesting novelties could be deduced concerning the tensile properties. The fiber has a very high tensile strength, especially when compared to other natural fibers such as *Spanish broom*. Moreover the longitudinal elasticity modulus is in line with literature values. As a direct consequence, the indirect tensile tests (Brazilian test) carried out on cylindrical samples of concrete have showed an improvement in the tensile strength of the samples, which starts from a threshold value: from 0.6% in weight of added fiber, there is an increase in strength resistance, as well as the Young's modulus increase. Much more tests are anyway needed in the future, with different percentages of added fiber to reach values comparable, at least as a scale, to the stiffness of steel.

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REDUCTION OF PLANT WEIGHT LOSS IN THE PROCESS OF HAY BALING USING WATER STEAM

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Abstract: *Hay is a bulky part of the meal that is most often used in the winter period of the year in all types of ruminants, while the role of hay in the meal of high-milk cows is invaluable. The most common way to produce hay is to dry the cut grass on the surface of the land in the field, using the energy of the sun. In the process of hay production, there is a reduction of nutrients in relation to the green mass, where the achieved yield and quality of hay largely depends on the technological operations that are performed during storage. In the baling process, the dried mass is exposed to the mechanical treatment of the working elements of the press, as a result of which the leaf mass decreases. Loss of leaf mass, which contains a large amount of nutrients, can greatly affect the achieved yield and quality of the obtained hay. One of the possibilities to reduce losses is the application of "DewPoint" technology, which involves the use of water vapor in the baling process. The steam produced by the device is injected into the mass-hay after lifting by the pickup device and further until the mass enters the pressing chamber. Mass treatment is achieved by injecting steam through a series of nozzles located inside the press. Water vapor is an extremely efficient medium for the controlled hydration of hay during the baling process, where approximately 450 l of water vapor can be produced from 1 l of water. By applying this technology, water consumption is 5-7 l per 1 t of hay, producing 2250-3150 l of water vapor. This amount of steam enables efficient treatment of individual plants (tree, leaf) in a mass of 1t to the desired humidity level.*

Keywords: *: hay quality, baling, losses, water vapor, hydration*.

1 INTRODUCTION

In the total livestock production, special importance is given to the production of so-called bulky fodder (green mass, hay, haylage - silage, by-products of industrial food processing, etc.). Adequate amount of quality bulk fodder is one of the important factors that greatly affect the stability and productivity of modern livestock production [15,17,5]. Quality hay is an almost irreplaceable bulky food in the winter for all types of ruminants as well as horses [33,30]. The nutritional value of the plant mass depends on the type of plants and the phenophase in which the plant is at the time of harvest, while the yield and quality of the obtained hay largely depends on the process during hay storage and applied agrotechnical measures [8,4,1,31] .

In the process of preparing hay, the main goal is to preserve as tender parts of the plant as possible, such as leaves, flower buds. The reason for this is certainly the content of nutrients that are most abundant in these parts [32,3]. Alfalfa hay contains about 70% protein and about 90% carotene in the leaves, which fall off very easily in the dry state [33,12]. In the process of hay production, the most critical phase is in the period when the moisture content of the plant mass falls below 40%, after which there is a loss of mass with falling leaves, and thus a decrease in nutritional value [29,27,14,6].

Hay in a loose state is difficult to transport and store with the inevitable occurrence of losses. At the same time, hay has a small bulk density, so the utilization coefficient of means of transport is quite low with a simultaneous increase in transport costs. It should also be emphasized that the procedure of hay manipulation is significantly more difficult. In order to overcome these shortcomings, the process of hay production involves the implementation of agro-technical measures of baling, which increases the bulk density of hay and significantly facilitates manipulation procedures [16,17,7].

The process of hay production implies the application of different types of machines with the aim of performing the necessary technological operations (mowing, kneading, conditioning, collecting, pressing, transport) in the shortest possible time [2,20,32,9]. The technological phase of hay baling is an operation in which the possibility of losses is greatest. At the moment of baling, the moisture content within the mowed mass is 18–20% [15,28]. With such a moisture content, individual plants within the mowed mass become very brittle, and leaves and flowers can easily fall off [18]. The baling process implies lifting the mass from the surface of the soil using a pick-up device whereby the metal fingers capture the dried mass which is further transported to the chamber in which the pressing is performed. Due to the mechanical treatment during the capture of the mass, there is a drop of leaves that end on the surface of the plot, which creates direct losses [17,19,21].

Reduction of losses in the baling process can be performed by returning a certain percentage of moisture to the dried mass, which reduces the possibility of leaf and flower loss [22,19]. In practice, this meant that the baling procedure was performed in the early morning hours when we had the appearance of "perfect natural dew" on the plot. However, in real production conditions, perfect natural dew for specific localities (plots) occurs rarely, lasts for a very short time or is completely absent. Hay producers in arid climates usually do not have enough moisture due to dew for optimal wetting of hay, while in humid climates this moisture content is often higher than optimal [19,24,11].

One of the possibilities for reducing plant mass losses in the hay baling process is the application of the "DewPoint Hay Steamer" dew simulation system [22,23,24,10]. The application of this system involves the controlled addition of water vapor (rehydration) to the dried material during the baling process [26,28]. The main purpose of adding water vapor is to increase the moisture in dry hay in order to prevent mechanical damage to the hay during the baling process. The application of this system enables the baling procedure to be performed throughout the day, regardless of the appearance of dew and with minimal losses [26,21].

2. THE ROLE OF THE "DEWPOINT" SYSTEM FOR STEAM PRODUCTION

The application of "DewPoint" technology involves the rehydration of dried plant material (hay) by applying water vapor during the hay bale process. Water vapor is an extremely effective medium for moistening the material and controlled hydration of hay. Hay treatment means that water vapor is injected into the material from the moment the mass separates from the soil surface, ie. from the moment the mass is captured by the pick-up device until the mass enters the pressing chamber. Water vapor is injected into the material through a number of special injectors that are additionally installed in the pick-up device of the press which bales the hay. During the rehydration process, the current moisture of the hay is continuously monitored and the injection rate and the amount of water vapor are adjusted depending on the current values of the material moisture. In this way, it is possible to maintain optimal humidity values of the material to be baled at all times. The production of a sufficient amount of water vapor necessary for the controlled hydration of hay on the plot itself is ensured by adding a dedicated device for the production of water vapor [26].

The device for the production of water vapor is in the form of a towed attachment machine which is added to the standard tractor-press unit. The device is aggregated for the tractor from the rear over the drawbar and placed between the tractor and the press Fig.1.

Figure 1. Position of water vapor production device between tractor and press

Figure 2. Appearance of the device pulley and PTO shaft connection

The construction of the device enables the aggregation of presses of different types, manufacturers and constructions from its rear side (Fig. 2), which achieves the universality of the application of this device. Along the device, from the front to the rear end, there is a through cardan shaft at the ends of which there are standard connections. By placing the PTO shafts between the tractor and the device and the device and the press, the torque is transferred from the tractor to the press. In this way, the operation of the press elements during the baling procedure is enabled [23].

3. CONSTRUCTION OF "DEWPOINT" SYSTEM FOR STEAM PRODUCTION

The device for production of water vapor, which is applied together with the process of baling hay, consists of support wheels and frame construction on which different types of mechanical, electrical and electronic components of the system are housed as one unit. Shown in Figure 3 [23].

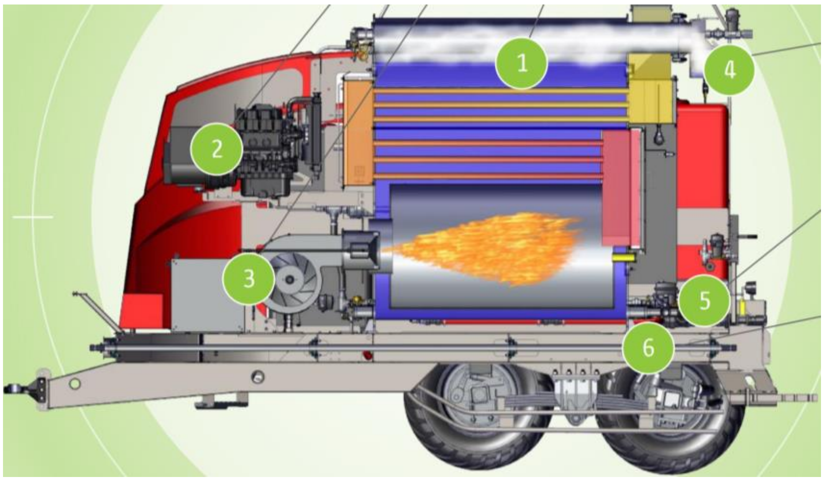

Figure 3. Scheme of a device for the production of water vapor: 1- Boiler :, 2- Generator, 3- Burner, 4- Steam valves, 5- Feed water system, 6- PTO Shaft, 7 - Tires, 8 - Fuel Tanks, 9 - Water Tanks [26]

The basis of the device for steam production is the boiler (fig. 3 position 1). The boiler is designed and adjusted so that it enables maximum efficiency of heat utilization at low pressure. Exhaust gases that occur as a product of burner combustion are directed towards the steel pipes through which the water moves. The flow of combustion products over the surface of the pipe heats the water. The water is heated up to the temperature when the physical state changes from liquid to gaseous, as a result of which the water turns into steam.

Generator (fig. 3, position 2), is an electrical device that converts the mechanical energy into electrical energy that is used to power all the electrical components of the machine. The generator is powered by a separate internal combustion diesel engine.

The burner (fig. 3, position 3) represents a heat source that leads to heating of water and transition to water vapor. The most commonly used burner is diesel fuel burner. In this type of burner the combustion of a mixture of diesel fuel and air is performed in a special chamber, which releases heat, which is then used to heat water.

Steam valves (fig. 3, position 4) are located on the lines located at the outlet of the boiler from where the steam is further delivered to the pick-up device. Solenoid valves are connected by electrical lines to the control unit located in the tractor cab. The action of the valve controls the flow and selects the position of application of water vapor produced in the boiler.

The water supply system (fig.. 3, position 5) allows a constant water pressure inside the boiler system. With the production of water vapor and its application in the process of hay rehydration, a part of the liquid (water) inside the heating system (boiler) is consumed and disappears. Continuous production of water vapor in the system requires the addition of a certain amount of new liquid in order to keep the set pressure inside the system constant.

Cardan shaft (fig. 3, position 6) is placed along the device for the production of water vapor. At the ends are standard PTO shaft connections. The task was to transfer the torque from the tractor to the press, which enabled the drive of the working elements of press and the baling procedure.

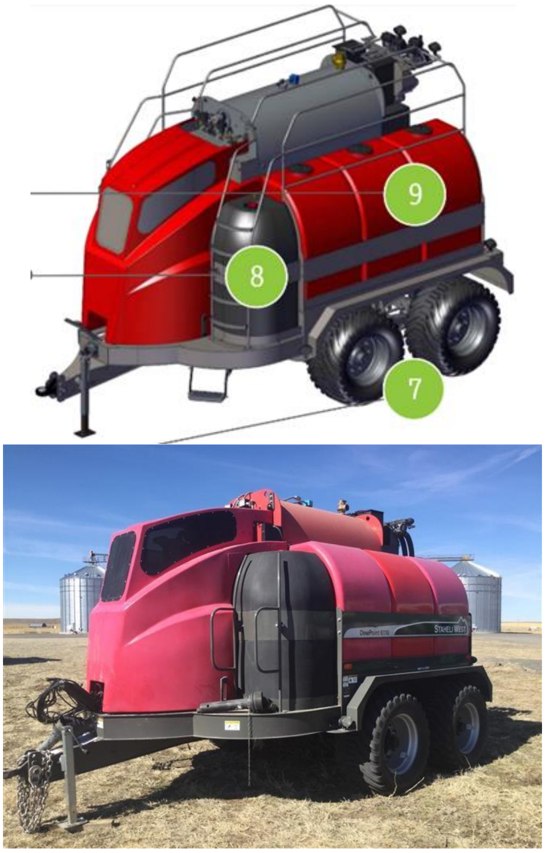

Figure 4. Water vapor production device: 7 - Transport system; 8 - Diesel fuel tank; 9 - Water tanks [26]

Considering that the device for the production of water vapor is in the form of a towed tractor attachment, the role of the transport system in figure 4, position 7, allows the device to move during operation. A system of double axles was applied in combination with specially designed radial flotation tires, which reduced plant damage and soil compaction. On the front of the device is a tank (fig. 4, position 8) for diesel fuel which is necessary for burner operation and water heating. Consumption of diesel fuel in average operating conditions is 1.9 l per ton of baled hay. The water used as a medium for the production of water vapor is placed in a separate tank (fig. 4, position 9). Depending on the crop yield, the amount of steam produced and the specific conditions in the field, the operator can bale between 0.8-1.2 ha with a water consumption of 3600 l [23].

Inside the tractor cab, there is a control unit that is connected to the electronic components of the device via electrical lines. The control unit enables continuous monitoring of operating parameters as well as control of system operation. The system of management and control of operating parameters is based on PLC technology [25].

Figure 5. Control unit installed in the tractor cab

The screen of the control unit is touch-sensitive, which allows the operator complete control and adjustment of operating parameters during operation. A large number of operating parameters can be monitored on the screen of the control unit at the same time, which simplifies the control of the entire process.

4. WATER VAPOR DISTRIBUTION IN THE HAY REHYDRATION PROCESS

The steam treatment of the material is performed from the moment of capture and lifting of the mass by the pick-up device until the mass enters the pressing chamber. Within the pick-up device of the press, it is necessary to make a modification, adding dividers through which water vapor is injected into the material, etc. 6. Water vapor obtained by heating water in the boiler of the device is transmitted by elastic lines (fig. 2) to the distributor in the press where further distribution performed. There is a valve on each of the steam lines. The main task of the valve is the continuous regulation of the amount of water vapor that is delivered to the individual distributors during operation. With the command from the tractor cab, the operator controls the operation of the valve by adjusting the amount of water vapor that passes through each of the distributors. The operation of each of the valves is independent, which enables the adjustment of the amount and zone of action of water vapor on the material in specific operating conditions [26].

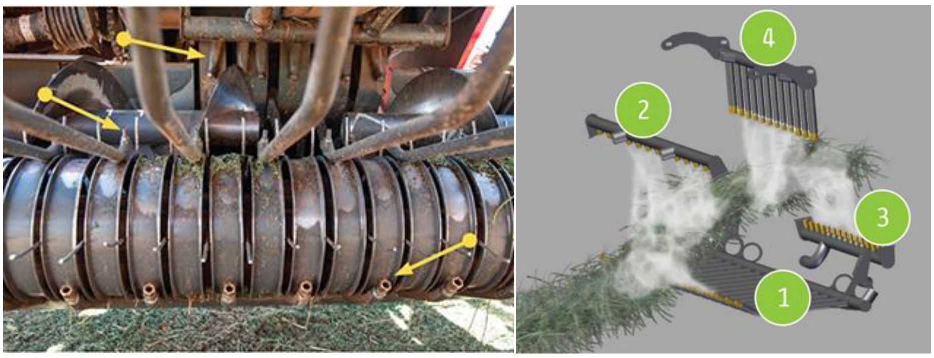

Figure 6. Position of the water vapor distributors [26].

In order to improve the quality of work of the device for rehydration of hay and adaptation to specific conditions, which may differ from plot to plot, a device for measuring moisture can be added to the existing system (fig. 7). The basic function of this device is to continuously monitor the moisture content of the material during the baling process and to provide additional information to the operator. In this way, it is possible for the operator to adjust the speed and amount of water vapor injection during operation in order to maintain optimal moisture conditions in the material at all times.

Figure 7. "Gazeeka" Device for measuring the humidity of the material installed on the press [34].

The non-contact device for measuring the humidity of the manufacturer "Gazeek" is installed at the outlet of the chamber in which the hay is compacted and the bale is formed. The device consists of transmitters and receivers that are installed on opposite sides of the chamber. The transmitter generates and sends a beam of microwave energy through the formed bale to the receiver of the device. Microwaves are sent through the bale 50 times per second. The water molecules in the hay slow down the speed of microwaves and absorb some of the energy sent. The receiver on the opposite side collects microwave energy that the bale has not absorbed. This information is compared with the amount of energy that is emitted. Based on the obtained information on the transfer rate and the absorbed amount of energy, the device determines the value of the moisture content of the material with an accuracy of 0.5% [34].

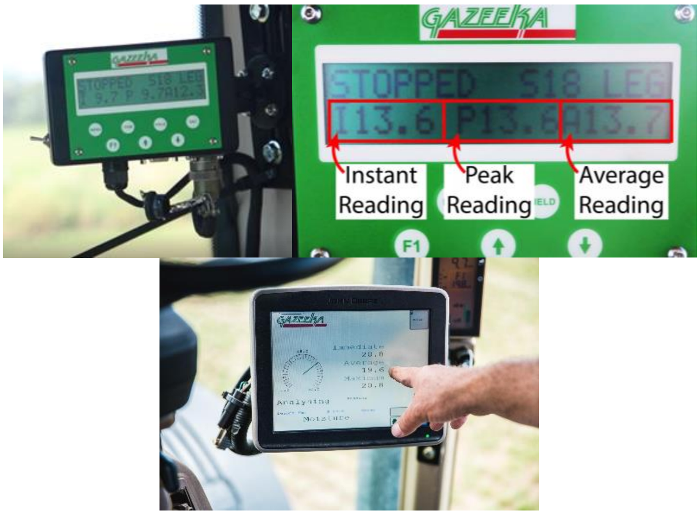

Figure 8. Gazeeka device display [34].

An additional display of the "Gazeek" device is placed inside the tractor cab, on which the value of the humidity of the material passing through the press can be read at any time. The device displays values that are read at 5 second intervals. In addition to the read current value, the device has the ability to simultaneously display the maximum and average values of moisture read in the material to be pressed (fig. 8). The humidity of the bale is continuously monitored and based on the read values. Operator is given the opportunity to precisely adjust the operating parameters of the device for rehydration of hay and maintain optimal humidity. In addition to the visual display of values, the device has the possibility of an audible warning if the humidity value is above or below the set value [34].

5. CONCLUSION

For decades, hay producers have been facing the problem of large losses of plant mass, especially leaves in the process of baling hay. Returning a small amount of water to the dried mass can greatly reduce losses. Some producers perform the baling process until the mass is completely dry (humidity above 20%), while other baling procedures are performed in the early morning hours when there is dew in the field. Baling a mass with a higher water content is risky, while the appearance of dew in nature is often absent during the summer. One of the possibilities for reducing losses is the application of "DevPoint" technology, which involves the use of water vapor in the process of baling hay. The application of this technology allows producers to bale hay at any part of the day whenever the mass is dry enough, without having to wait for the appearance of natural dew. Studies have shown that controlled steam application in the baling process can reduce leaf loss by 58% compared to baling performed when the hay moisture content is below 18%. By reducing leaf losses, the achieved yield and the quality of the obtained mass are greatly affected.

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THE IMPACT OF ADJUSTMENT OF VACUUM PLANTER ON PLANT EMERGENCE AND YIELD

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Abstract: *The correct adjustment of vacuum maize planter has a great effect on plant emergence and growth. Two filed trials were executed in 2020 using vacuum maize planter Amazone ED 4500. In the first trial we adjusted five different planting depths, namely 3 cm, 4 cm, 5 cm, 6 cm and 7 cm. Daily emerged palnts were counted. Later the distances between plants in the row were measured and at the end also the grain yield. In the second trial we combined the pre-seed soil cultivation with rotary harrow using 540 and 1000 rpm and the use of clod remover in the vacuum palnter. Alsi in this trial similar parameters were monitored as in the trial with the planting depth. The results of both trials will be presented in this article.*

Key words: *vacuum planter, adjustment, plant depth, clod remover, emergence, grain yield.*

1. INTRODUCTION

Most agronomist agree that 5 cm planting depth is optimal for maize establishment in northern latitudes. A shallower planting depth , less than 3,8 cm may lead to early season root lodging associated with shallow nodal root development or injury from pre-emergence herbicides. In addition, shallow planting depth (< 3,8 cm) when soil conditions are dry could result in drying out the seed, thereby reducing emergence or delaying emergence until precipitation alleviates the dry soil conditions. Planting deeper than 5 cm may delay emergence, especiallly when planting under cool conditions in April or early May. Also planting deeper than 5 cm may reduce emergence because of crusting problems, especially on heavier clay soils, or pest problems, associated with the delayed emergence as well as plant populations at the emergence 1..

The objective of the research was to establish the influence of planting depths, soil preparation with rotary harrow and clod remover by the planting machine on plant emergence and maize yield.

2. MATERIALS AND METHODS

In year 2020 we conducted two field trials with planting maize on moderate heavy soil in Globodol, Slovenia. In first trial we tested 5 different dephts, namely 3 cm, 4 cm, 5 cm, 6 cm and 7 cm. The depth of planting we adjusted on 6-rows vacuum maize planter Amazone ED 4500. The soils were two times pre-seed cultivated with rotary harrow Amazone KE 3000.

In second trial we tested soil cultivation with rotary harrow using 540 and 1000 rpm and clod remover in the vacuum planter. The planting depth was 5 cm by all treatments.

All agrotechnical operations were conducted with principles of good agricultural practice. Plowing was carried out with a 4-furrow reversible plow in February 2020. Before tillage, we applied NPK 7-20-30 fertilizer at a dose of 500 kg / ha. The soil was treated with a rotary harrow in two passes before planting. Planting was carried out at a speed of 7.5 km / h on April 20, 2020. A hybrid P 9757 FAO 390 was used. The planting density was 80,000 grains / ha or 16.7 cm between plants.

In both experiments, after planting, the emergence of plants was determined daily for a period of 7 days after planting to 27 days after planting by counting the emerging plants at a distance of 16.7 m. At a distance of 16.7 cm, we picked the maizecubs by hand, dried them in the dryer, and machine-extracted the grains. The grains were weighed with a Kern digital scale. In addition, we measured the grain moisture with a HE 50 meter, Pfeuffer. Thus, we calculated the yield with 14% moisture. There were three repetitions at each treatment. Data were presented in the form of tables and graphs. Statistical differences were presented by the Duncan test at a 5% risk level. We used the Statgraphics Centurion software.

3. RESULTS AND DISCUSSION

At a planting depth of 3 cm first emerging plants appeared only 10 days after planting date. Emergence means 50 % of plants emerging through the soil surface. The earliest emergence (50%) occurred at a planting depth of 7 cm, 18 days after planting (Fig. 1). A day later, emergence was achieved at planting depths of 3 cm (71%) and 6 cm 56%). The latest emergence was achieved 20 days after planting at depths of 4 cm (69%) and 5 cm (66%).

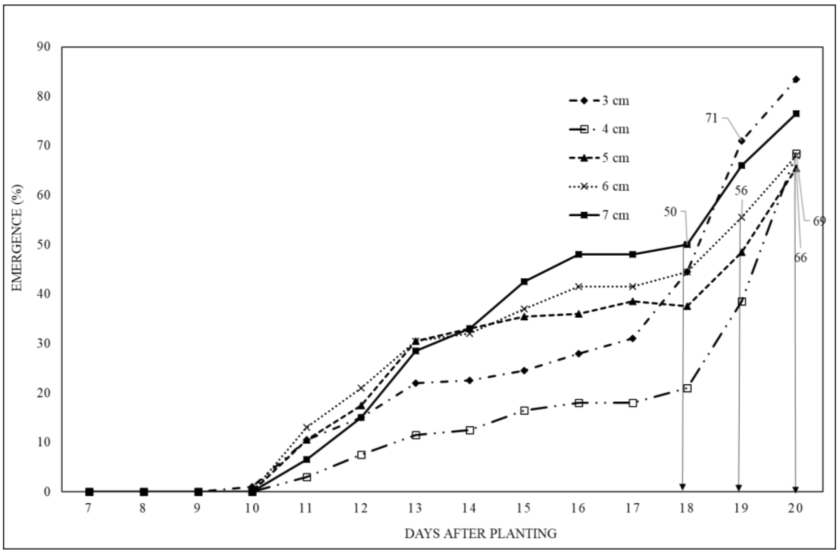

Fig. 1 Plant emergence at different planting depths

To better illustrate the effect of the set planting depth on emergence, the sum of emergence was calculated in the period 18 days after planting. Thus, we can better see at what planting depth, the emergence of plants was greatest. The highest sum of emergence was at a planting depth of 7 cm, namely (272%) (Fig. 2). A similar sum (261%) was achieved at a planting depth of 6 cm. At a planting depth of 4 cm, the lowest sum of emergence in the period of 18 days after planting was reached, namely 108%. This is followed by a planting depth of 3 cm with 199% and a planting depth of 5 cm with 239% of emergence.

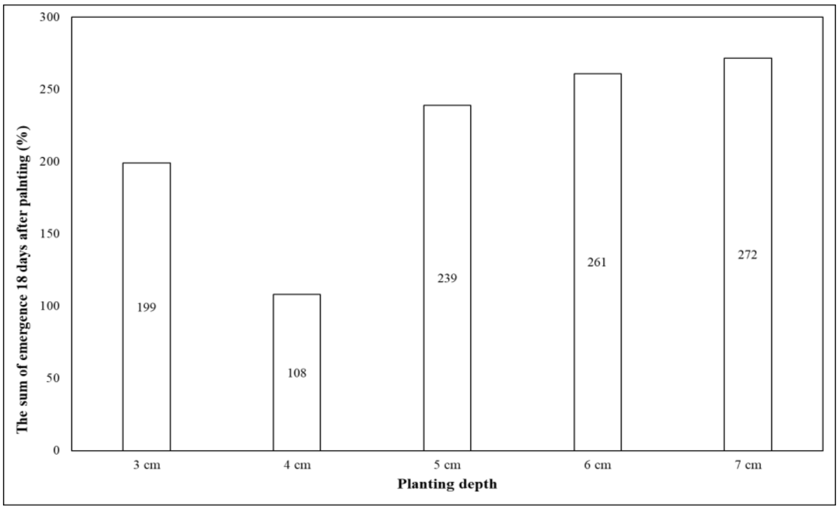

Fig. 2 The sum of emergence in the period 18 days after planting

In the period of 21 to 27 days after planting, emergence stopped at the maximum value. It ranged from 79% at planting depths of 5 and 6 cm. At planting depths of 3 cm it was the highest and amounted to 87%, and at a depth of 4 cm 86% (Fig. 3). 1.states that planting depth should be shallower on heavier soils but not always as indicated by 5 cm and 6,3 cm depths having the greatest plant populations beacause of dry conditions. 2.5 cm planting depth is to shallow because of dry soil conditions or can result in herbicide damage to the shallow planting seed.

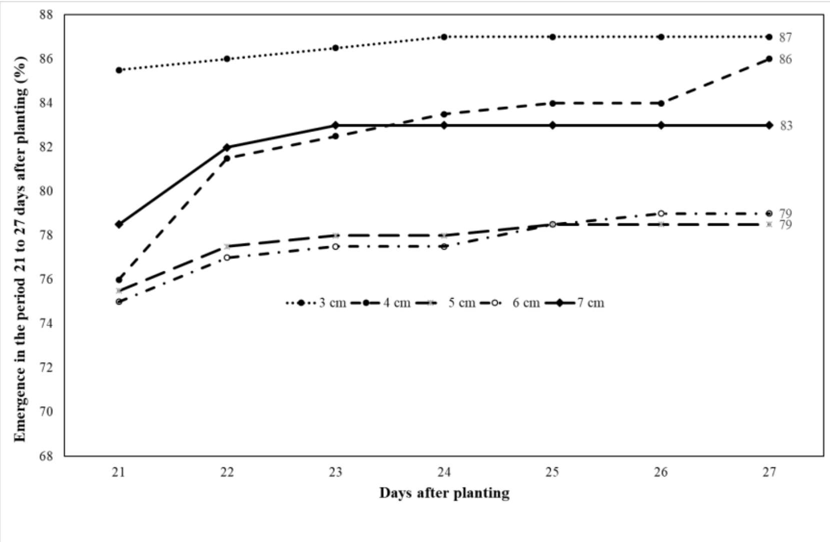

Fig. 3 Plant emergence in the period of 21 to 27 days after planting

There were no significant differences in grain yield between planting depths (Fig. 4). The results show that the plant emergence ultimately had no effect on grain yield. At planting depths of 5 cm and 7 cm, the yield was around 13900 kg/ha. Based on the yield results, we can conclude that the planting depth of 3 cm is to shallow despite the rapid and high emergence. Despite the fact that there were no statistical differences in yield, the yield at planting depth of 4 cm was very high (14,913 kg/ha), despite poorer emergence in the period of 18 days after planting.

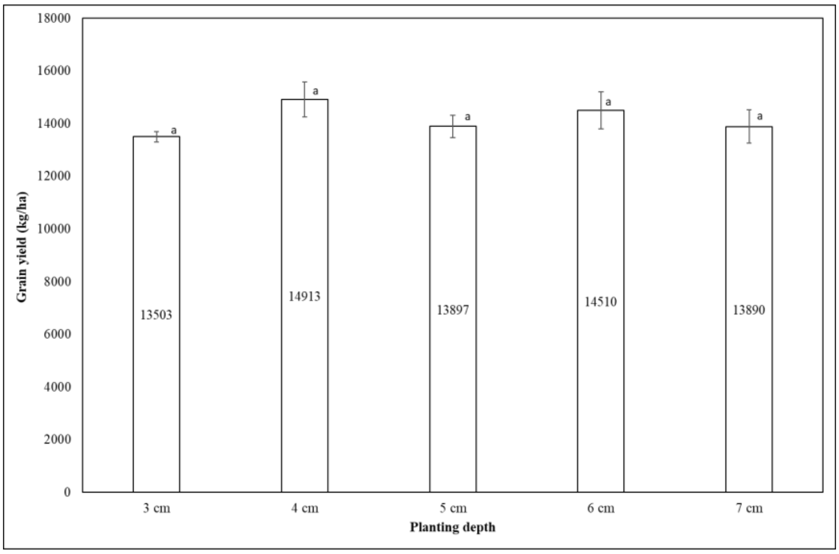

Fig. 4 Grain yields at different planting depths

2. stated that germination was similar at about 85% for planting depth of 3.8 cm and 6.4 cm. Shallow planted seeds are more likely to produce stunted plants with poor root development in comparison to deeper planted seeds. Consequently, the yield of the crop planted at a shallower depth (3.8 cm) was consistently lower during all years of study. 3. states that planting at 5.1 cm resulted in the highest overall yield from 2016 to 2020. However optimal planting depth per location ranged between 3.8 cm and 7.6 cm, depending on field conditions. Planting at 2.6 cm resulted in an average 800 kg/ha lower yield. On the other hand, planting at 8.9 cm resulted in an average 500 kg/ha yield loss. 4. found out that planting depth affected yield in a higher organic matter field, but had no effect in a lower organic matter field. 5,6. stated that deeper planting (6.4 - 7.6 cm) was favorable for emergence rate and uniformity when temperatures after planting were warm, but was unfavorable in one year of the study when temperatures were colder. 7. reports that maize should never be planted less than 3.8 cm, because too shallow planting can hamper nodal root development by placing crown too close to the soil surface.

In the second experiment, we considered the impact of tillage with a rotary harrow (540 and 1000 rpm) and the use of a clod remover on a maize planter (with and without). In most treatments, more than 50% emergence was achieved on the 20th day after planting. The highest emergence was in treatment 540 rpm with clod remover (76%), followed by 1000 rpm with clod remover (61%) and 1000 without clod remover (57%). The lowest emergence wasat treatment 540 rpm without clod remover (43%) (Fig 5).

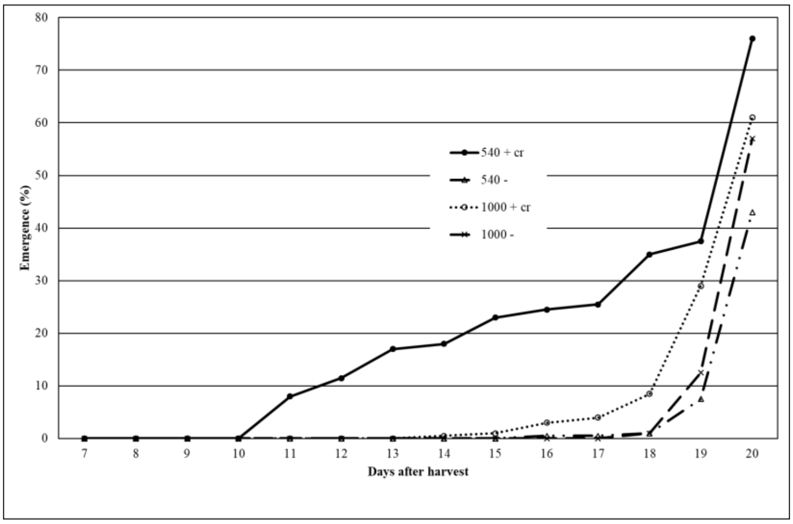

Fig. 5 Emergence at two different rotary harrow speed and usage of clod remover

A more accurate picture is given by the sum of emergence 18 days after planting, where we see that without the use of a clod remover the sum of emergence is lower (Table 1). The highest difference occurs between treatment 540 with clod remover (276%) and 540 without clod remover (53%) treatment, which is very large. Between 1000 with (107%) and 1000 without (71%) treatment, this difference is smaller. 27 days after planting, the matter changes as there are no major differences in emergence between treatments. Apparently, the clod remover and tillage have the greatest impact until the period when 50% is emerging (18 days after planting), but later this difference is no more (27 days after planting).

Table 1: The sum of emergence 18 days after planting (%) and emergence 27 days after planting (%)

Treatment	The sum of emergence 18 days after planting (%)	Emergence 27 days after planting (%)
540 + cr	276	84
540 -	53	88
1000 + cr	107	82
1000 -	71	85

Legend:
540 + cr = 540 rpm of rotary harrow and use of clod remover on the planter
540 - = 540 rpm of rotary harrow and no use of clod remover on the planter
1000 + cr = 1000 rpm of rotary harrow and use of clod remover on the planter
1000 - cr = 1000 rpm of rotary harrow and no use of clod remover on the planter

Figure 6 shows the grain yields at different treatments. In the treatment, where the soil was treated with 540 rpm and a clod remover was used on the planter, the highest yield was 15,414 kg / ha. In all other treatments, the yields were similar, and there were no differences between them. For stronger conclusions, the trial should be repeated in the following years. There is little research on the use of a rotary harrow and a clod remover when planting maize. 8. reports that planting depth of 3.8 cm to 5 cm is a fairly all purpose range that works well in most situations. Newly planted maize starts imbibling moisture in the first 24 to 48 hours after planting. So it is important to adjust planting depth to the conditions on the field. He also states that a dense surface crust can impede penetration of the seedlings coleoptile whether the seed was planted 3.8 cm deep or 7.5 cm deep, if the crust develops shortly after planting.

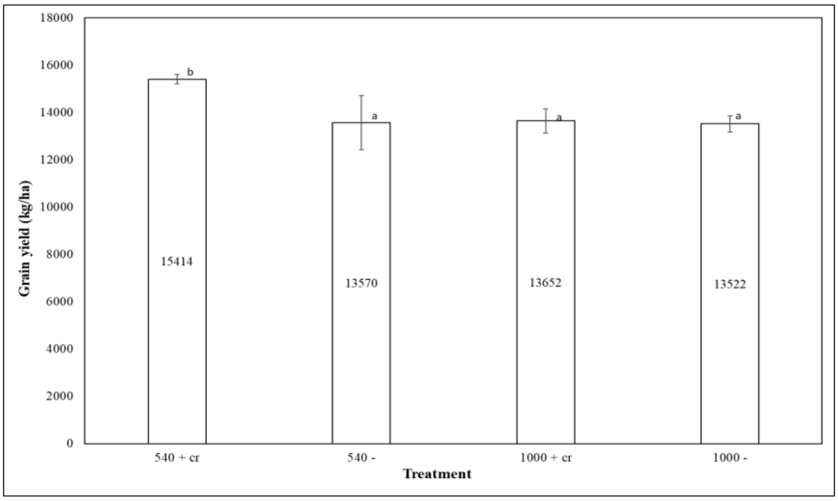

Fig. 6 Grain yield at different treatments

4. CONCLUSIONS

In both trials we came to the following conclusions:

- When planting at the depth of 7 cm the fastest emergence apperared (18th day after planting)
- The latest emergence date was at the planting depth 4, 5 and 6 cm (Day 20 after planting).
- No differenes were noted in yield at the 14 % moisture between different planting depths.
- When plot was cultivated with 540 rpm of rotary harrow and clod remover on maize planter was used, the highest plant emergence (76%) was achieved 20 days after planting.
- By the treatment 540rpm with the use of clod remover higher grain yield appeared than in other treatments.

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WORKING HOUR DEMAND OF THE MECHANISED FIELD TOMATO PRODUCTION CONSIDERING THE TASKS OF THE MATERIAL HANDLING

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Abstract: *This paper focuses on introducing the up to date mechanized production technology of direct-seeded canning tomato, by determining the machine operational hours needed for the production technology and for the transportation task, like input material-, and end product transport.*

The investigations prove that the number of machine operation hours of field tomato production are high. It helps that the self-propelled tomato harvester completely utilizes its annual operating hour by harvesting 100 hectares of land, which means that its utilization and specific cost is favourable.

The results of the research show that 69 % of the total machine operational hours of the logistical tasks are related to end product transport from which the transport to the processing company takes 53 %. It is followed by harvest (10.5 %) and the proportion of the working hour demand of the other material handling operations of the technology almost reaches 5 % or 1 % in some cases.

Due to the long distance transportation of the end product 74.4 % of the total machine operation hours of tomato production are related to harvesting and the connected logistical tasks. It is easily recognisable that the time of crop transport depend on the distance between the place of harvest and the processing company. This could be more time-consuming than the plant production, so the post-harvest logistics could be very important and significant.

By the very careful handling of the product the harvester does not cause much damage to the tomatoes. Much more damage is caused during transport, so it is very important to take the crop to the processing company in the shortest possible time.

Key words: *working time demand, transportation, logistics, tomato production, machine utilisation*

1. INTRODUCTION

In this paper the field vegetable production is introduced by using the production technology of the most important vegetable, tomato as examples. Tomato is one of the most popular vegetables in the world, produced on very large lands. Canning tomato is a very significant vegetable in Hungary as well, traditionally produced on more than four thousand hectares – by transplanting or direct seeding methods. (**Magó** et al. 2005)

An up to date production technology with modern power and working machines had been developed and will be introduced, which help us to determine some technical parameters of the technology. The target of the research was to convince the importance of transportation tasks and the significant value of working hours through to the input material-, and end product transport. (**Magó** 2013, 2016)

2. MATERIAL AND METHOD

The introduction of the production technology

The introduction of the machinery for canning tomato production is shown in **Table 1**. The table includes the name of operations, the applied machine for each operation and the power of the tractor they are mounted on. The table also show the operational performance of the machine unit (a tractor and a working machine). (**Erdeiné** 2020) (**Magó** 2012)

Stubble stripping with a disc harrow is very essential to work the stem remains of the fore crop into the soil and to prevent the field from weeding. Stubble stripping is followed by a semi-deep loosening of the soil and then by ploughing. The nutrient supply of soil includes the transport of suspension and spraying. Then the suspension after spraying has to be worked into the soil by a seed-bed former then the surface of the soil has to be levelled a couple of times. Then the appropriate seed-bed has to be formed. The seeds are sowed by twin-row sowing method. Mechanical weed control by using a cultivator is necessary to kill weeds between the rows at least three times during the vegetation period, while nutrient supply is also indispensable. Chemical weed control (spraying) is also necessary at least seven times during the vegetation period. Irrigation in the vegetation period is also very important in order to increase yields and to improve quality. Linear irrigation systems are applied to irrigate tomato fields.

In this technology traditional soil cultivation machines are used for preparing the surface of soil. The ACCORD MINIAIR SUPER pneumatic direct seeder is used for sowing, the LINEAR irrigation system is used for irrigation and a row fertiliser broadcaster is used for fertilising crops.

The GUARESI G-89/93 self-propelled tomato harvester – which is equipped with a unit that sorts tomatoes by their colour – is used for harvesting tomato. It lifts, cleans sorts and grades tomatoes in one operation. (**Bártfai et al.** 2009, **Kovács et al.** 2014)

Table 1: The economic figures of the operations of canning tomato production on 100 hectare

Name of operation	Machines in the technology: working machines type	Machines in the technology: tractors power	Operational performance (ha/h)	Machine operational hours
Stubble stripping	KÜHNE KNT-770-7.2	140 kW tractor	3.5	28
Semi-deep loosening	KÜHNE KML-700-3 with 3 knives	140 kW tractor	0.8	125
Ploughing	KUHN VARIMASTER 151 5T	140 kW tractor	1	100
Levelling of the surface	S-2 H/M	140 kW tractor	4.8	20
Suspension transport	DETK-115	65 kW tractor	6	16
Suspension spraying	HUNIPER HDE 3000MT/18RQ	70 kW tractor	6	16
Working in the suspension	UNIMAT 6,6	140 kW tractor	4.1	24
Levelling of the surface	NSH-3 430/550	65 kW tractor	3	66
Forming the seed-bed	RAU Terramax	140 kW tractor	4.1	24
Sowing in twin rows	ACCORD MINIAIR 12 twin-row	70 kW tractor	2.8	35
Cultivating (3 times)	ZSMK 12-row	65 kW tractor	2.4	123
Solid suspension transport	MBP 6,5R	70 kW tractor	4	25
Solid suspension spraying	RCW 5	65 kW tractor	4	25
Spray transport (7 times)	DETK-115	70 kW tractor	4.8	140
Spraying (7 times)	GAMBETTI GB EXP 1500/16	65 kW tractor	4.8	140
Irrigation	VALMANT linear irrigation system		1	100
Harvest		GUARESI G-89/93	0.2	500
Crop transport	HL 92.02 (road)	130 kW trailer		2500
Total				**4698**

The introduction of the machines of the technology

The ***ACCORD MINIAIR SUPER pneumatic direct seeder*** **(Figure 1)** is used for sowing vegetables that have small seeds (up to 4 mm). Its parts are: a blow-down-exhaust fan mounted on an axis, adjustable press wheels, a drive and sowing units (with seed discs). The shortest distance between the seeding carts can be 120 mm, but tandem carts can also be applied if necessary, then the distance between the twin-rows will be 80 mm. Coulters, which are appropriate for sowing with 65 mm row distance, can also be mounted on the sowing units. Different seed discs are used for different seeds which means that distance between seeds varies between 20 and 250 mm. Clod sweeps and wheels to compact the soil can be mounted on sowing units in order to achieve better quality sowing. (**Magó** 2015)

The GUARESI G-89/93 self-propelled harvester **(Figure 2)** is the most important machine in the ***canning tomato production technology***. It lifts tomatoes, separates them from their stem and sorts them by their colour. It is also appropriate for separating stem remains, clods, and damaged tomatoes, and to take the crop to the transport vehicle which is synchronised with the harvester. The performance of the harvester is 20-25 tons an hour if 90 percent of the tomatoes are red. The unit that sorts the tomatoes by their colour can separate 95 percent of green tomatoes from ripe ones.

The tomato bushes are lifted from the ground by moving rods and then a knives cuts the roots of the crop just under the surface of the soil. There are rollers under the lifter in order to provide better tracking of the ground and more effective lifting. The lifted bush is taken to a shaker with rods which shakes the tomatoes off their stems by its floating and circular move. Then it takes the stems to the stem wing tripper and the tomatoes to the tomato wing tripper. The stems leave the machine and are dropped on the ground. The tomatoes are taken to the lateral belt and then to the unit which sorts them by their colour. After that they are taken to another sorter and then to the synchronised transport vehicle. (**Dimény et al** 2004; **Hajdú et al** 2003)

Figure 1: ACCORD MINIAIR SUPER pneumatic direct seeder

Figure 2: The GUARESI G-89/93 self-propelled tomato harvester

3. THE RESULTS OF THE INVESTIGATIONS

The time of the machine operation necessary for the cultivation of 100 hectares was determined for machine units. (**Table 1**.)

It is conspicuous that the capacity need of transport during tomato harvest is very high, 2500 operating hours, since in this case crop was directly transported with vehicles of 15 tons of capacity to the processing company which was 80 km away from the place of harvest. Our calculations show that the crop of one hectare requires four turns from transport vehicles. The time of one turn is about 6 hours which means that 4 turns require about 25 hours.

Canning tomato production on 100 hectares require 4698 hours of machine operation. The introduced production technology consist of three tractors. One is bigger with his 140 kW power, and two smaller with 65 – 70 kW. The tractor of higher power does not have too many tasks except soil cultivation which means that its operation time is not very high. However tractors of lower power are operated for a much longer period during plant protection and harvest tasks. The operation of the self-propelled harvester is also very significant (500 operating hours). Moreover extra tractor capacity is also required during harvest because it has to draw a trailer synchronised with the harvester to collect the crop because naturally the road transport vehicle is not appropriate for moving slowly beside the harvester.

Sixty-nine percent of the total machine operational hours are related to end product transport from which the transport to the processing company takes 53 %. It is followed by harvest (10.5 %) and the proportion of the working hour demand of the other material handling operations of the technology – like 7 times of spray transport with 4.3 % and suspension-, and solid suspension transport with 0.3 – 0.5 % – are under 5 %, even under 1 % in some cases.

Due the calculations, it could be determined that the machine operation cost of tomato production technology is 1460 EUR per hectare.

4. CONCLUSIONS AND RECOMMENDATIONS

The investigations prove that the number of machine operation hours of field tomato production are high. It helps that the self-propelled tomato harvester completely utilizes its annual operating hour by harvesting 100 hectares of land, which means that its utilization and specific cost is favourable.

Due to the long distance transportation of the end product 74.4 % of the total machine operation hours of tomato production are related to harvesting and the connected logistical tasks. It is easily recognisable that the time of crop transport depend on the distance between the place of harvest and the processing company. This could be more time-consuming than the plant production.

By the very careful handling of the product the harvester does not cause much damage to the tomatoes. Much more damage is caused during transport, so it is very important to take the crop to the processing company in the shortest possible time.

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BIOMASS ASH UTILIZATION FOR SOIL AMENDMENT - IMPORTANCE OF THE PREDICTION OF PERSISTENT ORGANIC POLLUTANTS DEGRADATION PROCESSES

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Abstract: *Ash, as a by-product of combustion of various biomasses, contains a large number of substances, such as potassium, calcium, magnesium, phosphorus, micronutrients etc., which can be useful for plant growth. Therefore, it can be added to the soil to improve its properties, instead of being deposited and thus represents a problem in the environment. Since ash also contains substances that are both harmful and persistent, it is necessary to take into account both investigations in model systems and numerous experiments performed under conditions close to real, all in order to create mathematical models that could enable the prediction of the fate and behavior of such substances in the environment.*

Key words: *biomass ash, soil amendment, persistent organic pollutants, degradation, environment*

1. INTRODUCTION

High diversity and availability, as well as the advantages of biomass fuels compared to fossil fuels (low CO2 emission during combustion, lower CO- and total organic carbon emission levels), brought to the development of different combustion technologies in past decades 1.. The ash amount produced during biomass combustion (bottom and fly ashes from cyclone or filter) depends on the type of feedstock, used combustion technology and operating conditions 2.. During the combustion of agricultural biomasses, such as wheat or soybean straw, ashes with plant nutrients in relatively soluble forms (potassium, phosphorus, magnesium and calcium) are produced. It makes promising the application of agricultural biomass ashes for soil amendment. Fertilization by biomass ashes may reduce of use of artificial fertilizers 3,4.. Simultaneously, ash utilization represents an environmental challenge due to the presence of heavy metals and persistent organic pollutants such as polycyclic aromatic hydrocarbons (PAHs) and a great ash sorption capacity for various pollutants 5-7..

It is well-known that the fate of some pollutants in the environment depends on their physicochemical properties. Since water solubility, volatility, hydrophobic or lipophilic properties of various pollutants vary widely, the differences in their distribution in water systems, atmosphere and soil are significant 8.. Octanol-water partition coefficient (Kow), bioconcentration factor (BCF), persistence (P) and water solubility (WS) can be used to predict the behavior of pollutants, such as PAHs, in the environment. Kow is related to the solubility of an organic compound in water. Its use enables the prediction of the mobility of some pollutants in the environment and their sorption by soil 9.. BCF reflects the ability of contaminants to accumulate in living organisms from the surrounding environment 9.. PAHs water solubility (WS) is associated with their mobility, leaching and plant uptake 10.. The persistence (P) is related to pollutant stability in the environment 11..

When some organic pollutants enter into soil, they can undergo processes such as volatilization, leaching, chemical and biological degradation. Sorption and transportation processes may cause these chemicals to go into the soil matrix or mineral particles. As a result, these pollutants may stay in the soil for a long time, resulting in potential health or biological risks. Therefore, the extractable or total amount of PAHs may be of limited utility when assessing their environmental significance. Instead, these contaminants' fraction distribution and availability are the most important indices for risk assessment 12..

The aim of this study was to characterize bottom and fly ashes from cigar burner biomass combustion system located in Agricultural Corporation PKB, compare the environmental risk of the potential use of these ashes for soil amendment and estimate the dependence of PAHs content on time.

2. MATERIALS AND METHODS

2.1. Chemicals

LGC standard PAH-Mix 14 (PAHs concentration 2000 µg/mL) in acetone/benzene as solvent (Dr. Ehrenstorfer GmbH, Augsburg, Germany) which contains 16 priority PAHs was used.

2.2. Sample collection and storage

The soybean straw has been applied as a fuel for greenhouse heating in the Agricultural Corporation PKB for more than a decade. Around 2 kg of both bottom ash (BA) and fly ash (FA) were taken. BA was collected from the combustion chamber and FA from the cyclone of the plant. Ash samples were homogenized and stored at a dark place under a temperature below 15°C.

2.3. Determination of PAHs by LC/DAD

PAHs were extracted from the soybean ash samples by a solid-liquid extraction. For extraction of ash samples n-hexane (p.a. grade, Carlo Erba), acetone (p.a. grade, Zorka Pharma) and 18.2 MΩ deionized water were used. 5 g of ash was mixed with 90 mL of 1:1 (v/v) hexane:acetone mixture and stirred on an IKA KS130 orbital shaker with a maximum speed of 800 rpm for 90 min. After that, the mixture was filtered through Whatman No. 44 filter paper and ash was washed out several times within a total of 20 mL of acetone:hexane mixture (1:1). Then, the extract was transferred quantitatively into a separating funnel; deionized water was added. After shaking, the upper hexane layer was dried by anhydrous Na_2SO_4 (Sigma Aldrich) and concentrated up to 1 mL by a vacuum rotary evaporator (Heidolph Instruments GmbH, Germany). After that, the concentrated extract was evaporated to dryness in a nitrogen stream, 0.5 mL of acetonitrile was added and filtered by syringe filter before further analysis. To check the reproducibility of extraction, the procedure was done in triplicate.

A Thermo Fisher Scientific Dionex UltiMate 3000 HPLC system with a diode array detector (DAD) was used. Envirosep-PP 125×2 mm column, with particle size 5 μm (Phenomenex) was used. The mobile phase has consisted of 10% acetonitrile in water and acetonitrile in gradient conditions [13,14. at a constant flow rate of 0.35 mL/min. For chromatographic separations, HPLC grade acetonitrile from J.T. Baker and deionized water were used. Setting experimental conditions and analysis of experimental data was done by software Chromeleon 7.

2.4 Data analysis

Physicochemical, toxicological and ecotoxicological parameters of organic compounds can be determined using the Vega QSAR platform 15.. The Vega platform allows access to information from QSAR models. These data can be utilized to predict the behavior of some pollutants in the environment based on their structure. To facilitate the evaluation of environmental risk, PAHs were divided into groups according to their physicochemical properties (WS, Kow, BCF and P) 14..

To express the carcinogenic potential of PAHs in ash samples and estimate the risk of soil contamination by PAHs, the benzo(a)pyrene equivalent concentration (BaP_{eq}) is calculated 16,17..

2.5 Dependence of PAHs content on time

Using literature data, the prediction of PAHs concentration depending on the time elapsed after the ash was added to the soil (3, 6, 9 and 12 months) was made 18,19..

3. RESULTS AND DISCUSSION

3.1 PAHs content in ash samples

The overall PAHs content for fly ash (1.85 mg/kg of ash) is higher than for bottom ash (0.09 mg/kg of ash). This difference among ashes could be attributed to a lower temperature and higher specific surface area of fly ash comparing to bottom ash. In Table 1, the content of PAHs with different ring numbers depending on time is shown.

Table 1 Dependence of content of PAHs with different ring numbers (in ng/g of ash) as the function on time for bottom ash (BA) and fly ash (FA)

	BA				
t (months)	0	3	6	9	12
R2	2.86	1.99	1.64	1.37	1.28
R3	25.38	16.80	15.79	14.25	13.80
R4	52.56	35.96	33.38	31.74	30.79
R5	7.80	5.96	5.75	5.35	5.14
R6	0.24	0.20	0.20	0.19	0.19
	FA				
t (months)	0	3	6	9	12
R2	16.17	11.24	9.27	7.72	7.21
R3	548.32	355.56	327.99	290.17	281.23
R4	1179.65	803.67	743.77	709.63	689.05
R5	60.70	45.57	43.76	41.29	39.56
R6	45.53	38.46	37.35	36.23	35.27

As shown in Table 1, the content of 3- and 4-ring PAHs for both ashes is the highest, indicating incomplete soybean straw combustion. The estimated decrease of PAHs with different ring numbers after 12 months is the highest in the case of 2-ring PAHs (more than 55%) and the lowest for 6-ring PAHs (around 22%). The decrease of PAHs content and degradation rate is the highest in the first three months after ash addition. The most pronounced decrease in PAHs content is seen after three months from the moment of mixing with the soil for 3- and 4- ring PAHs and amounts to 34%, while their content in the next nine months decreased by an additional 11% of the initial content.

3.2 Estimation of the environmental impact of PAHs in ash samples

Monitoring PAHs content in the environment is necessary since they pose carcinogenic and mutagenic potential. PAHs are generated during the combustion of fossil fuels and biomasses. There is no single regulation defining permitted concentrations of PAHs in different types of samples (soil, water, air, food, etc.) worldwide, especially concerning the soil samples. Different countries have various regulations. Besides, in some countries, such as Serbia, monitoring PAHs content in soils (except if used for organic production) is not mandatory.

Different parameters connected to PAHs' physicochemical, toxic, and ecotoxic properties (such as Kow, BCF, P and WS) could be used to divide 16 priority PAHs into groups 14,15.. For example, the distribution of PAHs into groups (Kow1-3, BCF1-3, P1-3 and WS1-3) is shown in Table 2. Such distribution could facilitate the comparison among different ashes and simplify the estimation of their possible environmental impact and the risk assessment of their utilization for soil amendment.

Table 2 PAHs division into groups according to octanol-water partition coefficient (Kow1-3), bioconcentration factor (BCF1-3), persistence (P1-3) and water solubility (WS1-3) 14,15.; abbreviations of 16 EPA priority PAHs

Group	List of PAHs
Kow3	Nap, Acy, Ace, Flu
Kow2	Phe, Ant, Fla, Pyr, BaA, Chry
Kow1	BbF, BkF, BaP, DahA, BghiP, IP
Group	List of PAHs
BCF3	Nap, Acy, Chry
BCF2	Ace, Flu, Pyr, BaA, BaP, DahA, BghiP, IP
BCF1	Phe, Ant, Fla, BbF, BkF
Group	List of PAHs
P3	Nap, Acy
P2	Ace, Flu, Phe, Ant
P1	Fla, Pyr, BaA, Chry, BbF, BkF, BaP, DahA, BghiP, IP
Group	List of PAHs
WS1	Nap, Acy, Ace, Flu, Phe
WS2	Ant, Fla, Pyr, BaA, Chry, BbF, BaP
WS3	BkF, DahA, BghiP, IP
Abbreviations: Naphthalene (**Nap**); Acenaphthylene (**Acy**); Acenaphthene (**Ace**); Fluorene (**Flu**); Phenanthrene (**Phe**); Anthracene (**Ant**); Fluoranthene (**Fla**); Pyrene (**Pyr**); Benzo a.anthracene (**BaA**); Chrysene (**Chry**); Benzo b.fluoranthene (**BbF**); Benzo k.fluoranthene (**BkF**); Benzo a.pyrene (**BaP**); Indeno 1,2,3-cd.pyrene (**IP**); Benzo g,h,i.perylene (**BghiP**); Dibenzo a,h.anthracene (**DahA**)	

In Table 3, the content of PAHs groups formed according to their octanol-water partition coefficient, bioconcentration factor, persistence and water solubility is shown as the function of time. The content of each of these groups was determined as a sum of individual PAHs content in ng/g of ash.

According to Table 3, the downward trends of PAHs groups are similar, but there is a difference among portions of BA and FA. The average decrease in the content of Kow and WS groups after the whole year is estimated to be approximately 40% and 41%, respectively. These average reductions in the case of BCF and P groups after 12 months are predicted to be around 43% and 46%, respectively. It is noticed that the decrease in the content of PAHs groups is most pronounced after three months from mixing the ash with the soil.

Table 3 Dependence of content of PAHs groups (in ng/g of ash) made according to physicochemical parameters as the function on time for bottom ash (BA) and fly ash (FA)

	BA			FA		
months	Kow1	Kow2	Kow3	Kow1	Kow2	Kow3
0	8.04	64.88	15.92	106.23	1576.25	167.89
3	6.17	43.40	11.35	84.03	1044.23	126.25
6	5.95	40.38	10.44	81.11	969.92	111.11
9	5.54	37.94	9.42	77.52	910.27	97.25
12	5.33	36.92	8.95	74.84	887.40	90.09
months	BCF1	BCF2	BCF3	BCF1	BCF2	BCF3
0	52.24	29.06	7.54	1204.30	473.28	172.79
3	35.36	19.68	5.88	796.52	318.98	139.00
6	32.95	18.64	5.17	739.30	300.55	122.29
9	31.01	17.32	4.56	694.55	282.67	107.82
12	30.45	16.45	4.29	684.08	268.03	100.21
months	P3	P2	P1	P3	P2	P1
0	4.39	23.85	60.60	108.31	456.18	1285.88
3	3.20	15.59	42.13	84.20	282.61	887.71
6	2.67	14.77	39.33	71.01	266.25	824.88
9	2.24	13.38	37.28	60.20	237.70	787.15
12	2.06	13.01	36.12	54.58	233.86	763.89
months	WS1	WS2	WS3	WS1	WS2	WS3
0	27.72	55.83	5.29	539.75	1258.30	52.32
3	18.42	38.50	4.00	349.14	861.86	43.52
6	17.09	35.83	3.85	320.66	799.25	42.23
9	15.29	34.07	3.54	282.18	762.16	40.71
12	14.76	33.02	3.42	273.27	739.46	39.59

After three months, the reduction was between 21% (Kow1-FA) and 34% (Kow2-FA) for the Kow groups. For BCF1 and BCF2 group reductions are similar for BA and FA, and the smallest changes are observed for group BCF3 (19.5%, FA). For P groups, the largest decrease of 38% in concentration after three months is observed for P2-FA, and after one year, the P3-BA decrease is 53%. PAHs that are less soluble in water have lower content reduction (WS3-FA 24%; WS3-BA 35%) than those that are more soluble (WS1-FA 49%; WS1-BA 47%).

3.3 Toxicity of PAHs in ash samples

To measure the toxic potential of ashes, BaP_{eq} values for initial BA and FA samples are equal to 1.80 and 38.98 ng/g, respectively. Values estimated for ash samples after 12 months are 1.11 ng/g (BA) and 23.78 ng/g (FA), which is almost 40% of their initial values. According to the Canadian Council of Ministers of the Environment 20., the safe BaP_{eq} value is lower than 600 ng/g.

4. CONCLUSION

As biomass utilization as fuel becomes more intensive, a greater amount of ash is generated. The need for its application grows since ash storage is not an option due to potential environmental risks. The amendment of soil by the addition of biomass ash has potential. Still, it is important to determine the initial content of hazardous pollutants (such as PAHs) and optimize the mixing ratio between soil and ash. That is significant for the safety of the plants grown on amending soil and from the environmental point of view. After adding ash to the soil, it is of great importance to monitor PAHs content periodically. Lower mass PAHs undergo different degradation processes more intensive than PAHs with higher molar masses.

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THE COMPARISON OF DEGRADATION OF ORGANIC POLLUTANTS FROM BIOMASS AND COAL ASHES MIXED WITH SOIL – A REVIEW

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Abstract: *The overall content of polycyclic aromatic hydrocarbons (PAHs) in biomass and coal ashes is comparable, but the content of each of PAHs depend on many factors such as feedstock type, burning conditions. In many countries, such as Canada and USA, both biomass and coal ashes are used for soil amending, if background soil content of PAHs is low. For the reduction of PAHs content different processes could be responsible. Since PAHs represent hydrophobic compounds, they can be adsorbed to soil particles which makes them to be more persistent to the action of various processes. PAHs degradation can be induced by the action of sun light (photodegradation), soil microorganisms, phytoremediation (by fast growing trees like willow, maize, cereals), fungi and others.*

Key words: *biomass ash, coal ash, organic pollutants, PAHs, degaradation*

1. INTRODUCTION

The main electricity producer in Serbia is Elektroprivreda Srbije (EPS), with a capacity of 7662 MW. Thermal power plants (TPPs) generate power mainly through lignite combustion. EPS consumes around 32 million tons of lignite from Kolubara and Kostolac basins annually. The amount of fly ash and slag produced in TPPs is approximately 7 million tons per year. As an illustration, the total installed capacity of Kolubara A block is 245 MW with rates of lignite consumption of 350 tons/h and ash production of 64 tons/h.

The main source of renewable energy is hydropower, with a capacity of 2835 MW, while only 4% comes from other renewable sources. Electricity supply from bio-energy has been rising more intensively since 2010. According to the National Renewable

Energy action plans published in 2014, biomass consumption in 2020 was projected to be 22% higher than in 2012.

The combustion of coal generated a greater amount of ash comparing to biomass combustion. Around 50,000 tons of coal ash is used for agriculture annually. Many farmers add fly ash to soil routinely to nourish vegetables and crops. Moderate addition of fly ash brings to the enhancements of crop yields, stabilization of soils, reduction of the need to throw huge quantities in landfills, availability of different nutrients necessary for plant growth (phosphorus, calcium and others), increasing of soil capacity to hold water. The disadvantages of ash utilization include toxic metals (arsenic, lead and mercury) and various organic compounds such as polycyclic aromatic hydrocarbons (PAHs).

PAHs are widely present as contaminants in the air, soil, aquatic environments, sediments, surface and groundwater [1-3.. It is well-known that PAHs are emitted due to the incomplete combustion of organic materials from natural sources (forest fires) and anthropogenic sources (domestic and industrial burning of fossil and biomass fuels, vehicles emissions). PAHs emission from anthropogenic sources fairly exceeds their emission from the natural sources, while global transport phenomena bring to their distribution worldwide. PAHs get dispersed from the atmosphere to the aquatic and terrestrial ecosystems due to dry and wet deposition. They reach vegetation which leads to bioaccumulation and introduction to various food chains [4,5.. Since PAHs are hydrophobic compounds, they can be sorbed onto soil particles which leads to their higher persistence. PAHs inflow into water systems could bring problem concerning water quality and aquatic biodiversity [6..

The aim of the present study is to compare PAHs content of ashes, PAHs degradation rate in biomass and coal ashes mixed with soil and the potential risk of their use as a soil fertilizer.

2. PAHS DEGRADATION IN SOIL

Feedstock type and combustion conditions affect overall PAHs content in ashes. PAHs are toxic, carcinogenic, and environmentally persistent and tend to bioaccumulate. The behavior in the environment depends on its structure. The carcinogenicity of PAHs increases with the increase of ring number and molecular weight while their volatility decreases. According to ring number, PAHs are classified as low molecular weight (LMW), medium molecular weight (MMW) and high molecular weight (HMW). HMW PAHs are known to be more persistent and toxic in the environment than LMW PAHs. Often literature data about PAHs in biomass and coal ashes are limited to a determination of their content. Initial PAHs concentrations are comparable for biomass and coal ashes. Due to their toxic effects on humans, animals and the environment, additional research related to risk assessment is desirable. In some recent studies, PAHs formed by coal and biomass combustion (fly and bottom ashes) have been investigated [7-9..

The fate of PAHs and their content depending on the environment. PAHs can undergo different photooxidation processes in the atmosphere, but the mail process for decreasing their content is deposition. PAHs in soil could be exposed to a great number of processes.

Photooxidation, chemical oxidation, microorganisms (algae, bacteria and fungi), leaching, phytoremediation by fast-growing trees (willow), maize and cereals are some of them. Lighter PAHs are partially lost by volatilization [10,11.. By bioremediation, some pollutants are transformed into less hazardous or nonhazardous forms 12,13.. The microbial degradation of PAHs represents the main degradation process in the soil 14,15.. However, the changes in microbial communities are unpredictable, so the microbial community is termed a 'black box' 16.. The bioremediation rate depends on many factors, including pH, temperature, oxygen, microbial population, accessibility of nutrients, the chemical structure of the compound and many others 17..

3. COMPARISON OF COAL AND BIOMASS ASH TOXICITY AND CARCINOGENICITY

The toxicity and carcinogenicity of PAHs represent key concerns. Table 1 shows the division of US EPA priority PAHs according to their carcinogenicity and toxicity.

Table 1 Division of priority PAHs into groups according to their carcinogenic and toxic potential [18,19.

Group label	List of PAHs	Carcinogenic potential
C1	BaA, BaP, DahA	carcinogenic (1)*
C2	BbF, BkF, IP	probably carcinogenic (2A)
C3	Phe, Fla, Pyr, Chry, BghiP	possibly carcinogenic (2B)
O	Nap, Acy, Ace, Flu, Ant	other; non- classifiable (3)
Group label	**List of PAHs**	**Toxic potential**
T1	BaP, DahA	the most toxic (TEF** = 1)
T2	BbF, BkF, IP, BaA	(TEF = 0.1)
T3	Ant, BghiP, Chry	(TEF = 0.01)
O	Nap, Acy, Ace, Flu, Phe, Fla, Pyr	other (TEF = 0.001)
Abbreviations: Naphthalene (Nap); Acenaphthylene (Acy); Acenaphthene (Ace); Fluorene (Flu); Phenanthrene (Phe); Anthracene (Ant); Fluoranthene (Fla); Pyrene (Pyr); Benzo a.anthracene (BaA); Chrysene (Chry); Benzo b.fluoranthene (BbF); Benzo k.fluoranthene (BkF); Benzo a.pyrene (BaP); Indeno 1,2,3-cd.pyrene (IP); Benzo g,h,i.perylene (BghiP); Dibenzo a,h.anthracene (DahA)		
*- classification of International Agency for Research on Cancer ** TEF - toxicity equivalency factor		

The International Agency for Research on Cancer (IARC) categorized PAHs into four groups. Group 1 consists of PAHs carcinogenic to humans, while groups 2A and 2B contain PAHs, which are probably carcinogenic and possibly carcinogenic to humans, respectively. Group 3 is not classifiable as carcinogenic to humans [18.. The labels of PAHs groups made according to carcinogenic potential are given in Table 1 (C1-3 and O).

Benzo a.pyrene (BaP) is taken as a toxic benchmark, with toxicity equivalency factor (TEF) equal to 1. The total PAHs concentration is expressed as BaP equivalents (BaP_{eq}) to simplify comparisons among samples. BaP_{eq} represents a sum of products of individual

PAH concentration with correspondent TEF value. In the case of T2, T3 and O groups of PAHs (Table 1), TEF values are 0.1, 0.01 and 0.001, respectively [19..

To illustrate how degradation processes affect PAHs content and could impact the toxic and carcinogenic potential of PAHs, coal and biomass fly ash samples are chosen to predict PAHs content and to compare them. PAHs content after three and six months was calculated based on literature data from several studies in which the influence of different degradation models was examined in laboratory conditions or the field [20,21.. Fig. 1 shows these data.

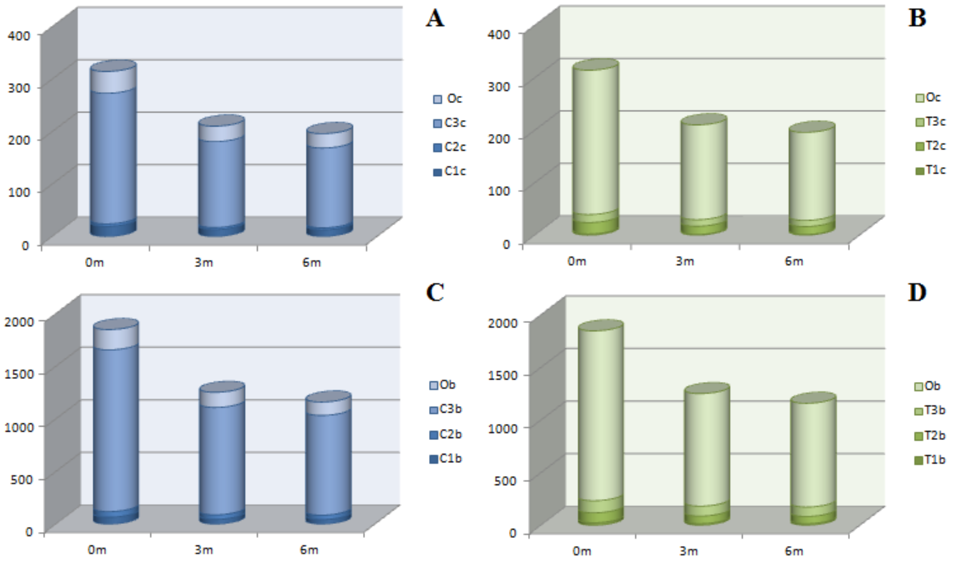

Fig. 1 Dependence of content (in ng/g) of PAHs groups (according to their carcinogenic (A, C) and toxic potential (B, D)) on time – 0m (initial); 3m (after three months) and 6m (after six months); coal ash (A, B) and biomass ash (C, D)

The coal fly ash sample was taken from the electrofilter of the thermal power plant in which lignite is used as a fuel. Biomass fly ash originates from the cyclone of the cigar burner combustion system in which soybean straw is used as a fuel.

Table 2 Time dependence of BaP equivalents (in ng/g of ash) of biomass (BMA) and coal fly ashes (CA)

months	0	3	6
BMA	38.98	27.71	26.46
CA	5.49	3.87	3.70

As can be seen from Table 2, BMA has a higher BaP_{eq} value (38.98 ng/g) than CA. However, this value is under the limit which is recommended [22.. It means that both ashes are convenient to use for soil amendment. Besides, it is noticeable that BaP_{eq} values decrease with time, and a significant decline is observed in the first three months after adding ashes to the soil.

The carcinogenic potential can be expressed as a portion of seven carcinogenic PAHs (benzo a.pyrene, dibenzo a,h.anthracene, benzo a.anthracene, benzo b.fluoranthene, benzo k.fluoranthene, chrysene and indeno 1,2,3-cd.pyrene) comparing to overall priority PAHs content. In Figure 2, the time dependence of seven carcinogenic PAHs content comparing to overall PAHs is shown.

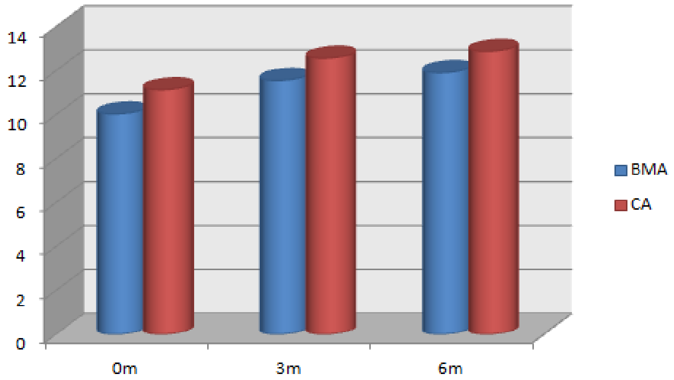

Fig. 2 Time dependence of portion of seven carcinogenic PAHs (in %) in overall PAHs content in biomass ash (BMA) and coal ash (CA); 0m (initial); 3m (after three months) and 6m (after six months)

According to Fig. 2, the portion of 7 carcinogenic PAHs in overall PAHs content increase with time for both ashes. This increase is significant for the first three months, i.e., 15.22% (BMA) and 12.83% (CA). During the following three months, correspondent carcinogenic PAH portion increases are much lower, i.e., 3.50 and 2.86%. This increase is due to the more pronounced decrease of non-carcinogenic PAHs content than the case for carcinogenic ones. The content of carcinogenic PAHs comparing to their initial values decrease more than 20% for both ashes during the first three months after mixing ash and soil.

4. CONCLUSION

It is important to characterize ash before its addition to the soil and mix it with soil in an optimal ratio, depending on the content of different pollutants. Rates of PAHs degradation in coal and biomass ash are similar. PAHs degradation does not greatly impact the change of physicochemical parameters of ash samples, except in the case of BaP_{eq}. Ash is convenient to use as a soil fertilizer, but continuous monitoring of the content of toxicological concerns is necessary.

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BURNING OF AGRICULTURAL BIOMASS WASTE ON FIELDS - ESTIMATION OF ENVIRONMENTAL RISK

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Abstract: *Despite numerous appeals not to burn agricultural waste after harvest, after pruning fruits and vineyards, removing weeds or preparing land for new sowing, a great number of farmers are trying to speed up the removal of agricultural waste in this way. Such actions can cause, especially in the summer months, great material damage, because there is a danger that the fire will spread uncontrollably to neighboring fields, as well as other direct or indirect consequences. In this paper, we deal with the estimation of pollutant emission and environmental risk assessment, especially with regard to the impact of carcinogenic compounds created during biomass burning.*

Key words: *agricultural waste burning, harmful pollutants emision, environment, risk estimation*

1. INTRODUCTION

Open biomass burning represents the combustion of living and/or dead vegetation, induced by anthropogenic activity or different natural reasons such as unfavorable weather conditions (lightning strikes). Even if "controlled incineration" is carried out in a designated area, open-fires in agriculture could spiral out of control and thus could lead to forest and field fires in which a great number of pollutants are released and damage or destroy entire areas that are nearby 1.. More than 90% of all forest and field fires are initiated by human disregard.

Globally, it is estimated that about 8700 Tg of dry matter is burnt yearly. China is one of the greatest sources (approximately 122 Tg of crop residues and 140 Tg of straw annually) 2.. For this reason, since 1997, the Chinese government has brought in a series of regulations and laws to prohibit open-field burning. Farmers were encouraged to return crop residues to agricultural soils as a fertilizer.

2. PROBLEM OF BIOMASS BURNING IN SERBIA

In Serbia, although the Law on Fire Protection prohibits the burning of stubble and other plant remains in the open, farmers have done so in previous years. Therefore, the Ministry of Environmental Protection, the Ministry of Agriculture, Forestry and Water Management, and the Ministry of Interior, with the support of the Global Environment Facility (GEF) and the United Nations Development Program (UNDP), are implementing a campaign throughout Serbia with an appeal not to burn stubble. Biomass burning is an illegal way of removing harvest residues from fields and could induce multiple harmful consequences. Such activities represent a great risk to the life and health of people, their property and could lead to great damage to agriculture, the environment and nature. Furthermore, huge amounts of particles are emitted into the atmosphere when burned in the open and are transported by airflow over long distances 3-8..

Fig. 1 Removal of vegetation by open-field burning

As an illustration, during 2019, almost 19 thousand open fires were recorded in Serbia, 14 citizens lost their lives, and 40 were injured. According to the Ministry of the Interior data, in September 2019 and 2020, more than 1900 and almost 1600 open-field fires were recorded in Serbia, respectively. In the same periods in the Belgrade area, nearly 300 and more than 260 fires in the open were registered, respectively. Low vegetation was burning the most (hundreds of hectares), but forests, meadows, orchards, wheat fields, and vineyards were also damaged. It is known that every year in Serbia, tens of hectares of forests burn, and often these fires occur due to uncontrolled burning (more than 95%).

When the work on the fields is the most intensive (spring and autumn), the competent services often appeal to the farmers not to burn agricultural waste. Numerous workshops are organized, reminding them that it is a violation that high fines are prescribed and in case of causing damage, the extent to which it entails criminal liability. Such appeals also try to raise the level of awareness of the population.

Most of the biomass burning in the last decade was observed in Vojvodina, the northern part of Serbia, in which large areas are covered with crops. The highest frequency of open burning is during spring and autumn when the works are most intense. Since the risk of fire spreading is higher after a dry summer, more attention is paid to the transition period between summer and autumn. In Fig. 2, the frequency of open fires in Serbia is shown for September 2018 as an illustration.

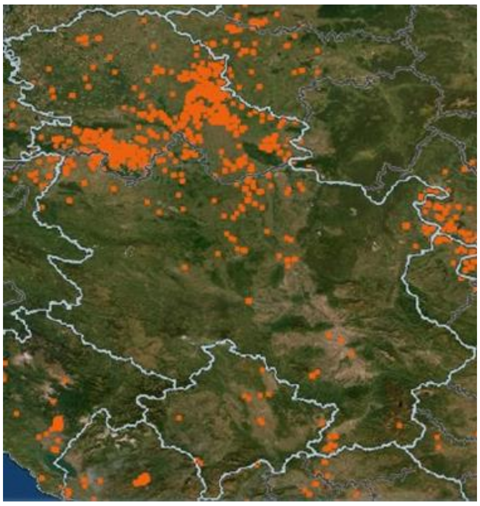

Fig. 2 Satellite overview of Serbia from Fire Information for Resource Management System (FIRMS); September 2018 - https://firms2.modaps.eosdis.nasa.gov/map/

2.1. Biomass burning in Vojvodina during the last decade

Figure 3 shows a satellite image of Vojvodina from July to September 2011, illustrating the frequency of burning agricultural residues in the fields in these three months. Several fires were recorded in July, while there were dozens of fires during September. This period of the year is characterized by intensive agricultural activities such as removal of excess vegetation (crop residues, weeds and waste) by burning of cultivated fields.

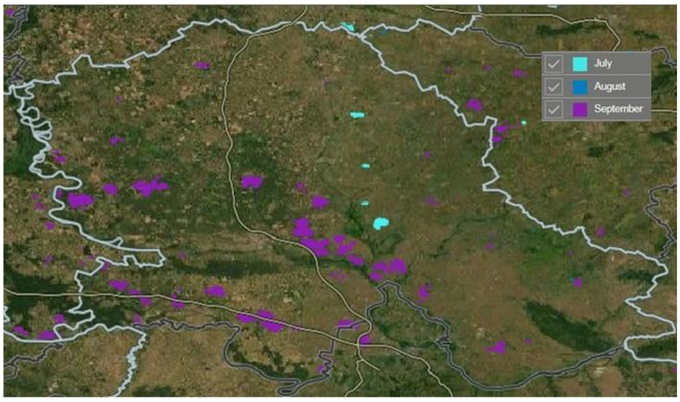

Fig. 3 Satellite overview of open-field fires in Vojvodina from July to September 2011 (https://firms2.modaps.eosdis.nasa.gov/map/)

Since September is a month with the most intensive biomass burning among summer months, the satellite overview of the frequency of open fires for chosen years in the last decade is shown in Figure 4.

According to Figure 4, it is obvious that open-field biomass burning frequency depends on many factors. Among them, the most important are: meteorological conditions, the campaign's intensity against the open burning of agricultural biomass in all available media, and constant reminders to the farmers that the fines are high. Nevertheless, it is encouraging that the number of fires in 2020 is lower. If the declining trend continues in the following years, it will be a positive sign that raising farmers' awareness has yielded results.

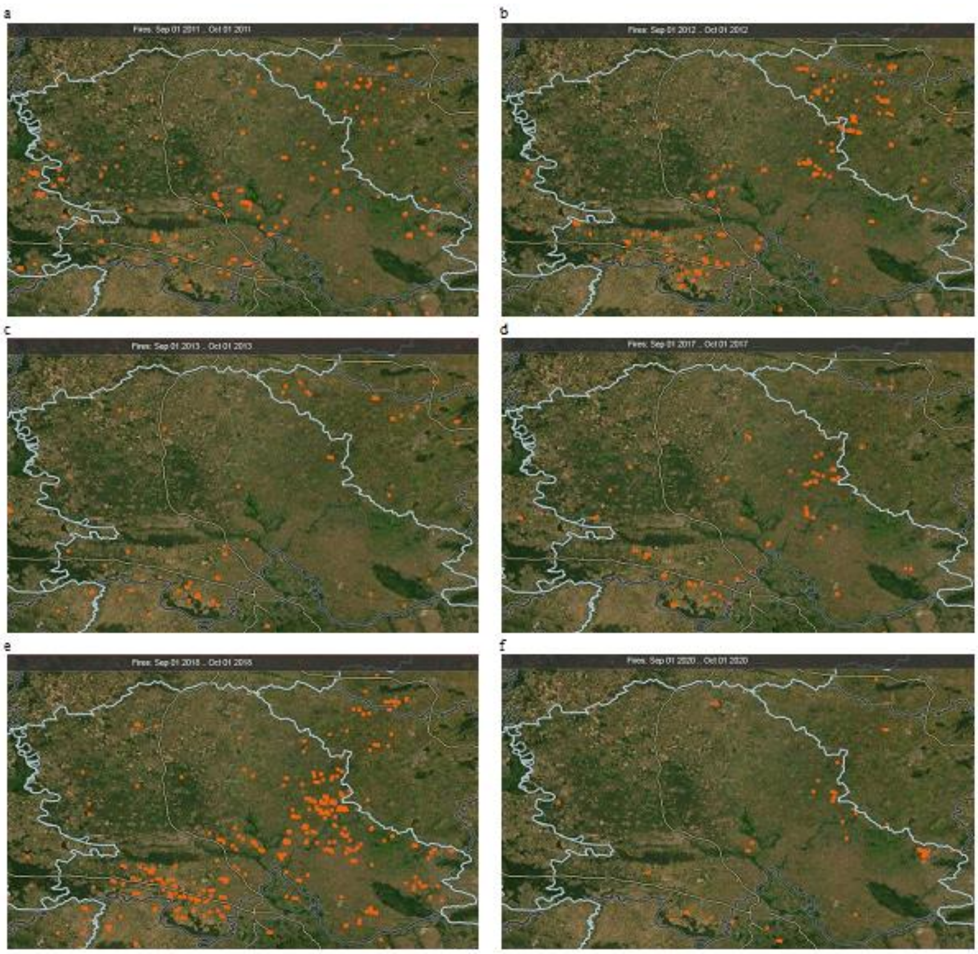

Fig. 4 Satellite overview from FIRMS for the month of September for following years: a) 2011; b) 2012; c) 2013; d) 2017; e) 2018; f) 2020 (https://firms2.modaps.eosdis.nasa.gov/map/)

2.2. Possible solutions to solve the problem of agricultural waste disposal

The burning of agricultural waste damages soil by destroying organic matter (humus) and soil structure and decreasing productive capacity. At the same time, this material could be a potential resource. As mentioned previously, open-field burning of agricultural biomass is still in use no matter its prohibition by the government. More innovative solutions should be presented to farmers since the effectiveness of this ban is limited.

One option is to return the straw to the field as a natural fertilizer that improves soil fertility. The advantages of plowing plant residues left in the fields after harvest are numerous. By burning straw, the nutrients contained in the straw are irretrievably lost. By plowing, some nutrients are returned to the soil and are available to the plant during its growth. By ignition, about 6 kg of nitrogen per ton of straw is lost, i.e., returned to the atmosphere. Different straws contain 0.2-0.8% nitrogen, 0.09-0.2% phosphorus (V) oxide and 0.4 -1.2% potassium oxide. Plowing creates a loose layer on the soil surface, which helps moisture-retaining in the soil. It is extremely important since droughts are becoming more frequent in the summer months. The moisture content of the land on which agricultural residues were plowed in autumn is 2 to 2.5% higher than in fields where waste was incinerated. Plowing the remains after the harvest is also useful because the germination of weed plants is accelerated, easily destroyed by further tillage. In this way, weeds are destroyed very efficiently, and at the same time, the use of pesticides is reduced 3-8..

Another option could be to use agricultural waste as fuel. However, it is associated with technical problems such as its collection, transport from the fields and storage. The agricultural biomass, especially straw, has a large volume, making it difficult to collect in the short term after the harvest to avoid the delay of the sowing season. Furthermore, much space is needed for agricultural straw storage before its utilization.

3. HARMFUL CONSEQUENCES OF BURNING AGRICULTURAL WASTE IN THE OPEN

During the summer months, the open-field fire can spread and thus destroy entire ecosystems, endangering wild plants and animal species. In addition to being dangerous, burning in the open increases the cost of agricultural production. It leads to some negative consequences to soil quality, especially if it is carried out every year. High temperatures during outdoor incineration lead to the destruction of beneficial microorganisms, earthworms and other small animals in the soil essential for humus formation. By heating the ground, the humus in the soil is ignited. The loss can be up to 3 tons of humus per hectare, and it is known that it takes an entire century to create 1 cm of humus in nature. After burning, the surface layer of the soil is covered with ash, which could easily blow away by the winds or be washed away by rains, which impoverishes the soil. In addition, smoke generated during the combustion of crop residues in adverse weather conditions near roads can cause major traffic safety problems, leading to reduced visibility 3-8..

Air pollution is a serious environmental problem worldwide. Over the past decades, increasing international attention has been paid to fine particles released due to open-field biomass burning 9.. Biomass combustion emissions contribute significantly to the amount of particulate matter (PM), toxic gaseous pollutants (CO, methane, volatile organic compounds - VOCs), inorganic species (water soluble ions, heavy metals) and a great number of organic compounds in the atmosphere 9.. Biomass burning can be an important source of different semi-volatile organic compounds (SVOCs) including polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) to the atmosphere, as well as water soluble organic carbon (WSOC) and some pesticides 9,10.. Atmospheric aerosols from biomass burning have high mass concentrations of fine particulate matter - $PM_{2.5}$ (particles diameter lower than 2.5 µm). Carbon is one of the main components of atmospheric PM, and its content varies from 20 to 70% of the fine particulate mass. The major source of carbon in aerosols is fossil and biomass fuel combustion. Carbon species in PM include organic carbon (OC), elemental carbon (EC) and black carbon (BC). Reports suggest that OC and EC account for 55% and 8% fine particle mass, respectively 2.. Open-field biomass burning (in forests, meadows, crop residues in the field) accounted for 74% of total global OC emissions. In comparison, high EC emissions of around 40% of the worldwide total came from open-field biomass burning. Open burning is the single largest source of BC emissions globally, producing over one-third of such emissions (approximately 2700 Gg or 36%). Short-lived pollutants, such as CH_4, BC, and tropospheric ozone, can greatly impact climate and temperature. The ozone formation in the troposphere is related to photochemical reactions of VOCs and NOx 1,11.. Trace inorganic species, mostly dominated by potassium, chlorine and calcium, account for approximately 10% of the mass of fresh smoke. The emissions of OC, EC and PM have two peaks, from May to June and in October, corresponding to periods with the most intensive agricultural activities 1,2,12..

PAHs represent hazardous pollutants produced due to the incomplete combustion of organic materials, such as different biomasses. Biomass burning is an important source of PAHs. Due to favorable conditions for PAHs formation, high emission factors (EFs) of low mass PAHs (such as naphthalene, acenaphthylene, acenaphthene, phenanthrene, anthracene, fluorene and pyrene) are noticed. The emission of the heavier PAHs is negligible comparing to light 11.. PAHs emission is positively correlated with PM, so the biomass fuels simultaneously have high EFs both for PM and PAHs, which increases health and environmental risk 11.. According to laboratory studies, PAHs emission factors (overall particulate and gaseous phase) in the burning of rice, wheat, and corn straws were 5.26, 1.37 and 1.74 mg/kg, respectively. Total PAHs emission from burning these agricultural crop residues in China in 2004 was 1.09 Gg 13..

4. CONCLUSION

Open-field burning of agricultural waste is widely used as an inexpensive means of its disposal. Despite prohibitive laws, changes in practice worldwide were not widely adopted by farmers. Rapid change is possible when it responds to farmers' own self-interest. In Poland and Baltic countries, widespread open burning was reduced to EU levels in a period of 5 years. The required efforts should represent a combination of farmer extension education, political will and financing.

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APPLICATION OF CONTEMPORARY TECHNICAL SYSTEMS IN CHEMICAL PROTECTION OF FIELD CROPS: CASE STUDY OF WHEAT PRODUCTION IN SERBIA

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INVITED PLENARY LECTURE

Abstract: *The application of precision agriculture in chemical plant protection enables the realization of high yields while preserving natural resources. The quality of chemical applications depends on the type of technical system that performs for this job. The task of the technical system is to protect the cultivated crop precisely, economically and while preserving the environment, and all that depends on the precission and the quality of application of the protective liquid. The use of UAV´s in chemical plant protection enables precise application of protective liquid, so their application is increasing in the protection of numerous crops. The same trend has been observed in field production, where the use of UAV´s is on the rise. The paper compares the exploatational and technological characteristics of the field sprayer (FS) and unmanned aerial vehicle (UAV) in the chemical protection of wheat. The amount of deposited protective liquid on plants and losses of deposited on the surface of the earth were monitored. Using UAV (T4: V = 3 m·s^{-1}, H = 1 m), the amount of protective liquid on the plant was determined to be 0.185 mg·l^{-1} compared to 0.037 mg·l^{-1} at FS, while the losses were 0.01 mg·l^{-1} at FS and 0.085 mg·l^{-1} at UAV. The presence of Fusarium (Fusarium spp.) after chemical protection was analyzed according to the compared technical systems and set treatments. It was recorded for 20% higher efficiency in protection against Fusarium (Fusarium spp.) using UAV (T5: V = 3 m·s^{-1}, H = 2 m) compared to FS. The values of wheat yield were measured according to the compared technical systems and set treatments, where the highest wheat yield was achieved using UAV (T5) with 10,667.7 kg·ha^{-1}, while using FS, 14.84% lower yield was achieved. The application of UAV´s in the segment of chemical plant protection enables us to effectively protect crops, economical and optimized production, while preserving the environment in a way that has been completely new and unknown until now.*

Keywords: *unmanned aerial vehicle - UAV, field sprayer, protective liquid, quality of application, yield.*

1. INTRODUCTION

The growing need for food in the 21st century has led to the intensive development of agricultural production. The growth of agricultural production relied primarily on the application of modern agricultural machinery and adequate use of pesticides. To achieve the highest possible yields and profits, inappropriate treatment norms are often applied and the basic principles of chemical plant protection are not respected. Inadequate application of chemical agents in plant production causes a decrease in the quality of soil, water and air. The impact of such bad practices is particularly reflected in the quality and safety of food for human and animal health 5, 9, 10..

Chemical plant protection is one of the important agro-technical measures that affects the quality and quantity of field crops. Properly performed chemical protection can significantly reduce the occurrence and intensity of pests on cultivated crops, and thus the scope of chemical protection. The better and more timely the chemical protection, the less need for additional chemical measures is, and the more successful the protection itself. The crucial factor on the effect of chemical protection of field crops is the selection of the appropriate pesticide and its proper application to the cultivated crop 8.. Rational use of pesticides implies application in a given norm by means of a technically correct and adjusted technical system.

Precision agriculture offers several different techniques and technologies whose applications can successfully overcome the problems in the field of chemical plant protection. With the help of various sensors, the parameters of production processes can be determined and recorded in real time, on the basis of which the reasons for efficient/inefficient operation can be precisely determined 9, 10.. The use of precision agriculture technologies in chemical plant protection has enabled an increase in the results of agricultural production, but also a reduction in the negative impact on the environment from the excessive use of chemical agents 10.. The full effect of the application of precision agriculture is visible through the economy of production, optimization of the costs of inputs in production, reduced engagement of agricultural machinery and human labor, as well as a positive impact on environmental protection 7..

The last decade has been marked by the study of the effects of the application of precision agriculture on various operations in agriculture. The various technologies of precision agriculture that are used in the chemical protection of crops are interesting from a professional but also scientific point of view, where the goal is to verify the set assumptions. Some of the current technologies are: VRA of pesticide, Spot Spray Systems, Unmanned Aerial Vehicle sprayers - UAV sprayers 2, 3.. The application of UAV sprayers in chemical protection was originally intended to protect crops on smaller plots and plots with inaccessible terrain 4, 11.. In recent years, the application of UAV sprayers in the chemical protection of field crops has become more intensive, so the question arises: what is the quality of chemical protection of field crops using UAV sprayers?

In this paper, a comparative analysis of the operation of the field sprayer and UAV sprayer in the chemical protection of wheat is performed, with reference to the production results during wheat cultivation, as well as the operational characteristics of the applied technical systems.

2. MATERIAL AND METHODS

The research was conducted during 2020/21 wheat production year, on a field near Belgrade (44°50'44.5"N 20°11'08.7"E) on a plot of 60 ha. Data on qualitative and quantitative indicators of performed chemical protection in wheat production were collected in the experimental field. The wheat cultivar Apilco Ig was grown in a conventional production system. During the year, the crop required only one chemical protection treatment, which was performed in parallel using two technical systems: a field sprayer and a UAV sprayer. The same mix of pesticides was used in both technical systems used: Prosaro 250 EC (a.s. Tebuconazole 125 $g \cdot l^{-1}$; a.s. Prothioconazole 125 $g \cdot l^{-1}$) with an amount of 1 $l \cdot ha^{-1}$; Vantex 60 CS (a.s. Gamma-cyhalothrin 60 $g \cdot l^{-1}$) with an amount of 50 $ml \cdot ha^{-1}$.

The field sprayer (Kubota - iXtrack T3) used in the experiment has a working width of 21 m and a tank volume of 2,600 l. Lechler IDKT 12005 sprayers were used on the field sprayer. The working parameters of the sprayer were: speed of movement 5 $m \cdot s^{-1}$; system operating pressure 0,8 MPa; treatment rate 200 $l \cdot ha^{-1}$. The UAV sprayer (M4E TTA) used in the experiment has a working width of 4 m and a tank volume of 4 l. Lechler 110-015 sprayers were used on the UAV sprayer. The operating parameters of the UAV sprayer were: flight speed (V1 = 3 $m \cdot s^{-1}$; V2 = 5 $m \cdot s^{-1}$); flight altitude (H1 = 1 m; H2 = 2 m); system operating pressure 0,5 MPa; treatment rate 40 $l \cdot ha^{-1}$.

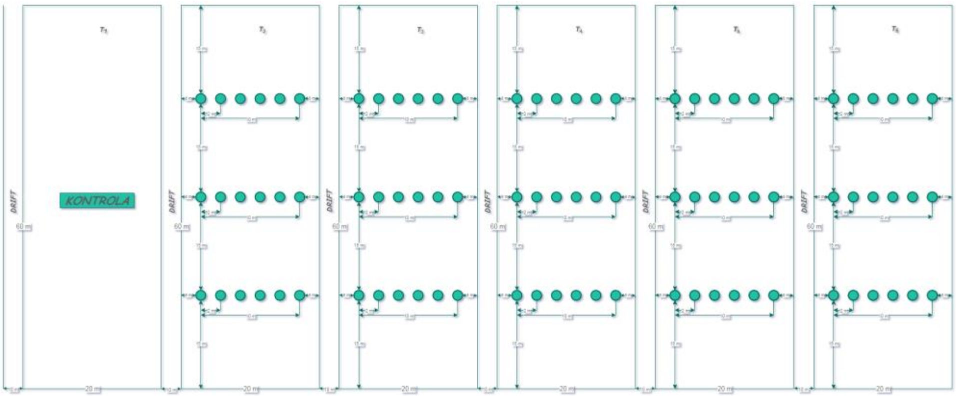

Figure 1. Scheme of the experiment

The labels used in Figure 1 have the following meanings:

B - Working width of the technical system

V - Speed of movement of the technical system during chemical protection

H - Height of application of protective liquid when treating wheat

T1 - Treatment where no chemical protection of crops was performed (control plot)

T2 - Treatment with a field sprayer (B = 21 m; V = 5 $m \cdot s^{-1}$; H = 0.5 m)

T3 - Treatment with UAV sprayer (B = 4 m; V = 3 $m \cdot s^{-1}$; H = 1 m)

T4 - Treatment with UAV sprayer (B = 4 m; V = 5 m·s^{-1}; H = 1 m)

T5 - Treatment with UAV sprayer (B = 4 m; V = 3 m·s^{-1}; H = 2 m)

T6 - Treatment with UAV sprayer (B = 4 m; V = 5 m·s^{-1}; H = 2 m)

Drift - The part of the experiment from which no samples were taken, due to the possible drift of the protective liquid

Figure 1 shows the scheme of the set experiment, where the measuring points (from which the samples were taken) are marked with green circles. Samples were taken after chemical protection from two heights, in three surface zones for each of the experimental treatments, with 6 repetitions. The distance between the sampling points is 2 m, and the distance between the sampling zones is 15 m. The exact locations of the sampling sites were verified using a Garmin eTrex GPS locator. At each sampling point, metal support was placed on which water-sensitive paper WSP2 (dimensions 26 mm x 76 mm) and filter paper (diameter 90 mm) were placed. Water-sensitive paper is used to assess the characteristics of the protective liquid (coverage area, droplet size), while filter paper is used to determine the deposition-retention of protective liquid on plants. The applied pesticide mix was colored red (Allura red) at a dose of 450 g·ha^{-1} to facilitate the determination of the deposition of protective liquid on plants.

Control of disease and insects occurance was performed before and after chemical protection 6.. The control of the presence of insects was performed the day before the chemical protection, and the efficiency of the insecticide action was determined after the 3rd and after the 7th day from the performed protection treatment. From each treatment in the experiment, 50 plants were taken by the method of random sampling, where the number of present insects was recorded. The appearance of the disease was followed by sampling the same number of samples after the 15th day of chemical protection of wheat.

The speed of airflow during the performance of chemical protection was recorded with the help of the Testo 410i Smart Probe device, while the temperature and humidity of the air were determined using the Voltcraft DL-140TH device. The analysis of the filter paper was performed in laboratory conditions on a WTW PhotoLab 6000 spectrophotometer. The analysis of water-sensitive papers was performed using the DepositScan software in laboratory conditions (the papers were originally scanned at a resolution of 600 dpi). Analysis of yield parameters (morphological characteristics and yield) were performed in laboratory conditions after taking five samples from each of the treatments (all plants were removed from an area of 1 m^2 - per sample). All collected data were processed by statistical methods using the software package SPSS 17.0.

3. RESULTS AND DISCUSSION

The results the filter paper samples analyzes for the treatments from the experiment are shown in Table 1. The values in Table 1 indicate the percentage of deposition of protective liquid on wheat leaves in the examined leaf zone. The obtained results show that the deposition is higher in the higher zones of the plant. Between the treatments, it was noticed that higher deposition is achieved by applying a UAV sprayer when flying at a flight speed of 3 m·s^{-1} (in treatments T3 and T5), regardless of the set flight altitude.

Table 1. Results of coverage of analyzed filter paper samples (%) by treatments

Sampling site	Treatment	T2	T3	T4	T5	T6
The middle of the height of the plant		10,7	21,4	7,7	23,4	6,5
At the ground		3,9	16,0	4,0	10,9	5,5

Figure 2 shows a graph showing the percentage of plant leaf mass area on which the protective liquid (leaf coverrage during chemical protection) was applied after the chemical protection was performed. Leaf coverage during chemical protection, which we detected via water-sensitive paper, is best in T2 treatment when using a field sprayer. The reason for such a high coverage lies in the sprayer treatment rate of 200 l·ha^{-1} compared to 40 l·ha^{-1} as the UAV sprayer treatment rate.

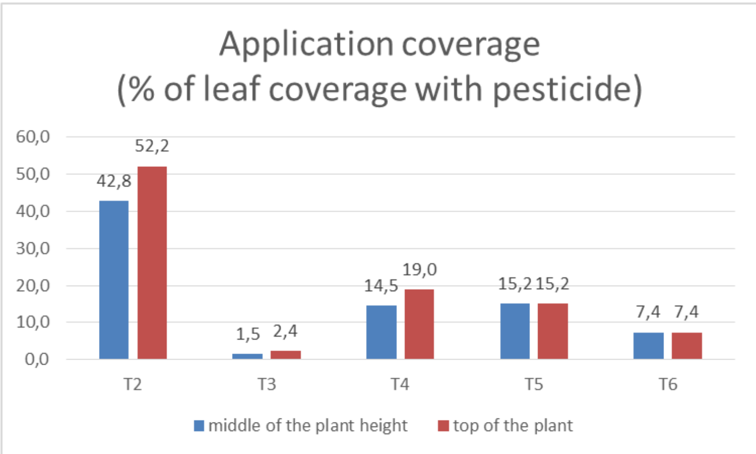

Figure 2. Achieved coverage of wheat leaf mass with protective liquid after treatments

After the 15th day from the day of applied chemical protection, sampling for the presence of the disease was performed and compared with the results from the samples taken immediately before the chemical protection. It was found that the greatest effect of protection against Fusarium (80% protection) was achieved by using a UAV sprayer in the T5 treatment. The T2 treatment performed with the field sprayer had a 60% effect of protection against Fusarium. The results of the samples analyzed for the effectiveness of protection of applied pesticides against Fusaruim are shown in Figure 3.

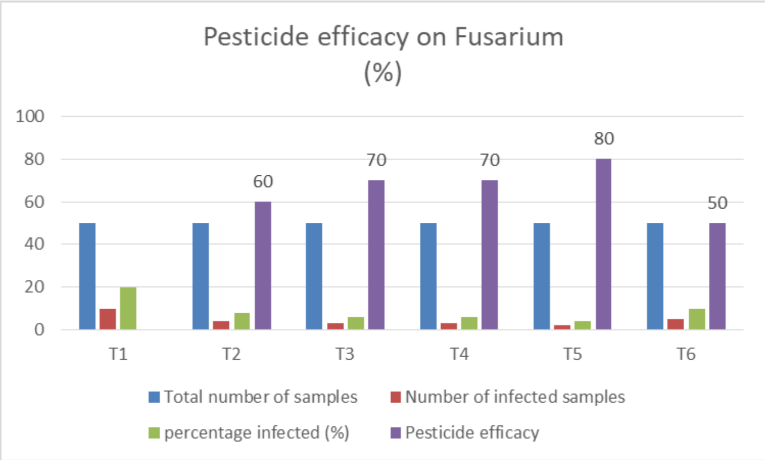

Figure 3. Achieved level of protection from Fusarum on wheat by different treatments

Of all yield parameters, grain yield was singled out as the most important in wheat production. The yield was determined by two methodological principles: analysis in a macro experiment; and sampling in a micro experiment. Sampling in the micro-experiment was performed by standard methodological principles (yield data collected from measuring points from an area of 1 m^2) 1., while in the macro-experiment it was performed by measuring the total wheat yield sample from the entire observed treatment (analysis of data from harvesting by combine). Data from micro and macro experiments are uniform and show that the highest wheat yield was achieved in the T5 treatment where chemical protection was applied by UAV sprayer. Figure 4 shows the realized yields by treatments depending on the applied technical system of chemical protection and operating parameters. It is evident that UAV sprayer flight speeds over 3 $m \cdot s^{-1}$ negatively affect the achieved yields (visible in treatments T4 and T6).

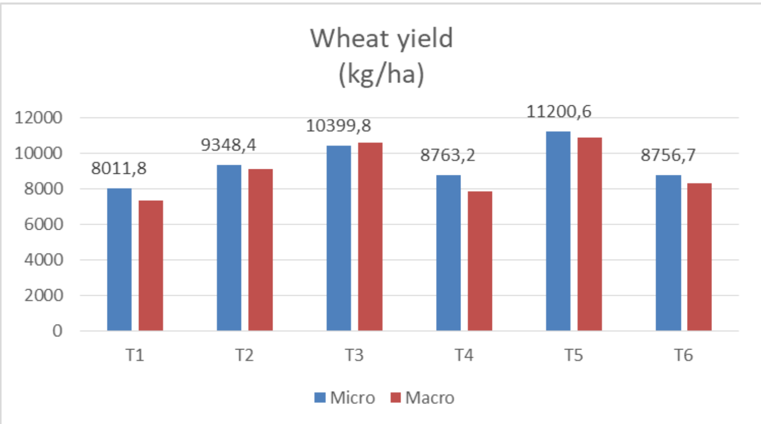

Figure 4. Realized wheat grain yields by treatments

Wheat yields recorded through the macro experiment give a more comprehensive and accurate presentation of the realized yields in the field compared to the results from the micro experiment. The reasons for such a setting are based on the larger sampling area and the cancellation of specific deviations caused by random sampling of yields in micro-experiments.

4. CONCLUSION

A comparative analysis of the achieved results in the quality of the performed chemical protection between the field sprayer and the UAV sprayer showed that the field sprayer with a higher treatment rate achieves better coverage of the wheat leaf surface. However, the higher coverage achieved with field sprayers does not imply greater penetration of the protective liquid into the deeper layers of wheat. The lower permeability of the protective liquid during the application of the field sprayer is reflected in the lower efficiency in the protection against Fusarium, and consequently in the lower yields.

During the application of UAV sprayer, it was noticed that the higher flight altitude enables better coverage of the leaf mass, but weaker penetration of the protective liquid into the lower layers of plants. The T5 treatment achieved a 16.5% higher yield compared to the yield achieved by the application of the field sprayer. This data indicates a serious potential application of UAV sprayer in chemical protection of field crops. If we observe only treatments where the chemical protection of wheat was performed only by UAV sprayer, higher yields were achieved in treatments where the flight altitude was 1 m, regardless of the flight speeds used during application. The highest yield of 11,200.6 $kg \cdot ha^{-1}$ was achieved in the T5 treatment when the flight speed was $V = 3\ m \cdot s^{-1}$, and the flight altitude $H = 2$ m. The application of UAV sprayers in chemical protection will consequently have an increasing popularity and thus a higher number of UAVs used in field production.

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SYSTEMS FOR FLUE GASES TREATMENT AT THE COMBUSTION OF (AGRICULTURAL) BIOMASS

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Abstract. *Biomass combustion has many advantages compared to fossil fuels due to reduction of carbon dioxide emissions, but several issues are present during biomass combustion. One that must always be considered is emission of nitrogen oxides (NOx), which have significant impact on the environment and health. At biomass combustion, main mechanism responsible for NOx emission is oxidation of fuel-bound nitrogen. Increased NOx emissions are particularly present at agricultural biomass combustion, due to its increased nitrogen content, which is further expressed by the use of nitrogen fertilizer. Denitrification methods are classified as pre-combustion, combustion control and post-combustion (flue gas treatment) methods. Aim of this paper is to provide insight in different flue gas denitrification methods (DeNOx measures) from the review of existing literature, with emphasis on post-combustion methods, since they have higher efficiency. Also, pre-combustion and combustion control methods at agricultural biomass combustion often do not provide reduction below emission standards. Selective catalytic (SCR) and selective non-catalytic reduction (SNCR), wet scrubbing, adsorption, electron beam, electrochemical method, non-thermal plasma and microbial approach were considered. For each method, mechanism of NOx reduction is given and discussed, alongside with efficiency that could be achieved. Overall comparison of advantages and disadvantages for these methods is provided. Further research of denitrification and optimization of described methods, to overcome NOx emission problem is required. Application of these methods in commercial use and increasing their efficiency, while solving cost and methods disadvantages, is key for biomass to be used as a renewable energy source and fossil fuel replacement.*

Key words: *biomass, combustion, nitrogen oxides (NOx), denitrification, selective catalytic reduction (SCR), selective non-catalytic reduction (SNCR)*

1.INTRODUCTION

Biomass combustion has many advantages compared to fossil fuels due to the reduction of carbon dioxide emissions and can be considered a renewable energy source if used properly. Since biomass is part of the Earth's carbon cycle it can be assumed that biomass is almost carbon neutral. One of the issues present during biomass combustion is the emission of nitrogen oxides (NOx). It is not possible to reduce carbon monoxide, carbon dioxide, hydrocarbon emissions and nitrogen oxides at the same time. This is particularly pronounced with the use of fuel containing a high percentage of bound nitrogen, such as biomass feedstocks (plants, wood, waste). When examining the impact of CO_2 on NO formation it was concluded that the NO release was increased with char conversion for a gas mixture of CO_2/O_2, while for H_2O/O_2 the release decreased 1.. In general from agriculture biomass combustion the pollutant emissions can be divided into unburnt pollutants (CO, PAH, HC, CxHy, PM, tar and char particles) and pollutants which emissions are influenced by fuel characteristics. Alongside NOx (NO and NO_2) in the second group of pollutants is an emission of nitrous oxide N_2O as well 2.. Compared to NOx, the emission of N_2O is significantly lower and is usually not taken into consideration in standards and emission limits. N_2O is not only direct greenhouse gas but also has an indirect effect on the depletion of the ozone layer 3.. Recently more attention is given to this matter 4.. In this paper, only NOx emission is taken into consideration. NOx harm the human respiratory system, they affect O_3 formation, vegetation damage, photochemical smog formation, etc. 5,6.. Increased NOx emissions are particularly present at agricultural biomass combustion, due to its increased nitrogen content, which is further expressed by the use of nitrogen fertilizer. The steam, gas and electricity supply are the largest source of NOx emission in Serbia (fig. 1) 7..

Formation mechanisms for NOx 8.: 1) Thermal mechanism – oxidation of the molecular nitrogen with oxygen in combustion air, present at high temperatures (above 1300°C); 2) Prompt mechanism – fast reactions in the flame zone of the fuel-bound hydrocarbons radicals and nitrogen from the atmosphere (N_2) at low temperatures and fuel-rich conditions; 3) Oxidation of fuel-bound nitrogen (fuel-N). At biomass combustion, the main mechanism responsible for NOx emission is the oxidation of fuel-N. Temperature, residence time, mixing conditions, and excess air ratio affect NOx formation and reduction as well. Thermal-NO and prompt-NO can be neglected for agricultural biomass (low-temperature combustion, below 1000 °C). The catalytic effect for NOx reduction can be provided by char and ash. Since agricultural biomass generally contains high contents of volatile matter and low contents of fixed carbon, the effect of char on the NOx and N_2O formation is usually insignificant. The catalytic effect of the ash is important for residues with high CaO/alkaline oxides contents (mustard husk, cotton husks, groundnut husks, etc.). Simultaneous reduction of CO and NOx is very problematic 8-11.. This paper aims to provide the importance of NOx emissions reduction and give a review of existing and promising methods in development.

2.DENITRIFICATION METHODS

According to various authors 10,12., denitrification methods can be classified as pre-combustion, combustion-control and post-combustion methods. Pre-combustion and combustion control methods at agricultural biomass combustion often do not provide reduction below emission standards, so the emphasis is on post-combustion methods since they have higher NO reduction efficiency for this type of fuel.

Pre-combustion methods include: proper selection of fuel (biomass), pretreatments that affect reducing heterocyclic-N compounds 10., application of fuel additives, biomass fuel blending and co-combustion with fossil fuels.

Combustion-control (primary measures) refer to a modification of the combustion process or operating conditions on existing furnaces without the use of additional pollution abatement equipment behind the main combustion zone. Since the biomass is being burned, strategies for modification of operating conditions that can be applied are reduction of oxygen concentrations in the combustion zone and improving mixing conditions. Modifications of the biomass combustion process that are applicable for NOx reduction are fuel staging, flue gas recirculation and low NOx burner. **Air staged combustion** provides good mixing conditions (combustion air and combustible gases from gasification and devolatilization) 17.. During two-stage combustion primary air is injected into the fuel bed, secondary air is successively injected in the combustion chamber. This way fuel-rich primary and fuel-lean secondary zones are created. It is required that the primary air is under stoichiometric condition (0.7-0.9) since it causes nitrogen from volatiles to form nitrogen containing NOx precursors (NH_3, HCN, HOCN, NO), than in the second stage sufficient air is added, to achieve complete burnout, and it enables NO reduction. NOx here acts as an oxidant agent for nitrogen containing emissions and products of incomplete combustions (NH_2, NH_3, CO, etc.) 9.. With the application of **fuel-staging** fuel is supplied to the furnace at two levels. Primary fuel is combusted with excess air above 1. Secondary fuel is fed with the last portion of the air above the combustion zone, creating a fuel-rich secondary combustion zone in which NOx from the primary fuel-lean zone is reduced 9.. **Flue gas recirculation** (FGR) affects flame temperature reduction and excess air. Recirculated flue gas is considered an inert gas mainly of CO_2, H_2O with low concentrations of products of incomplete combustion. FGR act as NOx reducing agents. **Low NOx burners** are used in utility boilers for steam and electricity production, so they are considered for coal and biomass co-combustion 18..

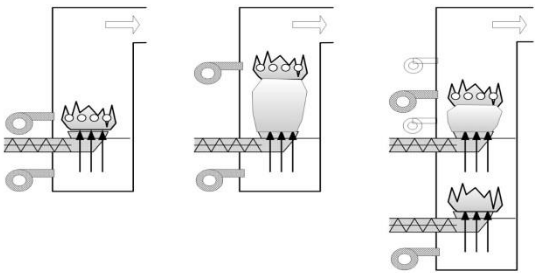

Fig. 2 Combustion: conventional, air staged and fuel staged (left to right) 3.

Post-combustion methods (secondary measures) – Flue gas treatment include two main approaches: 1) NOx removal from flue gas (absorption or adsorption processes); 2) NOx destruction (transformation of NOx into non-toxic products) 19.. For the first approach additional medium is needed, also in most cases waste is generated and appropriate treatment is required.

3. FLUE GAS TREATMENT

Selective catalytic reduction (SCR) is a technique of NOx conversion into N_2 and H_2O vapor with catalyst support. The reductant is being added to a stream of flue gases by injection before reaching catalyst placement. In reactions of a mixture of flue gases and reducing agent with catalyst, NOx are being removed. System arrangement is shown in the scheme in fig. 3. Reducing agents that are currently in use are ammonia (NH_3-SCR) or urea, hydrocarbons (HC-SCR), hydrogen (H_2-SCR), carbon monoxide (CO-SCR). Reducing agent NH_3-SCR can be used in liquid form as anhydrous ammonia or aqueous ammonia. Hydrogen (H_2) is considered a clean, non-toxic reducing agent compared to ammonia (no secondary pollutants). H_2-SCR proceeds at relatively low temperatures. Difficulties that come along with H_2 usage are transportation and the formation of explosive mixtures in presence of oxygen 20.. Hydrocarbons (HC) are characterized by practicality and cost-effectiveness. Unburnt HC from exhaust gas can be used (especially promising in the automotive industry). The problem with HC is their composition of various alkanes, alkenes and alkynes, which leads to a more difficult prediction of their behavior through the NOx reduction. This occurs because the effect of the mixture is different than when they are being used individually 21.. H_2-SCR and HC-SCR show lack of reacting selectively with NOx in flue gases (more likely they will react with O_2). Besides, at higher temperatures (>500°C) HC are consumed in combustion reactions. As a result, these reducing agents are applicable at lower temperatures (<200°C) on supported noble metals (Pt and Pd), which drastically increases the cost of their application. Contrary to that, ammonia and urea can be used at higher temperatures, and regardless of the presence of oxygen, they prefer to react with NOx. Urea is being used as crystal granules dissolved in water 10.˙ Carbon monoxide (CO), as one of the contaminants in the combustion process, is more available and has a more affordable price than NH_3. As a reducing agent, CO gives good results in NOx reduction and gives the possibility of simultaneous extraction of NO and CO from flue gas 22.. This method also requires the development of specific low-temperature catalysts and is still in the testing phase. Catalyst is necessary for SCR to be functional and effective, it should possess high selectivity and activity for N_2 and poisoning resistance. It can be made of a single component, a combination of multiple components, or an active phase. Reduction occurs in catalyst activated sites, which are practically catalyst's pores. For different operating conditions various catalysts have been developed: form noble metals, supported noble/transition metals, supported transition metals oxides, transition metals, metal oxide, zeolites, mixed oxide catalysts, carbon materials, etc. Noble metals are non-toxic and clean as reducing agents and when used formation of secondary pollutants doesn't occur. They have poor resistance to sulfur dioxide and are highly costly. Copper-based catalysts have low cost, they are characterized by, stability, catalytic activity, and selectivity 6., 20.. In addition to the above, catalysts differ in catalytic activity temperature domain, and therefore have different locations in combustion systems, which can be seen in more detail in 10.. Problems that could arise are the deactivation and contamination of catalysts from fly ash particles and aerosols, as well as N_2O formation as a by-product of reactions on SCR catalyst 6..

Selective non-catalytic reduction (SNCR) is based on a chemical reduction of NOx, which occurs when the is injected into a stream of hot flue gas. In the reaction of the reagent with flue gas, NOx are being converted into N_2 and H_2O vapor. System arrangement is shown in the scheme in fig. 4. NOx reduction is achieved due to high temperatures, at which reagent tends to react with NOx rather than with other components from flue gas, hence the name selective non-catalytic reduction.

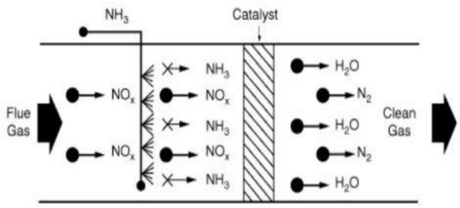

Fig. 3 SCR 10.

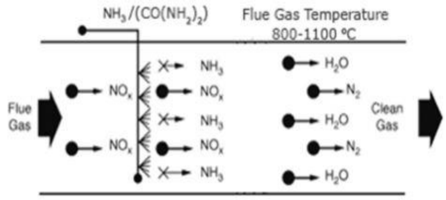

Fig. 4 SNCR 10.

Reagents that are currently in use for SNCR are ammonia (NH_3-SNCR), urea ($CO(NH_2)_2$) and cyanuric acid ($C_3H_3N_3O_3$). Among reducing agents urea is most environmentally friendly due to non-toxicity, therefore storage is easier. The main drawback for urea usage is higher cost and possible increased N_2O generation during reduction 18.. From the literature review, the following can be concluded for SNCR. It is crucial to accomplish the temperature window for all operating conditions and boiler loads (at temperatures >1100°C decomposition of reactants occurs, and at < 800°C there is no reaction of NO reduction at all). There are variations in the temperature of flue gases along with the height of the furnace, which is a consequence of the variable composition and calorific value of biomass and deposits formation on the exchange surfaces (in the latter case, as a rule, the temperature window shifts upward). The temperature range depends on the reagent being used, as well as the ratio of NOx from flue gas and reagent. Since reagents have different optimal temperature ranges, reagent replacement for the same system to adapt to the current temperature window is a possible solution. Choosing an appropriate place for reagent injection is important, to avoid uneven distribution across the boiler cross-section. Multilevel injection location, as well as prediction of the additional ones, are important. If this is not satisfied, the so-called ammonia slip happened, which results in higher NOx and excess NH_3 at the end of the process. The enhancers (also called additives) can be used for lowering the temperature range for SNCR: CO, H_2, CH_4, a combination of hydrocarbons, ethylene glycol, furfural, hexamethyl tetra-amine, syngas, sodium compound, and CH_3NH_2 20.. Their influence on NOx reduction is realized due to radicals for the initiation of the reaction, that they provide. Residence time has a significant impact on NOx reduction with SNCR and depends on the temperature range that is applied. When stricter NOx reduction is required hybrid SNCR-SCR system can be applied (SCR in the duct). When ammonia as a reagent is used, from SNCR ammonia slip is purposely generated to feed SCR catalyst. Reduction of NOx to 90% with reduced SCR catalyst volume is possible with hybrid system application.

The wet scrubbing technique has the ability of simultaneous NOx and SOx reduction and is considered an environmentally benign method. As by-products N_2O, N-S complexes and NH_3 are formed during the reduction of NOx and SOx. In the reduction process, NO_2 and other water-soluble gases as CO_2 and SO_2 pass through alkali solutions where their transformation in acids occurs. Afterward, the process of neutralization is used. Removal of NO is more complicated because of lack of water- solubility, so additives are necessary 23.. As a solvent freshwater is mostly used. 24. have researched electrolyzed seawater usage for NOx and SOx removal in semi-continuous bubble column reactor using scrubbing system. With an increase of active Cl concentration of electrolyzed seawater NOx reduction efficiency increased as well. Initial pH has a significant impact on NOx removal, if it is in a convenient range process is less sensitive to inlet NO concentration and reaction temperature. Different aqueous solutions are used: sodium chlorite ($NaClO_2$), hydrogen peroxide (H_2O_2), potassium permanganate ($KMnO_4$), urea solution ($CO(NH_2)_2$), ozone (O_3), ($NH_3/NaClO$), etc. In combination with Fe, Co, Cu and Ru are used different chelated compounds as ethylenediaminetetraacetate (EDTA), nitrilotriacetic acid (NTA), dimercaptopropanesulfonic acid (DMPS), citrate and diethylenetriamine pentaacetic acid (DTPA). Other absorption systems include activated carbon fibers (ACF), zero-valent iron (ZVI), FeO, fly ash, microalgae and fungi.

Electron beam flue gas treatment is also a method for simultaneously NOx and SOx removal. Before irradiation ammonia is being injected into the flue gas stream. By irradiation of flue gas with fast electrons, chemical changes are initiated. They make NOx and SOx removal easier. Then in the interaction of fast electrons and flue gas components (N_2, O_2, H_2O, CO_2) oxidants, like those produced by UV sunlight are being produced, with a difference at concentration levels several orders of magnitude higher. In the reaction of these oxidants with NOx and SO_2 nitric and sulfuric acids are formed, which create a solid powder of ammonium nitrate and sulfate. Lastly, by-products are being filtrated. A generated by-product is a mixture of ammonium sulphate and nitrate. 25.

With the **electrochemical method (EM)**, NOx from flue gas are being converted into harmless gases (N_2 and O_2), without waste as spent scrubbing solution. NOx reduction occurs on the cathode when potential is applied to the solid-state electrochemical cell. At the cathode N_2 and O_2^- (oxide anions) are formed from NOx. Through the electrolyte oxide anions are being transported to an anode where oxygen formation occurs. For NOx reduction in an oxygen-rich environment, the cathode of an electrochemical cell must have high selectivity towards NOx so that oxidation reaction does not prevail. Adding NOx adsorption materials (alkali metal oxides or alkaline earth metal oxides) to the cathode affects the increase of its selectivity. 26.

Non-thermal plasma (NTP) can be induced by: electron beam irradiation, pulsed corona discharge, dielectric barrier discharge and as microwave plasma. Reduction of NOx and SO_2 with NTP is almost simultaneous, takes place at atmospheric pressure, and it occurs due to reactions with free radicals (H, N, O, OH, O_3, HO_2, etc.). Firstly the energetic electrons in plasma collide with H_2O, N_2 and O_2 to form gas-inducing primary radicals (HO, O, N) and ions. Excited molecules, like oxygen, in rapid reactions with the main gas quench and generate more HO and O radicals. More secondary radicals are being produced in reactions of the electron-ion and ion-ion and possessing higher energy than gas molecules. In the oxidation of NOx and SO_2 by these radicals, HNO_3 and H_2SO_4 are being formed almost instantly ($<10^{-3}$ s). The obtained products are neutralized using NH_3. As a result, NH_4NO_3 and $(NH_4)_2SO_4$ are produced. It is a new and promising deNOx technique that has importance especially in the automotive industry as a hybrid method with HC-SCR. 27.

Microbial approach is a novel alternative treatment method involving the usage of autotrophic microorganisms, which are capable of making their own food in the transformation of inorganic substances into organic nourishment. Inorganic sulphides are being used as electron donors, NOx reduction occurs through biochemical reactions and at the same time microorganisms are being fed and can grow. The whole process can be divided into the dissolution phase, in which SO_2 and NOx are being transferred to the liquid phase while passing the gas-liquid double membrane, and the biochemical phase in which they are consumed by microorganisms. Most of NO is being adsorbed on the surface of microbial cells. A small amount can dissolve in the solution and can be oxidized into nitrates (by denitrifying microorganisms) or reduced to N_2 (nitrogen reductase). NO_2 is reduced to N_2 after being converted to nitrate/nitrite (nitrogen reductase). 12. This method merits further study because according to the available literature, all tests were performed at temperatures below 60°C, so that at this stage of development they can only be used for further treatment of denitrification by-products, such as at wet scrubbers 28..

4. CONCLUSION

Although the problem of emission of nitrogen oxides is not new, it is still being investigated for an efficient solution to be found. In addition to improving conventional methods, new methods and approaches are being developed. There is no general solution for this problem, it is necessary to adapt to the existing conditions and to choose the reduction method that is most optimal for the considered system. This especially refers to modified systems that have switched to working with biomass. In the table 1 is given overview for reviewed methods alongside with their main advantages and disadvantages. Further research of deNOx and optimization of described methods, to overcome NOx emission problem is required. Application of these methods in commercial use and increasing their efficiency, while solving cost and methods disadvantages, is key for biomass to be used as a renewable energy source and fossil fuel replacement.

Table 1: Overview for reviewed methods

Method	SCR	SNCR	Wet scrubbing	Electron beam	EM	NTP	Microb. approach
Efficiency %.	60-90	30-70		70-90	approx. 60		40-90
Temp. range °C.	150-590	800-1100	Ambient temp.		400		> 60
Advantages	High efficiency Good selectivity Cost effectiveness Simple system Mature method	Simple solution Implementation on existing systems is easy Lower cost Combination with other deNOx methods Mature method	PM and acid gases removal No high temp. No extraneous chemicals Easy regeneration Low cost of equipment and additives Mature method	No waste generation By-product can be used for fertilizer production	Reductant is not required Simple, clean and compact technology	Simple system and operation No waste generated By-product are useful and can be used for fertilizer production	Reduction of CO_2 Less secondary pollution Low energy consumption High removal rate No need for catalysts or chemicals
Disadvantages	High cost, lifespan and disposal of catalyst Storage of reducing agents High cost and corrosion of equipment Ammonia slip	Less reduction Downstream equipment cleaning is necessary High operating temp. Ammonia slip	Slow removal rate Low efficiency Liquid waste	High energy consumption Prevention of radiation problems Complex equipment Not tested in real-scale systems	Still not developed and implemented	Low efficiency High cost and energy consumption Reactor complexity Cost and lifetime of the plasma power supply Physicochemical property change of by-products	Unstable removal efficiency Short lifespan of mircoorganisms Insufficient temp. for FGT High sensitivity to temp. fluctuations

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ACCIDENTS IN AGRICULTURE AND FORESTRY - INFLUENCE OF RURAL DEVELOPMENT PROGRAM ON WORK SAFETY IN THE REPUBLIC OF SLOVENIA AND THE REPUBLIC OF SERBIA

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Abstract: *From 1981 to 2020, accidents in forestry agriculture in the Republic of Slovenia tragically killed 1,756 or an average of 43.9 people a year. There is a noticeable trend of decreasing number of accidents with fatalities with tractors, especially in public transport, and less when working outside public roads. The first major decline in the number of accidents and fatalities with tractors in the R. of Slovenia was after the mandatory introduction of the cabins for all tractors in 1986, and the second decline in the number of tragic casualties was after the introduction of homologation on May 1, 2004. In forestry, the number of fatalities in the Republic of Slovenia remains high and with significant oscillations over the years, and especially when there were significant natural disasters. The question of the impact of the application of incentives (subsidies of the State of Slovenia through the Ministries for Investments in Agricultural and Forestry Technology) from the rural development program on the safety of work in these areas is raised. Recipients of incentives for forestry equipment in the period from 2014 to 2021 participated in the survey on accidents during the work performed. The number of accidents in the group of forest owners and forestry workers was numerically small, so it can be concluded that such a measure and investments in new equipment for agriculture and forestry have a positive impact on occupational safety.*

In the Republic of Serbia from 1980 to 2020 a total of 2,450 or an average of 61,25 people a year were tragically killed in accidents directly in the field of agriculture and forestry.

In public transport situation, accidents with tractors in this period amounted to about 7,25% of the number of all accidents in public transport (average of 2 accidents with tractors per day, most often in September). This resulted in an average of 63,45 deaths of people during this period.

Today, the R.Serbia has a significant trend of decreasing the number of accidents with fatalities with tractors in public transport. Significant decline in the number of accidents and fatalities in the primary areas of application of tractors (agriculture and forestry) was after the mandatory introduction of cabins or safety equipment, accessories and tractor markings, and especially the implementation of the new version of the Law on Road Safety in R. Serbia, after year 2009. Incentive measures from the institutions of the state of the R. Serbia for the purchase of new *tractors in the period from 2012 to 2020. The year did not bring significant changes in the described problems of accidents when using tractors.*

The safety of tractor use in the Republic of Serbia is not at a satisfactory level.

Keywords: *Republic of Slovenia, Republic of Serbia, agricultural and forestry equipment, accidents in public transport, accidents in agriculture and forestry, incentives from rural development programs*

1. SITUATION IN THE REPUBLIC OF SLOVENIA

1.1.INTRODUCTION

In the last 20 years, great and significant changes have taken place in the agriculture of the Republic of Slovenia, -still characterized by a small agrarian structure, although the number of agricultural farms that cultivate land is constantly decreasing. Thus, at the end of 2020, that number was 69,900. On average, each farm used 6.9 ha of agricultural land and 5.2 ha of forest. 231 legal entities (companies) owned an average of 110 ha of agricultural land 1.. The number of investments in agricultural machinery is decreasing, and stronger, more efficient, Western European machines are being bought. If we look at the total number of tractors and agricultural machinery, that number is statistically at the same level as in countries with developed agriculture, but their quality and technical properties are at a lower level.

Approximately 20% of tractors are not registered and do not have a cab / safety frame even though it is prescribed by law, regardless of where the tractor is used. The number of accidents in agriculture and forestry is continuously decreasing, but it still remains at a high level. When working in agriculture, there is a great danger of accidents everywhere. Occurence of people injuries are possible in the work with a tractor or other machines, in the forests, with livestock, with cargo, with electricity etc.. The causes can be can be very different and then complete prevention is hardly possible. But in the most cases, the cause is ignorance of the danger, inexperience and insufficient attention at work. One of the most common causes of accidents in agriculture and forestry are machines and tractors. The causes can be divided into a group of accidents are the result of inadequate manufacture and equipment of machines, and another group of accidents are the result of inadequate use of machines 2.. The question of the impact of the application of incentives (subsidies from the EU and the state of Slovenia for investments in agricultural and forestry equipment) from rural development programs on occupational safety in these areas is raised. There is a widespread public opinion that farms buy most of this equipment through subsidies, which is not the case. In the rural development program for the period 2007-2013, only 13.8% of purchased new tractors were co-financed from public funds. The purchase of 1,536 tractors was subsidized, and in the same period, 11,500 new tractors were procured. The situation is similar with equipment and working machines, but we cannot confirm that with numbers, because data on the sale of these machines are not available 3.. It is also generally accepted that the measures of the rural development program, with the subsidizing of investments in the purchase of new machines, affect the improvement of safety at work. This was done on the example of in the case of fatal accidents in forestry.

1.2. MATERIAL AND METHODS

For the analysis of fatal accidents in agriculture and forestry, the data of the Ministry of the Internal affairs with agricultural and forestry equipment for the period 2020 to 2020 are used, which are generally available 4.. Data on accidents of forestry workers since 1998 have been collected by the Forestry Institute of Slovenia on the basis of publications in the media and notifications of workers of the institute 5.. Based on data from countries with more consistent statistics, it is estimated that the number of other accidents (falls in buildings, animal damage, poisoning, etc.) is at least 20% of accidents with agriculture and forestry equipment. On the same basis, it is estimated that on at least 100 to 500 injuries a single fatal accident occures 6.. Data on newly registered tractors were obtained from monthly publications of the Ministry of Infrastructure of the Republic of Slovenia. According to this, in June 2021, 117,297 two-axle tractors were registered 7.. In the case of fatal accidents in forestry, data on recipients of subsidies and casualties at work in the forest have been improved. But this was impossible due to the protection of personal data on victims in police data on accidents at work in the forest. These data were obtained through a survey within the research project no. V4-1812 "Development of indicators and methodologies for monitoring the provision of services in forestry" 8..

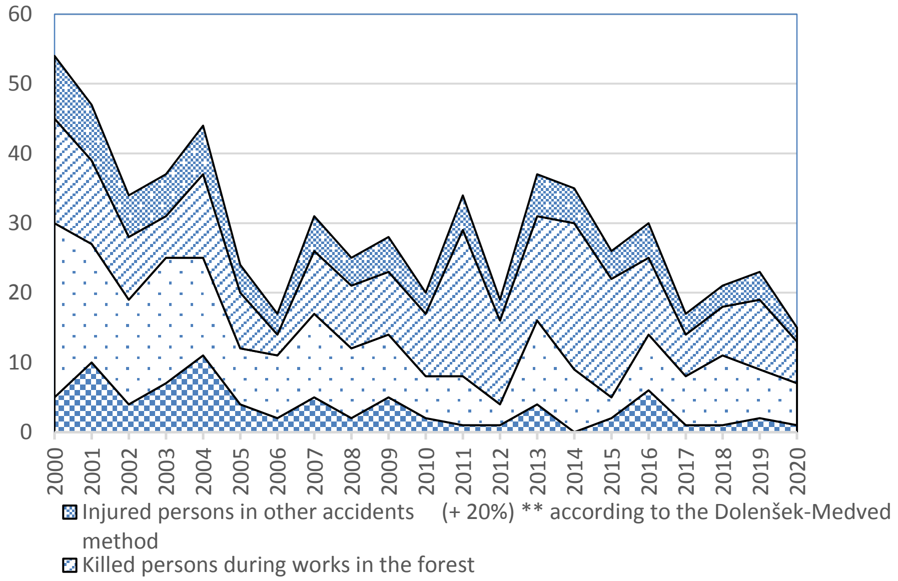
1.3. RESULTS OF RESEARCH

1.3.1. Fatal injured in accidents in agriculture and forestry in the Republic of Slovenia

From 2000. to 2020., 518 people or 24.6 people a year were tragically killed while working with agricultural and forestry machines in the Republic of Slovenia (Table 1). The research method Medved & Dolenšek 6., predicts an increase of + 20% of other fatalities (falls in buildings, injuries from animals, poisoning by plant protection chemicals, etc.), 618 people died in agriculture and forestry or an average of 29.4 persons per year.

Tab. 2. Tragically killed persons in agriculture and forestry of the Republic of Slovenia from 2000 to 2020.

Year	People killed in traffic accidents with a tractor	People killed in work accidents with a tractor in agriculture	Killed persons during works in the forest	Injured persons in other accidents (+ 20%) ** according to the Dolenšek-Medved method	Total casualties 2000-2020
2000	5	25	15	9	54
2001	10	17	12	8	47
2002	4	15	9	6	34
2003	7	18	6	6	37
2004	11	14	12	7	44
2005	4	8	8	4	24
2006	2	9	3	3	17
2007	5	12	9	5	31
2008	2	10	9	4	25
2009	5	9	9	5	28
2010	2	6	9	3	20
2011	1	7	21	5	34
2012	1	3	12	3	19
2013	4	12	15	6	37
2014	0	9	21	5	35
2015	2	3	17	4	26
2016	6	8	11	5	30
2017	1	7	6	3	17
2018	1	10	7	3	21
2019	2	7	10	4	23
2020	1	6	6	2	15
Total	**76**	**215**	**227**	**100**	**618**
Average/Year	**3,6**	**10,2**	**10,8**	**4,8**	**29,4**



Graph. 1. Trend of tragically killed persons in agriculture and forestry of the R.Slovenia from 2000. to 2020.

Graph. 1, shows that at the beginning of the analyzed period of the last 20 years, accidents in traffic with tractors prevail, which are continuously decreasing in the Republic of Slovenia. The most important (critical) period is 2011-2012. year with the introduction of mandatory cabins and protective frames for all new and used tractors. The owners have properly equipped and registered tractors that are used on public roads. But other owners are less up-to-date in equipping tractors because they were not registered and used outside public roads.

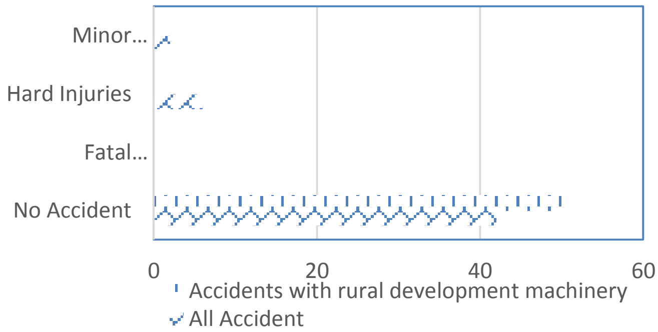
Therefore, the number of fatal accidents with tractors outside public roads (work operations and accidents with tractors) has significantly decreased or even increased in the last ten years of this analyzed period. Most of these accidents happen to tractors that were not equipped with a cab or safety frame to protect the driver when overturning.

The inconsistency in equipping tractors with cabins or safety frame (ROPS) is also shown by the comparison with Germany and Austria, which, like Slovenia, prescribed by law the mandatory equipment of all tractors (including navigable ones) with cabins or safety frames. In Germany, ten years after the introduction of mandatory equipment, 0.7 tractor drivers were killed per million inhabitants, in Austria 4.8, and in Slovenia as many as 16.8.

In order to improve the situation, the Law on Motor Vehicles stipulates that tractors must have a mandatory cab or safety frame (ROPS) from 1.7.2011. This allows control and penalization by the police and inspection services. Another problem is not using a seat belt. Tractors registered after May 1, 2004 (a total of 47,308 pieces or 41.2%) have a seat belt installed, but drivers rarely use it. The problem is with older tractors, there were 69,989 such units or 61.0% on June 30, 2021, which do not have a built-in seat belt system. During the period under review, an average of 12.4 people were killed annually in the operation of machines and tractors in the forests. By 2001, an average of 18 people were killed in that work each year. Until 2010, except in 2004, the number of deaths in forests was always less than 10. Unfortunately, since 2011, the number of deaths in forestry has been increasing - an average of 12.6 per year. This can be attributed in particular to the increased number of people working in smaller private forests where workers are not sufficiently trained, equipped and with lack of adequate experience. In addition, there is a growing interest in timber production or timber sales due to the worsening economic situation, but on the other hand, legal forest maintenance is required. Part of the cause can also be attributed to the regulations for work in the forest, since the vast majority of forest owners are not prescribed education or equipment with mandatory personal protection. This obligation only applies to registered forest contractors and owners who are insured as farmers, of whom there are only 9,000 9.. The Author estimates that between 50,000 and 60,000 forest owners and members of their families occasionally work in the forests of Slovenia.

1.3.2. Impact of rural development programs on occupational safety

Surveys were sent to all recipients (277 persons) of funds for forestry equipment in the programming period 2014-2020 of the rural development program of the Republic of Slovenia, who provided an email address (214 persons). Fifty surveys were received with answers to questions about accidents at work in the forest. Analyzes show that 242 respondents or 84% did not have an accident at work in the forest, and 8 respondents or 16% had an accident at work in the forest, of which 6 severe and 2 mild. The survey shows that there were no deaths. Of all 50 respondents who answered the question about accidents at work in the forest, none had an accident with machinery and equipment co-financed in the Rural Development Program for investments in the procurement of new machinery and equipment for work in the forest. Thus, it can be concluded that such a measure and investments in new technology for agriculture and forestry have a positive impact on occupational safety.



Graph. 2. Accidents of 50 respondents while working in the forest

2. SITUATION IN THE REPUBLIC OF SERBIA

2.1.INTRODUCTION

According to the data 14,15,19., which was published at the end of 2012, the Republic of Serbia has 408,734 tractors of all categories for performing various works on 4,086 million ha of agricultural land. A total of 628,555 family farms are registered, cultivating 2,816 million ha of agricultural land.

The average family farm has 4.48 ha of agricultural land divided into 5 plots of 90 acres. The total number of two-axle tractors on family farms is 405,728, of which 94.87% are older than 10 years. 2,421,065 attachments are also used, of which 93% are older than 10 years 19.. The age structure of agricultural machinery is very unfavorable and exceeds 10 years in the state and 15 years in the private sector, or over 35% of tractors are older than 15 years 19.. Due to the shortcomings of new and modern tractors, domestic agriculture has numerous consequences, and one of the significant consequences is the impact of old tractors on human safety and health.

Agricultural machinery (tractors, working machines and cultivators) can have a significant impact on traffic safety and the occurrence of traffic accidents in a particular area, 16,17..

Research in our country and in the world, shows that traffic accidents with tractors have consequences with dead and injured people, while almost regularly there is a high value of material damage.

The presence of agricultural machinery on public roads is directly related to the agricultural production of a country, ie the degree of agricultural development in a particular area.

For example, on the territory of Južnobački okrug 20, 21., which has the biggest number of tractors in Vojvodina, a total of 491 people were killed in traffic accidents with tractors in the period from 2001 to 2011. More than 50% (257 people) were killed in traffic accidents caused by tractor drivers.

If we analyze only the number of dead persons 16, 17., 13. in traffic accidents with tractors, in the period 1999 -2009. in the public transport of the Republic of Serbia, an average of 62 tractor drivers or participants. Of the total number of dead, over 67% lost their lives in direct traffic accidents with tractors. This indicates the fact that traffic accidents caused by tractor drivers are, as a rule, severe traffic accidents with tragic consequences. In the Republic of Serbia, from 2000 to 2020, a total of 1,477 or an average of 69 people a year were tragically killed in accidents directly in agriculture and forestry. In public transport, accidents with tractors in this period were about 7.25% of the number of all accidents in public transport (average of 2 accidents with tractors per day, most often in September). This resulted in fatalities of an average of 69 people on tractors during this period. Today, the Republic of Serbia has a declining trend in the number of accidents with tragically injured people with tractors in public transport and agricultural and forestry activities. Significant decline in the number of accidents and fatalities in the primary areas of application of tractors (agriculture and forestry) was after the mandatory introduction of cabins or safety equipment, accessories and tractor markings, and especially the implementation of the new version of the Law on Road Safety in Serbia after 2010.

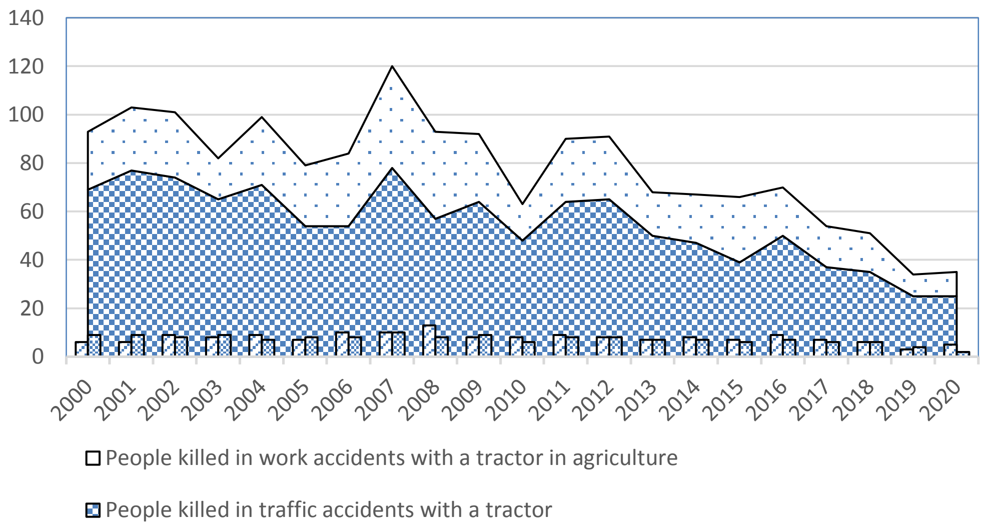
2.2. MATERIAL AND METHOD

The research of the causes of traffic accidents with tractors in the Republic of Serbia was analyzed on the basis of statistical data obtained from the Ministry of Internal Affairs (Traffic Police Directorate) of the Republic of Serbia 12. and the Traffic Safety Agency of the Republic of Serbia 10.. The data refer to the number, causes, and consequences that occurred in traffic accidents with tractors. The analysis includes traffic accidents in which tractors participated in the territory of the Republic of Serbia, for the period 2000-2020.. Part of the data necessary for the research presented in this paper includes the collection and analysis of records from the scene of accidents (agricultural areas and forest areas) obtained from the Basic Courts from 18 administrative areas of the Republic of Serbia 13.. This field method collected relevant data that studied accidents, from the aspect of official institutions and persons who follow such events (records of the Ministry of Internal Affairs, records of investigating judges and other documents).

2.3.RESEARCH RESULTS

2.3.1. Fatal injured people in accidents in agriculture and forestry in the Republic of Serbia

From 2000 to 2020, a total of 1,798 people or 86 people a year were killed while working with tractors in the Republic of Serbia. If the method of Medved & Dolenšek 6. increases by 20% the occurrence of other types of tragic accidents (falls in buildings, injuries from animals, poisoning by plant protection chemicals, etc.), during this period in agriculture and forestry fatalities were 1950 persons or an average of 92.9 persons per year.



Graph. 3. Trend of tragically killed persons in agriculture and forestry of the R.Serbia from 2000. to 2020.

Tab. 2. Tragically killed in agriculture and forestry of the Republic of Serbia from 2000 to 2020.

Year	People killed in traffic accidents with a tractor	People killed in work accidents with a tractor in agriculture	Killed persons during works in the forest	Injured persons in other accidents (+ 20%) ** according to the Dolenšek-Medved method	Total casualties 2000-2020
2000	69	24	6	9	92
2001	77	26	6	9	98
2002	74	27	9	8	98
2003	65	17	8	9	89
2004	71	28	9	7	95
2005	58	25	7	8	76
2006	54	30	10	8	78
2007	64	42	10	10	104
2008	45	36	13	8	86
2009	57	28	8	9	88
2010	48	15	8	6	67
2011	64	26	9	8	87
2012	65	26	8	8	87
2013	50	18	7	7	69
2014	47	20	8	7	68
2015	39	27	7	6	59
2016	50	20	9	7	74
2017	37	17	7	6	57
2018	35	16	6	6	53
2019	25	9	3	4	37
2020	25	10	5	2	37
Total	**1148**	**487**	**163**	**152**	**1950**
Average/Year	**54,7**	**23,2**	**7,8**	**7,2**	**92,1**

*2000-2010 According 15..

Graph. 3. and Tab.2., show that at the beginning of the analyzed period of the last 20 years in the Republic of Serbia, accidents in traffic with tractors, continuously but slowly decrease. A characteristic period with the beginning of the decline in the number of accidents is from 2010, primarily due to the application of the Law on Safety on Public Roads, which obliges the use of proper equipment for tractors and work machines, and especially the mandatory installation of cabins and protective frames (ROPS) categories of new and used tractors. In order to improve the situation, the Law on Motor Vehicles stipulates that tractors must have a mandatory cab or safety frame (ROPS) from 1.7.2010. This enables the control and penalizing by the traffic police and inspection services.

During the analyzed period (Table 2), an average of 7.8 people died annually in the work of various machines and tractors in forests (approximately 1.95 million ha or 29.1% of the area of the Republic of Serbia 22.). Accidents in forests can be attributed to an increasing number of people working in private forests where workers are not sufficiently trained or equipped and where there is a lack of adequate experience in heavy forest work. In addition, there is an increased interest in the production and sale of wood due to the economic situation in energy supply. Part of the occurrence of accidents in the forests of the Republic of Serbia can also be attributed to the fact that for the vast majority of forest owners there is no adequate prescribed education or equipment with mandatory personal protection to perform work in the forest. According to the data of the Author 19, 22., approximately 150,000 to 200,000 forest owners and members of their families occasionally work with various activities in the forests of the Republic of Serbia.

2.3.2. Impact of rural development programs on occupational safety

Incentive measures from state institutions of the Republic of Serbia (Ministry of Agriculture and Forestry, Directorate for Agrarian Payments, IPARD funds) for the purchase of new tractors in the period 2012-2020, did not bring significant changes in the described problems of accidents when using tractors. In the period 2015-2019. year, 20,075 tractors were purchased, or an average of 4,015 new tractors of various categories and purposes per year, 19..

Measures to encourage the purchase of new tractors and attached machines with the financial assistance of the above institutions of the Republic of Serbia in the period 2012-2020, did not bring significant changes in the described problems of accidents when using tractors, given the total number of these agricultural machinery. The share of new tractors and agricultural machinery did not exceed 5-7% of the total number of funds in the field of agriculture and forestry. Due to all the above, the safety of use of tractors and agricultural machinery in the Republic of Serbia is not at a satisfactory level. Research into the impact of new financial investments through state institutions in the field of agricultural machinery and tractors on the safety of use and a significant reduction in the number of tragic events is a very important activity that should continue in the future in the Republic of Serbia.

3. CONCLUSION

Agriculture and forestry are labor-intensive activities where safety and impact on the health of participants is still a current problem that needs much attention.

The situation with non-professional workers is especially problematic because everyone who has an interest, time and land or forest is engaged in agriculture and forestry.

Although in the past in the Republic of Slovenia and the Republic of Serbia a lot of energy, efforts and measures have been invested to increase safety at work in agriculture and forestry, every year a large number of people are tragically killed or injured.

The causes of accidents in agriculture and forestry are very complex, and above all: ignorance of the work process and dangers, the unpredictability of accidents, inexperience and insufficient attention in certain phases of work.

One of the most common accidents in agriculture and forestry with machines and tractors are the consequences of inadequate production of some parts, equipment and technical condition of machines, and the second group which is a consequence of inadequate use of machines (no constant and adequate user education)

New and safer technology (tractors and machines) can reduce the number of tragic accidents, so subsidizing purchases from public funds of the state or rural development funds is justified.

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ENERGY EFFICIENCY OF INCUBATOR STATIONS

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Abstract: *Energy efficiency will be of increasing importance in the future, and the aim of this research is to determine the consumption of human and machine work on three types of incubator stations for one-day-old chicken production. These stations differ in production volume, technical and technological characteristics. The energy efficiency of incubator stations was determined with chronograph measurement of human work, energy consumption for each machine and equipment involved in the incubation process. Comparison of obtained data was performed in numerical values of production per chicken. Mini-incubator station had the lowest energy efficiency with 83,15% of energy related to the incubator, 16,62% of lighting, and 0,23% of the ovoscope. This station consumed 652,2 machine work hours or 6,52 hours/chicken, human work 24,4 hours or 0,24 hours/chicken and electricity 31,75 kWh or 0,31 kWh/chicken. The medium-sized incubator station consumed 670,7 hours of machine work which is about 0,018 hours/chicken, human work 291,82 hours or 0,1076 hours/chicken, and electricity 8 341,21 kWh or 0,22 kWh/chicken. The large-sized incubator station consumed 1 310,1 hours of machine work or 0,013 hours/chicken, human work 769,14 hours or 0,008 hours/chicken and electricity 30 672,71 kWh or 0,32 kWh/chicken. The incubator station, Poljovet d.o.o., recorded a medium positive correlation between machine and human work and a strong positive correlation between machine work and electricity. Also, mini-incubator station in Pazarić recorded a strong positive correlation between machine and human work and a medium positive correlation between machine work and electricity. We concluded that energy efficiency was most affected by the heating system and large incubator stations had an advantage over small ones.*

Key words: *incubator, chicken, energy, efficiency*

1. INTRODUCTION

Modern poultry production achieves high efficiency, but requires constant analysis of technical and technological process to improve production. Practical measurement studies are needed to examination all technological processes, as well the applicability and stability of all mentioned types of energy saving technologies in incubator stations 1.. Design of incubator station have evolved from small rural to large integrated with annual production up to 85 million one-day-old chicken. In parallel with technical progress, the technology from single-phase to multi-phase incubation of chicken is being improved. New technological approaches have shortened production cycle of broiler fattening to 42 days and chicken weight reaches up to 2,6 kg per chicken. These indicators require a high level of control of all production processes. Traditional incubators use electric heating to meet the necessary heat demand, ventilating the lower-temperature fresh air to provide oxygen for the metabolism period of the incubation 2.. When placed in the incubator box with an optimal condition, chicken embryos begin to develop. Several studies have shown that a constant environment temperature of 37.5 or 38 ^{0}C is a crucial factor for incubation effecting the hatchability 3, 4.. During the metabolism period of incubation, chicken eggs will have an obvious heat production, which has been measured by many researchers 5, 6.. The presence of various pathogens can make negative consequences at the beginning of egg incubation, which can be transmitted to the fattening process. In Bosnia and Herzegovina (BiH), the volume of incubator stations production exceeded situation from the year of 1992. It is estimated that the current production capacity is 4.58 million eggs for hatching, of which there are 40 incubator stations in Republic of Srpska (RS) with capacity of 1.7 million and the same number of incubator stations in Federation of Bosnia and Herzegovina (FBiH) with capacity of 2.88 million eggs. 7.

Considering that the capacities of production have increasing and they have requiring constant analysis of production processes, we decided to research production capacities of the companies: „Poljovet“ d.o.o from Gračanica, „Brovis“ d.d. from Visoko and mini-incubator station from Pazarić with analyzing of energy efficiency of production process at different incubator stations. These are three different technical and technological processes of one-day-old chicken production, which differ in the consumption of machine and human work. Chronographic measurements of machine and human work consumption in the incubation process were performed by experimental research. The research hypothesis is based on the expectation that, large incubation systems for chicken are more economical compared to smaller ones and obtained energy efficiency results will indicate peak loads of production and possibilities for improving production.

2. MATERIAL AND METHODS

In this research, three types of incubator stations were selected for the production of one-day-old chicken, which differ in production volume, technical and technological characteristics. The experimental part of the research was performed in the incubator stations: Poljovet d.o.o from Gračanica, Brovis d.d. from Visoko and mini-incubator station in Pazarić. These are large, medium and small capacity stations that reflect production conditions in BiH. To determine the energy efficiency of three types of incubator stations in this research, the method of chronographic measurement of energy consumption was applied for each machine and equipment involved in incubation process. Indicators of several days of human and machine work at incubator stations were measured. Processing the collected data, indicators of energy consumption, production volume and structure of business will be obtained. For the purpose of mutual comparison, the obtained indicators will be expressed in numerical values of production per chicken. Since these are manufacturers of different volume capacities, we used data from only one production section. To better understand the type of incubator stations, we provide details of technical and technological characteristics as follows:

- *Medium-sized incubator station "Poljovet" d.o.o. Gračanica*

The equipment consists of six pre-hatcheries with a capacity of 38 400 eggs, installed power of 4.5 kW. Heating is done with hot water from a solid fuel heating system. The production brand of the incubator station is an international company called "*PAS REFORM*". The dimensions of the pre-hatchery are: width 4,834 m, depth 2,599 m and height 2,459 m, + 0,50 m highest point 8.. One pre-hatchery was used in this research. This incubator station has two hatcheries with a capacity of 19 200 eggs, installed power of 3.5 kW. The type of machine is *Tiros Disk* ("*PAS REFORM*"). The dimensions of the hatchery are: width 3,235 m, depth 2,210 m and height 2,445 m, + 0,50 m highest point. The machines are heated with hot water.

Egg stacking machines are installed power of 1 kW. The machine has the ability to take 30 pieces of eggs. It also has egg transfer machine with an installed power of 2 kW and a capacity of 150 eggs. Heating and regulation of ventilation in pre-hatchery and hatchery rooms is done through the climate. The electric motor on the air conditioner has an installed power of 1.1 kW, and the radiator with hot water has a power of 50 kW. It works in the winter months when temperatures are low. Four air extraction fans with an installed power of 0.6 kW: in the fumigation room (4 hours), in the chicken removal room (16 hours), in the packaging fumigation room (4 hours) and in the room for washing box (works 10 hours).

The machine for washing box, carts and rooms has an installed power of 2.5 kW. It heats the water by burning oil, and work engagement is around 15 hours. The cooling air in the egg storage room has an installed capacity of 3 kW. It works as needed when storing eggs in the summer months. The air condition in the room with pre-hatcheries has an installed power of 5 kW. It works 12 hours a day in the summer months. The air condition in the room with hatcheries has an installed power of 5 kW. It works 10 hours a day in the summer months. The air condition in the room for removing and storing chicken works for about 24 hours in the summer months.

The water-cooling system has an installed power of 2 kW and works with the help of Freon. It is used in the summer months when the temperature of tap water is higher than 15º C. Lamps ("*OVOSCOPE*") are used for 30 minutes when switching, with an installed power of 0.35 kW. There is an unit for additional power supply, installed power 100 kW and used in case of emergency.

Water supply is made from two water supply systems, and there is a reserve capacity of about 20 m^2. Electricity is supplied from the existing network. The lighting of the building is done with neon lamps with a power of 2 x 36 W and there are 57 in the building. The duration of illumination is about 10 hours. The lighting of the building circuit was solved with reflectors of power per 1 kW. The duration of illumination is about 8 hours. Lighting is done as needed and it is separate in each room.

The incubator is equipped with: a digital microcomputer for temperature which is graduated in ºC with a deviation of 0.1 ºC. The digital microcomputer controls percentage of relative humidity in % with a deviation of 1%. The scale of the microcomputer is graduated from 0-99 %, with installed alarms for minimum and maximum temperature and minimum and maximum humidity, in case of fan shutdown, door opening, etc. The incubator has an automatic egg rotation and an automatic water-cooling system. The equipment is of high quality, which contributes to ideal climate in incubator. The equipment includes a trolley for easier handling of eggs. The egg rotation is regulated by a digital clock, which is located outside the incubator and is programmed from 10 to 999 minutes. Humidity is regulated by a speed reducer and an electronic system with sensor and display. The alarm goes on in case of: too low and too high temperatures, power failure, belt transmission cracks and engine downtime.

- *Large-sized incubator station "Brovis" d.d. Visoko*

The equipment inside the incubator station is manufactured by *Airstreamer* type *12s-focus*. This station has eight pre-hatcheries, four of them have a capacity of 38 400 eggs and the other four have a capacity of 57 600 eggs. The installed power of these machines are 8.3 kW (38 400 eggs) and 9.1 kW (57 600 eggs). Heating is done with hot air through a heater on electrical power. The type of machine is *Petersime*. Two incubators were used for the research, the first with a capacity of 57 600 eggs and the second with a capacity of 38 400 eggs. The dimensions of the larger pre-hatchery are: width 4,191 m (addition of bases 4,236 m), depth 3,636 m and height from floor to roof 2,960 m. The dimensions of the smaller pre-hatchery are: width 3,369 m (base addition 3,414 m), depth 3,636 m and height from floor to roof 2,830 m.

Hatcheries are from brand *Petersime*, 5 pieces, capacity 19 200 eggs, installed power 4.2 kW. Overall dimensions of the hatchery are: width 3,414 m (base additions 3,369 m), depth 2,116 m and height from floor to roof 2,850 m.

The egg stacking machine has an installed power of 0.4 kW. The capacity of the machine is 30 pieces. There are two machines in operation. Egg transfer machine with an installed power of 1.2 kW and a transfer capacity of 150 pcs.

The ovoscope has an installed power of 0.6 kW and a capacity of 150 pieces. Shell crusher has an installed power of 6.6 kW. Sorter and chicken counter are powered by three electric motors with a power of 0.37 kW, which makes a total power of 1.11 kW.

The machine for washing the wrapping material has an installed power of 1.2 kW. The compressor is used to start the egg rotation. The pressure is set to minimum 8 and maximum 10 bar. Works about 15 min / h. Installed compressor section power is 5.5 kW. The climate for maintaining the water temperature has a working engagement of 51 min / h. The installed power of the air condition section is 46.5 kW.

The hot air heater has an installed power of 2 kW and its work engagement is 2 hours / day. The air condition for heating and spraying humid air has an installed power of 8.21 kW, and the work engagement is 24 h / day (it always works). The interior lighting consists of 161 luminaires (neon lights 2x36 W). They work as needed with an average work of 8 h / day. Outdoor lighting consists of 13 luminaires (12 neon lights and 1 reflector). The neon lights are 2x36 W, and the reflector is 1 kW. They work as needed, on average 7 h / day.

The building has 15 fans with the following characteristics:

- 5 fans behind hatcheries with operation of 48 hours / cycle.
- 2 fans in the corridors behind the hatcheries with a work engagement of 24 hours / day;

- 1 fan in the pre-hatchery room works 4 hours a day;
- 2 fans in the egg fumigation room with a work engagement of 2 hours / day;
- 1 fan in the room for removing chicken with a work of 4 hours;
- 2 fans in the room for fumigation of packaging with work of 3 hours;
- 2 fans in the corridors behind the pre-hatchery rooms with a work engagement of 4 hours / day;
- The installed power of all 15 fans is 0.51 kW.

The auxiliary power supply unit has an installed power of 200 kW and is used in the case of a power failure.

- *Mini-incubator station in Pazarić*

It is a single-layer incubator intended for household needs, i.e. performing chicken for own needs. The annual capacity of this incubator is 1 700 eggs. This is a small incubator made of a combination of wood and plastic material. It is easy to wash and maintain. The thermoregulator is an electronic one which regulates the temperature inside the incubator, keeping it within the limits of physiological requirements. A fan with power of 0,04 kW is used to circulate the air inside the incubator. The hot air heater power is 0.15 kW. Humidity is maintained by evaporation from a small water container that needs to be replenished once a day with lukewarm water. The capacity of these types of incubators is 100 eggs per cycle. Turning the eggs is manual.

Microsoft Office package and *IBM SPSS Statistics* for statistical data processing were used to process and present the results.

3. RESULTS AND DISCUSSION

The process of incubation of one-day-old chicken is very demanding in terms of both technical and technological procedures. Both segments intertwine within the production process. The technical part is reflected in meeting of set parameters of air conditioning, egg rotation and energy consumption. Technological indicators are reflected in the quality of eggs, the given parameters of the microclimate and the number of hatched eggs. The final result of these indicators is reflected in number of successfully hatched eggs and the price of a one-day-old chicken produced. Energy efficiency can significantly affect these indicators, which can be seen in the example of the comparison of the tested incubator stations. The structure of energy consumption of the medium-sized incubator station "Poljovet" d.o.o. Gračanica is shown in Figure 1.

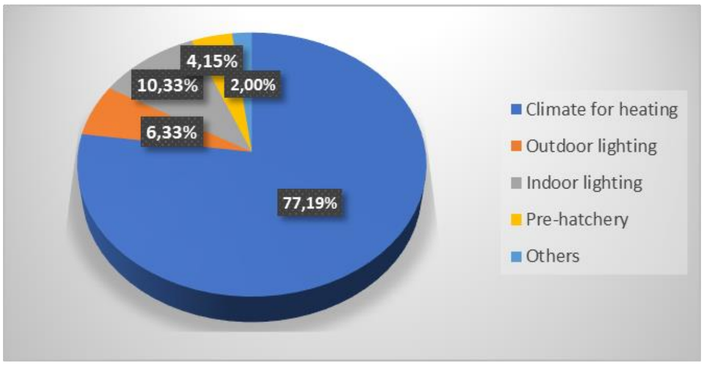

Fig. 1. The structure of energy consumption of the medium-sized incubator station "Poljovet" d.o.o. Gračanica

From the processed results (Fig. 1) of incubator station “Poljovet” d.o.o. it can be seen that most of energy was spent on the operation of the heating climate, 6 438,6 kWh or 77,19% of the total energy, which was to be expected because the measurements were made in January. Next is indoor lighting with 861,84 kWh or 10,33% of total energy consumed and outdoor lighting with 528 kWh or 6,33%. All data refer to 21 working days and both, indoor and outdoor lighting working as needed. Pre-hatchery and hatchery did not work continuously, but they were turned on and off by the system with sensor. System work is based on 1 second of work and 5 seconds of rest, because both devices are connected to the central heating system. During the January, about 11 tons of charcoal were used to heat the incubator station. Combustion of one ton of charcoal produces about 10 000 MJ of energy. According to the statements of “Poljovet” d.o.o. management, heating with charcoal provides energy savings of up to 200 € per month.

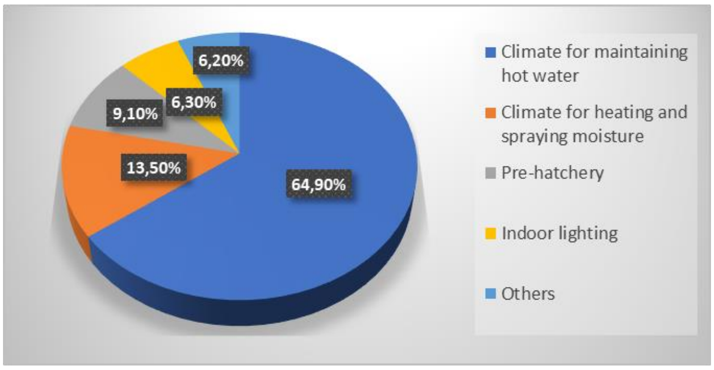

Fig. 2. The structure of energy consumption of the large-sized incubator station "Brovis" d.d. Visoko

At the incubator station "Brovis" d.d. from Visoko, the measurement of machine work was performed in the winter months. The obtained results indicate that it is a larger incubator station, in relation to "Poljovet" d.o.o. The highest energy consumption refers to the climate for maintaining hot water in incubators, which is result to the high work engagement and large installed power. Consumption during the cycle was 19 920,6 kWh or 64,90% of total energy. Other large consumers are air conditioners for heating and moisture dispersion with 4 137,84 kWh or 13,50%, and pre-hatcheries with 1 573,2 and 1 227,6 kWh or 9,13% of total energy consumed.

The results of energy indicators of the mini-incubator station from Pazarić can be seen in Figure 3.

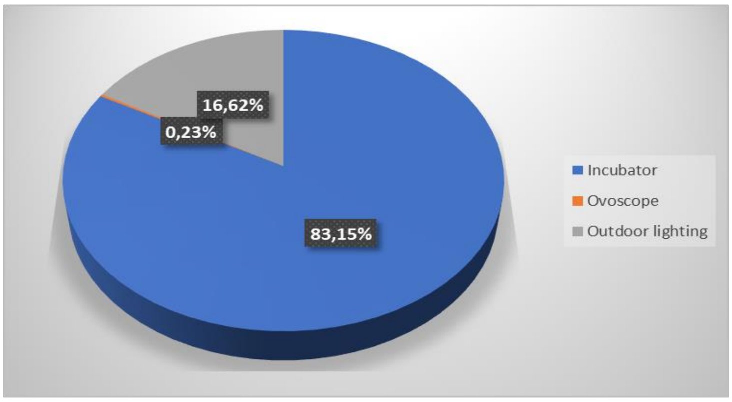

Fig. 3. Mini-incubator station from Pazarić

The heater on the incubator is turned on and off at intervals of 1 minute work and 12 minutes pause. The fan runs all time for about 22 days. The energy consumed for the incubators work referred to the heaters work that was at times turned on (1,6 hours) and the fans work that was constantly turned on, which spent 26,4 kWh of total energy or 83,15% on the incubators work. Other 16,85% or 5 355 kWh of total energy consumed refers to the ovoscope (0,075 kw / hours) and outdoor lighting (5,28 kwh).

Human work was analyzed in the segment of preparatory time, auxiliary time, effective time and time loss. The largest incubator station ("Brovis" d.d. Visoko) in the part of researched production volume of 96 000 chicken per cycle spent 765,05 hours, the medium-sized station capacity of 38 000 chicken (Poljovet d.o.o.) spent 291,82 hours and mini-incubator station from Pazarić with a capacity of 100 chicken, spent 24,41 hours of human work.

The following figure shows the structure of human work consumption in three examined incubator stations.

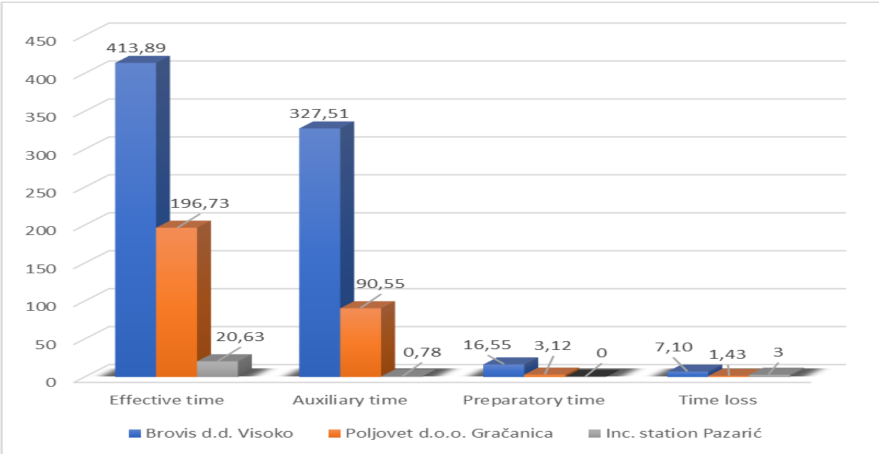

Fig. 4. Structure of human work in the examined incubator stations (working hours)

Based on Figure 4, it can be concluded that in all three examined incubator stations, most of the total work spent belongs to effective time, then to auxiliary time, to preparation time and other to time loss.

If we consider the examined working capacity of the incubator station, in "Brovis" d.d. was spent about 0,478 minutes, "Poljovet" d.o.o. 0,460 minutes and a mini-incubator station from Pazarić 14,64 minutes, of human work per one chicken.

To get a complete picture of incubator stations efficiency, it is necessary to consider summary indicators that include machine and human work with indicators of energy consumption.

Tables 1 and 2 shows summary and statistical indicators of energy efficiency of incubator stations.

Table 1. Summary indicators of energy efficiency of incubator stations

Incubator stations	**Machine work (hours)**	**Human work (hours)**	**Consumed electricity (kWh)**
„Brovis“ d.d. Visoko	1310,1	765,05	30 672,71
„Poljovet“ d.o.o. Gračanica	670,7	291,82	8 341,21
Mini inc. station Pazarić	652,2	24,4	31,75

Table 2. Statistical indicators of energy efficiency of incubator stations

Statistical indicators	Brovis d.d. Visoko			Poljovet d.o.o. Gračanica			Mini inc. station Pazarić		
	Machine work per chicken	Human work per chicken	Electricity per chicken	Machine work per chicken	Human work per chicken	Electricity per chicken	Machine work per chicken	Human work per chicken	Electricity per chicken
	(h)	(h)	(kW/h)	(h)	(h)	(kW/h)	(h)	(h)	(kW/h)
Average	**0,0132**	**0.008**	**0.32**	**0,018**	**0.0076**	**0.22**	**6.52**	**0.24**	**0.32**
Max	0.0160	0.009	0.34	0,021	0.0079	0.24	6.62	0.27	0.34
Min	0.0110	0.006	0.30	0.015	0.0072	0.19	6.42	0.21	0.29
Std dev.	0,0015	0.0009	0.011	0.0015	0.0002	0.013	0.049	0.018	0.013

In the largest tested incubator station (Brovis d.d. Visoko), duration of incubation process was 21 days and 6 hours. It was consumed about 1 310,1 machine working hours, which is 0,013 hours/chicken, 765,05 human working hours, which is 0,008 hours/chicken and 30 672,71 kWh of electricity or 0,32 kWh per chicken. Person's correlation coefficient between machine and human work was -0,479 which indicates a weak negative correlation. The correlation between machine work and consumed electricity was -0,214 which indicates that there is no correlation.

In the medium-sized incubator station (Poljovet d.o.o.) duration of the incubation process was 21 days and 10 hours. It was spent 670,7 hours of machine work or 0.018 hours/chicken, human work 291,82 hours or 0,0076 hours/chicken and electricity 8 341,21 kWh or 0,22 kWh per chicken. The reason of low level of energy consumed per chicken in relation to the previous incubator station is in the heating system of the pre-hatchery which was connected to the central heating with charcoal, which created a monthly saving of approximately 200 €/month in relation to electric heating. The correlation coefficient between machine and human work was 0,537, which indicates a medium positive correlation. The correlation between machine work and consumed electricity was 0,894, which indicates a strong positive correlation.

The smallest incubator station (Pazarić) had a duration of the incubation process of 22 days. It consumed 652,2 hours machine work or 6,52 hours/chicken, human work 24,4 hours or 0,24 hours/chicken and electricity 31,75 kWh or 0,31 kWh per chicken. The reason for the high energy consumption per chicken is of a constructional nature, where is for the heating used an ovoscope and the heat transport through the incubator by a fan that had to work continuously during the incubation process. Coefficient of correlation between machine and human work was 0,833, which indicates a strong positive correlation between the consumption of human and machine work. The correlation between machine work and consumed electricity was 0,762, which indicates a medium positive correlation.

4. CONCLUSIONS

Work process of incubator station requires constant monitoring of technical and technological process. Possible omissions are reflected in the increase chicken's mortality and efficiency of production process. In this research, the effects of large, medium and small incubator stations were analyzed and we can conclude that:

- The mini-incubator station had the lowest percentage of successfully hatched eggs. It consumed 652,2 machine operating hours or 6,52 hours/chicken, human work 24,4 hours or 0,24 hours/chicken and electricity 31,75 kWh or 0,31 kWh per chicken. The analysis of energy consumption in relation to the other two types of stations showed the lowest energy efficiency, with 83,15% of energy related to the incubator, 16,62% of lighting and 0,23% of ovoscope.
- The medium-sized incubator station consumed 670,7 hours of machine work, which is 0,018 hours/chicken, human work 291,82 hours or 0,0076 hours/chicken and electricity 8 341,21 kWh or 0,22 kWh per chicken. The reason of the relatively low level of energy consumption is in the concept of heating water that was connected to the central heating system. Within the consumed electricity, 77% is for climate, 4% for pre-hatchery, 11% for indoor lighting, 6% for outdoor lighting and other electricity consumers accounted for 2%.
- The large-sized incubator station consumed 1 310,1 hours of machine work, which is 0,013 hours/chicken, human work 765,05 hours or 0,008 hours/chicken and 30 672,71 kWh of electricity or 0,32 kWh per chicken. Within the consumed electricity, the climate for hot water maintenance consumed 64,9% of electricity, the climate for heating and moisture dispersion 13,5%, pre-hatchery 9,1%, lighting 6,3% and other electricity consumers 6,1%.

Based on the obtained results, it can be concluded that energy efficiency is most affected by the heating system and the large incubator stations have an advantage over small ones. The concept of heating hot water with charcoal has its advantages when it comes to energy consumption, but it also has disadvantages in terms of human work consumption, environmental pollution and the precision of maintaining the temperature.

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AN OVERVIEW OF BIOMASS COMBUSTION TECHNOLOGIES WITH AN EMPHASIS ON THOSE FOR AGRICULTURAL BIOMASS

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Abstract. *Nowadays increasing energy needs are experienced, while facing environmental issues as air pollution, global warming and acid rains. Due to many disadvantages of fossil fuels biomass is considered as a possible replacement. For energy purpose biomass could be used in direct combustion or in biogas and biodiesel production. This paper provides a review of different direct biomass combustion technologies, with emphasis on agricultural residual biomass as an energy source. Properties of biomass being used directly affect design of combustion furnace and operating parameter. Many agricultural raw materials which might be considered as a potential waste in fact have a great energy potential and when used for combustion this waste management problem can be reduced or even solved. With biomass usage potential issues are present as storage, high moisture contents, lower heating values and possible high emission of NOx during the combustion. New promising technologies and conventional combustion systems have been considered, among which are furnaces with combustion on grade, pulverized combustion, combustion in the fluidized bed and combustion in pushing furnace. Different agricultural biomass types are contemplated, alongside with applied technologies. Systematic comparison of described technologies is given in accordance with several different criteria, including overview of advantages and disadvantages. To achieve sustainable energy development, new technologies are necessary as well as advancement of the existing ones. In order for that to be achieved, it is important to systematize and categorize biomass combustion technologies.*

Key words: *combustion technologies, agriculture (residual) biomass, cigarette (cigar) combustion*

1.INTRODUCTION

Nowadays increasing energy needs are experienced, while facing environmental issues as air pollution, global warming, and acid rains. Due to the many disadvantages of fossil fuels, biomass is considered as a possible replacement. For energy purposes, in Serbia, biomass is mostly used in direct combustion. It is estimated that 63% of the biomass in Serbia comes from agricultural production 1.. Many residues of agricultural goods, which might be considered as a potential waste have a great energy potential. When used for combustion, this waste management problem can be reduced or even solved. This paper provides a review of different direct biomass combustion technologies, with emphasis on the agricultural residual biomass as an energy source. Lately, there is more focus on the research of the type of biomass that is burned. Thus, in scientific papers, in addition to straw, sunflower husk, oats, root crops, and sewage sludge, the spent coffee grounds, tea leaves, spent mushroom substrate and olive cake are also mentioned 2.– 5.. For biomass usage, potential issues are storage, high moisture contents, lower heating values, and high emission of NOx. Other challenges that must be taken into consideration for biomass combustion technologies are shown in Fig. 1.

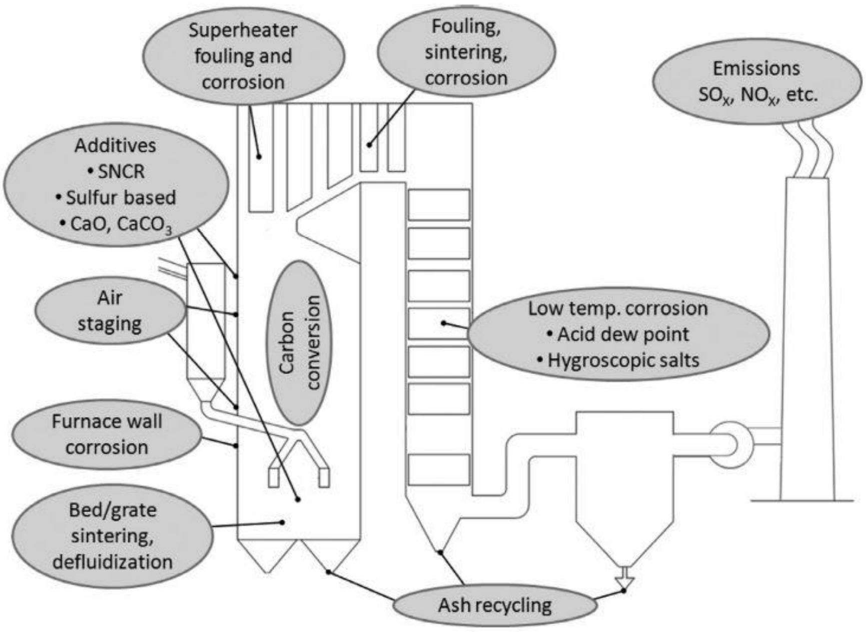

Fig. 1 Biomass combustion technologies: chemistry-related challenges 6.

2. BIOMASS COMBUSTION TECHNOLOGIES

The most commonly used technologies for agricultural biomass combustion are fixed-bed combustion with grate furnace, pulverized combustion, and fluidized bed combustion. The usage of different types of biomass in the same boiler significantly complicates its operation. However, that can be convenient due to the uneven availability of agricultural biomass throughout the year. Biomass combustion systems that have been considered in this review are shown in Fig. 2. Comparison of these technologies concerning temperature, mixing conditions (turbulence), and needed residence time is shown in Table 1.

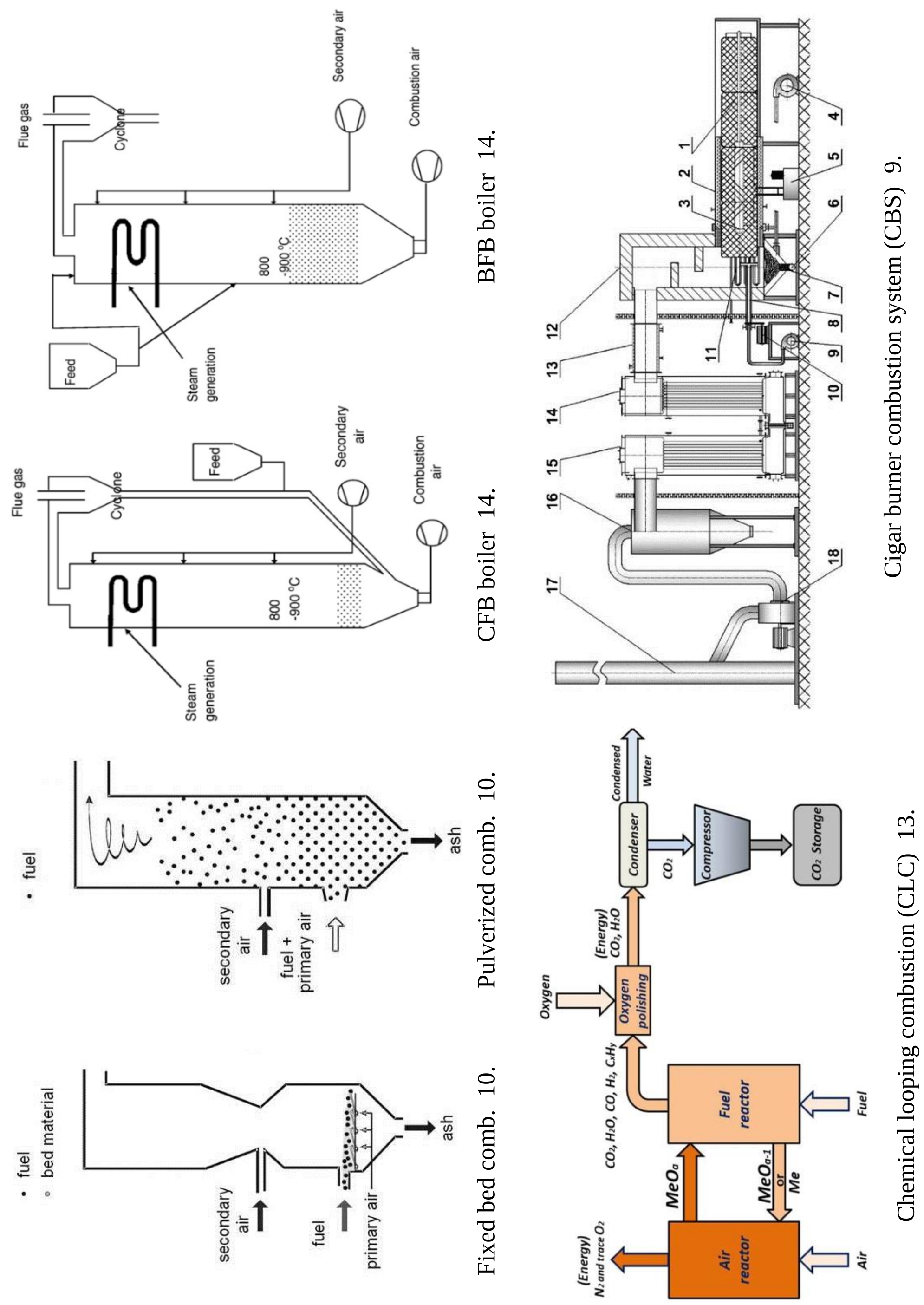

Fig. 2 Biomass combustion technologies

Table 1 Temperature, turbulence and residence time for combustion technologies 7.

Grate furnaces	**Pulverized combustion**	**Fluidized bed combustion**
Intermediate temperature	High-temperature	Low-temperature
Low mixing	Good mixing	Good mixing
Very long residence time	Very short residence time	Long residence time

1.1. Fixed bed combustion

Fixed bed combustion technologies can be divided into systems with grate furnaces and underfeed stokers. There are various solutions for **grate furnaces:** fixed grates, moving grates, traveling grates, rotating grates, and vibrating grates. The difference in grate design allows the combustion of different types of fuel. These technologies have a great ability to adapt to various fuel types. The primary air supply must be divided into sections so that adjustment to the required amounts of air for different combustion zones is possible. The effect of air supply and oxygen (O_2) enrichment on the biomass combustion in the grate boiler was investigated by 8.. It was concluded that O_2 enrichment of the primary air flow promotes the fuel burnout, but also increases the maximum temperature. They suggested that it is optimal for the secondary/primary air ratio (SA/PA) to be 57/43 for the 1.5 excess air, which is similar to the air ratio mentioned by 7. (SA/PA tends to be 60/40). Other suggested improvements are flue gas recycling (FGR) and optimized grate assembly. With FGR the excess air, slagging, as well as emissions of NOx and dioxins could be reduced. However, there are various practical difficulties that come with FGR in these systems. For high-moisture fuels, like silage and municipal solid waste, grates can be air-cooled. As a result, grates are kept under relatively high temperatures 7..

Cigar burner combustion systems (CBS) are developed for bale combustion (straw and cereal). Hot water CBS boiler with thermal power of 1.5 MW is shown in Fig 1. Firstly, bale (1) is delivered to the isolated combustion chamber (12) through a water-cooled feeding channel (2) by a hydraulic feeder (3). Through an air fan (4) primary air (PA) is provided for combustion. PA is divided into two streams, the first is distributed around the bale and the second air is entered through the ash hopper, at the bottom of the furnace (7). The screw extractor (6) is used for the ash (7) removal and maintenance of the fluidized bed, of own ash, height. During combustion, ash falls through a water-cooled gate (11). The secondary air is delivered with an air fan (9) into the combustion zone through a water-cooled inlet (8), which can partially translate to regulate power and rotate to remove ash with a partially burnout segment from the front part of the bale. These movements are provided by the transmission mechanism (10). Flue gas exit combustion chamber (13), enter the first (14) and the second (15) sections of the heat exchanger (gas-water), flow through multi-stage cyclone (16) and leave the system. Flue gas extraction is achieved with the flue gas fan (18), through the chimney (17) (Fig. 2). Experimental investigation of CBS was performed by 9.. It was concluded that described technology is convenient for agricultural biomass with higher ash melting temperature, such as soybean straw. In cases of lower ash melting temperature, like the one that wheat straw has, the usage of additives is necessary. During the combustion of soybean straw bales, a slightly higher NOx emission was recorded and therefore, denitrification methods have to be applied. In 1., alongside primary measures for deNOx, selective catalytic reduction and selective non-catalytic reduction techniques were suggested.

Underfeed stokers, so named because they use ram to force a fuel up underneath the burnning fuel bed, are considered safe and inexpensive. The fuel is fed from below with screw conveyors. Afterwards, it is transported upwards to the grate. The grates can be outer or inner, but the first solution is more often implemented due to the easier appliance of the automatic ash removal system. The combustion air is divided into two streams, the primary air is introduced through the grate, while the secondary air is provided at the beginning of the secondary combustion chamber. Underfeed stokers provide good flexibility for load changes and their control. One of the important problems that could arise with this technology is the appearance of ash deposits on the upper surface. 10.

1.2. Pulverized combustion

Pulverized biomass combustion systems can be found in literature as suspension-fired furnaces. The term suspension comes from the fact that biomass has a fibrous structure very difficult to fracture. During pulverized combustion, biomass particles have a larger size and uneven shape compared to coal. For pulverized combustion, a significant amount of energy is required for biomass preparation. Fuel is injected into the furnace with the primary air which is used as a transportation fluid. Pulverized coal combustors were widespread, their adaptation for biomass combustion still presents a challenge. Overcoming such problems for small and intermediate, horizontally fired, industrial scale boilers was investigated by 11.. They suggested including a pre-combustion chamber for performance improvement of the adopted pulverized coal combustor (0.5 MW). Pulverized straw combustion in a low-NOx multifuel burner was researched and compared to coal combustion by 12.. They noticed that straw flame was significantly longer and that the particle size of biomass, as well as their shape and distribution, are the most influential parameters during combustion. Alongside the particle size, biomass quality must be constant. Fuel supplying can be problematic due to possible explosion-like gasification 10.. This technology enables good flexibility in load changes.

1.3. Fluidized bed combustion (FBC)

During fluidized bed combustion, the primary air is supplied from below, through a nozzle distributor plate. This affects the formation of fluidized bed, the mixture of particles and bubbles at high temperatures. The bed consists of solid particles (silica sand, dolomite, etc.) located in the bottom of the furnace, which has been stationary before start-up. **Bubbling fluidized bed (BFB)** is characterized by lower fluidization velocities (1-3 m/s) compared to **Circulating fluidized bed (CFB)** (3-6 m/s). Due to higher velocities in CFB solid particles are continuously taken away from the bed, increasing height above distributor plate. For CFB, the external cyclone is necessary to separate the bed particles and return them into the bed alongside the additional particles and fuel. The fluidized bed has a defined surface for BFB and has to be heated before fuel (1-2 % of the bed material) is fed. The cyclone separator exists in solution with the BFB furnace as well, the difference is that separated particles are usually taken out of the system. The secondary air is supplied at the top of the bed (and higher). FBC is characterized by low excess air needed, good mixing conditions, and intense heat transfer. For FBC usage of high alkali biomass, such as agrarian, is problematic due to ash agglomeration.

1.4. Chemical looping combustion (CLC)

Chemical looping combustion is novel combustion technology with carbon dioxide capture. Oxygen carrier (OC) is used for oxygen transport between two reactors - fuel reactor (FR) and air reactor (AR). OC consists of metal particles, usually metal oxide. After oxidation in AR, oxidized OC is introduced into FR for fuel combustion (oxidization of the fuel, reduction of OC to metal or less oxidized state). Afterwards reduced OC is supplied into AR and through oxidization with air returned to initial state. Then OC is once again brought to the FR in the second loop, hence the name chemical looping combustion. Important for CLC is that the flue gas does not include nitrogen, mostly it is from carbon dioxide and water vapor. The main advantage of CLC is that carbon dioxide capture is possible. Most of the fuel reactors used are based on fluidized bed reactors. For solid fuel usage, the reaction between fuel and OC is slow, so improvement is needed: fuel gasification inside FR with the recirculated flue gas (in situ gasification chemical looping combustion) or usage of specific OC as copper oxide (chemical looping oxygen uncoupling). For OC is important to have a high melting temperature, high oxygen transport capacity, good fluidization characteristics, a great thermodynamic and kinetics capability of convert fuel to H_2O and CO_2 in the CLC operation, without releasing carbon dioxide from the AR, low cost and to be safe 13.. Although tests have been performed with biomass, and especially on mixtures of biomass, as a highly volatile fuel and coal, as a fuel with a highly pronounced char content, this technology has not yet come to practical application on large-scale systems. What is posed to the authors as a crucial issue is the economic viability of such systems that would be applied to real-scale plants, because biomass is already considered as a CO_2 neutral fuel that is therefore not subject to CO_2 taxes.

3. CONCLUSION

To achieve sustainable energy development, new technologies are necessary as well as the advancement of the existing ones. For that to be achieved, it is important to systematize biomass combustion technologies. This paper is providing a review of existing technologies and summarizing their most important features. A comparison of described technologies is given in Table 2 with their main advantages and disadvantages. Description of biomass content is given alongside types of biomass that could be used. Serbia has a significant potential for biomass usage, which is not used enough. This is especially present for biomass from agriculture. Switching to biomass combustion instead of coal combustion would result in carbon dioxide reduction, which presents one of the major issues nowadays. However, for agricultural biomass to truly be considered a renewable energy source, it needs to be used in the right way. This includes the control of nitrogen oxides, which are especially present for this type of biomass (due to the high content of bound nitrogen in the fuel), as well as emissions of particulate matter. Solutions for overcoming the limitations of biomass usage could be the development of new and improvement of existing combustion technologies, as well as the modification of existing coal combustion plants.

Table 2 Overview of biomass combustion technologies 5., 9., 10., 13-15.[1]

	Advantages	Disadvantages	Fuel - Biomass
Grate furnaces	Low operating cost Slagging is less problematic	No mixing with wood fuel Combustion conditions not homogeneous deNOx measures are necessary[2]	High moisture content Various fuel particle size High ash content Good fuel flexibility; Mixtures[3] (vibrating grates, rotating grates)
Cigar-firing	Low investment and operating costs Compact combustor design Short start-up period Combustion of whole bales No energy consumption for fuel preparation Good load-following performance	deNOx measures are neccesary[1] Sophisticated process control system Larger storage space	Biomass bales (straw and cereal)
Underfeed stokers	Continuous fuel feeding Low fuel mass in the furnace Good partial-load behavior	Not applicable for fuels with high ash content and low ash-melting point such as agricultural biomass	Fuel particle size <50mm Low ash content Woodchips, sawdust, pellets
Pulverized bed	deNOx with air staging Good load control	Limited fuel particle size Hard fuel preparation with high energy consumption Low fuel flexibility Extra start-up burner is necessary	Fuel particle size <10-20mm Sawdust and fine shavings
CFB furnaces	Without moving parts in the combustion chamber deNOx by air staging Not sensible to the moisture content in fuel High specific heat transfer capacity	High investment and operating costs Bed agglomeration, high dust load in flue gas (higher than BFB) Sensitivity to ash slagging Loss of bed material	Fuel particle size <40mm Various fuel mixtures Not for high alkali biomass fuels
BFB furnaces	Without moving parts in the combustion chamber deNOx by air staging Not sensible to the moisture content in fuel	High investment and operating costs Bed agglomeration, high dust load in flue gas	Fuel particle size <80mm Various fuel mixtures Not for high alkali fuels Low ash-melting temperature
CLC	Efficient char conversion Power generation with integrated carbon capture Flue gases free of nitrogen	Difficult to achieve full volatiles conversation The effect of biomass alkalis is not well known Formation of deposits, corrosion, bed agglomeration Not tested on systems larger than 50 kW	Methane, hydrocarbons (propane, ethane) Co-firing with sulfur-containing fuels, or using sulfur addition

[1] Fuel particles size from [10]

[2] Primary and secondary measures (Combustion control and flue gas treatment)

[3] Hard to achieve, applicable only with mentioned furnaces, hence they provide good mixing conditions

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SOME POSSIBLE EFFECTS OF CONSTRUCTION AND DEMOLITION WASTE LANDFILL ON THE ENVIRONMENT

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Abstract: *In cases of inadequate waste management, there is a tendency for inappropriate disposal of construction and demolition (C&D) waste, especially when its production surpasses the capacities of official disposal sites. By disposing of C&D waste on the edge of the protected natural area during the spring of 2021, a C&D landfill was formed near Reva pond, Belgrade. In this work, the qualitative composition of C&D waste in the field was assessed, including chemical analysis of landfill soil which was investigated by comparing its elemental composition with the control soil by utilizing SEM-EDS analysis. The presence of various C&D waste components, typical (concrete blocks, bricks, armature, glass shards, wood, soil of various origin) and atypical (furniture, industrial-type glass shards, paint bottles and cans), indicated that waste disposal was only partially controlled. Due to the high heterogeneity of the disposed soil, analysis can neither confirm nor exclude the possibility of heavy metal contamination. Herbaceous plants are already naturally colonizing the landfill; also, the aggressively spreading, heavy metal accumulator, honey plant species - the False indigo bush (Amorpha fruticosa), is abundant in the area, and it is expected that it will recultivate the landfill site. To get a full assessment of the landfill's impact on local ecosystems, continuous monitoring is recommended.*

Keywords: *C&D waste; waste disposal; excavated soil; environmental pollution; heavy metals;*

1. INTRODUCTION

Construction and demolition (C&D) waste is generated in the process of building, as well as the preparation of building sites - which commonly includes demolition. Each construction project leaves significant amounts of C&D waste in the form of inert waste, non-hazardous (brick, concrete, wood, and other materials) and hazardous (asbestos, materials containing heavy metals, etc.). Urban development and related construction create various pressures on the environment, including waste generation and changes in land use. When it comes to C&D landfills, these two issues overlap. The disposal of C&D waste has become a pressing global issue, especially due to the low recycling rates, and its full effect on the environment remains largely unknown 1.. In cases of inadequate local C&D waste management, there is a tendency for inappropriate disposal of C&D waste, especially when its production surpasses the capacities of official disposal sites. Because there is a tendency for illegal or badly managed C&D waste disposal on uninhabited land in close proximity of the city, forestry and agricultural sectors are especially exposed to pressures from C&D waste generation, adding to the already high pressures from the construction industry in general 2.. Projects across the world are considering repurposing of soil found in C&D waste, but with caution due to the possible pollution of these soils 3..

Reva is part of a former distributary of the Danube floodplain, which extends in an east-west direction. The C&D landfill is located between the protected natural area “Reva pond” and the protective embankment in the flood zone of Danube (municipality Krnjača, Belgrade) and, according to the environmental inspection, spans across 7 hectares. The formation of the landfill in early 2021 was marked by many irregularities, and the official cease of all disposal activities happened in June 2021. The vegetation on the terrain is characterized by hybrid poplar plantations, hydrophilic deciduous mixed forest, wetland vegetation and ruderal flora along the embankment, with 84 species total recorded 4.. All these habitats are infested with False indigo bush, *Amorpha fruticosa*, an invasive species introduced and renowned as a quality honey plant. Thus, the location may be an important forage area for bee hives in 2.2-10 km radius 5.. Additionally, Reva pond is a part of the internationally recognized Important Bird Area “Usce Save u Dunav” (The confluence of the Sava and the Danube), and also represents a legal hunting ground.

This paper compares the chemical composition of soil found on C&D waste landfill “Reva”, Belgrade with the natural soil sampled in the same area by utilizing SEM-EDS spectral analysis as a comparison method. The overall goal of the study was to gain insight into the properties of the landfill material and the native soil in order to predict the possible future influences on the natural ecosystem.

2. MATHERIALS AND METHODS

Field observation was conducted before samples collection which included the basic visual environmental assessment of the state of the landfill, with the focus on the disposal method, present materials, present vegetation, and the state of original vegetation (specifically, trees) on the site. Soil samples were collected by using standardized soil sampling methods for monitoring pollutants 6, 7., slightly modified due to the location’s specifics. For the landfill sample, forty-seven individual samples were obtained from 0-10 cm depth, taking into account both the leveled material and the unleveled, separate piles of C&D waste (mostly soil) that could be safely reached. Collected individual samples were well-mixed and further mixing with removal of large particles and quartering was used to obtain a representative sample. The control sample was taken from a meadow in a close proximity of the landfill, but still physically separated from the landfill. The layer of vegetation was removed and the representative sample was obtained in the same manner as the for the landfill sample, only with a fewer number of individual samples (four), due to the habitat’s uniformity.

In order to compare the morphology of two types of samples, scanning electron microscopy (SEM) was applied using JEOL JSM-6390 LV Scanning Electron Microscope at electron beam acceleration voltage of 30 kV. To attain electroconductivity, the samples were coated with gold before analysis in a sputtering chamber (BAL-TEC SCD 005 Sputter Coater, 100 s at 30 mA). Elemental composition was performed using X-Max Energy Dispersive X-ray Spectrometer (EDS) (Oxford Instruments, UK) and AZtecEnergy software (Oxford instruments, UK).

3. RESULTS AND DISCUSSION

3.1. Field observations

The greatest part of the C&D waste was deposited and leveled, rising 4-5 m above the original ground level matching the height of the nearby embankment. On the leveled surface, many aggregations of C&D waste are present in the form of separate piles. These include various types of soil, clay, demolished brick and concrete. Besides the typical C&D waste, the presence of discarded furniture, paint and spray cans, glass bottles and other non-C&D waste was noted, but not in prevalent numbers. Industrial-type chunks of broken glass were present throughout the site, and their origin is unknown. The presence of informal scrap metal collectors was noted, as well as the traces of fire and burning possibly related to their activities. The damage to the surrounding forests is visible at the edges of the landfill, where waste dumping has knocked over trees, indicating that the site wasn’t properly prepared for the waste disposal. At the time of sampling, the herbaceous vegetation has already started to colonize the landfill. This novel plant community mostly consisted of ruderal vegetation. Separate unleveled aggregations of soil contained different plant species and communities, leading to a conclusion that the seeds of these plants were brought along with the excavated soil, allowing introduction of plant species not native to the area. Since the invasive False indigo bush (*Amorpha fruticosa*) is abundant in the area, it can be expected to cultivate the landfill in the upcoming years.

3.2. Soil samples analysis

Microstructure of soil samples collected at control and disposal site is presented at Figure 1. It is known that soil is built from mineral particles that differ in terms of size, shape, agglomeration and organic matter in different phases of degradation 8.. It can be seen from the upper micrograph at Figure 1 (a) that such a description can be attributed to the control sample whose aggregates vary in size, shape and inner structure indicating natural origin of soil. On the other hand, a micrograph of soil from the disposal site at Figure 1 (b) is showing a rough surface texture consisting of larger irregularly shaped agglomerates, separated from each other whose dimensions do not vary significantly. It can be noticed that these particles could be compared to the coarser soil particles such as sand whose specific surface area is small and chemical activity weak. Coarse textured soils have weak waterproof ability which increases water circulation and consequently spread of contaminants 8.. Such a structure is evidently related to the disposed construction waste since C&D waste is a heterogeneous mix of cement and clay-based composite building materials. Its largest portion is made out of concrete waste, different kinds of brick and asphalt, with impurities such as ceramic and roof tile. Production and further crushing of C&D waste leads to the formation of a rough fractions consisting of primary aggregates such as gravel, stone, crushed brick, but also, fine particles of sizes smaller than 5 mm are generated 9..

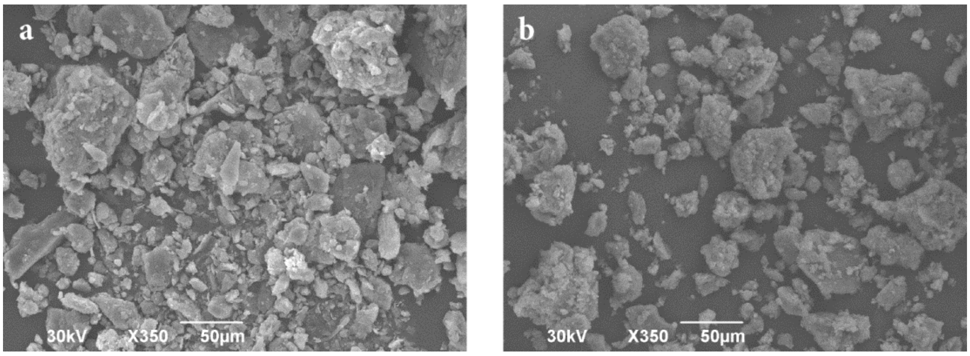

Fig. 1 SEM micrographs of soil samples from: a) control and b) disposal site.

A semi-quantitative chemical analysis of the surface layer of samples collected at control and disposal site was done by SEM-EDS method. The results of the analysis in this paper are considered as an estimation that is used to compare the elemental composition of the samples. In Table 1, the chemical composition is presented as a sum of elemental content given in weight percentage normalized at 100%. The limit of detection of examined elements was 0,1%. Concerning carbon as a light element, it is usually excluded from SEM-EDS analysis because during the collection time of EDS spectrum contamination of the specimen could occur as a normal part of detection process, however, carbon wasn't excluded here since the results are used for comparative analysis. From Table 1, it can be seen that percentages of carbon (of organic or inorganic origin) are much higher than its natural value in the Earth's crust (0,03%) 10.. The differences of its percentages between samples could originate from the organic matter present in samples or from the construction material which is known to be the source of organic (asphalt, plastic, wood) and inorganic (mortar, concrete) carbon 11..

The most abundant elements in the Earth's crust are oxygen (46,6%) and silicon (27,7%) and the silicates containing both elements are the most abundant minerals 10.. The similarity in percentages of these two elements between investigated samples (Table 1) is related to their common origin in soil. Quartz (SiO_2) is dominant compound of each mechanical fractions of the naturally occurring soil 8.. On the other hand, in construction waste samples, quartz is attributed to sand particles used for concrete and brick production. Concrete is usually made out of quartz and amorphous carbonates, and quartz and calcite with the addition of clay minerals represent the most common compounds of brick material. However, in the production process that involves high temperatures clay minerals decay and crystal structure is lost leading to the formation of silicon dioxide at the end 9.

Table 1. The chemical composition given as wt.% of samples analyzed in this study

Element	Line Type	C&D-1	Error	C&D-2	Error	Control	Error
C	K series	54.76	0.13	44.17	0.17	38.29	0.34
O	K series	32.47	0.11	38.31	0.13	40.65	0.25
Na	K series	-	-	0.34	0.01	-	-
Mg	K series	0.42	0.01	0.55	0.01	0.88	0.02
Al	K series	2.09	0.01	2.75	0.01	4.32	0.03
Si	K series	4.86	0.02	7.12	0.03	10.38	0.06
K	K series	0.50	0.00	0.57	0.00	0.98	0.01
Ca	K series	2.16	0.01	3.09	0.01	1.67	0.01
Fe	K series	1.17	0.01	1.75	0.01	2.83	0.02
Cu	K series	0.57	0.01	0.47	0.01	-	-
Zn	K series	0.45	0.01	0.39	0.01	-	-
Mo	L series	0.36	0.02	0.33	0.02	-	-
Ba	L series	0.18	0.01	0.16	0.01	-	-
Total:		100.00		100.00		100.00	

Figure 2 and Figure 3 are showing elemental mapping images of soil collected from control and disposal sites, respectively. Elemental mapping of samples microstructures by SEM-EDS method was possible if the element’s weight percentage was above 0.1%. It can be seen from Figure 2. that in the control soil five elements other than O, C, and Si could be detected: Al, Fe, Ca, K, Mg which natural distribution in the Earth’s crust is significant (8.1%; 5.0%; 3.6%; 2.6%, 2.1%; respectively) 10.. It was noted that elements weight fractions of the control sample which was in descending order (%): Al<Fe<Ca<K<Mg (Table 1) exactly corresponded to their presence in the Earth's crust. Trace elements which were most likely present in the control sample could not be detected here due to limit of detection of examined elements of 0,1% and hence difficulties to separate their characteristic X-ray peaks from the background spectrum. Based on the Al and K elemental mapping, their uniform distribution in the control sample could be observed, while Ca, Mg, and Fe are found in the distinct agglomerates containing their characteristic minerals (Figure 2). Overlapping maps of all detected elements generated one dominant color indicating natural origin of examined soil.

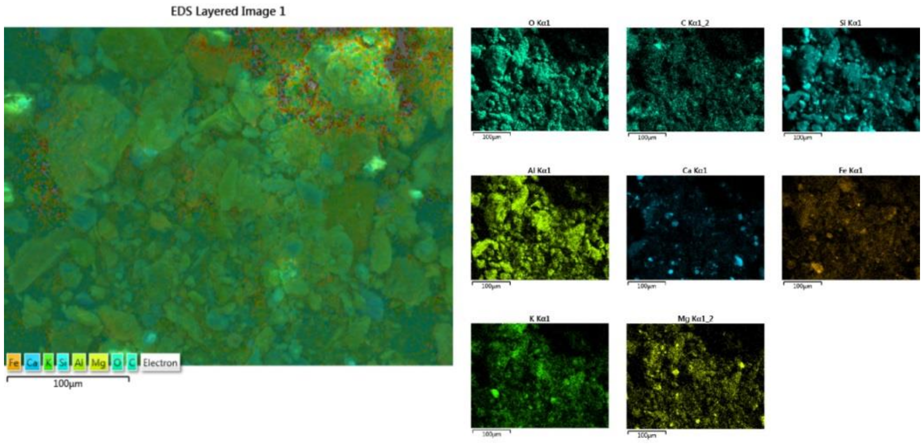

Fig. 2 SEM-EDS elemental mapping images for O, C, Si, Al, Ca, Fe, K, Mg of the control soil sample.

In the sample collected from the disposal site (Table 1, Figure 3), besides major elements Al, Fe, Ca, K, Mg, the traces of Cu, Zn, Mo, Ba were also detected. In the Earth's crust, the sum percentage by weight of all trace elements is 1,5 % 10.. Elements from the C&D-1 sample were aligned in the decreasing order by weight (%): Ca<Al<Fe<Cu<K<Zn<Mg<Mo<Ba (Table 1). It can be noticed that alignment like that is suggesting some soil modifications. The EDS elemental map (Figure 3) revealed homogeneous dispersion of Mg, Cu, Zn within the sample while Al, Ca, K, Fe, Mo and Ba have shown heterogeneous behavior and were concentrated in individual particles (agglomerates) of the sample. Overall mapping of the sample is showing significant differences in the chemical composition and structure compared to the sample from the control site. It could be concluded that there was an evident modification of natural soil due to introduction of C&D wastes. However, the exact origin of introduced material by waste disposal cannot be exactly quantified since all the various inputs were integrated in the soil over time.

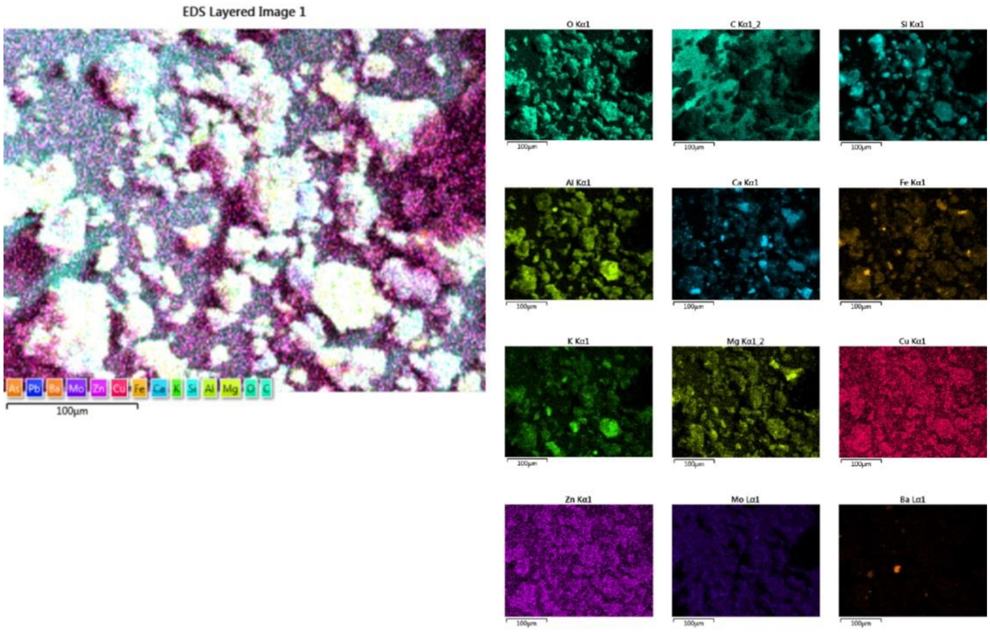

Fig. 3 SEM-EDS elemental mapping images for O, C, Si, Al, Ca, Fe, K, Mg, Cu, Zn, Mo, Ba of disposed soil sample (C&D-1).

A study of a large number of C&D waste samples in City of Skopje showed heterogeneous nature of the collected materials and consequently a high variability of major and trace elements. The highest concentrations there were always related to the SiO_2 present in silicate aggregates, constituents of concrete and mortars, followed by moderate concentrations CaO from lime, gypsum, and cement binders and by lowest concentrations of Al_2O_3 and K_2O from bricks, tails, ceramics, and soils containing clay minerals 11.. Results of another study of C&D waste samples showed Zn concentrations of up to 800 mg/kg and about 10 times higher maximum concentrations for Al and Fe, while Ba, which was also detected in examined samples, had concentrations less than 90 mg/kg 12.. Authors explained that characteristics and age of the concrete are related to the carbonation process which occurs when the cement hydrate phases react with CO_2, precipitate as calcium carbonate ($CaCO_3$) and develop carbonated material. As a result, aging and carbonation decreases the material pH which is why leachability of Si is increasing and for Ca, Ba and K is decreasing 12..

4. CONCLUSIONS

According to the conducted analysis, no chemical threats arising from the landfill were detected and abnormal presence of heavy metals cannot be confirmed, but cannot be fully excluded either due to the method's limitations. The limitation of the analysis was also the highly heterogeneous content of the landfill. Many aggregations of excavated soil, demolished building blocks and other C&D waste were left as separate piles, some highly inaccessible, making the formation of a truly representative sample challenging. Some of the unsampled aggregations could still be contaminated, so multiple analyses should be performed. SEM-EDS method allowed gaining insight about the main physical and chemical properties of the soil, but to exclude the possibility of contamination, a standard chemical laboratory analysis should be performed, and should also include persistent organic pollutants (POPs), organometallic compounds, asbestos, oil-derived hydrocarbons (C^6-C^{40} fractions), radionuclides, and pathogenic organisms, as per Regulation on systematic monitoring of land condition and quality 13.. The return of the original vegetation is unlikely due to changed C&D landfill soil quality. In the future, sampling and analyzing of *A. fruticosa* plant organs can become one of the ways to check the content of heavy metals once it colonises the landfill, as the plant is a known heavy metal accumulator 14.. Also, using the accumulator properties of *A. fruticosa* for phytoremediation is a possibility to explore.

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THERMAL ENERGY STORAGES – MATERIALS AND APPLICATION

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INVITED PLENARY LECTURE

Abstract: *Thermal energy storage (TES) is a technology that gives an opportunity for using energy in the period when the production of energy is at a lower level or does not exist. TES are used when there is a mismatch between energy demand and energy supply. They increase heat generation capasity, enable better operation, increase system reliability, shift energy purchases from high to low-cost periods, they take role of expansion vessel and so on. This paper will present the field of Thermal Energy Storages (TES), methods and materials that are used as working mediums. The problems of using PCM materials as storing mediums were shown and discused. The technics for overcoming the problem of low thermal conductivity of PCM were listed and described. At the end of the article the main applications of TES were given.*

Key words: *Thermal energy storage, PCM, heat transfer enhancement,*

1. INTRODUCTION

As a result of the fact that it is impossible to use energy without environmental impact and growing energy consumption on the world, environmental problems have taken more attention in the last decades. Energy consumption permanently increases, except in 2020. when total energy consumption fell as a result of lockdown and transport restrictions caused by Covid-19 1.. The usage of energy from non-renewable sources leads to the growth of greenhouse gases emission that mainly causes global warming. Climate change and global warming significantly impact the Earth and all species and, therefore, the agriculture sector. The problems of energy use, environmental impact and environmental protection have become particularly relevant in the last decades. Hence, it is essential to improve the energy efficiency of the systems and use clean energy from renewable energy sources, including solar, biomass, wind, geothermal etc. The main problem of using renewable energy sources is that they depend on geographic locations, weather conditions and, finally, economic profitability. For example, the clean energy that the Sun emits is approximately 63 MW/m2. A tiny part of it reaches the Earth, but that energy that comes in 84 minutes would be enough to meet the world's energy needs in one year 2.. That means there is enough energy, but there are problems with catching this energy with low density and storage. The stores of any form of energy imply the accumulation of appropriate energy potential in the desired period and later use the stored form of energy for various purposes, such as performing some useful work, heating or cooling space, etc. There are different forms of energy such as kinetic, potential, chemical, nuclear, thermal (internal) energy, etc. In various systems, such as heating, cooling, air conditioning systems, etc., storing thermal energy plays an essential role in increasing energy efficiency and ensuring the safety of those systems. Devices in which the storing of thermal energy is performed are called Thermal Energy Storages or shortly TES. TES increase heat generation capasity, enable better operation, increase system reliability, shift energy purchases from high to low-cost periods, they take role of expansion vessel, etc 3.

2. THERMAL ENERGY STORAGES

TES are used in systems where there is the possibility of using waste heat from different kinds of processes and when there is a mismatch between energy demand and energy supply. Depending on the method of storing energy, TES can be classified into three types 3.:

1) Sensible - STES (the storing of energy occurs when the temperature of the storing medium, e.g. water, raises)

2) Latent – LTES (the storing of energy occurs when the storing medium changes its phase, e.g. melting, evaporation of a phase change material-PCM)

3) Thermochemical (the storing/realizing of energy occurs during chemical reactions)

Depending on the period during which storage is performed, storing of energy can be:

1) daily,

2) weekly,

3) monthly,

4) annually (seasonal).

The main characteristics of the TES are 4.:

- the amount of stored energy per unit of volume,
- the temperature range in which the storing of energy is carried out,
- heat transfer during charging and discharging processes and realized temperature differences,
- temperature layering in the TES,
- auxiliary energy for the process of charging and discharging the TES itself,
- features of the reservoir of TES and other structural elements included in the storage system,
- control of heat losses in the environment,
- price.

3. MATERIALS AND METHODS

Depending on the type of TES different materials are used as storing mediums. For sensible TES (STES) water is the most useful storing material. Water has a large heat capacity, it is in abundance, and it is not poisonous or flammable. The main disadvantages of using water as a storage material are the possibility of freezing, corrosive action and relatively low boiling temperature. In STES the storing thermal energy is based on temperature change of working medium:

$$Q = \int_{T_1}^{T_2} mc_p dT = \int_{T_1}^{T_2} \rho V c_p dT$$

where Q is the stored thermal energy, m is the mass of storing medium, c_p is the specific heat capacity of working medium at constant pressure, T_1 is the initial temperature of working medium and T_2 is final temperature of working medium, ρ is density, V is volume. The main disadvantage of using water is the fact that boiling temperature at atmospheric pressure is too low, and consequently, water is mostly used for storing thermal energy up to 100°C.

The storing of thermal energy in TES with PCM (Phase Change Material) as a working medium is primarily based on the heat of the phase change that is absorbed during the change in the phase of the working medium. For example, compared to water, applying PCM can store up to 14 times the amount of heat compared to a TES of the same volume filled by water 5.. In addition, the advantage is that the PCM changes its phase at a specific temperature or at a certain temperature range, which is also one of the important advantages given the fact that heat exchange takes place at a lower temperature difference 6..

During the phase change, the heat supplied to the working medium is used to take phase change, i.e., tearing of intermolecular ties. In addition, in most cases, the phase change processes are isobaric, and the temperature in which the phase changes can be considered constant. Therefore, the amount of thermal energy that is stored in PCM during phase change of the working medium can be determined as follows:

$$Q = m \cdot x_m \cdot r_m$$

where x_m is the mass fraction of melted/solidified PCM, m is the mass of PCM and r_m is the latent heat of fusion. However, the heating process of PCM consists of heating the PCM from the initial temperature to the melting temperature, then melting the PCM (phase change process) and heating the melted PCM to the temperature that is higher than the melting temperature. Therefore, the stored thermal energy in a PCM can be calculated as follows:

$$Q = \int_{T_1}^{T_m} mc_p dT + mr_m + \int_{T_m}^{T_2} mc_p dT$$

where T_m is the melting temperature. When the process of phase change starts at one and finish at another temperature, then the stored thermal energy can be calculated as follows

$$Q = \int_{T_1}^{T_{m1}} mc_p dT + mr_m + \int_{T_{m2}}^{T_2} mc_p dT$$

where T_{m1} is the temperature at which the melting process starts (solidus temperature), while T_{m2} is the temperature at which the melting process ends (liquidus temperature). The main advantages of STES over LTES are the lower price, simple construction, and easy manipulation, i.e. control of the heat accumulation process. The main disadvantages of this type of TES are the transient temperature difference between the temperature of the working (storing) medium and the fluid that absorbs/realize heat (Heat Transfer Fluid) 3.. Unlike STES, LTES mainly stores heat during the phase change is accompanied by a minor change in PCM because of fact that the main part of the heat is absorbed during the process of phase change 3.. That is a desirable feature of working medium because equipment and devices that are connected with a TES can work in nominal working conditions. In addition, the advantage of LTES is a greater accumulation of energy per unit of volume, i.e. per unit of mass of working medium. The stored amount of energy per unit of mass of working medium is on average 5 to 10 times higher in favour of LTES than STES 7.. Energy storage density for most available and potential PCM takes values from $90\ \mathrm{kJ/kg}$ up to $330\ \mathrm{kJ/kg}$ 8., 9.. However, despite all the advantages of LTES mentioned above comparing to STES, the application of LTES is limited by the small value of the thermal conductivity of PCM 10. 11.. Low thermal conductivity of PCM causes difficult heat transfer through PCM and thus prolongs the process of charging or discharging TES. It also leads to several undesired effects such as overheating, sub-cooling, or degradation of PCM 3..

According to their origin, all PCM can be classified into the following groups 7., 12., 13.:

1) Organic PCM,
2) Inorganic PCM.

The most used organic PCM are paraffin waxes. They are chains of *n*-alkanes with physical properties presented in Table 1.

Table 1 Thermo-physical properties of some paraffin waxes 14.

Name	Carbon atoms	Melting temperature	Density	Thermal conductivity	Latent heat of fusion
	–	°C.	kg/m^3.	W/mK.	kJ/kg.
n - Dodecane	12	-12	750	0.21^s	–
n - Tridecane	13	-6	756	–	–
n - Tetradecane	14	4.5-5.6	771	–	231
n - Pentadecane	15	10	768	0.17	207
n-Hexadecane	16	18.2	774	0.21^s	238
n - Heptadecane	17	22	778	–	215
n - Octadecane	18	28.2	814^S 775^L	0.35^s , 0.149^L	245
n - Nonadecane	19	31.9	912^s, 769^l	0.21^s	222
n - Eicosane	20	37	–	–	247
n - Heneicosane	21	41	–	–	215
n - Docosane	22	44	–	–	249
n - Tetracosane	24	51	–	–	255
n - Pentacosane	25	54	–	–	238
Paraffin wax		32	785^s, 749^L	0.514^s, 0.224^l	251
n - Hexacosane	26	56	770	0.21^s	257
n - Heptacosane	27	59	773	–	236
n - Octacosane	28	61	910^s, 765^l	–	255
n - Nonacosane	29	64	–	–	240
n - Triacontane	30	65	–	–	252
n - Hentriacontane	31	–	930^s, 830^l	–	–
n - Dotricontane	32	70	–	–	–

Based on Table 1. it can be concluded that there is an important difference between the thermal conductivity of solid and liquid phase of paraffin wax, but both values are too small. On the other hand as an example of inorganic PCM, hydrate salts are most often mentioned in the literature. They consist of salt and water. The water in such salts is incorporated into the crystal lattice of the salt during the curing process. Table 2 shows some of the salts used, as well as their basic thermo-physical properties. It can be concluded that salts as PCM can be used at low temperature ranges and their thermal conductivity is approximately two times larger than paraffin wax. The disadvantages of these working substances lie in the problems of salt degradation that occurs due to local sub-cooling of PCM during the solidification process, which leads to the displacement of water molecules from the salt crystal lattice. This results in a change of the thermo-physical properties of the PCM, which over time leads to a decrease in the latent heat of fusion and a reduction in others, for the heat accumulation of favourable thermo-physical properties.

Table 2 Thermo-physical properties of hydrate salts 15.

Name	Melting temperature °C.	Density kg/m³.	Thermal conductivity W/mK.	Latent heat of fusion kJ/kg.
LiClO3·3H2O	8	–	–	253
$NH_4Cl \cdot Na_2SO_4 \cdot 10H_2O$	11	–	–	163
$K_2HO_4 \cdot 6H_2O$	14	–	–	108
$NaCl \cdot Na_2SO_4 \cdot 10H_2O$	18	–	–	286
$KF \cdot 4H_2O$	18	–	–	330
$K_2HO_4 \cdot 4H_2O$	18.5	1447^{20C},	–	231
$Mn(NO_3)_2 \cdot 6H_2O$	25	1738^{20C},	–	148
$LiBO_2 \cdot 8H_2O$	25.7	–	–	289
$LiNO_3 \cdot 3H_2O$	30	–	–	189-296
$Na_2SO_4 \cdot 10H_2O$	32	1485^{24C}	0.544	251-254
$Na_2CO_3 \cdot 10H_2O$	33-36	1442		247
$KFe(SO_4)_2 \cdot 12H_2O$	33	–	–	173
$CaBr_2 \cdot 6H_2O$	34	1956^{35C},	–	115-138
$LiBr \cdot 2H_2O$	34		–	124
$Na_2HPO_4 \cdot 12H_2O$	35	1522	–	256-281
$Zn(NO_3)_2 \cdot 6H_2O$	36	1828^{36C},	$0.464^{39.9C}$,	134-147
$Mn(NO_3)_2 \cdot 4H_2O$	37	–	–	115
$FeCl_3 \cdot 6H_2O$	37	–	–	223
$CaCl_2 \cdot 4H_2O$	39	–	–	158
$CoSO_4 \cdot 7H_2O$	40.7	–	–	170
$CuSO_4 \cdot 7H_2O$	40.7	–	–	171
$KF \cdot 2H_2O$	42	–	–	162-266
$MgI_2 \cdot 8H_2O$	42	–	–	133
$CaI_2 \cdot 6H_2O$	42	–	–	162
$Ca(NO_3)_2 \cdot 4H_2O$	43-47	–	–	106-140
$Zn(NO_3)_2 \cdot 4H_2O$	45	–	–	110
$K_3PO_4 \cdot 7H_2O$	45	–	–	145
$Fe(NO_3)_3 \cdot 9H_2O$	47	–	–	155-190
$Mg(NO_3)_3 \cdot 4H_2O$	47	–	–	142
$Na_2SiO_3 \cdot 5H_2O$	48	–	–	168
$Na_2HPO_4 \cdot 7H_2O$	48	–	–	135-170
$Na_2S_2O_3 \cdot 5H_2O$	48	1600		209
$K_2HPO_4 \cdot 3H_2O$	48	–	–	99
$MgSO_4 \cdot 7H_2O$	48.4	–	–	202
$Ca(NO_3)_2 \cdot 3H_2O$	51	–	–	104
$Na(NO_3)_2 \cdot 6H_2O$	53	–	–	158
$Zn(NO_3)_2 \cdot 2H_2O$	55	–	–	68
$Ni(NO_3)_2 \cdot 6H_2O$	57	–	–	168
$MnCl_2 \cdot 4H_2O$	58	–	–	151
$FeBr_3 \cdot 6H_2O$	27	–	–	105
$FeCl_3 \cdot 2H_2O$	56	–	–	90
$CO(NO_3)_2 \cdot 6H_2O$	57	–	–	115

To overcome the low thermal conductivity of the phase change materials, many authors have investigated different techniques for enhancing heat transfer. All of these techniques can be classified into the following groups 16.:

- extended surfaces-fins
- metal networks-metal foams
- composites PCM
- multiple PCM
- encapsulations

▪ *Extended surfaces-fins*

Extended surfaces are surfaces that take the role of thermal bridges that brings energy throughout a PCM. It is well known that convection is the dominant form of heat transfer during the melting or solidification process, and fins improve the lack of heat transfer by conduction. Fig.1 shown an example of inserting fins into PCM. HTF flows through the pipe located in the centre of TES 10., 11.. The heat transfer enhancement exponentially depends on the number of fins inserted into PCM. Rudonja et al. 10., 11. experimentally and numerically analyzed the influence of using rectangular copper fins on reducing the time of melting process of paraffin wax. They introduced a geometrical parameter, i.e. the surface ratio for tracking the influence of extended surfaces on melting time of PCM and consequently on heat transfer enhancement. Ahmed H.N.Al-Mudhafar et al. 17. used specially shaped fins for improving heat transfer inside the cylindrical thermal energy storages (heat exchanger). The tracking of enhanced heat transfer was done by tracking the melted mass fraction of PCM during the time and concluded that specially shaped fins were better than rectangular fins. As a working medium, RT82 was used.

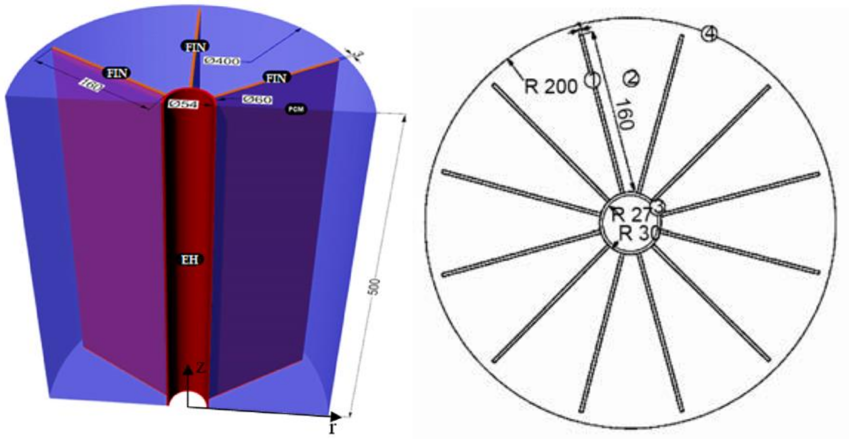

Figure 4 Extended surface-fins inserted into PCM **10. 11.**

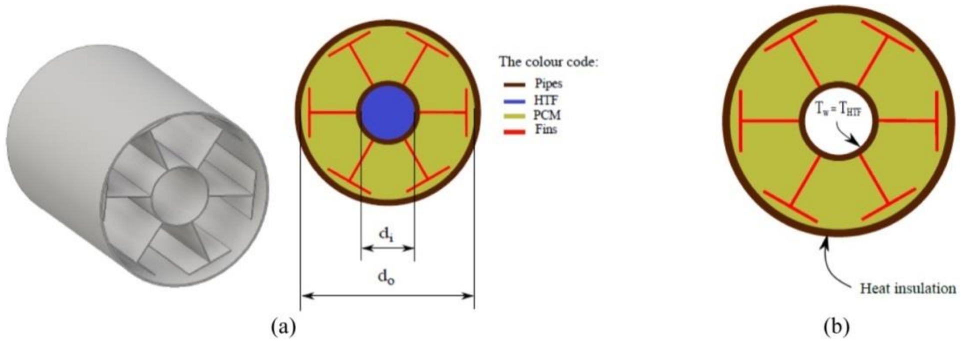

Figure 5 The physical model of TES left 3D, right the cross-sectional area, (b): the computational domain with the indicated boundary conditions for the TES with six tee fins 17.

Cláudia R.E.S.Nóbrega et al. 18. numerically and experimentally studied one axially finned tubes for cold applications. As the PCM water was used. Their results showed that increasing the number of fins and width and reducing the tube wall temperature reduces the total solidification time.

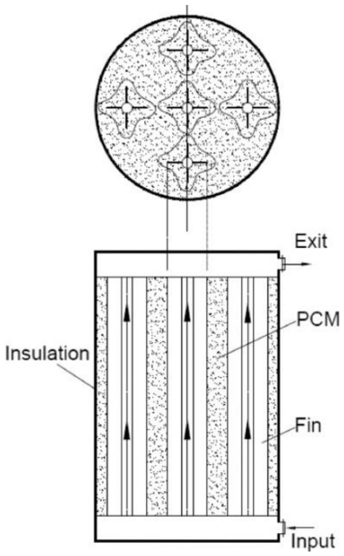

Figure 6 Simplified latent heat storage unit

- *Metal foams*

Heat transfer rate can be enhanced by using (porous) metal foams 19.. Heat transfer material is metal (copper) foam, while PCM is inserted inside foam (Fig.3). The main problem of using this enhancement technique is reducing PCM mass with increasing mass of used metal foam. Increasing the mass of metal foams leads to reduction in latent heat capacity. Hence, it is necessary to use the optimum foam mass.

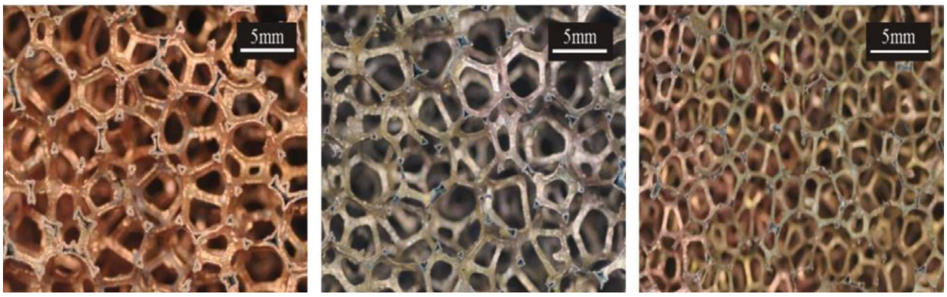

Figure 7 Copper foam samples with different pore densities and porosities 19..

- *Composites PCM*

In order to overcome the problem of low thermal conductivity into PCM are inserted materials that have a high value of thermal conductivity. Those materials are graphite, expanded perlite etc. Graphite has a high value of thermal conductivity that takes values from 24 to 470 W/(mK) 20.. Graphite used in latent heat storage materials are natural graphite flakes, expanded natural graphite, and ground expanded natural graphite (Fig.4) 21..

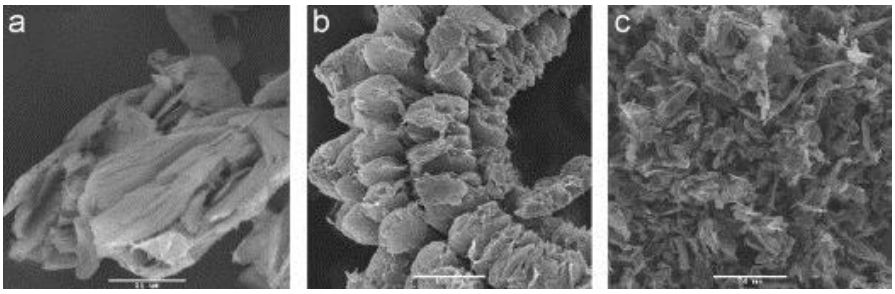

Figure 8 (a) natural graphite flakes; (b) expanded natural graphite; (c) ground expanded natural graphite 21.

Increasing of overall thermal conductivity of a composite PCM is closely a linear function of the mass fraction of used graphite (Fig.4) 4..

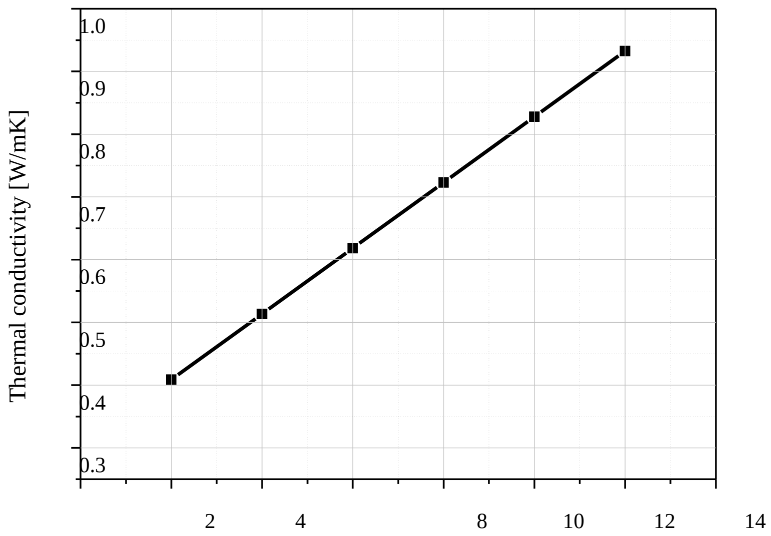

Figure 9 Thermal conductivity dependence on the mass fraction of expanded graphite 4.

- *Multiple PCM*

In this method, PCM are arranged in the way that their melting temperature decreases while the temperature of HTF also decreases 22.. In Fig. 7, it can be seen that Heat Transfer Fluid, during the charging process, flows from left to right side, and PCM are arranged so that PCM-1 has the highest melting temperature, while PCM-5 has the lowest melting temerature. HTF flows from the right to the left side during the discharging process.

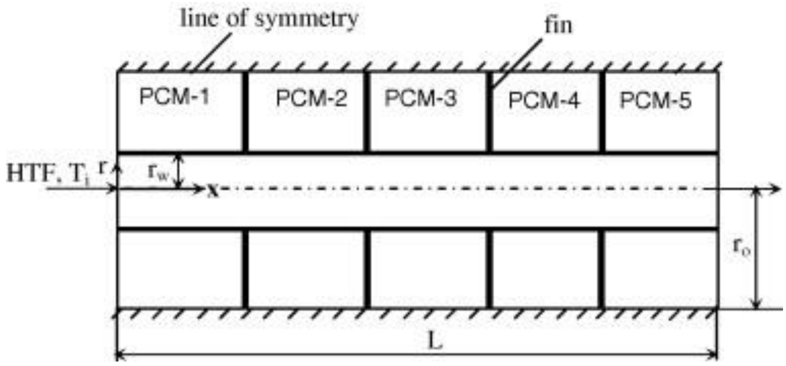

Figure 10 Schematic of the finned-tube multiple PCM LHTS unit 22.

LiangPu et al. 23. numerically investigated the heat transfer performance of shell-and-tube thermal energy storage unit consisting of multiple coaxial PCM and single PCM. They reported that utilization of a single PCM showed better heat transfer effectiveness than the use of multiple radial PCM. The results implied that the multiple radial PCM have no advantage in thermal storage compared to a single PCM. This is an important conclusion because arranging PCM in multiple thermal energy storage sometimes can produce decreasing heat transfer in TES.

- *Encapsulation*

Except for extending surfaces, another helpful method for overcoming the low thermal conductivity of PCM is encapsulation. Encapsulation increases the heat transfer surface between the PCM and the heat transfer fluid. The encapsulation can be at the micro or macro level. In micro-encapsulation of PCM micro size, PCM particles are enclosed in a sphere or cylinder. The shell can be made of the wide range of materials, including natural and synthetic polymers 24..

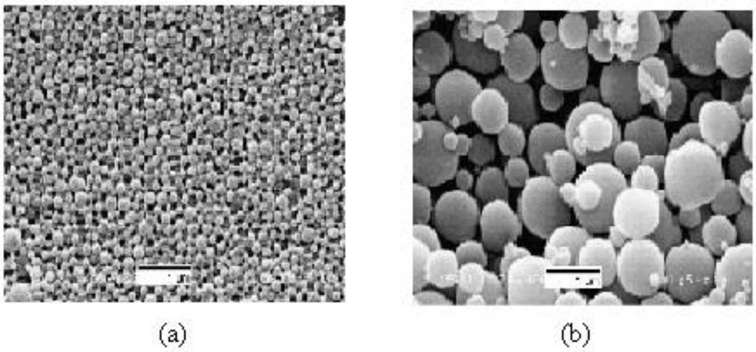

Figure 11 Microscope profiles of microencapsulated PCMs: (a) from spray-driedmicroparticles (b) from coacervation microparticles 24.

On the other hand, in macro-encapsulation PCM is inserted into metal vessels like boxes (Fig. 9), spheres (Fig. 10), panels (Fig. 11), etc. In this way, the surface of the metal shell in contact with PCM is higher and consequently, the heat transfer rate is improved.

Figure 12 Commercial rectangular macro-encapsulated PCM 25.

Figure 13 PCM encapsulated in spheres 26.

Figure 14 PCM encapsulated in metal balls 26.

Figure 15 PCM encapsulated in aluminum panel 26.

4. APLICATION

Thermal energy storages have found a massive application in both the commercial and industrial sectors 27. 28.. TES are used in systems where there is a possibility of using waste heat from various processes 29., and then when there is a discrepancy between the need for heat and its availability, which occurs, for example, in using solar energy for heating 30. 31.. TES can also be used in cooling systems where, in conditions of reduced cooling demand, a part of the realized cooling capacity is stored, which leads to a reduction in cooling costs during subsequent use, as well as to the possibility of using refrigeration units with less power 32.– 34..

In agriculture, TES are used i.e. for the accumulation of heat obtained from combustion biomass as a part of the system for heating vegetable greenhouses 35.. A Schematic of the heating facility that was built in PKB Padinska Skela, which included TES is shown in Fig. 13 35.. In Agricultural Corporation PKB greenhouses were built for vegetable production. The specified greenhouses were covered an area of 1 ha in total. Greenhouse heating was provided via a newly 1.5 MW facility comprising a biomass boiler burning soy straw. In this manner, heavy fuel oil, previously used for greenhouse heating, was substituted by biomass, in this particular case a by-product of soy production at the PKB. TES in this system was used for storing a high quantity of energy obtained in a short period because biomass combusts fastest than other types of fuels (wood, coal). The storing material was water, while the dimension of the TES was 8 m in height and 4 m in diameter ($100m^3$).

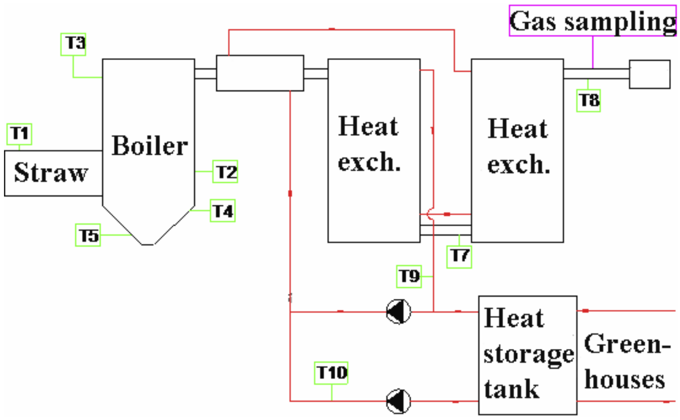

Figure 13 Schematics of the biomass burning heating system with TES 35.

Figure 16 TES in PKB Padinska Skela

The heating of greenhouses in agriculture can be directly by Sun (solar energy). However, when there is no solar energy or not enough, the heating can be realized by solar energy stored in TES. In the direct solar systems the water from the TES flows through the solar circle and there is no heat exchanger between the solar circle and the accumulation fluid. In this type of system, water in whole systems plays the role of thermal storage medium.

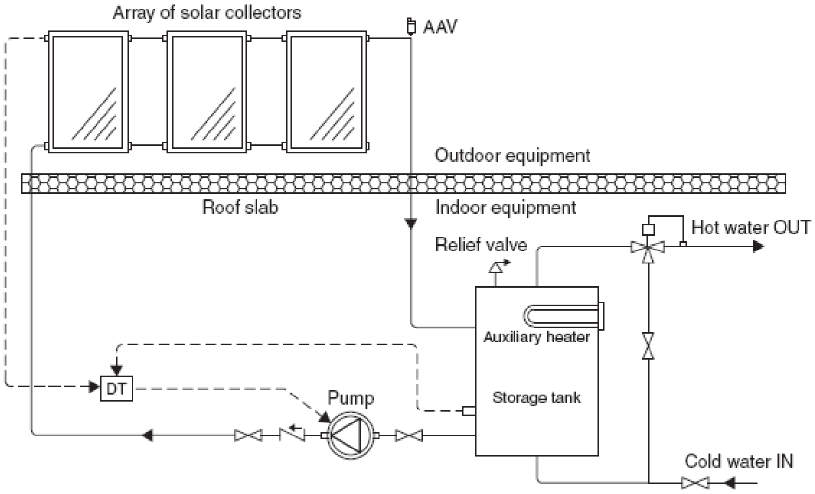

Figure 17 Direct solar water-heating system with TES 2.

If the system is indirect, then the liquid in the collector's circle does not mix with the water in the TES, the heat from the solar circle is transferred to the TES through the heat exchanger.

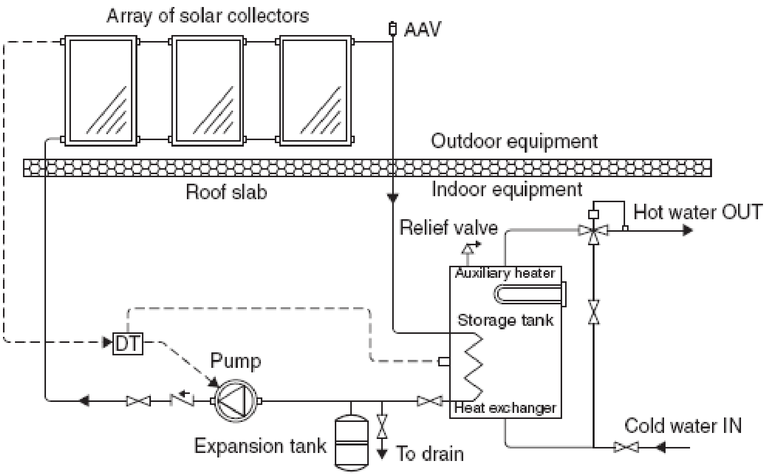

Figure 18 Indirect solar water-heating system with TES 2.

One of the most attractive applications of thermal storage is in solar thermal power plants. In those systems as working mediums are used salts. In the period of a surplus of solar energy, energy is transferred to molten salt that is pumped from cold to hot storage (Fig. 17).

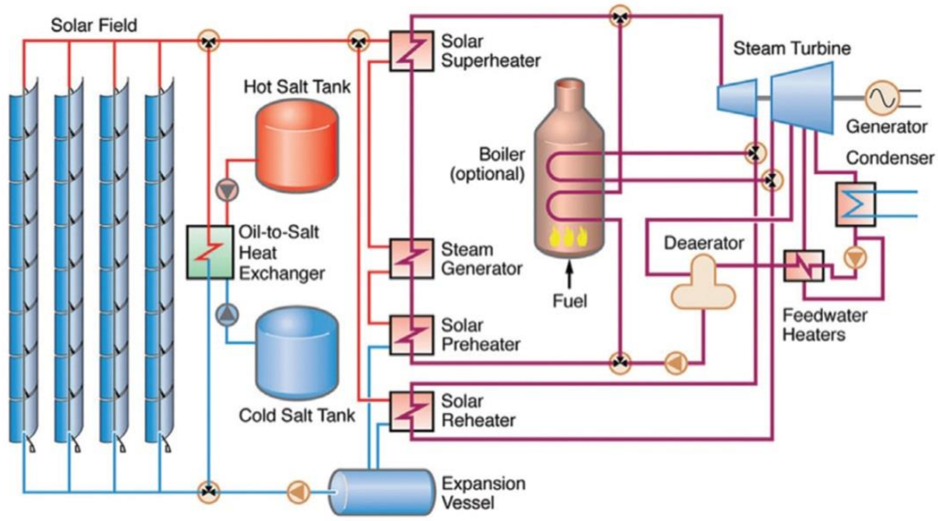

Figure 19 Parabolic trough CSP plant with indirect molten salt TES 37.

In the period when solar radiation is not sufficient, energy is transferred from melted salts to the working medium of the Rankine cycle.

Hence, the primary role of TES is storing energy. However, storing energy is not the only role of TES. For example, in the district heating systems, TES are used for pressurization of the district piping system or for acceptance of excess water due to temperature change (Fig. 18). The pressure at the connection point between the tank and the network will be determined by the level of the water surface in the tank 36..

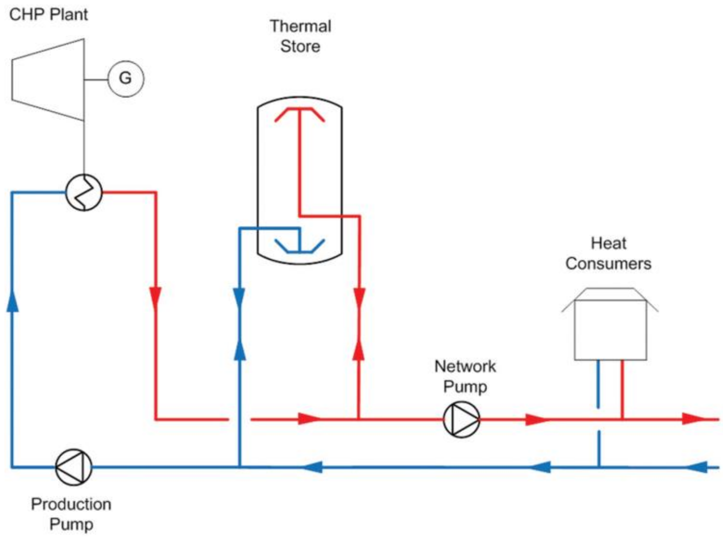

Figure 20 Thermal energy storage directly connected to a district heating network 36.

5. CONCLUSION

Thermal energy storages are an important part of any energy-efficient system. They are used for overcoming the problem of mismatch of energy supply and energy demand. They are also used in the huge district heating systems to pressurise pipeworks and as a receiver of a part of the water that appears during its temperature changes. The utilisation of working mediums is limited by temperature ranges and their own thermo-physical properties. Low thermal conductivity is a considerable problem that limits the utilisation of PCM as working mediums in TES. There are a few technics for enhancement heat transfer rate through PCM, such as extended surfaces, metal foams, composite PCM, multiple PCM and encapsulation. But, use of those enhancement methods increase investment cost and reduces latent heat capacity.

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ANALYSIS OF ENERGY USE AND POSSIBILITY OF IMPROVING ENERGY EFFICIENCY IN GOAT FARM-DAIRY "BEOCAPRA", SERBIA

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Abstract: *Nowadays people face challenges of rising energy consumption, energy costs, environmental impacts, consequence of global warming etc. All trends are directed to reduce those negative effects. In terms of energy consumption, the main goal of any production is to reduce energy consumption per product unit. At the goat farm and dairy Beocapra, located in Kukojevci in Serbia, energy was used for technological processes that include heating and cooling different types of working mediums as well as for heating and cooling spaces of the dairy. In this article the structure of used energy, energy quantities, temperature regimes and quantities of mediums and power consumption of the biggest systems were presented. The measures for improving energy efficiency and possibilities of using renewable energy sources for covering a part of energy demands were proposed. At the end of the article benefits of using proposed renewable energy sources were given.*

Key words: energy, dairy, energy efficiency, renewable energy sources

1. INTRODUCTION

Milk production is the largest sector within Serbian agriculture, bearing in mind the fact that it accounts for 7.92% of the value of agricultural production (average 8.12% for 2008-2013) 1.. However, the analysis of the market from 2008 led to the data that only 0.4% of the total amount of milk produced was given by goats. If this figure is compared with the average 3-5% in EU countries, it is clear that Serbia is an excellent ground for significant progress in the development of dairy goat breeding. The fact that the dairy industry in the Republic of Serbia is one of the strongest food industries, not only in the country, but also in the region, should be added to this.

Increasing the economic profitability of agricultural production can be achieved by reducing the share of energy costs within the direct production costs of certain agricultural products. In the field of milk production and processing, this can be achieved, among other things, by using highly efficient systems that use renewable energy sources for their work. On the example of the company "Beocapra" from Kukujevci, which is the leading company from Serbia in the field of goat breeding and production and processing of goat milk, an analysis of the energy use on an annual level in the production process of the dairy was conducted. The measures to improve energy efficiency, which are based on the use of solar energy in the milk production process, have been proposed.

2. DESCRIPTION OF GOAT FARM AND DAIRY COMPANY "BEOCAPRA"

The company “Beocapra d.o.o.” is founded in 2009. The company's headquarters are located in the village of Kukujevci, Šid municipality, about 100 kilometers from Belgrade. At this locality, on the land owned by the company, with an area of about 4 hectares, there is a farm and a dairy (Figure 1). The farm came to life at the end of 2009, when 179 goats and 5 billy goats of the San breed were imported from Austria. The plant for processing raw goat's milk and production of dairy products started operating in November 2010.

a) A facility for housing and feeding goats b) Dairy

Figure 1. Goat and dairy farm of the company "Beocapra"

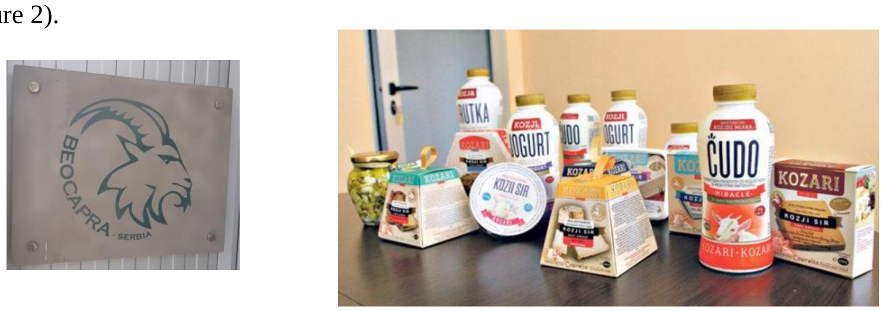
"Beocapra" farm, which covers an area of about 3000 m^2, includes facilities for housing and feeding goats and kids, automated milking, as well as auxiliary facilities for goats, storage of bulky food and manure disposal. The construction of the facility is based on a detailed conceptual and technological project. A concept based on a central feeding corridor with laterally placed boxes for housing animals has been implemented, which is otherwise very rarely used in goat breeding facilities in our country. This concept provides enough accommodation (about 1.75 m^2 per head), as well as the optimal diet. Vertically movable, automatic curtains are placed along the entire length of the barn walls, which provide quality ventilation of the space. The milking parlor is completely automatic, with the measurement of the amount of milk at each milking place and with the collection of milk in a closed milk freezer. For the nutrition of goats, only the highest quality raw materials are used, such as dried alfalfa, ensiled alfalfa and corn, specially prepared concentrate, that is, mixtures of cereals and prekims, etc. Most of the animal feed "Beocapra" produces or prepares itself, while the rest is procured from proven producers.

Milk processing plants are based on modern solutions, respecting the basic principles of material and human flow. The entire facility is built of quality sandwich panels made of plasticized steel, while the floors are made of the most modern BASF masses, all in order to meet all the requirements of the food industry. Maintenance of the entire production plant hygienic regime - washing and cleaning of pipelines, tanks, milking devices, pumps, freezers and other process equipment, is carried out without its dismantling using an integrated CIP (Cleaning In Place) system. After receipt, sterilization, homogenization and pasteurization of milk is performed, after which its part is used in further production of sour-milk products. The dairy has three cold stores that are used during certain production processes, as well as for storing finished products. Since they operate in different temperature operating modes, three separate refrigeration plants have been used to provide them. Ventilation of the dairy production part is done with the help of an air chamber. The complex process pipe distribution with fittings provides distribution of hot and cold water for the needs of production, as well as warm water for the operation of the CIP system. Industrial steam is provided for the purpose of labeling bottled products. The production and office part of the dairy, with a total area of about 600 m^2, is equipped with an electrical installation for lighting, in the form of LED bulbs, as well as an electrical installation for the operation of all machines and electrical devices.

"Beocapra" also took care of the maximum possible saving of natural resources. Therefore, the dairy is equipped with a water-to-water heat pump, with a power of 10 kW, which, in conjunction with fancoil heat exchangers, is used for heating and air conditioning of office space. At the same time, water is supplied from the pumping well of the heat pump, with a depth of over 100 meters.

The capacity of the dairy at this moment is 4-5 thousand liters of milk, with work in two shifts. Since the possibility of automation of all processes is left, with relatively small investments, a significant expansion of capacity is possible. "Beocapra" has certificates on the implementation of quality management systems required by international regulations.

KOZARI is a brand under which "Beocapra" produces and sells top quality goat milk products, such as: probiotic drink "miracle", yogurt, pasteurized milk, whey, white cheese in slices, smoked cheese, cheese in olive oil, cheeses with molds and accessories, etc. (Figure 2).



a) Company logo b) Some of the products of the brand KOZARI

Figure 2. Goat milk production program of the company “Beocapra”

The work of the company "Beocapra" is based on the business of feeding and reproduction of goats, milking, collection and processing of raw milk, production of premium goat milk products, and bookkeeping, commercial and distribution. The company's goal is to use other resources and "by-products" of goat breeding. The plan is to build a plant for the production of goat humus, as well as to establish cooperation with the meat processing industry.

3. ENERGY USE ANALYSIS

The farm and the dairy use two basic energy sources - electricity and liquefied petroleum gas (LPG gas). The farm is supplied with electricity from the low voltage network, and LPG gas is delivered by tanker truck and stored in a tank on the farm. In the office part, for the needs of heating and air conditioning, through the heat pump, geothermal groundwater energy is used as a renewable energy source.

LPG gas is an energy source for the operation of a hot water gas boiler with a power of 250 kW. Its operation provides hot water with a temperature between 97-98^{o}C, required in technological processes during the production of milk and dairy products (Figure 3).

Figure 3. Part of the dairy production plant - line for thermal processing of milk

When it comes to the electricity use, in addition to the above (process devices for milk production and processing, pumps, compressors, ventilation system, lighting, mills for preparing animal feed, milking system) is used to drive an electric steam boiler, power of 45 kW, in order to produce saturated water vapor pressure of 1.8 bar (water vapor saturation temperature is 116.93^{o}C). The produced steam is used in the packaging of bottled products (Figure 4) for the process of gluing slip labels.

Figure 4. Part of the dairy production plant - bottled product packaging line

Heating of the warm water for the CIP system needs, as well as preheating of the feed water for the electric boiler, is done at the expense of condensation heat recovery that occurs during the operation of refrigeration plants. In addition to the listed refrigeration plants that are used to maintain the temperature in the cold stores, the dairy also has a refrigeration installation with a pool of ice water, necessary for the production process. The process cold water temperature is 1-2^{o}C.

The amount of energy used on an annual basis, determined on the basis of monthly electricity bills and data on the amount of LPG gas delivered, is shown in Figure 5.

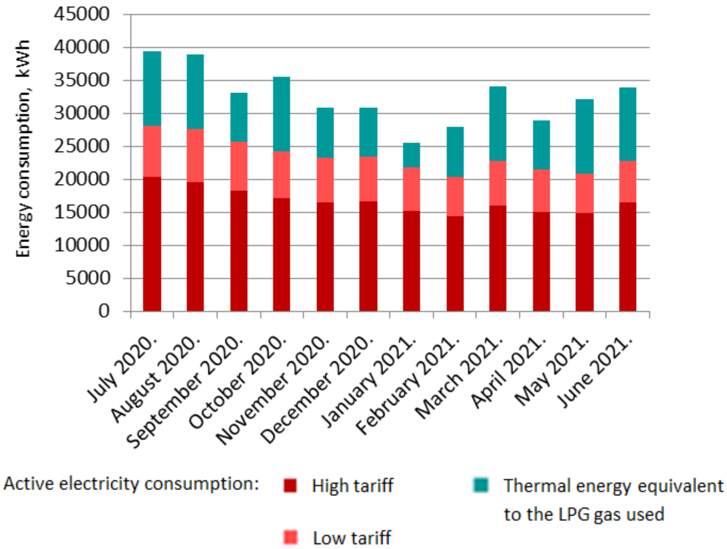


Figure 5. Consumption of basic energy sources on the farm and in the dairy on an annual basis

Based on the analysis of used LPG gas and active electricity, it can be concluded that the amount of energy used during the year is variable. The maximum consumption of electricity, which was recorded in the summer months, comes from the more intensive operation of ventilation and air conditioning systems, i.e. refrigeration systems due to the greater need for cooling. During the winter months, there is a slight decline in energy use due to reduced production - gas consumption is lowest in January and active electricity consumption in February.

The amounts of energy used per unit of raw material, i.e. specific energy used in the dairy industry, which indicate the degree of plant efficiency, are shown in Table 1. The value of this specific energy represent the ratio of the total energy used for production of a certain dairy product and the amount of processed milk, as input raw material for the production process.

Table 1. Specific energy used in the dairy industry 2.

Reg. no.	Dairy product	Specific energy used	Unit
1.	Drinking milk	0.1 – 0.6	MWh/t of processed milk
2.	Cheese	0.1 – 0.22	
3.	Fermented milk	0.2 – 1.6	

As the "Beocapra" dairy produces all three of these dairy products, as the recommended value of the energy amount used per unit of processed milk, the average value was adopted, which ranges from 0.1 to 0.8 MWh/t of milk.

Figure 6 shows the specific energy used by the dairy on a monthly basis. It is important to note that the displayed values are not measured, but it is an estimated value. The dairy has monthly reports on the amount of processed milk and that information is known. The total energy used for the production process in the dairy is the sum of the estimated active electricity and thermal energy equivalent to the LPG gas used. The value of electricity used in the dairy was obtained by subtracting from the total electricity used on a monthly basis the estimated amount of electricity used on the farm for animal husbandry, which is one third of the total active electricity used 2..

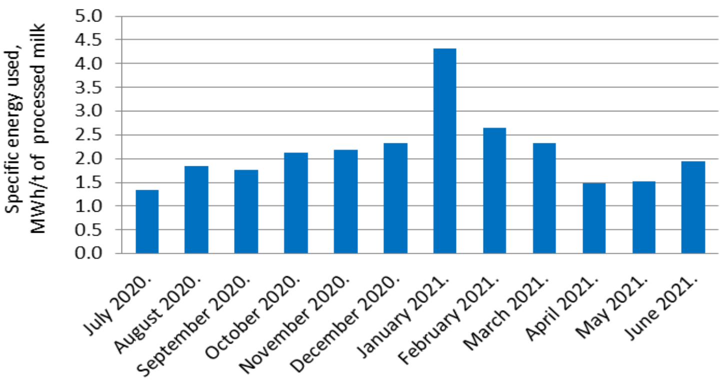


Figure 6. Specific energy used by the dairy on a monthly basis

Based on the analysis of the presented values, it can be concluded that they are above the upper limit of the prescribed values of the specific energy used in dairies, and range from 1.3 MWh/t of milk in July 2020 to 4.3 MWh/t of milk in January 2021. These deviations are most significant in the period from October to March, which is a consequence of the reduced volume of production in that period, i.e. the reduced amount of processed milk. At the same time, the reported monthly values of the energy used per unit of processed milk suggest that there is a significant potential for energy savings.

4. POSSIBILITY OF IMPROVING DAIRY ENERGY EFFICIENCY

As already mentioned, the company "Beocapra" took care of the maximum possible saving of natural resources, which is why the dairy is equipped with a geothermal heat pump for space heating and air conditioning. Among other things, the operation of the ventilation system is largely optimized. Ventilation control is automatic and is performed according to the outside temperature. Object lighting is also optimized. LED lamps are used, which are periodically replaced during regular maintenance. Nevertheless, there is room for further energy savings.

Based on the temperature regimes of hot water used in technological processes during the production of milk and dairy products (hot water temperature is between 97-98^{o}C), it can be concluded that there is a huge potential for the application of solar thermal collectors. The use of solar collectors with vacuum tubes would be optimal 3.. Their application would simultaneously provide heating of water for the operation of the CIP system, as well as preheating of water that goes to the electric steam boiler. For the purposes of this paper, an analysis of the use of solar energy for heating was performed. The sizing of the solar system was carried out in such a way that in July it fully covers the needs for thermal energy, which is equivalent to the LPG gas used and about 30% of the electricity used for thermal needs. The analysis was conducted by months for the climate data of Belgrade 4., for selected solar vacuum collectors. The *f-chart* method 5. was used in the calculation, which enables the determination of the solar share in the total required thermal energy of the dairy (Figure 7).

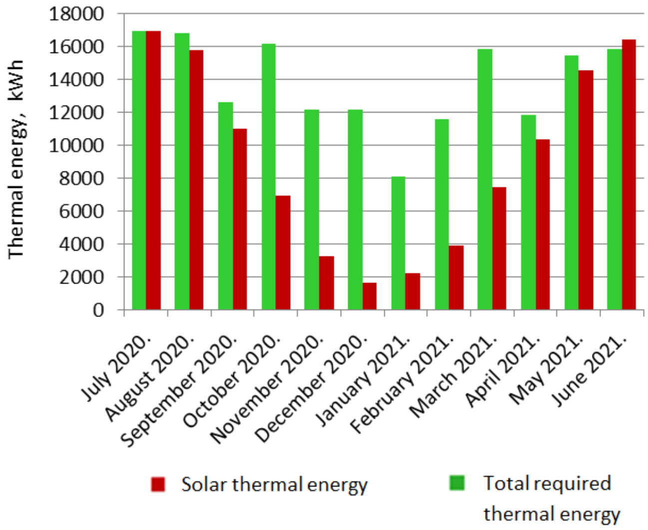


Figure 7. The share of thermal energy of solar panels in the total required thermal energy of the dairy

Figure 7 shows that in the period from April to September, solar thermal energy covers a significant part of the total required thermal energy in the dairy (in June and July in full). At the same time, in this period, it leads to a decrease in the specific energy used by the dairy on a monthly basis, whose values are now in the recommended interval or at its upper limit (Figure 8). The percentage reduction of the specific energy used by the dairy ranges from 7.2% in December 2020 to 62.1% in June 2021.

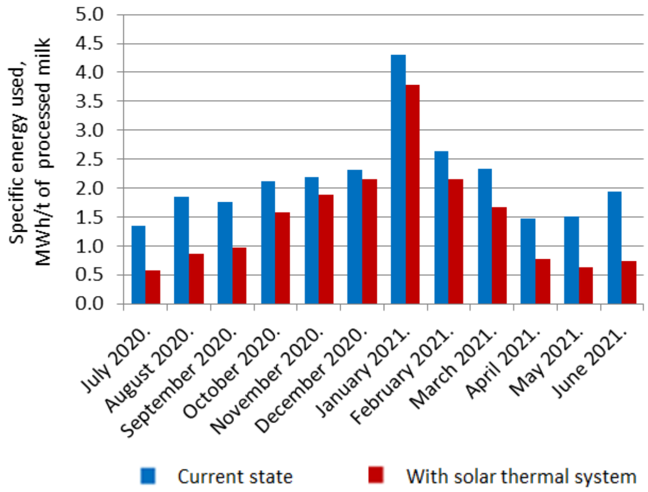


Figure 8. The specific energy used by the dairy on a monthly basis with and without a solar thermal system

The values of the specific energy used are more than recommended in the period from October to March. This suggests that an additional part of the active electricity used should be replaced by a system that uses renewable energy sources for its production. For these purposes, the use of solar photovoltaic collectors would lead to a further increase in the energy efficiency of the milk and dairy products production.

5. CONCLUSION

On the example of the company "Beocapra" from Kukujevci (Šid), which is the leading company from Serbia in the field of goat breeding and production and processing of goat milk, an analysis of energy use on a monthly basis during one year was conducted. The farm and the dairy use two basic energy sources - electricity and liquefied petroleum gas. The amount of energy used during the year is variable. The maximum consumption of electricity was recorded in the summer months, due to the more intensive operation of ventilation and air conditioning systems, i.e. refrigeration systems due to the greater need for cooling. During the winter months, there is a slight decline in energy use due to reduced production. The amount of energy used per unit of processed milk is above the prescribed values for the dairy industry, which suggests that there is potential for energy savings. The application of highly efficient solar thermal and photovoltaic systems would lead to a significant increase in the degree of energy efficiency of the milk and dairy products production.

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ESTIMATION OF THE SOLAR DESALINATION POTENTIAL TO COVER THE IRRIGATION CROPS IN THE GREEK ISLANDS

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Abstract: *Greece has a significant potential for the development of desalination plant. Especially in the Greek islands the available sea water is limitless and can be used to produce fresh water for various needs. At the same time fresh water is not available in sufficient amounts in the Greek islands and as a result many issues occur for activities especially during the summer months when drought is more intense. The development of agriculture in the Greek islands in small scale crops is of great interest specially to cover the local needs and to achieve lower cost products. Solar desalination plants could be low-cost solution for such projects as the solar energy potential in Greece is sufficient and can lead to the production of water amounts capable to cover the irrigation needs. In this study a theoretical study is performed, to estimate in which rate solar desalination can serve the irrigation needs of open filed agricultural crops in a few case studies of Greek islands. The irrigation needs of specific crop are calculated using the Penman method for the evapotranspiration of the crops and the local rain data of each region. Solar desalination potential is estimated via the solar intensity data for each region and the necessary energy for seawater evaporation. This study can be proven particularly useful in the initial phases of solar desalination plants installation as it provides information about the relationship between water production and needs. That way a preliminary evaluation of proper sizing and estimation of the desalination plant's viability can be performed.*

Key words: *desalination, irrigation, solar energy, islands*

1. INTRODUCTION

Food for covering the world population needs is a critical issue both for the current and future generations. It is estimated that the world population will reach almost 10 billion until 2050, and despite the profile of the population (urban or rural), additional food will need to meet its' needs. Considering that the consumption of calories is increased, and food types are getting more complex through the years, the estimation of agricultural production is that it will need to increase for almost 70% by 2050 1.. This situation is putting a sufficient pressure to the whole food supply chain. Agriculture and livestock are the main pillars of the food supply chain. The problems of available agricultural land and soil degradation are some of the barriers for increasing the open filed cultivation in existing lands. In fact, 33% of the world's land used for agriculture is degraded 2.. This degradation is affecting mostly dryland areas. The opportunities for further expanding land for agricultural use are limited. Additional available land is not suitable for agriculture use or utilizing existing land for agricultural production would cause other issues (economical, environmental, social etc.) 2.. Water resources and water availability is also an issue. Irrigated agriculture consumes most of the water globally as most of the times farmers are using this water for free or with exceptionally low cost. In fact, 70% of water use worldwide is due to agriculture irrigation needs 3.. Moreover, most of the irrigation needs are covered by intensive groundwater pumping. This practice leads to the depletion of aquifers and can also have negative environmental effects. Water resources are also polluted over the years by the development of all economic sectors including agriculture and livestock. One solution to overcome the up mentioned issues is to cultivate in lands where are not suitable for any other use and causing environmental constrains or cultivate in greenhouses. Also, the utilization of alternative water resources is a necessity to prevent existing water sources scarcity and degradation. Greece agriculture and food sectors have been traditionally some of the main sectors of the country's economy. According to the EU data, crop output corresponds to the 74,1 % of the total agricultural output of the country (the rest is from livestock production). According to the same source, most of the holdings are small both in utilized agriculture area (about 77,3% are holdings smaller than 5ha) and economic size (50% corresponds to less than 4000 €/ ha) 4.. In the chart of Figure 1, the profile of the Greek agricultural output is illustrated.

Most of the agricultural production is taking place in the mainland of Greece. On the map illustrated in Figure 2, the percentage of agricultural production per region in terms of cultivated area in Greece is shown. Greek islands' agriculture sector (excluding Crete) is not insignificant in total, but the activities are divided in many islands. The sustainable development of the agriculture sector in the Greek islands is of immense importance for many reasons. Greek islands' economy is based mostly in tourism, so other sectors need also to be developed to provide to the economy more diverse characteristics. Local agricultural production is also important for other reasons as well. The covering of local demand in low prices and the security in cases of isolation due to reasons such as severe weather phenomena or the recent bans due to COVID 19 pandemic are some of them. Moreover, many islands have a high-quality brand name for some of their agricultural products which must be retained. The main problems of agriculture development in the Greek islands are the available cultivated land and the water resources. As far as it concerns the available land, most of the agriculture fields in an island are in the island's mainland where fields might be in hilly or mountainous regions.

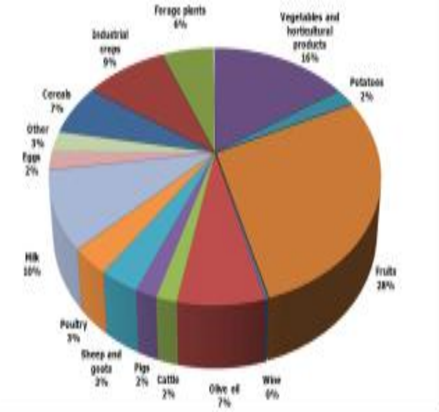

Fig.1 Agricultural components (2018-2020) of the Greek agriculture sector 4.

Fig.2 Agricultural fields allocation per region in Greece 5.

In any case, the agriculture fields are difficult to be irrigated as water resources are limited or don't have the proper characteristics (drill water with high salinity levels). In fact, at the Aegean islands, the cultivated area is about 162.612ha and only the 8,1% of those are irrigated, while at the Ionian islands, only a 5,6% of the 70.692ha are irrigated 6.. In Aegean islands the total available water was almost 1250 mil m^3/ year (80% surface water and 20% underground water) 6.. From this water amounts only a 9,4% is consumed in a yearly basis and the 6,4% is utilized in agriculture 6.. During summer periods where tourism is increased in most of the Greek islands water availability is even more limited. One cheap and easy solution is the rainwater harvesting 7.. However, Greek islands have low rainfall levels and the climatic trend projections shows that the situation will be worst in the future (18% less rainfall until 2050) 7.. A solution with immense potential is the use of desalinated water, as sea water or underground water with high salinity levels are more than available in islands. This type of water is not suitable for irrigation purposes if the salinity levels don't drop to the proper values. According to FAO, water with electrical conductivity more than 3 dS/m are not suitable for crop irrigation 8.. Since sea water electrical conductivity is almost 50-60 dS/m 9., 10., the removal of salt is essential to covert it in irrigation water. Desalination can be performed by various methods, with reverse osmosis to be the most common one. This method is the most effective, but it is applied in large plants which need to produce substantial amounts of salt and desalinated water 9.. Alternative methods for water desalination with lower cost and easier to applied for agriculture purposes in a smaller scale need to be sought. Solar desalination could be the solution for such applications since the solar energy potential is significant in the Greek islands.

Solar desalination methods have been examined in the literature and tested in pilot scale 11., 12., 13.. It has been found that with a relatively low and simple construction the quality of the water produced by these processes has the properties, to be used as irrigation water. The solar desalination process is based on evaporation of sea water and the separation of salt and desalinated water. The evaporation of seawater is performed using solar energy, usually in a covered greenhouse type structure. The amounts of desalinated water are proportionally varied with the surface of the area used 9..

In this work there will be an estimation of how feasible it is to use solar desalination to cover the irrigation needs of typical crops in islands of the Aegean Sea in Greece. The results of this study are of great interest for farmers and policy makers in Greece. If this is a realistic perspective, it will be the base for relevant actions towards confronting the issue of water scarcity for agricultural purposes in island regions in Greece and other countries, as well.

2. MATERIALS AND METHODS

In this research work 2 islands of the Aegean Sea will be used as case studies. In these islands it will be estimated that 3 typical crops will be cultivated in open field. It will be evaluated what crop area can be covered by a 1000 m^2 solar desalination unit installed in a nearby field. In Table 1, the islands and crop types that are going to be cultivated are described. The choice of the crop has been done with the criterion of low irrigation needs and in crops that don't have many requirements in terms of climate, soil etc. Many of these crops are already cultivated in islands. The islands are chosen randomly with only criterion the geographical dispersion, to evaluate the differences in the climate between islands of the north and south Aegean as shown in the Figure included in the Table.

Table 1. Islands case studies and crops with relevant code classification

	Crops		
Islands	Pepper	potato	Onion
Skiros	A1	A2	A3
Kos	B1	B2	B3

2.1. Irrigation needs estimation

The actual irrigation needs of an open field cultivation are calculated as shown in Equation (1) 14..

$$In=ETc-(Pe+GW+SM) \quad (1)$$

In: Actual irrigation needs (mm)

Etc: Evapotranspiration (mm)

Pe: Beneficial rain (mm)

GW: Underground water contribution (mm)

SM: Stored water at the root zone (mm)

In this study Equation 1 will be simplified by assuming that the parameters GW and SM are in exceptionally low levels and are zero. The evapotranspiration is calculated according to the modified Penman method as described by Equation (2) 14..

$$ETr = c\left[W \times Rn + (1-W) \times f(u) \times (e_d - e_a) \right] \qquad (2)$$

ETr: Basic evapotranspiration (mm)

c: Adjustment factor depend on the condition differences prevailing between day and night in a region

W: Weighing factor representing the effect of solar radiation on basic evaporation

Rn: Solar radiation of the region expressed in mm of evaporating water / day

f(u): Function of wind effect on evaporation expressed in km / day

ea-ed: The difference in sizes ea and ed express the effect of atmospheric humidity on evaporation. The magnitude ea is the water vapor saturation pressure as it appears at the average temperature of the area. Respectively the size ed is the actual water vapor pressure of the atmosphere. These values are expressed in mbar

The up mentioned factors are chosen by reference 14.. The rationale cannot be further explained here due to the considerable extent of the theory. Any factor chosen or assumed will be mentioned with a brief explanation at the results and discussion paragraph. The meteorological data that are necessary for the calculation of each factor are presented in relevant tables.

The actual evapotranspiration (ETc) occurs by multiplying the basic evapotranspiration with the factor kc according to the crop 14..

About the beneficial rain, it is estimated via the meteorological data which are available for the examined islands, and it is illustrated in Table 2 for each of the chosen regions.

Table 2. Monthly precipitation (Pe) for the examined islands in mm 15.

Island	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Skiros	113	77,5	58	46	46	44	10	9	42	74	55	95
Kos	185	112	81	43	30,5	14,5	2	2	19,5	70	102	149

The crops chosen as case studies require water in specific periods according to the phases of the plant development. For potatoes the main growth period is between end of September and beginning of December (Sep-Oct-Nov). In the case of onions, the seeding period is during middle-end of march and harvesting during July (Apr-May-Jun). For the peppers the growth phases where water will be chosen to be 3 months (Jul, Aug, Sep) 14..

2.2. Solar desalination potential

A simplified method to estimate the solar desalination potential is by calculating the evaporation achieved by the solar radiation in a region. The evaporation phenomena are complex and there are many parameters that must be considered to reach an accurate result. However, in Equation 3 9., a simplified approach is described.

$$Q=\frac{n\times H\times A}{2,3} \quad (3)$$

Q: Desalination water production (lt/day)

n: Performance rate (%)

H: Solar radiation (MJ/m^2 day)

A: Solar collection surface (m^2)

2,3: The energy required for seawater evaporation (MJ/lt)

The surface area will be initially estimated to be $1000m^2$. For the chosen regions the solar radiation potential is described in Table 3

Table 3. Monthly solar irradiance for the examined islands in MJ/m^2 16.

Island	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Skiros	176	264	471	634	698	832	860	806	560	381	243	167
Kos	242	298	494	655	790	892	910	826	651	492	290	239

3. RESULTS AND DISCUSSION

In order to calculate the evapotranspiration, the parameters of Equation 2 should be defined. The value W depends on the elevation and mean temperature of each region 9.. In the same rationale the value Ra depends on the latitude. So, for 40^o also the values for each month are chosen from relevant Tables of the literature 9.. The value of function f(u) depends on the wind speed of each region. The values of parameters ea and ed depend on the temperature and relative humidity. The adjustment factor c is also depended on the relative humidity, air velocity and actual solar irradiance of the region. In Table 4 all the meteorological data that are necessary for the definition of these parameters are described. It should be mentioned that it is assumed that every field is at the same elevation (500m).

Table 4. Meteorological data for the examined region 9., 15., 17., 18., 19., 20.

	Wind Speed m/sec.		**Average Temp ^oC.**		**Relative Humidity %.**		**Ra mm/day.**	
Month	Skyros	Kos	Skyros	Kos	Skyros	Kos	Skyros	Kos
Jan	6,8	6,2	11	13	72	69	6,4	6,4
Feb	6,9	6,3	12	14	73	70	8,6	8,6
Mar	6,2	5,8	13	15	72	69	11,4	11,4
Apr	4,9	5,3	15	16	73	70	14,3	14,3
May	4	4,3	19	20	73	70	16,4	16,4
Jun	4,2	5,3	22	23	72	69	17,3	17,3
Jul	4,8	5,8	25	26	72	65	16,7	16,7
Aug	5,1	5,6	25	26	72	66	15,2	15,2
Sep	5,1	5,6	24	25	70	66	12,5	12,5
Oct	6	4,9	20	21	72	65	9,6	9,6
Nov	5,6	5,4	17	18	74	66	7,0	7,0
Dec	6,4	5,8	13	15	72	67	5,7	5,7

In the case of the desalination water production, the rate of performance is assumed to be 30%. This value is chosen as a usual rate of performance for simple solar collectors. The structure is assumed to be a greenhouse type structure with a pond for collecting the seawater or drill water with high salinity. The operation rationale is out of the scope of the current work. The results of the calculation that will lead to the results of Equation 1, are shown in Table 5 for each scenario as described in Table 1.

Table 5. Daily Evapotranspiration, precipitation, and desalination potential in mm

Code	Month	Etr	Etc	Pe	Q	Code	Month	Etr	Etc	Pe	Q
A1	Jul	9,17	8,71	0,32	3619	B1	Jul	11,65	11,07	0,06	3829
A1	Aug	8,58	8,15	0,29	3391	B1	Aug	10,52	10,00	0,06	3475
A1	Sep	6,35	5,08	1,40	2435	B1	Sep	7,76	6,60	0,65	2830
A2	Sep	9,28	8,07	1,40	2435	B2	Sep	9,86	8,15	0,65	2830
A2	Oct	6,68	5,80	2,38	1603	B2	Oct	5,96	4,93	2,25	2070
A2	Nov	3,75	3,57	1,83	1057	B2	Nov	3,39	2,37	1,40	1261
A3	Apr	5,98	5,68	1,48	2757	B3	Apr	6,02	5,72	1,43	2848
A3	May	7,40	7,03	1,48	2937	B3	May	8,11	7,70	0,98	3324
A3	Jun	8,84	6,63	1,46	3617	B3	Jun	9,99	7,50	0,48	3878

As it occurs from Table 5 in each case scenario the irrigation needs that the solar desalination system can cover are not large but not too low either. In fact, in Table 6 it is shown the surface area that can be covered for each month and scenario.

Table 6. Potential area irrigation needs covered by the proposed solar desalination system in m^2

Code	Month	Surface	Code	Month	Surface
A1	Jul	431	B1	Jul	347
A1	Aug	432	B1	Aug	349
A1	Sep	661	B1	Sep	475
A2	Sep	365	B2	Sep	377
A2	Oct	468	B2	Oct	772
A2	Nov	686	B2	Nov	1300
A3	Apr	654	B3	Apr	663
A3	May	529	B3	May	494
A3	Jun	699	B3	Jun	552

According to the above results it occurs that in the island of Skyros the proposed method can cover a pepper field of 0,04ha, a potato field of 0,037ha and an onion field of 0,052 ha. In Kos the system can cover the needs of a pepper filed with surface 0,037ha, a potato field with surface 0,037ha and an onion filed with surface 0,049ha. These areas are satisfactory for a family farm when considering these specific products. It should be noticed though that the initial cost of the system hasn't been considered, which is a very important parameter for the sustainability of this irrigation method.

4. CONCLUSIONS

In this study, the theoretical estimation of an irrigation method for the case of two Greek islands is examined. According to the results, solar desalination systems can cover exclusively the needs of small farms in regions where the water needs are very intense. It is obvious that this system can operate as a support system if the field surface is large. It should also be noticed that the method requires land commitment so it should be applied in a region where this land is not suitable for cultivation or any other need. land Greek islands, or any island region, have many particularities in terms of climatic conditions, landscape etc. So, any case is a different case and needs to be calculated from the start, when studying the proposed system. However, to evaluate the system in total, both economical and technical parameters should be further examined. It has been proven that in actual conditions such systems, face many practical problems which are difficult to overcome.

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BIOCHEMICAL POTENTIAL FOR THE PRODUCTION OF BIOGAS FROM AGRICULTURAL WASTE SAMPLES

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Abstract: *Greece has a significant agriculture sector which is one of the biggest pillars for its economy. Nonetheless, the produced agricultural waste is not so insignificant and the need for its utilization is imperative. An innovative way to utilize the agricultural waste is through the anaerobic digestion process and the production of biogas to promote the use of Renewable Energy Sources. The aim is to reduce the environmental footprint, thus protecting the environment, which aligns with the global goals for a ''greener'' future while using renewable energy sources. The identification of the potential of agricultural waste materials used for biogas (hence methane) production will offer the possibility of low cost and environmentally friendly energy production solutions. Proper management and utilization of the agricultural waste can be achieved, through the anaerobic process, in order to cover a wide range of energy needs. for the benefit of the environment. Making agriculture more competitive through the complete utilization of agricultural waste provides huge potential and economic benefits which deserve to be explored. In this study an experimental study is performed, to estimate and determine the methane production potential in the laboratory of various agricultural waste samples. The biochemical methane production potential of the samples was determined following the Biochemical Methane Potential (BMP) method. In addition, the total and volatile solids were measured using the Standard Methods for the Examination of Water and Wastewater, APHA, 2005 and volatile fatty acid concentrations measurements took place in the solutions of the above samples, which were used in the batch reactors, upon completion of the biodegradation. This study can be proven particularly useful in the utilization of agricultural waste as it provides information regarding the methane potential of numerous waste samples byproducts of the agricultural activity. That way a preliminary evaluation and estimation of their potential can be performed.*

Key words: *agricultural waste, anaerobic digestion process, biogas, renewable energy sources, methane potential*

1. INTRODUCTION

In the recent years the dependence on fossil fuels becomes less and less important due utilization of renewable energy sources. Treating and recycling waste through certain processes is becoming the prevailing waste management strategy. In this context, there have been great progress in exploitation of agricultural waste through the anaerobic digestion process.

There is growing interest in the production of biogas through anaerobic digestion (AD) by processing agricultural waste since it is a renewable energy source low carbon emissions and contributes in the sustainable management of organic waste 1.. Most of the produced agricultural waste can be utilized as substrates in biogas plants, from various livestock manures and crop residues to domestic and food industry waste. The biogas derived from AD can be used for the production of green energy with an estimated reduction of 50% to 90% in greenhouse gas emissions 2..

The main components of biogas are methane (CH_4) and carbon dioxide (CO_2), with respective concentrations of 50–70% and 30–50%. Other notable gases present in biogas at low concentrations are, nitrogen (N_2), hydrogen (H_2), hydrogen sulphide (H_2S), ammonia (NH_3) and water vapors 3.. The purification and pressurization of biogas leads to biomethane, a process refer to as “Biogas Upgrading”. Biomethane is a renewable energy source that can act as a viable replacement for fossil fuels in both heat and power generation applications 4.. Anaerobic digestion (AD) is a biological process during which complex organic substrates are consumed for the production of biogas in the absence of oxygen. AD is a process that consists of four stages, hydrolysis, acidogenesis, acetogenesis, and methanogenesis. During the four stages the complex organic compounds are gradually reduced to simpler ones by different groups of microorganisms 5.. The last stage is methanogenesis, which defines the rate of the whole AD process since it consists of the slowest biochemical reactions. The group of microorganisms that produce methane are called methanogens. There are three types of methanogens, aceticlastic that consume acetate, hydrogenotrophic that consume CO_2 and H_2 and methylotrophic that convert methylated compounds to CH_4 6..

The methane potential of waste can be determined relatively easy by biochemical methane potential (BMP) tests. This method is applicable to all kinds on all kind of agricultural wastes and there a wide variety was tested in the present study. The biochemical methane potential (BMP) refers to the total volume of methane produced, per gram of volatile solids (VS) of a substrate. The BMP acts as an indicator of a substrate’s methane potential and its biodegradability during AD. The data obtained from the BMP can be used to estimate the performance of an AD process and to determine design parameters for the optimization of the methane yield 1..

2. MATERIAL AND METHODS

2.1. Samples and inoculum used

Agricultural waste samples were obtained from various cites from Northern Greece and they were stored at 4 ºC for 3 days before use. The samples were nine in total and represent a variety of agricultural activities. Specifically, they were corn silage, poultry manure, rendering, solid compost, olive mill wastewater, swine manure, cheese whey, fruit pulp and cattle manure. In addition, the anaerobic inoculum was obtained from an operating biogas plant near Thessaloniki (Biogas Lagada S.A.) and it was pre-incubated until there was no significant methane production. The purpose is to deplete any residual biodegradable organic matter present in it and the temperature of this process was 37 ± 0.5 ºC, identical with the biogas plant, where it originated from 7..

2.2. Experimental setup and design

The determination of BMP was performed in batch reactors using bottles with a nominal volume of 300 ml. For each agricultural waste sample, a triplicate of batch reactors was set up in order to ensure statistical significance. In addition, a treatment with inoculum only, was created, with the purpose of subtracting any methane produced from the assays with the agricultural waste samples. Therefore, the accumulative results, represent the gas production from the waste samples only. Each digester was filled with an amount of sample containing 1g VS of its designated waste sample and 50ml of inoculum which was measured to be an amount of 1.58g VS. The final ratio feed to inoculum in all batch reactors was 1/1.58, except for the inoculum assays. The final working volume of 150ml in each batch reactor was achieved using deionized water, which diluted the waste samples and kept the concentrations of the volatile solids of the samples withing the appropriate limits, required by the BMP test method 7.. The batch reactors' headspace was purged with pure nitrogen gas to ensure anaerobic conditions and then were tightly closed using silicon stoppers with screw caps and placed in a constant temperature furnace (37 ºC). Measurements of the quality and quantitative composition of biogas were taken at 2-3 day intervals. The waste samples were named accordingly, as shown in table 1.

Table 1. Sample naming

Sample	Name	Sample	Name
Inoculum	Inoc	Olive Mill Wastewater	OMW
Corn Silage	CS	Swine Manure	SM
Poultry Manure	PM	Cheese Whey	CW
Rendering	Re	Fruit Pulp	FP
Solid Compost	SC	Cattle Manure	CM

2.3. Analytical methods

Standard methods 8. were employed to determine total solids (TS) and volatile solids (VS).Volatile fatty acids (VFAs) samples were extracted from the designated sacrificial batch reactors during experiment 0.1 ml of H_3PO_4 was added in the 5 ml extracted from the batch reactors to preserve the VFA and the pH value was measured with Jenway, model 3520.

Volatile fatty acids (VFAs) were analyzed in a gas chromatograph (GC-2010plusAT, Shimadzu, Kyoto, Japan) equipped with a flame ionization detector (GC-FID) and a ZB-FFAP column, Zebron-Phenomenex (30 m × 0.53 mm i.d., 1 μm film thickness). Column oven temperature program was set for the first 3.5 min at 60°C, with temperature increase at 25°C/min to 130°C and then 10°C/min to 235°C and final hold of 5 min. The injection sample volume for the measurement of VFAs was 1 μL. Helium was used as carrier gas in the gas chromatographs 9..

The production of methane (CH_4) was determined by injecting gas samples from the reactors into a gas chromatographer (GC-2010plusAT, SHIMADZU, Kyoto, Japan) equipped with an appropriate detector and columns 9.. For each sample 150 μL of gas were acquired from the headspace of the reactor with a gas tight syringe outfitted with a pressure lock. During the first 10 days the reactors were monitored daily and after that on a bi-daily schedule. A standard gas mixture (60% CH_4, 40% CO_2) To determine the concentration (%) of CH_4 of each gas sample the obtained peak area is compared to that of a standard gas mixture (60% CH_4, 40% CO_2) injected at atmospheric pressure in the chromatographer. To calculate the volume of the produced CH_4 the headspace of the reactors is multiplied with the concentration (%) of CH_4 of each gas sample 9.. The calculation of daily methane production is performed by Equation (1):

$$mLCH_4 = \frac{\%CH_4 \times V}{400} \quad (1)$$

Where:

mL CH_4 : daily methane production (mL/d)

% CH_4 : daily methane percentage in batch reactor

V : Volume of the gas phase (headspace) of batch reactor

The experiment was terminated after 40 days because daily methane production was below 1% of the total volume of methane 10..

3. RESULTS AND DISCUSSION

Some of the waste samples had high solid content and most were homogeneous, except for the rendering, chicken manure and cattle manure, which may have affected the assessment of their methane potential.

3.1. Total and volatile solids

In Table 2 the ratios of the solid matter contained in the samples as well as the standard deviation of the measurements are presented. For each sample, three TS measurements were performed, except for the chicken manure. Six total measurements were required for CM because, high variations of the total solids were observed. This is most likely, due to the great heterogeneity of the sample. The results of the process seemed to agree with the literature and therefore, they were deemed reliable 11-19.. pH measurements were taken when the experiment was terminated to have a clear view of the process stability. pH can influence the growth of the microorganisms and affect other important compounds of the anaerobic process. The tolerable pH range for reactors in mesophilic conditions is between 6.5 and 8 20..The values of pH after the biodegradation are presented in Table 3 and vary from 7 to 7.4 which suggests a stable and normal process.

Table 2. Sample characteristics

Sample	TS (%Dry matter)	VS (%Dry matter)	VS (%TS)
Inoculum	4.63 ± 0.0005	3.16 ± 0.08	68.15 ± 1.64
Corn silage	39.66 ± 0.06	38.35 ± 0.69	96.69 ± 1.74
Poultry manure	67.17 ± 0.86	57.67 ± 1.18	85.85 ± 1.75
Rendering	21.60 ± 0.57	20.72 ± 0.06	95.92 ± 0.28
Solid compost	23.89 ± 0.07	20.44 ± 0.14	85.57 ± 0.60
Olive mill wastewater	7.43 ± 0.01	6.58 ± 0.05	88.56 ± 0.62
Swine manure	2.77 ± 0.06	2.15 ± 0.06	77.5 ± 2.12
Cheese whey	12.43 ± 0.31	12.25 ± 0.086	98.53 ± 0.69
Fruit pulp	17.31 ± 0.22	17.14 ± 0.01	99.02 ± 0.03
Cattle manure	22.33 ± 1.16	17.80 ± 0.09	79.71 ± 0.42

Table 3. pH values in the final samples after biodegradation

Sample	pH	Sample	pH
Inoculum	7.391	Olive mill wastewater	7.111
Inoculum	7.363	Olive mill wastewater	7.135
Corn silage	7.033	Swine manure	7.275
Corn silage	7.062	Swine manure	7.304
Poultry manure	7.229	Cheese whey	7.203
Poultry manure	7.203	Cheese whey	7.195
Rendering	7.199	Fruit pulp	7.129
Rendering	7.225	Fruit pulp	7.13
Solid compost	7.108	Cattle manure	7.108
Solid compost	7.132	Cattle manure	7.117

In figure 1 the total production of methane is presented per gram of volatile solids. The VS represent the organic substance consisting of a biodegradable and a non-biodegradable part. The methane to volatile solids ratio is an important parameter that enables the samples to be compared and evaluated as to their methane production, because methane production occurs due to the biodegradation of VS . The waste samples with the highest methane production were olive mill wastewater and the rendering with values of 776.29 and 813.76 mL/g VS, respectively. The lowest production was observed from the solid compost sample and was 158.06 mL/g VS, since compost is a product of aerobic digestion and part of its biodegradable matter has already been consumed.

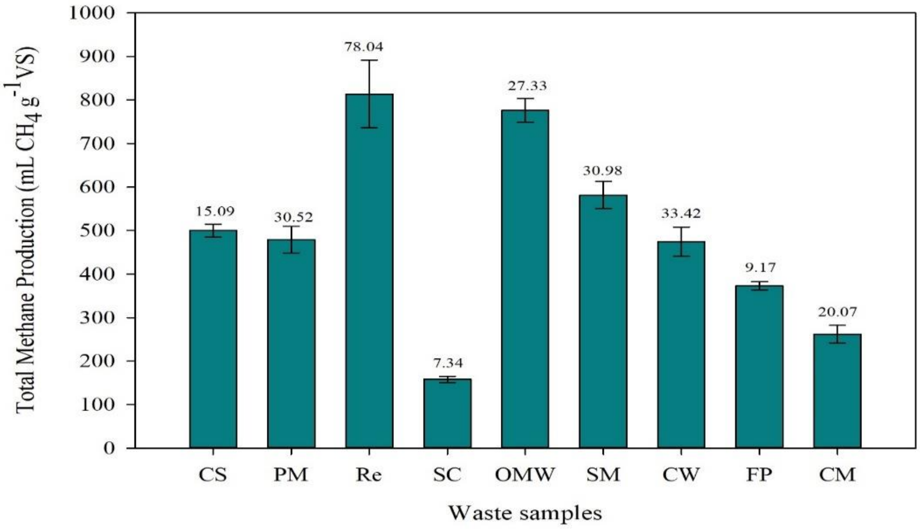

Fig. 1 Total methane potential of waste samples

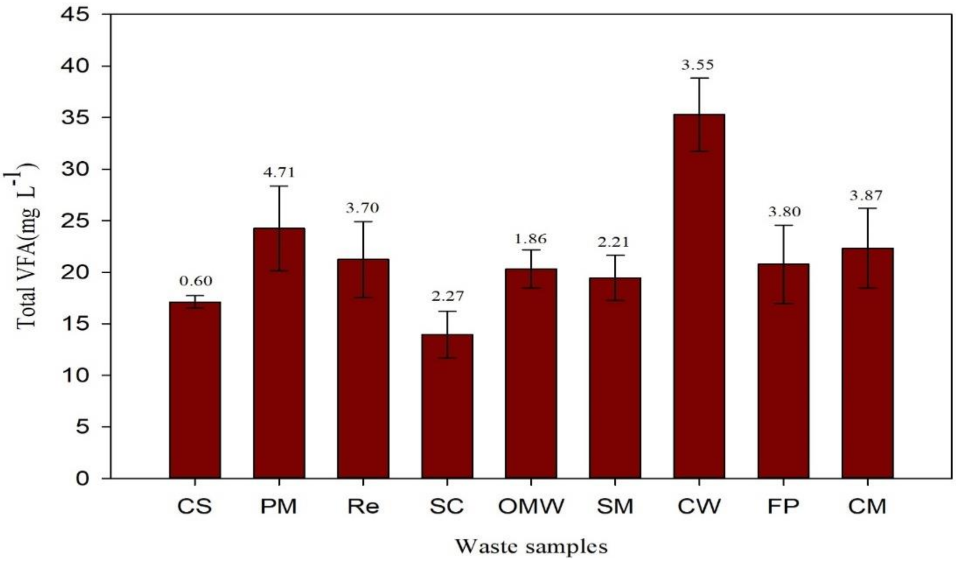

Fig. 2 Total VFA of waste samples after anaerobic digestion

As shown in figure 2 the final VFA concentrations of the samples were relatively low. This indicates that were no instabilities during the anaerobic digestion, which could have led to the accumulation of VFA. Values in this range suggest that the majority of the organic matter in the waste samples has been successfully digested and the process has been completed 21..

3. CONCLUSIONS

In this study BMP tests were performed on various agricultural waste samples in order to determine their suitability as substrates for industrial biogas plants. The results are generally, favorable and show positive prospects that these samples can be used commercially as substrates. The only exception is the solid compost, which is deemed inefficient. In future studies, different mixtures of the samples can be tested to evaluate their methane production. Additionally, the use of some protein rich substrates can cause ammonia toxicity 22. and therefore this probability should be investigated to avoid any instabilities in anaerobic digestion reactors.

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RETENTION OF BERRY FRUITS QUALITY BY FREEZE – DRYING: CHALLENGES AND RESULTS

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INVITED PLENARY LECTURE

Abstract: *Berry fruits are important crops in temperate regions such as R. Serbia and occupy an important position in the agriculture production. These attractive fruits are favored for their excellent taste and can be considered a very rich source of micronutrients and bioactive compounds with beneficial effect on health. However, berry fruits are highly perishable foods and have a rather limited shelf life, since they easily undergo degradation reactions by microorganisms, because of their high moisture content. The challenge is how to preserve this fruit in postharvest period and prolong availability during the year. Freeze-drying (lyophilization) is a modern process of drying that is increasingly used in industry of food processing. The process of water removing is done from the frozen samples by sublimation of ice under vacuum. The aim of this paper is to point out the benefits of freeze-drying in comparison to air-drying, through analysis of effect of two drying methods on the relevant parameters of quality of the strawberry, raspberry and blackberry fruits. The content of vitamin C, physicochemical properties, degree of rehydration, as well as evaluation of sensory characteristics of the fruits after freeze-drying and air-drying at 60°C were determined. The obtained results showed significantly better retention of vitamin C, physicochemical and sensory characteristics after freeze-drying of the berry fruits than air-drying. The degree of rehydration was also significantly higher in the freeze-dried samples. Generally, it may be concluded that freeze-drying represent a very suitable method for preserving these delicate berry fruits.*

Key words: *freeze-drying; air-drying; berry fruits; quality.*

1. INTRODUCTION

Berry fruits are important sources of essential dietary nutrients such as vitamins, minerals and antioxidant compounds with beneficial effect on health (Battino, et al., 2009, Novaković, et al., 2011). Since the moisture content of berries is more than 80%, they are classified as highly perishable commodities. In postharvest period these fruits may be stored fresh for a short period of time. For this reason, several industrial processes have been developed for their preservation. In addition, the challenge is to preserve the quality of delicate berry fruits, which is characterized by low mechanical resistance.

Drying is the most common method for berry fruit preservation, since water removal inhibits biochemical changes and microbiological activity and decreases the weight of the product, simplifying also its packaging, storage and transport. For these purposes, dried fruits should have moisture content lower than 25g/100g and water activity lower than 0.6 (de Bruijn, et al., 2016). Water activity (aw) is a measure of the quantity of water that is available for biological and chemical reactions, so it represents an indication of samples stability with respect to microbial growth (Oliveira, et al., 2016). Besides, it is a challenge and should be possible to recover the properties of the fresh fruit rehydrating the dried. Ability of rehydration depends on the degree of structural and cellular disruption; therefore, it is considered as a measure of the damage to the food structure caused by drying (Vega-Galvez, et al., 2015).

Although, different drying techniques have been proposed in literature the most popular and earliest dehydration method is air-drying, in which water is removed from samples by evaporation. But, some authors reported that this process can cause numerous adverse effects on fruits quality such as shrinkage, hardening, low rehydration ability and the modification of the sensory attributes (Maskan, 2001, Ratti, 2001). The challenge is how to dehydrate the delicate berry fruits and preserve it quality and safety, as well as initial properties.

Freeze-drying, also known as lyophilization, is a more recent method of drying and mainly is used to remove the water from sensitive products, mostly of biological origin. Freeze-drying is water removal at low temperature by sublimation of ice under vacuum where water passes from solid to gaseous state. The products to be dried are frozen under atmospheric pressure; then, in an initial drying phase called primary drying, the ice formed during the freezing is removed by sublimation under vacuum at low temperatures. In the second phase referred to as secondary drying, most of the remaining water is removed by desorption maintaining low pressures while the temperature of the sample is gradually increased. Due to very low process temperature all the deterioration reactions and microbiological activity are minimized and thus, provide better quality to the final product (Novaković, et al., 2011). However, the challenge is to preserve the quality of very delicate berry fruits during drying.

The aim of this work was to evaluate the effect of freeze-drying technology on the retention of quality related property of the strawberry, raspberry and blackberry, as well as to compare with the quality changes after air-drying of these fruits. The fresh strawberry, raspberry and blackberry fruits were used as control samples.

2. MATERIALS AND METHODS

The examinations have been realized on Strawberry (cv. ‘Senga sengana’), raspberry (cv. ‘Willamette’) and blackberry (cv. ‘Thornfree’) fruits from a commercial orchard harvested at processing maturity stage and collected manually.

Freeze-drying was performed in Freeze-dryer (Labconco, FreeZone 4,5, Kansas City), at temperature from -40ºC to -55ºC, at a pressure of 0,07 bar. The temperature during desorption did not exceed 30°C. Dehydration was performed to reach about 20% of water in the lyophilized samples.

Air-drying was performed in an experimental dryer (ACBP 10, EMA, R. Serbia), temperature of air was 60ºC. The strawberry, raspberry and blackberry fruits were arranged on 3 shelves in one layer and dried convectively in air flow. Dehydration was performed to reach about 20% of water in the samples, which makes the fruits stable in atmospheric conditions.

Total solids content of berry fruits was determined by drying at 105ºC until constant weight was reached. The difference in weight of the samples before and after drying was used to calculate the dry matter content (%).

Water activity (aw) was measured at temperature 25°C by Thermoconstanter NOVASINA CTD-33.

Soluble solids content were measured from the berry fruits juice by using a refractometer (RF-3, Br. 776, Germany) at temperature 20°C.

Total acid content was determined by method of neutralization with NaOH. The results were expressed as percentage of citric acid (g citric acid per 100 g of fresh weight).

Vitamin C was determined by iodometric titration method (Harris, 2000). The results were expressed as milligram of ascorbic acid/100 g of fresh weight of fruits.

Degree of rehydration was measured at room temperature. The dried fruits were measured first, then immersed in water of 20°C and after 120 min drained measured again.

Sensory analyses were carried out by scoring method. The samples were evaluated by trained panelists in terms of four sensory attributes: color, taste, flavor and firmness. The sensory panel consisted of 8 members of the Faculty of Agriculture, University of Belgrade staff who were experienced in sensory evaluation of fruit (4 men and 4 women). The intensity of each attribute was evaluated using a 5-point hedonic scale method, based on points (grades) from 0 (unacceptable product) to 5 (optimal quality level), where 4 was good, 3 was fair, 2 was poor, and 1 was very poor (Radovanović and Popov-Raljić, 2000-2001). The fresh strawberry, raspberry and blackberry fruits were used as control samples.

The results are expressed as the mean value ± standard deviations of triplicate determination (SD). Duncan's multiple range tests were conducted to compare the mean values at a 5% level of significance. All statistical analyses were performed using Statistica 7 (StatSoft, Inc., Tulsa, OK, USA).

3. RESULTS AND DISCUSSION

In the drying process, retention of physicochemical compounds is a very important issue. In Table 1 were presented total solids, water and soluble solids content in the berry fruits, and the results indicate that high water content was determined in the fresh samples, particularly in the strawberry. Water is an important compound of fruits, dissolve all the soluble solids and high water content makes them more difficult for handling and processing.

Despite the importance of water content in fruit, more attention is focused on the content of total solids (all constituents of the fruit excluding water). Significantly lower value of total solids content was determined in the fresh strawberry than in the raspberry and blackberry fruits (Table 1). That could be explained by the fact that raspberry and blackberry are aggregate fruit with a lot of small seeds, which may resulted in higher value of total solids in relation to strawberry. The berry fruits are dried until they reached about 80% of total solids content (Table 1). Similarly, Doymaz (2007) stopped the drying process when the moisture content reached 20% (w.b.).

Table 1. Total solids, water and soluble solids in fresh and dried berry fruits

Samples		Total solids %.	Water %.	Soluble solids (g/g dw*)
Strawberry	Fresh	9,23 ± 0,13	90,87 ± 0,12	0,661 ± 0,083
	Freeze-dried	78,86 ± 0,08	21,14 ± 0,07	0,635 ± 0,071
	Air-dried	79,21 ± 0,22	20,79 ± 0,21	0,574 ± 0,152
Raspberry	Fresh	14,82 ± 0,24	85,18 ± 0,23	0,434 ± 0,114
	Freeze-dried	80,17 ± 0,09	19,83 ± 0,09	0,427 ± 0,091
	Air-dried	81,28 ± 0,17	18,72 ± 0,18	0,374 ± 0,085
Blackberry	Fresh	15,37 ± 0,38	84,63 ± 0,37	0,524 ± 0,123
	Freeze-dried	80,83 ± 0,12	19,17 ± 0,11	0,531 ± 0,043
	Air-dried	80,60 ± 0,24	19,40 ± 0,25	0,502 ± 0,038

Values are the mean of three determinations ± standard deviation
dw* - dry weight

Soluble solids value is directly related to sugar content of fruits (Gonzales, et al., 2002). Sugars are basic and important components which form the taste and flavour of fruits (Battino and Mezzetti, 2006). Therefore, soluble solid values were measured in the fresh and dried strawberry, raspberry and blackberry fruits and results were presented in Table 1. The highest initial soluble solids content was determined in the fresh strawberry compared to raspberry and blackberry fruits. After drying, significant decrease of soluble solids was determined in air-dried berries. Besides, high retention of soluble solids in the freeze-dried samples was detected in all the analyzed berries.

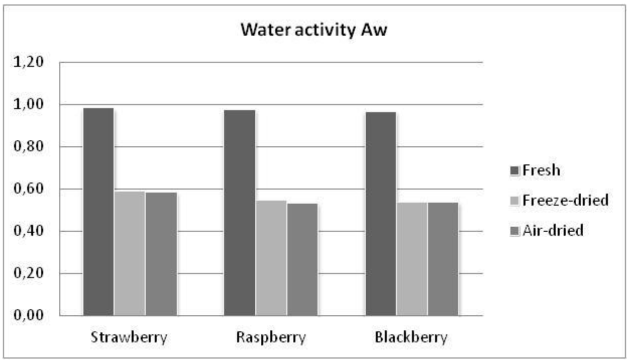

Fig 1. Water activity of fresh and dried berry fruits

The determined values of water activity Aw are presented in Fig. 1. Water activity is a property that has a significant impact on the stability and safety of dried fruit. A high water activity can lead to a shorter storage time of products, which is due to the possibility of adverse changes and microbial activity. The determined values for Aw in the analyzed fresh fruits were 0,971, 0,978 and 0,986 for the blackberry, raspberry and strawberry, respectively. According to the presented results in Table 1 and Fig. 1 it can be concluded that the berry fruits with high water content also possess a high Aw value. For the freeze-dried and air-dried berry fruits Aw values are in the interval from 0.537 to 0.593. The obtained results showed that Aw was lower than 0,6 in the dried strawberry, raspberry and blackberry fruits regardless of the drying method used. This indicates that it has been achieved stability by dehydration of samples, due to that water activity of about 0,6 is often referred to as the limit for stability.

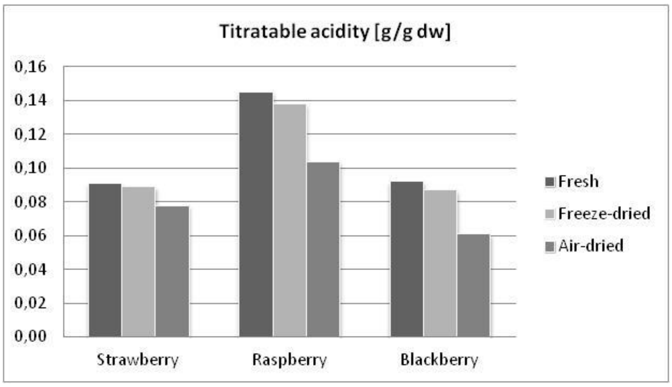

Fig. 2 Total acids content in fresh and dried berry fruits

The results in Fig. 2 show the values of total acids content of the strawberry, raspberry and blackberry fruits, expressed as titratable acidity (TA). The significantly higher value of TA was determined in the fresh raspberry compared to strawberry and blackberry fruits. Chemical compositions of berries contribute to their quality and TA content is important for fruity and fresh taste and flavor of fruits. Therefore, it is important to preserve them during processing. After both drying treatments decrease of

TA was occurred, but significant decrease was detected after air-drying of all the analyzed fruits.

In view of importance of berry fruits as a source of vitamin C in the human diet, the ascorbic acid content was analyzed. Berry fruits are known to be valuable sources of vitamin C, especially the strawberry (Milivojević, et al., 2011). Stability of vitamin C during the different drying treatments was evaluated and the results were presented in Fig. 3. Vitamin C is one of the most important parameters to be studied related to the nutritional and health-promoting quality of the fruits; a challenge is to preserved it during processing. The results indicated that the fresh strawberries had significantly higher initial content of vitamin C than the raspberry and blackberry fruits. Both applied drying processes affected the content of vitamin C, but significant decrease was detected after air-drying of the strawberry, raspberry and blackberry fruits. Changes in the content of vitamin C could be a good indicator for degradation reactions taking place during processing or storage of food (Skrede, 1996).

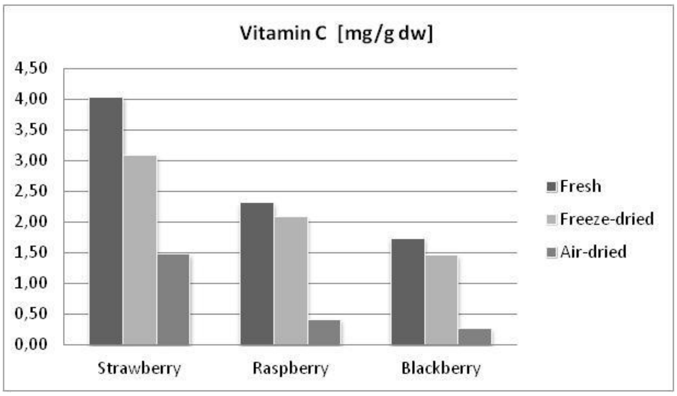

Fig. 3 Vitamin C content in fresh and dried berry fruits

And finally, the results indicate that freeze-drying highly preserved vitamin C in all the analyzed berry fruits. The applied low temperatures during freeze-drying contributed to the stabilization of vitamin C and influenced it retention in the final products. The obtained results confirm that freeze-drying has become one of the most important processes for the preservation of biological materials sensitive to heat (George and Datta, 2002; Liu, et al., 2008).

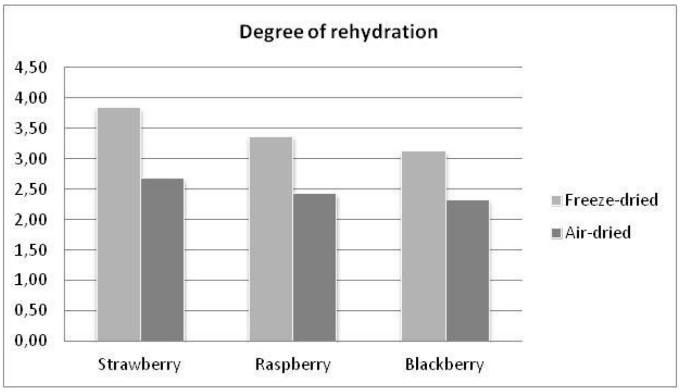

Fig. 4 Degree of rehydration of berry fruits

Also, a challenge is rehydration and should be possible to recover the properties of the fresh fruit rehydrating the dried. The obtained results (Fig. 4) show that degree of rehydration of freeze-dried strawberry, raspberry and blackberry was significantly higher than after air-drying. That was confirmed in all the analyzed berry fruits. Similarly, Ratti (2001) reported that air-drying caused considerable changes in the physical structure of products, such as reduction in volume, wrinkles, and decrease in porosity which is usually accompanied by low rehydration ability, as we detected (Fig. 4). Rehydration ability depends on the degree of cellular and structural disruption; therefore, it is considered as a measure of the damage caused by drying to the food structure (Vega-Galvez, et al., 2015). The presented results indicate to retention of the berry fruits structure after freeze-drying, as well as ability of rehydration. That may be explained by the porous structure of the freeze-dried fruits and better texture retention of the strawberry raspberries and blackberries during freeze-drying compared to air-drying. Also, Maskan (2001) reported long processing time and change in food structure and property as a reason for low rehydration capacity after air-drying.

Table 2. Sensory attributes

Attributes / Scores		Color 5	Taste 5	Flavor 5	Firmnes 5	Total scores
Strawberry	Fresh	5	5	5	5	20
	Freeze-dried	4,95	4,14	4,36	4,26	17,77
	Air-dried	3,57	3,29	3,57	3,36	13,79
Raspberry	Fresh	5	5	5	5	20
	Freeze-dried	4,86	4,14	4,43	4,16	17,59
	Air-dried	3,43	3,14	3,79	3,47	13,83
Blackberry	Fresh	5	5	5	5	20
	Freeze-dried	4,92	4,07	4,28	4, 21	17,48
	Air-dried	3,86	3,36	3,43	3,25	13,90

Sensory evaluation was conducted in order to determine which drying method was less affected and induced less changes in the sensory attributes of strawberry, raspberry and blackberry fruits. Therefore, color, taste, flavor and firmness were assessed by scoring method, whereas the fresh fruits were used as the control samples. The results of sensory evaluation were presented in Table 2, as well as calculated total scores for the fresh and dried strawberry, raspberry and blackberry fruits. The obtained results indicated that the color changes of the samples were significantly higher after the air-drying then freeze-drying treatment. Also, retention of the initial taste and flavor of the strawberry, raspberry and blackberry fruits were assessed significantly better in the freeze-dried samples. Moreover, the quality rating of all evaluated sensory attributes was significantly reduced after the air-drying in all the analyzed berry fruits; some important properties of the samples have changed such as loss of color, change of texture and shrinkage, chemical changes affecting taste and flavor. Similarly, Ratti (2001) reported that air-drying caused considerable modification of the sensory attributes.

The freeze-drying treatment has provided retention of berry fruits morphology in addition to removing a large amount of water. Besides, the calculated total scores, which indicate the acceptability of fruits with respect to their sensory characteristics, are significantly higher in freeze-dried strawberry, raspberry and blackberry than in air-dried fruits.

4. CONCLUSION

Despite the fact that the challenge is to processed and preserved very delicate strawberry, raspberry and blackberry fruits and to prolong their availability during a year, and the obtained results indicated that the retention of all the analyzed quality properties was significant after freeze-drying treatment. On the other hand, some important properties of the berry fruits have been changed after air-drying, such as loss of characteristic color, change of texture and shrinkage, chemical changes affecting nutrients, consequently taste and flavor. Finally, it can be concluded that the freeze-drying highly preserved quality of the strawberry, raspberry and blackberry fruits.

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DRYING TECHNOLOGIES IN FOOD ENGINEERING

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INVITED PLENARY LECTURE

Abstract: *Drying is one of the primary methods of food preservation in the agro-industry and is a complex and energy-intensive process. In recent years, research in the fields of natural and technical sciences has focused on optimising the energy requirements of industrial systems to sustainably develop and modernise various technologies. Many researchers deal with drying in the agro-industry, as evidenced by an enviable number of publications on this topic. In recent years, a large number of conferences and round tables on the implementation of energy-efficient technologies have been held in the Republic of Serbia. Conclusions have been adopted that the Republic of Serbia, except for the Law on Energy, has no accompanying regulations that would regulate designing and constructing of centres for drying, storage and processing of agricultural products. Drying is one of the basic technological operations in the food processing industry. Attention was drawn to the extremely high energy consumption of drying plants. Some of the proposed solutions are rationalising energy consumption at existing plants and adopting new, more economical plants based on new technologies. This paper reviews the available literature and research of a large number of international authors dealing with advanced drying technologies, improving the energy efficiency of drying systems and environmental aspects of drying to ensure sustainable development, with a tendency to provide a comprehensive insight into the complexity of the drying process, trends in the development of equipment and technologies, as well as ways to properly select the appropriate technologies depending on the specific feedstock being dried.*

Key words: *Drying, dryer classification, modern technologies, energy efficiency, ecology.*

1. INTRODUCTION

In the recent history of mankind, especially in the last hundred years, the changes in the biosphere have not been unnoticed and negligible, but, on the contrary, alarming. The constant development of science and technology, coupled with the dynamic way of life in modern society, has brought natural resources to critical limits, disturbing their global ecological balance. The demands of modern society have been and they continue to be supported by the existing stocks of fossil fuels on earth. However, those stocks are limited, and their complete depletion is inevitable. Research in the fields of natural and technical sciences in recent years has focused on solving this problem. Solutions are being sought to restore harmony and ecological balance in modern society without drastic effects on the quality of life and significant sociological changes.

Drying, as one of the most important methods of food preservation in the agro-industry, significantly affects the environment in ecological terms. A partial or complete separation of water from biological materials is a complex process that consumes a large amount of energy. Influential factors such as the time interval of the drying process, product quality, thermal sensitivity of the biological material to be dried and the like determine the drying regimes that are often a compromise between these factors. The adoption and widespread use of eco-friendly drying technologies are slow due to several factors, and short-term cost-effectiveness and current profitability are often the main reasons. Research in the field of drying must focus on solving these problems and demonstrate the possibilities of applying alternative technologies to educate manufacturers and users of drying systems.

This paper reviews the literature and research to promote modern drying technologies that are often obtained by a combination of existing technologies. The use of new technologies promises economic and environmental benefits, and a large number of researches deal with their application in drying systems. However, their mass use in the Republic of Serbia on farms and in the industry has not yet occurred despite efforts and promotion.

Accordingly, this lecture is designed to cover, combine and analyse all relevant categories important to describe the technology of drying food products, namely: basic principles and theory of drying, variety of equipment and drying systems, selection of appropriate drying technologies, the way of proper selection of drying systems, combined drying technologies, dried product quality, the energy efficiency of the drying process and ecological aspects of drying.

2. BASICS OF DRYING AND DRYING EQUIPMENT

Many authors have written about the theory and basic principles of drying in various books 1-7.. In addition to learning about physico-chemical concepts related to food dehydration and psychrometry, various commercial drying systems can be classified into four generations 7.:

1) dryers for drying solid feedstocks,
2) pulp and slurry dryers,
3) sublimation dryers and systems for osmotic dehydration,
4) dryers that apply specific drying techniques.

In addition to thorough theoretical analyses and discussions on the methods of classification, selection and design of dryers 6., the wider professional literature also discusses various aspects of experimental work related to drying. Thus, for example, it is pointed out that the general objectives of drying experiments 8. are: selecting appropriate drying equipment, establishing set requirements, testing the efficiency and capacity of the existing drying equipment, testing drying effects on the final product, and analysis of drying mechanism. Various experimental techniques have been carried out to determine the appropriate drying parameters, such as determining the optimal moisture content, establishing characteristic equilibrium states in the sorption and desorption processes, determining thermal conductivity, effective diffusivity, etc. In the food processing industry, research focuses on important factors such as food drying goals, determining residual moisture content for prolonged storage, monitoring certain food properties, optimising appropriate drying techniques, researching varieties suitable for dryers and researching to minimise negative changes of dried product quality 6..

The drying equipment and systems used in the agro-industry vary depending on feedstock. Different types of drying equipment are used for drying agricultural products 6., starting from complex grain drying systems, all the way to different principles of operations of fruit and vegetable dryers. Researching and collecting the necessary information for selecting and designing of drying systems are a complex and important work 9.. This is confirmed by data collected by reviewing commercial drying practices in parts of Europe, Africa and Asia, and analysing different types of dryers, factors influencing selection, drying different types of fruits and vegetables, preparation processes, quality control and dehydration economics 10..

3. CLASSIFICATION OF DRYERS

In modern industrial production, it can be stated with certainty that there is no product whose basic feedstock at some stage has not gone through some drying processes. The costs of energy transport in larger systems are not negligible and directly depend on the moisture content in the material to be dried, so it is desirable to implement different ways of saving energy 11.. In a mass-production system, even minimal savings at the local level can accumulate significant resources in the long run. The choice of adequate drying technology in certain branches of industry, such as the agro-industry, is very delicate and sensitive, especially in terms of preserving product quality. Going beyond the precisely prescribed time-temperature coordinates in the drying process can cause degradation of the quality of the dried product, which can be somewhat eliminated in recirculation types of dryers. Also, the food industry requires the application of continuous drying technologies.

A large number of studies are conducted to determine exactly what and how to dry 6.. Table 1 presents the possibility of using certain types of dryers depending on the mechanical characteristics and shape of the feedstock to be dried. In contrast, Table 2 shows and classifies the possibilities of using certain types of dryers depending on the total retention time of the feedstock in the drying process. The ways of classifying the types of dryers that can be found in the literature vary from author to author.

Table 1. Dryer selection versus feedstock form 6.

Nature of feed	Liquids			Cakes		Free-flowing solids					Solids
	Solutions	Slurries	Pastes	Centrifuge	Filter	Powder	Granules	Fragile crystals	Pellet	Fibers	
Convection dryers											
belt conveyer dryer							●	●	●	●	●
flash dryer				●	●	●	●			●	
fluid bed dryer	●	●		●	●	●	●		●		
rotary dryer				●	●	●	●		●	●	
spray dryer	●	●	●								
tray dryer (batch)				●	●	●	●	●	●	●	●
tray dryer (continous)				●	●	●	●	●	●	●	
Conductive dryers											
drum dryer	●	●	●								
steam jacket rotary dryer				●	●	●	●		●	●	
steam tube rotary dryer				●	●	●	●		●	●	
tray dryer (batch)				●	●	●	●	●	●	●	●
tray dryer (continous)				●	●	●	●	●	●	●	

However, three common principles can be noticed – the principles on which these classifications are based 2, 12., and they are:

1) the method of supplying heat to the material to be dried,

2) drying mode in terms of selected drying temperature (high or low) and drying pressure parameters (vacuum or atmospheric), and

3) how the material is treated in the dryer.

In accordance with these principles, it is possible to deepen the analysis, however, the further introduction of subclassifications has no practical significance, so it is sufficient to remain at the level of analysis of the above three principles.

Heat supply to the material to be dried is possible by any heat transfer mechanisms: convection, conduction or radiation. Convection is one of the most common ways, using atmospheric air (most often), inert gas (nitrogen, etc.), direct combustion products or superheated steam as a medium for transporting steam 6.. This drying method is also called direct drying. Conductive indirect drying is suitable for drying of very wet or very thin materials and is often performed using vacuum drying regimes. Indirect drying and direct drying are often applied at the same time. Radiation drying is achieved by emitting electromagnetic waves at different wavelengths, from the visible part of the spectrum to microwaves. This drying method is extremely expensive and is rarely used as the only one, but it is usually combined with convective drying methods.

According to 12., when heating the material during drying, four heating modes prevail: convective (Fig. 1a), conductive (Fig. 1b), radiation (Fig. 1c) and dielectric (Fig. 1d).

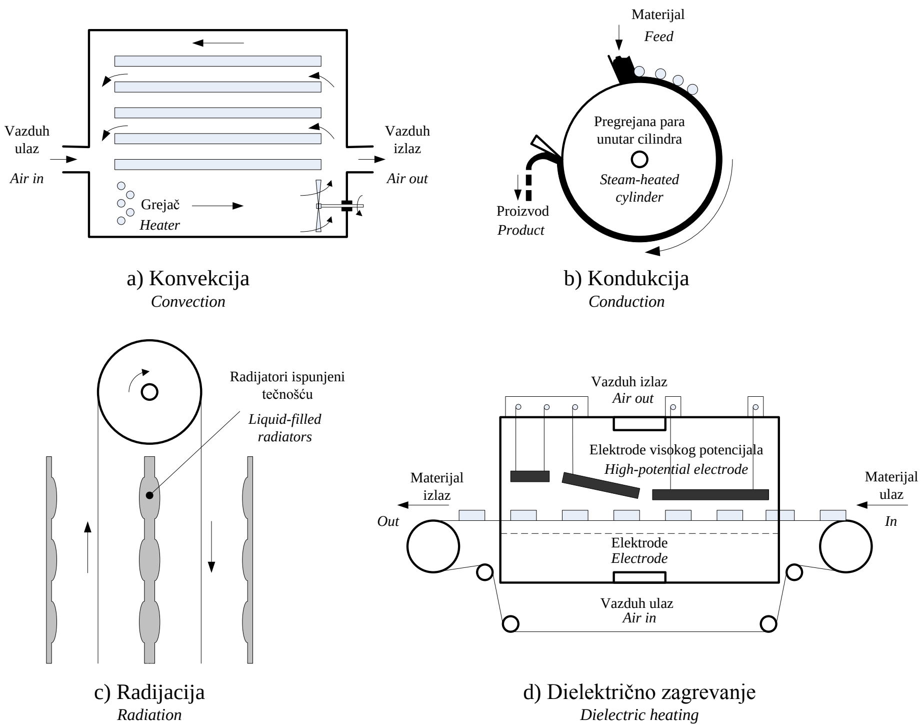

Figure 1. Heating methods in drying 12.

Most dryers work at pressures close to atmospheric, which greatly simplifies the construction of the dryer and the performance of the equipment used. However, in special cases when, for example, the material must be dried without oxygen or at low temperatures, the so-called vacuum drying (at low temperatures – sublimation drying) is used.

The way the material will be treated inside the dryer itself significantly affects the drying costs. Table 2 compares the usual material treatment method, the type of dryer and the type of material encountered in practice today.

Table 2. Capacity and energy consumption for selected dryers 6.

Method	Typical dryer	Typical materials
Material not conveyed	Tray dryer	Pastes and granules
Material falls by gravity	Rotary dryer	Granules
Material conveyed mechanically	Screw-conveyor, paddle	Wet sludges and pastes
Transported on trucks	Tunnel dryer	Wide range of materials
Sheet-form or roll materials	Cylinder dryers	Paper, textiles, pulp
Conveyed on bands	Band conveyor dryer	Pellets, grains
Material suspended in air	Fluid bed	Granules
Slurries and solutions atomised in air	Spray dryer	Milk, coffee, etc.

4. DRYER SELECTION

For the correct selection of the dryer, it is necessary to determine a few basic facts – pieces of information, which represent the necessary inputs for a correct selection process.

Some of the most important are:

- drying mode, i.e. whether the drying is tray or continuous;
- physical, chemical and biochemical properties of the wet material, as well as the desired properties of the dried material;
- the necessary pre-preparation of the drying material and the necessary procedures to be taken after the completion of the drying process;
- the moisture content of wet and dried material;
- drying kinetics;
- quality parameters;
- consideration of safety aspects of the drying process (fire resistance, explosiveness and toxicity of the process);
- product value;
- level of automatic regulation of the drying process;
- toxicological properties of the product;
- capacity;
- types and prices of fuel, energy resources or electricity;
- environmental impact;
- space for the accommodation of the plant.

In recent years, a large number of studies have emerged **13-16**. focusing on one or more aspects of drying. Modern drying technologies are compared with conventional methods **17**. to find alternative solutions for individual drying problems of certain specific materials 18-20.. More detailed information about the process of designing dryers is usually an industrial secret. Some researches **21, 22**. are directed towards unification and standardisation of the methodology of production of industrial dryers.

5. OVERVIEW OF DIFFERENT TYPES OF DRYERS

Indirect dryers (contact or conductive) are those dryers in which the heating medium is not in direct contact with the material to be dried, but indirectly, via a heated surface **23**.. The drying temperature for these types of dryers ranges from -40^{o}C (for sublimation drying) to 300^{o}C (for dryers that are heated directly by combustion products). There are four basic types of indirect dryers **24-26**.: tray dryer with shelves (bars/rungs), indirect-contact rotary dryer, tray rotary vacuum dryer and mixer dryer.

Rotary dryers have a rotating roller with an axis set at a small angle to the horizontal, by which the material is transported, mixed at the same time, and at the same time dried with a suitable agent, directly or indirectly 6, 27.. Fluidised bed dryers are mainly used for drying wet powders and granules, which can be fluidised. For this type of dryer, it is very important to know the hydrodynamic properties of the fluidised bed **28**., to know the minimum flow rates, and timely analysis of the main advantages and disadvantages of using this type of dryer on a specific material **29**..

Roller dryers are used for drying liquid organic and inorganic substances. On the inside of the roller, steam, hot water or oil flows, and on the outside, a thin layer of liquid or paste material is dried. These dryers are often used in the drying of slurries: rice 30., flour 31., etc., or pharmaceutical products **32**..

Material spray dryers have a chamber into which liquid material that is dried in an atomised state is inserted. Spraying is the most important operation in a spray dryer **33**., and the size of the spray drop and the distribution of agents and materials in the dryer need to be optimised **34**..

According to **35**., the sublimation dryer (vacuum) is cost-effective for use only when drying specific materials of organic origin such as blood plasma, hormonal solutions, superconducting materials, surgical material for transplantation, cells infected with bacteria and viruses. There is a justification and advantage of using this drying method in the food industry **36**., regardless of the fact that this technology is dominant in the pharmaceutical industry **37, 38**.. Microwave and dielectric drying first appeared at the beginning of the twentieth century. The use of electromagnetic waves of a certain frequency and wavelength is an efficient way to heat materials in industrial production **39**., and with proper selection and sizing of equipment **40**., the advantages of application in the food industry **41, 42**. are emphasised.

Solar drying is one of the oldest types of drying and technologies for using this type of renewable energy are constantly being improved. A large number of researches on the justification of investing in such installations have been conducted **43, 44**., while many authors deal with drying various materials, primarily food products, such as drying cereals, coffee, grapes, peanuts and fruits and vegetables **45.**, drying of grapes, walnuts, tobacco **46**., etc.

Fluidised bed drying has been used successfully since the 1950s. The geometric, physical and hydrodynamic characteristics of these dryers were addressed by **47, 48**.. Some authors point out the advantages of this type of drying of specific materials such as salt dehydration **49**., drying of pigments **50**. and the like.

Concentrated jet spray drying is used primarily during the continuous drying of the material, which is most often in the form of a roll (production of paper, photographic films, textiles, carpets, etc.). A large number of authors are engaged in research of heat and mass transfer in this type of drying: studying the shape of the jet **51, 52**., determining the value of Nusselt number **53**., determining the optimal angle at which the jet reaches the material to be dried **54**.. Pneumatic drying is the most commonly used type of continuous convective drying. Simultaneous pneumatic transport of particles and their drying is a complex process. Numerous authors deal with numerical simulations of these processes, namely: determining the optimal size of transported particles **55, 56**., software shaping and modelling 5., as well as experimental and numerical analyses of heat transfer processes and drying kinetics 57.. Conveyor drying is a type of drying that can be used with a large number of materials. The material is transported on a conveyor belt and at the same time blown with hot air **6**.. Infrared drying is the most commonly used type of drying in the industry and at the same time the type of drying that requires the largest amount of energy. According to research **58**., Russia is a country where there are most such dryers, followed by the United States and Eastern European countries. Theoretical research and experimental work on the use of these dryers were conducted in the paper, cardboard, textile and paint industries **59, 60**., while the research **61**. pointed out the advantages and disadvantages of the use for food drying in the food industry.

Superheated steam drying is one of the oldest drying concepts and it appeared in the nineteenth century at the time of the steam engine and the industrial revolution **19**.. Special advanced drying technologies are developed due to the requirements for high product quality, increased productivity, easier control, energy efficiency of drying plants, reduction of a negative impact on the natural environment. The main trends in the introduction of advanced technologies are **62**.:

- the use of superheated steam in direct drying,
- the use of indirect conductive heating,
- the application of combined heat transfer methods,
- the application of volumetric heating using microwaves and radio waves,
- the use of two-stage dryers,
- the use of special combustion technologies,
- the design of flexible multiprocess dryers.

6. COMBINED DRYING TECHNOLOGIES

At the end of the twentieth century, various drying methods were designed to obtain top quality products, in which energy consumption was reduced to a minimum due to various improvements in the process of mass and energy transfer.

In combined drying processes where two phases dominate 63.: 1. the phase of freezing, 2. the phase of contact (conductive) drying in vacuum, a very good looking product is obtained and its rehydration capacity is comparable to the capacities of sublimation of dried material. Also, with the technology that combines simultaneous osmotic and convective drying of grapes, which is achieved in a fluidised bed of sugar and semolina, with pre-treatment immersion in ethyl oleate, the duration of the drying process has been halved **64, 65**.. The use of microwaves for heating materials in drying systems has become popular in recent years. The possibility of selective microwave heating in combination with pneumatic transport of the material to be dried, using forced air flow, is used for different types of products, for example: drying thin-layered carrots **66**. or drying sliced potatoes **67**.. The quality of microwave-dried products improves when combined with osmotic drying **68**.. Also, some research shows that the combination of microwave drying and vacuum drying gives good results when drying fruit **69**., cranberries **70, 71**. and peas **72**..

7. QUALITY OF DRIED PRODUCT

According to some research, despite the fact that they are considered lower quality products among processed foods, dried food products are gaining popularity **65**.. This is confirmed by the constant growth of the dried food market. Analysing the mutual influence of drying on the quality of the final product **7**3., the concept of quality is quite complex in the food industry sector. By optimising the process of drying food products **74**., it is noticed that the concept of the quality of the dried products is often different for the consumer and for the industry.

The quality of the final product is often associated with those characteristics that are acceptable to consumers. Thus, for example, rehydration is the most researched quality parameter, in addition to colour and shrinkage **75**.. Numerous authors **75-80**. consider the kinetics of drying of individual foods determine various factors that affect the change in the quality and control the parameters to achieve the desired quality of the final product, for example: a colour change parameter as one of the important quality factors **75**., shrinkage (contractions) of products during drying **81-83**. or changes in the texture and physical structure of the dried material and determines their influence on reconstruction and rehydration, as well as on organoleptic characteristics such as mouthfeel **84**.. In research 85. that deals with drying fruits and vegetables, fruits and vegetables are subjected to various sub-treatments (immersion in alkaline solutions, bleaching, etc.) to improve and maintain their characteristics during drying. Sulfur dioxide treatment is used to preserve the colour of the dried product. Sulfur dioxide and sulfites act as inhibitors of enzyme activity and prevent discolouration. The relationship between drying parameters and product quality change can be described by special methods **86, 87**..

Properties that significantly affect quality can be classified into several groups **86**.:

1) Structural properties (*density, porosity, pore size, specific volume, ...*)
2) Optical properties (*colour, appearance, ...*)
3) Mechanical properties (*resistance to pressure and tension, ...*)

4) Thermal properties (*glassy, crystalline or rubber state of the product, ...*)
5) Sensory properties (*smell, taste, aroma, ...*)
6) Nutritional properties (*vitamins, proteins, ...*)
7) Rehydration properties (*degree of rehydration, rehydration capacity, ...*)

Quality characteristics are influenced by many factors that occur during drying, but all of them are ultimately related to the drying temperature and the dynamics of moisture removal from the material. The unique conclusion derived from the publications of the aforementioned authors is that the heat input and the exposure time of the product to elevated temperature and hot air during drying affect the nutritional quality of food products. It shows large chemical changes that occur during drying, such as browning, lipid oxidation and loss of original natural colours. In addition, the drying process affects rehydration, solubility, texture appearance and loss of aroma. Elevated drying temperatures and periods of exposure of the material affect its nutritional value, vitamin and protein contents, as well as the microbiological structure of the material. It has been shown that there is a noticeable loss of vitamin C and vitamin A during drying. Also, the loss of natural pigments such as carotenoids, chlorophyll and xanthophyll is associated with the discolouration of dried fruits and vegetables. Although the change in colour is sometimes associated with unwanted chemical changes that occur in the material, the real problem is in (non)acceptance by consumers. Preservation of these pigments during dehydration is very important mainly to make the product attractive and acceptable to consumers.

8. THE EFFICIENCY OF THE DRYING PROCESS

Exergy is work that is available in gaseous, liquid and solid materials as a result of its unbalanced state in relation to a reference state. The farther the system is from equilibrium, the more work can be obtained from it. The concept of exergy derives from the Second Law of Thermodynamics, and its meaning has been discussed by various authors **88-101**.. A common approach in exergetic analysis found in the literature is to identify all elements that contribute to the increase of available work in the analysed system. In contrast, exergy losses in the system are generated through the irreversibility of appropriate processes caused by imperfect performances in real conditions **97**.. By exergetic analysis, we can compare real performances in relation to those in which there is no or little necessary process driving force, i.e. that exergetic loss is higher when the process driving force is also higher **102-104**.. Theoretically, the only unavoidable loss in a heat pump dryer is that which occurs due to humidification of the air in the dryer chamber **105**.. This is in stark contrast to conventional dryers, where the heating of the process itself represents a loss. Exergetic analysis of heat pump drying can be performed at the level of physical and chemical processes in the system **106**.. In such analyses, the term “exergetic mixing change” is often used for the adiabatic process of air saturation in the drying chamber. Exergetic analysis of the drying process is desirable when considering drying at higher temperatures **107**..

9. ECOLOGICAL ASPECTS OF DRYING

In industrialised countries, where environmental awareness is at a higher level, special protocols regulate the production and application of appropriate drying technology, taking into account various influencing factors in the early stages of designing a drying installation. Thus, for example, the United States Environmental Protection Agency requires that special attention be given to when designing a drying system:

1) characteristics of the material to be dried,
2) the control of dust and particle production during drying,
3) the storage of dried products,
4) the control of humidity and temperature in the material to prevent bacteriological malfunctions,
5) the position of the drying system in relation to the sewage systems,
6) capacities of the system and infrastructure to which it is connected,
7) the collection and storage of waste material,
8) the energy efficiency of the plant,
9) safety risks and safety at work.

However, very few scientists and researchers, who carry out research in the field of drying, try to see the concept of drying in a global context of the mutual intensive interaction of this process and the environment. The application of environmentally friendly technologies in energy engineering, especially in the field of drying, can reduce irreversibility and increase entropy. There are few authors who look at the energy, exergetic and environmental aspects of the drying process from a global industrial perspective **98**.. The use of biogas, natural gas, waste gas in turbines and heat of solid combustion products in direct drying, as well as superheated steam and hot water waste in indirect drying, are increasingly the subject of research **108**.. Also, in recent times, the production and use of various biomass pellets and their use in drying systems as an energy source have been considered **109**..

10. CONCLUSION

Conducted research in the field of food drying, thorough theoretical analysis and discussion of ways to classify, select and design dryers indicate that drying and selection of drying equipment are a serious process that requires an even more serious approach. The selection of the dryer is influenced by numerous parameters. The justification of neglecting certain parameters may exist, but it is most often conditioned by external influences such as market and consumer requirements, availability of energy sources, accommodation capacities of drying equipment and the like. Most dryers can be used for drying a variety of materials, regardless of certain specifics, of course, within the limits of their design characteristics, so choosing the right dryer for a particular material is a very complex and delicate job. Most publications related to drying have one common conclusion – drying is one of the most energy-intensive operations in the process industry. In the absence of a universal framework for determining drying efficiency, exergetic analysis seems to be a suitable technique. However, exergetic analysis only indicates the potential or possibilities of improving the work process, but it cannot indicate whether it is possible to achieve improvement or how economically rational it would be. Consumers make the final judgment on the quality of the final product in the form of demand, which encourages competition among producers, who are thus forced to take care of more economical business and production on the one hand, and to ensure quality, on the other hand, with appropriate feedstock quality and adequate processing equipment.

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POST-HARVEST DRYING KINETICS OF OKRA (*ABELMOSCHUS ESCULENTUS*) UNDER GREENHOUSE DRYING AND HEAT PUMP DRYING

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Abstract: *Drying is carried out to prolong the shelf life of food products to reduce post-harvest losses by reducing the moisture content present in it. Thin layer drying kinetics of okra (Abelmoschus esculentus) has been compared with open sun drying, heat pump drying and greenhouse drying with different glazing material such as UV Polyethylene sheet and drip lock sheet under passive and active modes. The experimental results showed that the reduction in moisture content of okra from 87.65 % to 10% was achieved in 16 hours under open sun drying (OSD), 14 hours using UV polyethylene sheet greenhouse dryer under passive mode (UVPM), 13 hours under drip lock sheet greenhouse dryer under passive mode (DLPM) and in UV polyethylene sheet greenhouse dryer under active mode (UVAM), 12 hours to achieve the moisture content of 9.3 % using drip lock sheet greenhouse dryer under active mode (DLAM) and 8 hours in heat pump drying (HPD). The highest dryer efficiency of 38.78% was achieved under HPD and 14.15% was achieved under DLAM greenhouse drying. Higher effective moisture diffusivity value of 2.09 x 10^{-10} m^2 /s was achieved in HPD compared to other modes and lower effective moisture diffusivity of 1.04 x 10^{-10} m^2 /s was achieved under open sun drying mode in drying okra. Heat Pump dryer had a higher Specific Moisture Extraction Rate (SMER) value of 2.60 kg/ kWh compared to other methods of drying. It was found that the products dried with minimum drying time in HPD compared to greenhouse drying but still in the economic point of view greenhouse drying has low cost.*

Keywords: *Active mode, Drying kinetics, Effective moisture diffusivity, Greenhouse dring, Heat pump drying, Passive mode*

1.INTRODUCTION

In order to utilize the medicinal and nutritional benefits of the food products throughout the year, processing is done. Food processing helps to increase the shelf life of the food product. The important parameters that influence the food loss are moisture content, pH value, physical structure of the product, temperature and relative humidity. Some of the food preservation methods are thermal processing, cold processing, radiation, drying, chemical processing and curing. The major methods followed in food processing industries are drying and cold storage. Drying is the main method followed due to abundant solar energy.Drying is the process of removing the moisture present in the product. The drying process is carried out by heating the air to reduce the relative humidity of air. Once the relative humidity of air is reduced, the air is now capable of absorbing the moisture in the product to be dried 1.. The main objective of drying is to increase the shelf life of the product. In olden days sun drying was carried out to dry the products. The sun drying was the cheapest and easily available source of energy but still it has some limitations like contamination of dried products and dust in the dried products. In traditional open sun drying the product to be dried was laid down in direct sun light for drying and the method followed is dependent on sunlight. The time consumption under open sun drying was also more. To overcome the demerits nowadays drying is carried out in a closed unit to protect the products from contamination and birds. This has paved the way for solar drying to dry the product safely and to maintain the quality of dried product.

An analytical study was conducted under open sun drying mode for drying apple, peaches and cherry during summer and winter season to predict the hourly variation of product temperature 2.. It was found that even though the temperature was high at 1 PM, but still the surface temperature of product was found maximum at 3 PM due to the heat storage capacity of the product. The duration of time taken to dry the products during summer was 34 hours and 24 hours in winter due to the high moisture content in air during winter. A low cost natural convection solar dryer was developed for drying plantain to overcome the difficulties like lack of electrical energy and inadequate refrigeration systems for preservation 3.. The cabinet was made up of mild steel and covered with glass. Both the cabinet and collector were coated with black paint to absorb heat energy for drying. The plantain cut in to pieces of 3 mm thickness and put it in the tray for drying inside the cabinet. The final moisture content of 15.75 % was achieved in 20 hours with drying rate of 0.184 kg/hr. The collector efficiency of the low cost developed dryer was 46.4 % and system efficiency was 78.73 %. This low cost natural convection dryer will be suitable for poor farmers with low initial cost. In greenhouse dryer the solar collector is replaced by a glazing material to absorb the heat from the sun and utilize the absorbed heat energy for drying. The glazing material was fixed along steel frames to prevent dust and other contaminations entering the dryer. A greenhouse dryer working on with a fan or blower for providing air movement inside the dryer is active mode greenhouse dryer and the other operating without a fan or blower is passive mode greenhouse dryer. In passive mode greenhouse dryer air movement is achieved due to the density difference of air inside the dryer. Two types of greenhouse dryers under passive and active mode were developed to analyze the performance under no load conditions4.. The experimental results showed that passive mode greenhouse dryer experiences a high relative humidity of 62.6% and active mode greenhouse dryer experiences 42.8% inside the dryer. This clearly indicates the lower drying rate under passive mode. The relative humidity inside the active mode greenhouse is controlled by the exhaust fan. There was a 2% increase in efficiency in active mode dryer than in passive mode dryer. The drying rate increased by 31% in active mode greenhouse due to lower relative humidity inside the dryer. A forced convection greenhouse dryer was developed for drying bitter gourd under three different air mass flow rates 5.. The experimental results showed that optimum drying efficiency was achieved in 0.0551 kg/s mass flow rate and the safe moisture content for preservation was achieved in 17h. The moisture content of bitter gourd was reduced from 96.8% to 12.2% by using polycarbonate sheet as glazing material under forced convection mode. The experimental results showed that the highest efficiency of 19.7% was achieved in 0.0551 kg/s mass flow rate. The payback period of developed greenhouse dryer was found to be 1.5 yrs. A study had been conducted to determine the potential factors favoring the usage of heat pump dryer in food drying 6.. The dryer efficiency up to 95% can be achieved in a heat pump dryer. The drying rate was increased and drying time considerably reduced in a HPD. The HPD was found to be eco-friendly. The maximum SMER value up to 4 kg/kW h can be achieved in a HPD.

The main objective of the present work are; (i) to study the drying characteristics of Okra in Open sun drying, Greenhouse drying and Heat pump drying and (ii) Comparison of drying characteristics between Open sun, Greenhouse drying and Heat pump drying.

2. MATERIALS AND METHODS

Experimental Setup

The drying of okra was carried out in open sun drying, greenhouse drying and in heat pump dryer till the safe moisture content of the product is achieved to increase the shelf life. Blanching was done at 50^{0}C to 60^{0}C for okra to enhance drying operation and to prevent enzyme activities after drying. Okra of uniform size of 2.5 mm thickness is cut in to pieces and used for drying. Experiments were conducted in the month of March from 9am to 4pm and the dried products were kept in air tight plastic sheets to prevent absorption of moisture from atmosphere during night time. Drying is carried out till the safe moisture content for preservation is achieved.

- *2.1.1 Open Sun Drying*

The product to be dried were kept in a steel mesh wire tray and the product to be dried are cut in to equal size and spread over the wire mesh tray for drying (Figure 3.1). The drying was carried out till the moisture content of the product reaches less than 10%. Generally moisture content with less than 10% will increase the shelf life of the dried product.

Fig. 1 Open sun drying

- *2.1.2 Greenhouse Dryer*

An even span roof type greenhouse dryer was designed and fabricated with 1.2 x 1.2 m^2 floor area and ceiling 1m height. The structural frame of the greenhouse dryer is covered by UV polyethylene sheet and drip lock sheet as glazing material of 0.10mm thickness, to trap the solar radiation under passive and active mode (Figure 3.2). For enhancing the air movement in greenhouse dryer, an air vent is provided at the roof of the passive greenhouse dryer and a fan or blower is used in active mode. Greenhouse dryer was placed in east west orientation to have maximum exposure of solar radiation. Samples of one kg of okra placed in trays in greenhouse drying under passive and active mode using UV polyethylene sheet and drip lock sheet as glazing material. The glazing material is the sheet used to cover the roof of the greenhouse dryer for absorbing the heat incident in it. Some of the factors considered in selection of glazing materials are transmission of radiation, life of the glazing material, aging factor, cost of the glazing material, maintenance cost and ease of availability of sheet. Most significant advantage of glazing material is it prevents loss of heat. The absorbed radiation cause the crop temperature to increase and at the same time the radiation energy after heating the product may try to escape which is prevented by the glazing material. Thus the temperature inside the dryer is maintained which enhances the drying rate of the product.

(a) (b)

Fig. 2 Greenhouse dryers in (a) Passive mode (b) Active mode

- *2.1.3 Heat Pump Dryer*

The HPD used in the present work was a commercial based dryer manufactured by Ice Make Refrigeration system incorporated with a heat pump and dehumidifier. The main function of the heat pump is to add the latent heat and sensible heat. The heated air from the heat pump sent in to the drying chamber to absorb the moisture present in the vegetables to be dried. The hot air absorbs moisture from the product and converted in to cold humidified air and leaves the drying chamber. The HPD consists of two fans inside the drying chamber for circulation of heat uniformly. The refrigerant used in the heat pump dryer is R134. The dehumidification capacity is 2.5 (l/h) and maximum product capacity for drying in heat pump is 60 kg. The experimental set up of the heat pump dryer is shown in Fig. 3. The drying chamber consists of four racks with two trays in each rack (Fig. 4).

Fig. 3 Experimental set up of a heat pump dryer

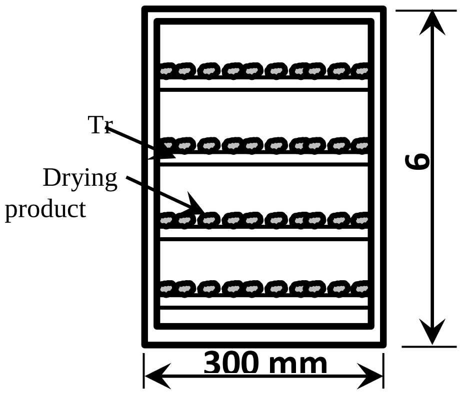

Fig. 4 Drying chamber

The number of trays can be decreased based on our requirement of the drying product. The drying chamber is of length 120 cm and width 55 cm. The maximum drying capacity of product can be placed in the drying chamber is 60 kg. The drying time and moisture content were found out for all the drying methods. Based on the moisture content and time taken for drying the drying rate and dryer efficiency was found out.

2.2 Instrumentation

A Halogen moisture Analyzer (Mettler Toledo) was been used to determine the initial moisture content of the product. A Solarimeter was used for measuring the solar radiation (range: 2000 W/m^2) with an accuracy of $\pm$5 W/m^2. A noncontact type infrared thermometer was used for measuring temperature up to 380°C with an accuracy of $\pm$1.5°C. An anemometer (Model: Benetech, range 0 to 30 m/s) was used to measure the wind speed.

2.3. Uncertainty Analysis

In the analysis of systems, there are some independent parameters. They were measured, like temperature, mass, time, etc. and some dependent parameters such as efficiency, power, etc. The uncertainty in the measured parameters was due to errors like sensitivity, calibration, reading, etc. (Table 1). Let x_1, x_2, $x_3 \ldots x_n$ are independent variables with uncertainty w_1, w_2, $w_3 \ldots w_n$ 7.. The result R is a dependent function of independent variables. The uncertainty in the result R is given by w_R in Equation (1).

$$\left[\left(\frac{\partial R}{\partial x_1} w_1\right)^2 + \left(\frac{\partial R}{\partial x_2} w_2\right)^2 + \left(\frac{\partial R}{\partial x_3} w_3\right)^2 + \ldots + \left(\frac{\partial R}{\partial x_n} w_n\right)^2\right]^{1/2} \quad (1)$$

Table 1 Uncertainty in the measured and calculated parameters

Parameters	Model/Measuring Instrument	Range	Uncertainty
Temperature (°C)	Noncontact type Infrared Thermometer	-50 to 380°C	$\pm$0.394°C
Solar radiation (W/m^2)	Solarimeter	2000 W/m^2	$\pm$0.714%
Wind velocity (m/s)	Benetech Digital Anemometer	0 to 30m/s	$\pm$0.2%
Mass of the products (kg)	HMS	5kg	$\pm$0.1%
Moisture ratio (%)	-	-	$\pm$1.09%
Drying rate (kg/h)	-	-	$\pm$1.24%

3. PERFORMANCE ANALYSIS

3.1 Moisture Content

The initial moisture content of the product was calculated by halogen moisture analyser at a drying temperature of 130°C and the moisture content was found. The moisture content of samples was calculated for each day using Equation (2) 8..

$$M.C = \left(\frac{W_w - W_s}{W_i}\right) X\,100 \quad (2)$$

where,

Ww = Weight of wet sample (g)

Ws = Weight of dry sample (g)

Wi = Initial weight of sample (g)

M.C = Moisture content of ivy gourd (%)

3.2 Moisture Ratio

Moisture Ratio (MR) is an important parameter to analyze and compare the performance of solar dryers. Moisture ratio is the ratio between mass of water to mass of solid in a sample. It is given by Equation (3) 5..

$$MR = \frac{(M_{int} - M_{eq})}{(M_{in} - M_{eq})} \quad (3)$$

where,

Mint is instantaneous moisture content (%),

Min is initial moisture content (%) and

Meq is equilibrium moisture content (%).

3.3 Drying Rate

The drying rate is the ratio between the difference in moisture content and total hours taken for drying to reach the safe moisture content for preservation 5.. Drying rate is calculated by Equation (4).

$$Dr = \left(\frac{M_i - M_f}{\text{Total hours of drying}}\right) \quad (4)$$

where,

Dr =Drying Rate (g/h)

Mi = Initial moisture content

Mf = Final moisture content

3.4 Dryer Efficiency

It is the ratio of energy required to remove the moisture to the energy supplied to dryer 8.. The dryer efficiency is calculated from Equation (5).

$$\eta_d = \left(\frac{M_w L_v}{I_c A_c\ t}\right) \tag{5}$$

where,

M_w = Weight of Moisture removed (kg)

L_v= Latent heat of Vaporization (J/kg)

I_c = Average solar radiation incident during drying (W/m^2)

A_c = Area of the dryer (m^2)

t = Time taken for drying (s)

3.5 Effective Moisture Diffusivity

The rate of moisture moved from the interior surface of the product to the surface is denoted by effective moisture diffusivity. The effective moisture diffusivity depends on moisture content of the product, drying temperature and porosity of the product 9.. The effective moisture diffusivity (D_{eff}) of the vegetables under different modes has been calculated by Equation (6).

$$ln\frac{M_{int}}{M_i} = ln\frac{8}{\pi^2} - \left(\frac{\pi^2 D_{eff}\ t}{4L^2}\right) \tag{6}$$

where,

D_{eff} = Effective moisture diffusivity (m^2/s)

M_{int} = Moisture content at time t (%),

M_i = Initial Moisture content (%),

L = Half the thickness of the slab (m)

t = Time (s)

3.6 Specific Moisture Extraction Rate (SMER)

Specific Moisture Extraction Rate (SMER) The specific moisture extraction ratio is the ratio between the moisture evaporated from wet product to the energy input to drying system 5.. SMER was calculated from Equation (7).

$$\text{SMER} = \frac{\text{Moisture evaporated}}{\text{Input energy}} \tag{7}$$

4. RESULTS AND DISCUSSION

4.1. Moisture content

The moisture removal is higher during the initial drying period due to the evaporation of moisture from the free surface of the product. During the later stages of drying, part of heat energy is utilized for migration of moisture from the inner surface of the product. It is found that reduction in moisture content is faster in heat pump dryer due to uniform supply of hot air inside the dryer (Fig. 5).

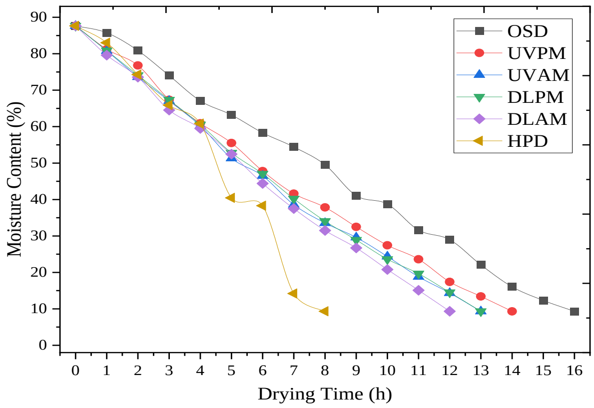

Fig. 5 Variations of moisture content of okra under different modes of drying

In greenhouse dryer drip lock sheet under active mode had high moisture removal rate because of more amount of heat transfer achieved by the air movement. The reduction in moisture content of okra from 87.65 % to 10% was achieved in 16 hours under OSD, 14 hours using UVPM, 13 hours under DLPM and in UVAM, 12 hours to achieve the moisture content of 9.3 % using DLAM and 8 hours with HPD.

4.2 Moisture Ratio

The final moisture ratio of around 0.1 had been achieved in 11 hours in DLAM, 12 hours in UVAM and in DLPM.Whereas, UVPM and OSD took 16 hours and 14 hours respectively to reach moisture ratio of 0.1. Final moisture ratio of 0.1 was achieved in 8 hours in HPD (Fig. 6).

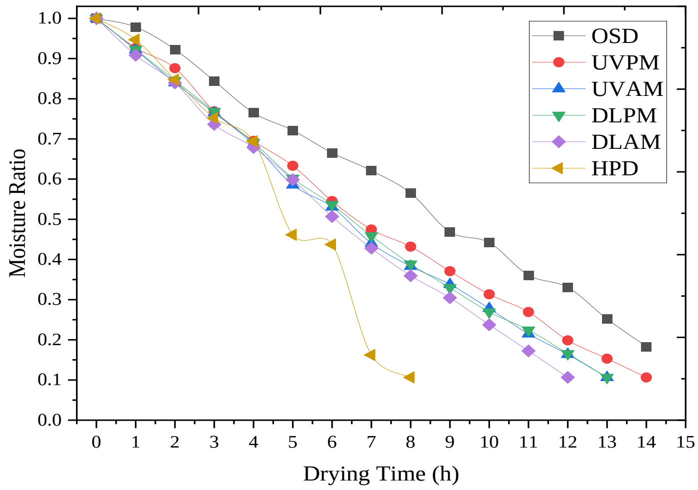

Fig. 6 Variations of moisture ratio under different modes in drying of okra

4.3. Drying Rate

Drying rate mainly depends on the glazing material used and the air temperature inside the drier. Higher the heat transfer higher will be the drying rate. From the experimental results it is found that the drying rate of 4.95 g/h is achieved in Heat Pump Dryer (HPD). The drying rate is found to be higher in drip lock greenhouse active mode dryer compared to OSD, UVPM,UVAM and DLPM because of the more amount of heat transfer enhanced by the air movement by fan and due to increase in temperature inside the greenhouse dryer by the glazing material used.

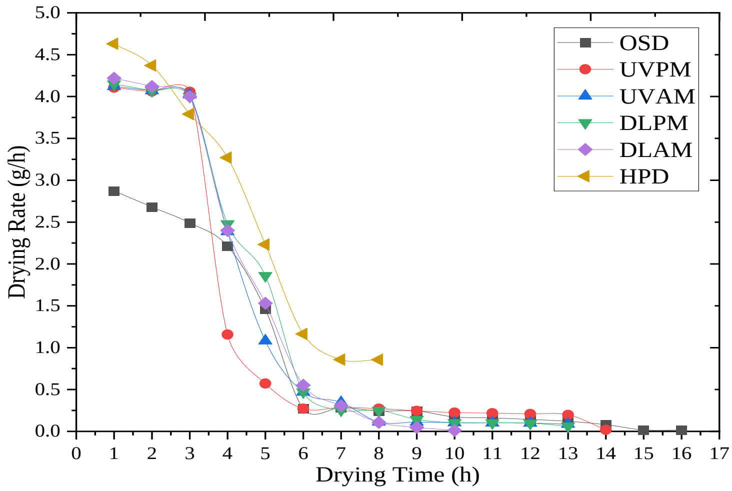

Fig. 7 Variations of drying rate under different modes in drying of okra

It is also seen that drying rate decreases continuously with time. All the drying process follow falling rate period. Diffusion of water in the solid governs the falling rate period during drying. The variations of drying rates for each day for different modes of drying of turkey berry are shown in Fig. 7.

4.4. Dryer Efficiency

The efficiencies of the dryer under different drying modes were calculated. For Okra, the dryer efficiency is 12.12 % in UVPM, 14.15% in DLAM, 13.06% in UVAM and DLPM. Whereas 38.78% of dryer efficiency was achieved in heat pump dryer. The increase in dryer efficiency in heat pump dryer was due to the increase in heat transfer inside the dryer and also due to retention of heat inside the dryer Fig. 8 presents the dryer efficiency of okra dried under different modes of drying.

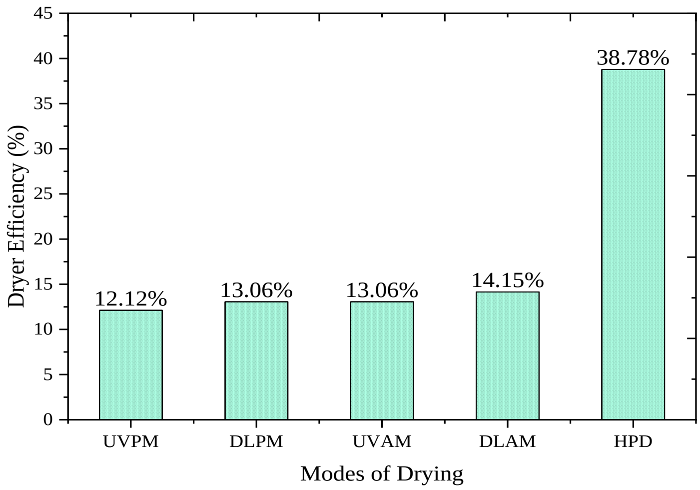

Fig. 8 Dryer efficiency under different modes in drying of okra

4.5. Effective Moisture Diffusivity

In okra higher effective moisture diffusivity value of 2.09 x 10^{-10} m^2 /s was achieved in HPD compared to other modes and lower effective moisture diffusivity of 1.04 x 10^{-10} m^2 /s was achieved under open sun drying mode in drying okra. Higher temperature and air velocity inside the HPD increased more heat and mass transfer to get higher effective moisture diffusivity. For all the other modes effective moisture diffusivity lie within the range of 10^{-2} to 10^{-12} m^2/s of food products 10..

4.6. Specific Moisture Extraction Rate (SMER)

A higher SMER 2.60 kg/ kWh were achieved under heat pump dryer in drying okra. It was found that Heat Pump dryer and active mode greenhouse dryer gave higher SMER values compared to passive mode because of increased mass flow rate. The other drying methods UVPM, UVAM, DLPM and DLAM gave 0.1877 kg/ kWh, 0.2021 kg/ kWh, 0.2021 kg/ kWh and 0.219 kg/ kWh respectively.

5. CONCLUSION

The post- harvest drying kinetics of okra was carried out and the following conclusions were drawn from the experimental results:

- Considerable amount of drying time was saved in drying to reach safe moisture content under Heat Pump Dryer (HPD) compared to greenhouse drying. The okra took 8 hours in HPD to reach safe moisture content.
- The maximum dryer efficiency of 38.78 was achieved in Heat Pump Dryer (HPD) in drying okra.
- A higher SMER of 2.60 kg/ kWh were achieved under heat pump dryer in drying okra. In green house dryer SMER of less than 0.57 kg/kWh were achieved in all modes of drying.
- The effective moisture diffusivity values under Heat Pump Dryer (HPD) were 2.09 $x10^{-10}$ for okra. For all the other modes effective moisture diffusivity was within range of 10^{-2} to 10^{-12} of food products.
- It was found that the products dried with minimum drying time in HPD compared to greenhouse drying but still in the economic point of view greenhouse drying has low cost.

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MODELING THE THIN-LAYER DRYING OF BEE POLLEN

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Abstract: *Bee pollen provides proteins, lipids, vitamins and minerals in bee nutrition. Bee pollen also has a significant nutritive value as a supplement to human nutrition. Fresh bee pollen must be dried in order to reduce water activity for the development of various microorganisms. Convective drying is common method for bee pollen dehydration. In this paper, several drying temperatures (40, 50 and 60◦C) were investigated during the 3 hours convective hot air drying. Several drying models used in literature were fitted to experimentally obtained drying curves in order to find most suitable one. The best fit was achieved with Two-term (for 60◦C) and Hii et al. (for 40◦C and 50◦C) drying models. The coefficient of determination was the primary criterion for selecting the best model to describe the drying curves.*

Key words: *Bee pollen, convective drying, drying models.*

1. INTRODUCTION

Bees voluntarily collect pollen and nectar from different varieties of plants. A part of oilseed rape pollen is later placed on the market for human consumption while the rest is used for making the brood food. Pollen is the main source of protein, fat, vitamins and minerals in bee nutrition (Nedić et al. 2003). The number of broods in the hive and the life expectancy of worker bees largely depend on the amount of pollen available in the food (Jevtić et al., 2009; Di Pasquale et al., 2016). The chemical composition of pollen varies depending on the plant from which it was collected and the method of storage and storage (Campos, 1997; Campos et al., 2010). In addition to its exceptional benefits for bees, pollen is also used in human nutrition and in apitherapy. Due to its valuable nutrients and biological ingredients, pollen is used as a natural dietary supplement. Pollen brought by bees is collected in the raw state by placing pollen traps at the entrance to the apiary. Water content has a crucial impact on maintaining pollen quality, varying in the range of 20 to 30 g per 100 g (Bogdanov 2004). Good beekeeping practice instructs beekeepers to collect pollen daily and then dry it at a temperature of 40oC. This avoids the occurrence of pollen fermentation, mold growth and the development of mycotoxins and a decrease in vitamin C content due to the potential decomposition of ascorbic acid in the aquatic environment (Petrović et al., 2014; Kostić, 2015). In dry pollen, the water content should be in the range of 4 to 8% (Mustaers, 2005; Official Gazette of the Republic of Serbia, 101/2015). This research is about examinating drying kinetics of bee pollen for several common drying regimes during hot air drying. Appropriate drying moddels were compared in order to find most suitable one for drying kinetics description.

2. MATERIAL AND METHOD

2.1 Drying material preparation

For the purpose of pollen drying a fresh sample of pollen (Fig. 1) was used in the experiments collected with pollen traps placed at the entrance of beehive on oilseed rape melliferous pasture (*Brassica napus L.*). Up to the moment of drying a fresh oilseed rape pollen has been vacuum packed and stored in a deep-freezer.

Figure 1. Fresh pollen sample.

The oven-dry method was used as one of the commonest methods of determining sample moisture content. It consists of taking a pollen sample, determining its exact weight, and dry the sample in an oven at a temperature of 105◦C for 24 hours, then weighing the sample and determining the moisture loss by subtracting the oven-dry weight from the moist weight. (Shreve et al., 2006) The obtained resultes showed 23.48% of water content at dry basis in fresh pollen sample.

2.2 Drying experiment and apparatus

Moisture analyzers (MA) type BTS110D was used for fast and precise moisture determination of a sample based on mass loss during heating process. Moisture analyzer has 2x100W halogen radiators for the material heating. Weigth measurement precision was 0.1%. Material drying temperatures were 40, 50 and 60◦C within drying time of aproxx. 3 hours.

2.3 Drying models

The change of moisture ratio (MR) was monitoring in time in order to describe drying process. The experimental data were fitted to the four suitable thin layer drying models given in Table 1.

Table 1. Mathematical models applied to the drying curves

Model no	Model name	Model eqation
1	Newton	$MR=exp(-a\cdot\tau)$
2	Page	$MR=a\ exp(-b\cdot \tau^{c})$
3	Two-term	$MR= a\cdot exp(-b\cdot \tau)+ c\cdot exp(-d\cdot \tau)$
4	Hii et al.	$MR= a\ exp(-b\cdot \tau^{c}) + d\ exp(-e\cdot \tau^{f})$

The moisture ratio was calculated from equation (Eq.1)

$$MR = \frac{M - M_e}{M_o - M_e} \tag{1}$$

where MR is the dimensionless moisture ratio, M, M_e and M_o are the moisture ratios at any time, the equilibrium moisture content and the initial moisture content in % wet basis respectively (Crank, 1975; Akpinar, 2003; Aghbashlo, 2009).

Non-linear regression analysis was performed for the drying data by using Table Curve 2D (Systat Software Inc. 2002) software. The coefficient of determination (R^2), refer to (Eq.2), was the primary criterion for selecting the best model to describe the drying curves. The higher the values of R^2, the better the goodness of the fit.

$$R^2 = 1 - \left[\frac{\sum_{i=1}^{N} \left(MR_{pre.i} - MR_{exp.i} \right)^2}{\sum_{i=1}^{N} \left(\overline{MR}_{pre.i} - MR_{exp.i} \right)^2} \right] \tag{2}$$

where $MR_{exp,i}$ is the *i*-th experimentally observed moisture ratio, $MR_{pre,i}$ is the *i*-th predicted moisture ratio and N the number of observations.

3. DISCUSSION ON THE RESULTS

Bee pollen samples were dried in thin layer without significant overlapping of the pollen layers (Fig. 1). All experimental measurements were performed with the initial mass of the pollen between 10 and 30 grams for one experiment. The results were obtained as average from several measurements per experimental setup. Moisture content of the material during time (Fig. 2) is shown by various temperatures. Moisture analyzer was used for moisture determination of a sample at 40, 50 and 60°C temperatures within approx. 3 hours period. Similar drying parameters were used by other authors (Ayla et al. 2018; Kanar and Mazi, 2019).

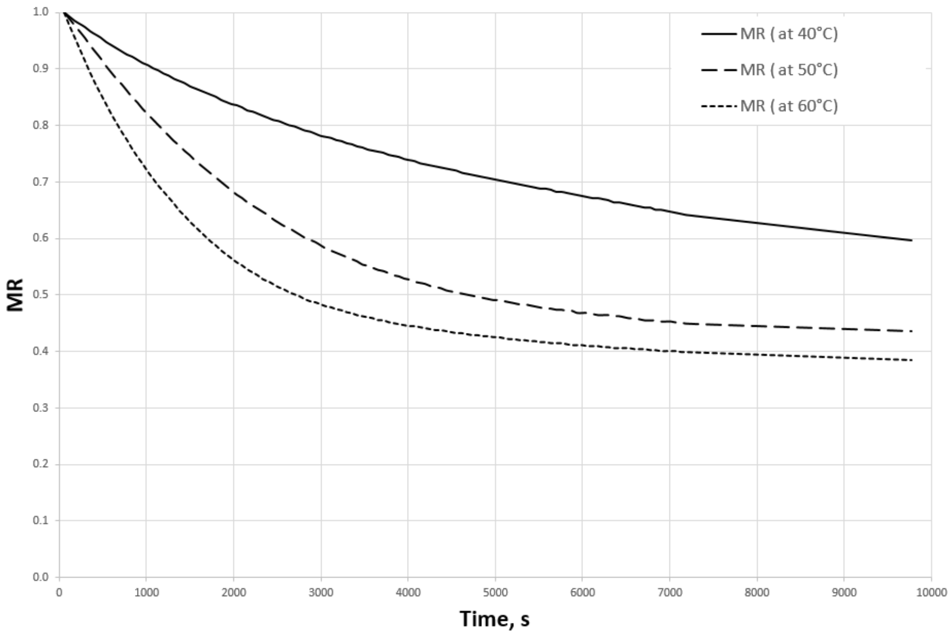

Figure 2. Experimental moisture ratio (MR) vs. drying time

Results showed that moisture content decreased significantly during the first hour and decreased slowly afterwards. The increase in drying air temperature speeded up the drying process. Drying temperature of 40°C, that is usually used in commercial bee pollen dryers, caused the lowest moisture losses of the material, i.e. longest drying process. Consequently, the temperatures of 50°C and 60°C provided significantly higher moisture losses and faster drying, especially during the first hour. However, these temperatures cannot be applied commercially because of the negative effect on bee pollen chemistry.

Table 2. Models statistical analyses results of drying of bee pollen

Modeli		Temperatura sušenja, ◦C		
		40	50	60
Newton	*a*	7.00E-05	0.000144923	0.000188471
	R^2	0.939450177	0.880916352	0.652645816
Page	*a*	1.041089474	1.17398675	1.547991912
	b	0.001938031	0.01263654	0.102953381
	c	0.62229691	0.494719869	0.296557935
	R^2	0.998690294	0.985763468	0.975768703
Two-term	*a*	0.7729104	0.347861731	0.425651713
	b	2.84E-05	-2.11E-05	9.38E-06
	c	0.231420855	0.67658605	0.605087952
	d	0.000387506	0.000375882	0.000706727
	R^2	0.999891682	0.999760904	**0.999832886**
Hii et al.	*a*	0.294024002	0.511453175	0.674503839
	b	0.000564436	0.000122151	0.001172592
	c	0.921854898	1.164404222	0.928837485
	d	0.715087533	0.513393603	0.397758832
	e	4.76E-05	0.007832316	1.578265722
	f	0.918535311	0.336645546	-0.64823896
	R^2	**0.999923003**	**0.999967006**	0.999700354

The influence of drying air properties on drying process was compared to the four commonly used literature models. The regression analysis, refer to Table 2, showed that the solutions of Hii et al. model provided satisfying match with the results obtained for the drying temperatures of 40°C and 50°C. The values of R2 in Hii et al. model were in range 0.999923003 and 0.999967006 respectively. For the temperatures of 60°C, best fit was achieved with Two-term model. The value of R2 in Two-term model models was 0.999832886.

4. CONCLUSION

The influence of drying air properties on drying kinetics were analyzed in this paper. Conventional sample heating was performed at drying temperatures of 40, 50 and 60°C. The higher moisture loss was achieved with drying temperature of 60°C, especially at the beginning of the drying process, i.e. first hour period. For this drying temperature regime, Two-term model provided best fit with experimental results, with highest R^2 value of 0.999832886. However, the drying model provided by Hii et al. can be widely used for the description of drying process at lower drying temperatures.

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RECENT ADVANCEMENTS OF SOLAR DRYERS WITH IMPLEMENTED PHASE CHANGE MATERIALS

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Abstract *Using solar energy for drying agricultural products is one of the oldest methods of preserving food. Excellent results are obtained by using solar dryers, both in the quality of dried products and in energy-efficient drying procedures. The problem occurs when the solar radiation is low intensity or absent, which makes it impossible for the solar dryer to work. This problem can be solved by implementing phase change materials (PCM) which improve the efficiency of the system and allow the dryer to work in a period during off sunshine hours. This review provides insight into the progress in the field of solar dryers in which PCM is implemented. The impact of using PCM on the quality and efficiency of product drying compared to solar dryers without PCM and open sun drying is shown. It has been noticed that the use of PCM improves the global thermal efficiency of the system. The temperature and the percentage weight of moisture removal was increased and the drying time of the product was reduced. Various cases of drying apples, tomatoes, basil, bitter melons, strawberries and medicinal herbs have been considered. Different positions of PCM in flat solar collectors increased the thermal efficiency of the flat plate collector in the range from 5.02% to 10.13%, and the overall efficiency varied from 21.92% to 25.72%. The use of hybrid systems consisting of two or more synchronized systems also have been considered. The hybrid solar dryer with implemented PCM and integrated geothermal system showed an improvement in performance efficiency of 20.5% compared to a flat plate solar collector. The progress of solar dryers with the implementation of PCM is given with the aim of further developing the application of renewable energy sources in food preservation.*

Keywords: *food, solar dryer, PCM, renewable energy*

1. INTRODUCTION

Drying is one of the oldest ways of preserving food by removing moisture. By drying, the process of product decay and the growth of microorganisms is slowed down, and the lifespan is extended without reducing the quality. The oldest procedures for drying food were based on the use of solar and wind energy. In this drying process, the product is exposed to direct sunlight, where part of the radiation is absorbed and converted into thermal energy. As a result, the temperature rises, and at the same time moisture is released from the product. Open sun drying causes large losses of thermal energy, so this method is not energy efficient. This drying process takes place in uncontrolled conditions. Product is exposed to open space for a long time, which can lead to contamination due to dust, birds, insects, and rodents and can cause a significant drop in the quality of the drying product.

Modern drying systems perform drying in controlled conditions, and the quality of the dried product is significantly better. However, such systems are expensive, their energy consumption is very high and they pollute the environment. Due to large increase in the price of fossil fuels and the harmfulness of gas emissions, it will be necessary to use renewable energy sources such as solar energy, wind energy, geothermal energy, and biomass in the near future 1..

Therefore, solar dryers that use solar radiation to extract moisture from the product could be used as an alternative. In typical solar dryers, solar radiation reaches the surface of the collector where it is absorbed and converted into thermal energy. The air in the collector is heated and as such enters the drying chamber and removes moisture from the product and then leaves the chamber. The problem occurs in hours when the intensity of solar radiation is very low or absent, which makes it impossible for further operation of the dryer. One way to solve this problem is to store the excess energy obtained in sunshine hours and use it later. Sensitive and latent heat storage are the most often used methods for storing energy. PCMs are proving to be the most promising materials for latent heat storage. Paraffin has proven to be one of the better PCMs 2.. It is not corrosive, chemically stable below 500 °C, has small changes in volume when changing phase, and is less expensive.

2. SOLAR DRYERS

A solar dryer is a device that converts solar energy into heat and is used to remove moisture content from the product being dried in it 3.. Solar dryers can be used for drying agricultural products 4., fruits 5., vegetables, and medicinal plants 6.. They can also find their role in the marine 7., automobile, rubber, paper, sugarcane, and tea industries 8.. The classification of solar dryers based on the construction and method of using solar energy 9. is given in Fig. 1. The basic classification of solar dryers according to the exposure of the product to solar radiation is into direct, indirect, and mixed solar dryers.

2.1. Direct solar dryers

The construction of a direct solar dryer is simple. It consists of housing whose side walls and top are covered with transparent glass and small holes through which air enters and exits. The product to be dried is exposed to incident sunlight and with the incidence of solar radiation the temperature of the food rises. The glass cover prevents the release of solar radiation into the atmosphere and increases the thermal efficiency of the dryer. In this way, the air temperature in the chamber rises and moisture removes from the product. Direct type solar dryers are being used for drying red peppers, mangoes, and meat.

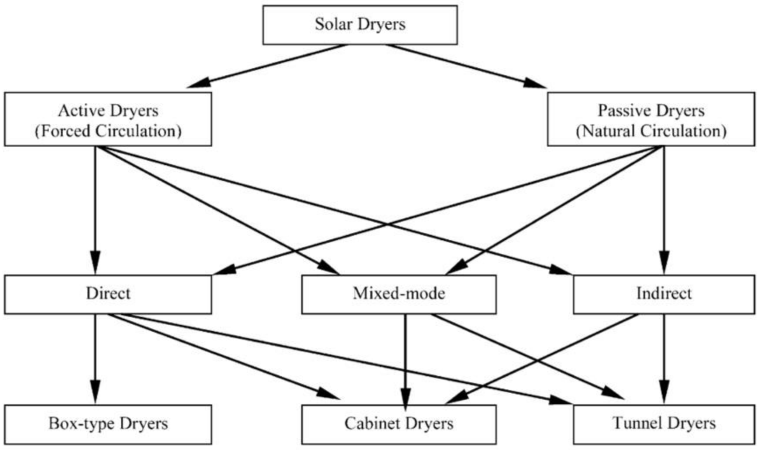


Fig. 21 The classification of solar dryers 9.

2.2. Indirect solar dryers

Indirect solar dryers 10. consist of a thermal solar collector and a drying chamber that are connected. Air heating takes place in the solar collector. Heated air enters the drying chamber and flows over the product, resulting in the release of moisture, and exits through the chimneys into the atmosphere. Airflow can be achieved by natural convection or forced by a fan. This type of dryer is used for drying beans, bananas, mangoes, chilies, and meat.

2.3. Mixed-mode solar dryers

Mixed-mode solar dryer is a combination of direct and indirect solar dryer. The dryer consists of a thermal solar collector and a drying chamber 11.. The top of the drying chamber is covered with transparent glass. This type of dryer has two heat sources. Solar radiation reaches the dried product in the drying chamber through the glass located at the top, and the heated air from the thermal solar collector enters the drying chamber. A mixed solar dryer is used to dry products such as tomatoes, bananas, coconut, pears, and seafood.

2.4. Hybrid solar dryers

The hybrid solar dryer consists of several synchronized systems and uses multiple heat sources. Solar energy is used as a primary source of heat, while wind energy, geothermal energy, photovoltaic modules, biomass, etc. are used as additional sources. This dryer can be used in direct and indirect mode or both.

3. PCMS USED FOR THERMAL ENERGY STORAGE

PCMs are used for latent heat energy storage and have the ability to absorb and release heat during a phase change cycle 12.. During the solidification process heat is released, while in the melting process heat is absorbed. Latent heat energy storage has the ability to provide a high-energy storage density per unit mass and per unit volume in an almost isothermal process 13.. Important physical capabilities of PCM are high specific heat and heat of fusion, high density and thermal conductivity, stable composition, and non-toxicity 14.. The use of PCMs for heat energy storage in solar dryers is becoming increasingly popular. The characteristics of some of the most commonly used PCMs for drying agricultural products are shown in Table 1.

Table 3 PCMs used for drying agricultural products

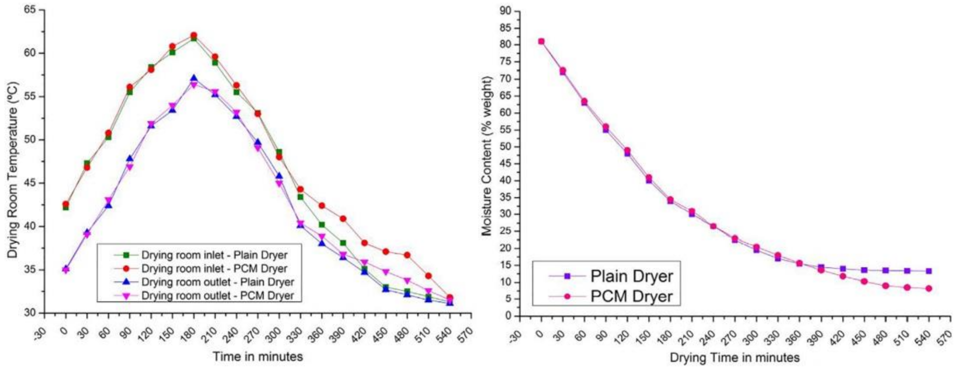
material	Melting temperature in °C	Density in kg/m^3	Specific heat in kJ/kgK	Thermal conductivity in W/mK	Ref.
Paraffin wax	35-60	775^l-786^l 833^s-861^s	2.44^l-3.89^l 2.35^s-2.94^s	0.15-0.4	15.
Calcium chloride hegzahidrat	30	1710	-	1.28	16.
Rubitherm RT 42	38-43	760^l, 880^s	-	0.2	17.
Rubitherm RT54HC	53-54	800^l, 850^s	2	0.2	18.
Paraffin wax 45	60	934	2.5	0.9	19.
Paraffin wax 60	41-46	880	2	0.2	19.
Octacosane	50	803	1.9	0.23	20.

^{s} solid phase
^{l} liquid phase

4. SOLAR DRYERS WITH PCM

The main disadvantage of solar dryers is the inability to work after sunset and low efficiency. All of this can be improved by integrating a PCM that can be integrated into three different ways: into a solar collector, heat exchanger, or drying chamber. Various improvements of solar dryers, as well as the results of drying different food materials are presented in this paper.

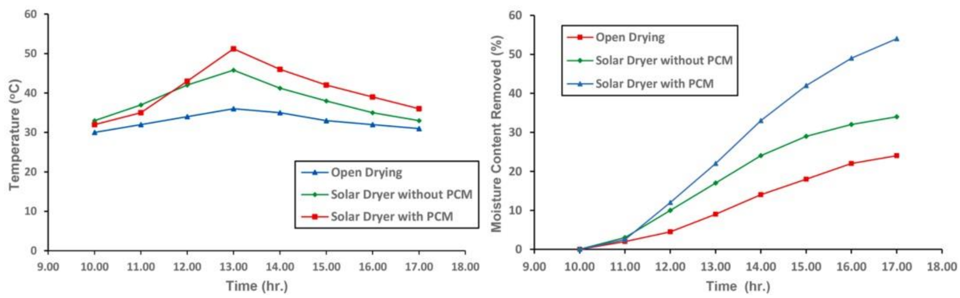
Vigneshkumar et al. 21. performed experimental research of drying sliced potatoes in an indirect solar dryer with and without PCM. Paraffin in the form of white-colored pellets with a melting point of 45 °C and a latent heat capacity of 180 kJ/kg was used as PCM. The PCM was placed under the absorber plate inside the flat solar collector. The experiment was performed for 9 hours from 10.00 a.m. to 7.00 p.m. and the average solar radiation in that period was recorded as 700 ± 10 W/m^2. The obtained results showed that the implementation of PCM inside the collector contributed to maintaining a significantly higher temperature in the dryer for another two hours after the sunshine period (Fig. 2a). The moisture content in the potato slices at the beginning of drying was 81%. Drying in a dryer without PCM the moisture content was reduced from 81% to 13.3%. Drying in a dryer with implemented PCM the moisture content was reduced to 8.2%, which is 5.1% more than in a solar dryer without PCM (Fig. 2b).



a) b)

Fig. 2 Comparison of (a) Drying room inlet and outlet temperature (b) moisture content of potato slices during drying period with and without PCM 21.

Rakshamuthu et al. 22. developed a greenhouse solar dryer consisting of a small rectangular drying chamber with the specifications of 100 (L) x 60 (D) x 20 (H) cm. Zinc nitrate hexahydrate with a melting point of 35 °C placed in a detachable tray was used as PCM. A comparative study of drying 1 kg of gooseberry was conducted to evaluate the performance of open sun drying, solar dryers without, and solar dryers with PCM. Experimental data showed that the drying air temperature in the solar dryer without PCM was increased by 27% compared to atmospheric temperature, while in the solar dryer with PCM it was increased by 43% (Fig. 3a). This indicates that the drying period in a dryer without PCM can be reduced by 27%, and with PCM by 43% compared to open sun drying. With open sun drying maximum of 25% moisture was removed in the period of 7 hours. During the same time, 34% of the moisture was removed in the solar dryer without PCM and 54% in the solar dryer with PCM (Fig. 3b). Open sun drying will take four days to completely dry the gooseberries, solar dryer without PCM will take three days and solar dryer with PCM will take less than two days.



a) b)

Fig. 3 Comparison of (a) Drying air temperature (b) moisture content removal of 1 kg goosebery during drying period with and without PCM and open sun 22.

Bhardwaj et al. 23. have developed a solar drying system that includes solar collectors with the integrated sensible heat storage medium and paraffin RT-42 (PCM) as a latent heat storage medium that is placed in a drying chamber (Fig. 4). During the experiment, 9 kg of Valerian rhizomes were dried. The initial moisture content was 89%. Drying to the final product with 9% moisture content in the open sun took 336 hours, in the dryer without PCM 216, and with PCM 120 hours. The mean value of energy efficiency of solar air collector without PCM was 9.8% while with PCM it was 26.1%. The mean value of exergy efficiency without PCM was 0.14% and with PCM 0.81%. The overall drying rate without PCM was 0.028 kg/h, and with PCM 0.051 kg/h. The mean value of exergy efficiency of the drying units was 30.28% and the overall efficiency of the drying system was 10.53%.

Fig. 4 Experimental setup 23.

Madhankumar et al. 15. analyzed and compared the performance of an indirect solar dryer in three different cases: without thermal energy storage (TES), with TES unit having PCM and with TES having fins inserted PCM, during spring and summer seasons (Fig. 5). Paraffin wax with a melting temperature of 52 °C was used as PCM, latent heat of fusion is 196.05 kJ/kg and specific heats for liquid and solid phases are 2.44 kJ/kgK and 2.35 kJ/kgK respectively. During the experiment, 2 kg of Momordica charantia with an initial moisture level of about 92% was dried until the moisture level of the final product was around 12%. Drying in the open sun required 17.1 h, while in test 1, 2, and 3 during the spring it took 15, 12, and 11 h respectively. Drying in test 4, 5 and 6 during the summer took 14.5, 11, and 10.5 h respectively. The maximum thermal efficiency of 19.41% was achieved in test 6 during the summer, and 19.37% in test 3 during the spring.

Hana Ebrahimi et al. 24. performed numerical and experimental research of drying tomato slices in a solar dryer with flat solar collectors with and without PCM. Paraffin wax was used as PCM. The results for four different PCM positions inside the collector were analyzed: a: the tube aligned with equal distances through the plate, b: the tube aligned with different distances through the plate, c: the tube aligned with equal through

2/3 of the plate, d: the tube aligned with equal distances through half of the plate (Fig. 6). It was concluded that the use of PCM contributes to a reduction in drying time of about 6.25–21.87% (Fig. 7). In case d, the highest average thermal efficiency of 40.20% and the total drying efficiency of 25.72% were achieved. The use of PCM had the effect of reducing energy consumption in the range of 7.29–18.97% compared to drying without PCM.

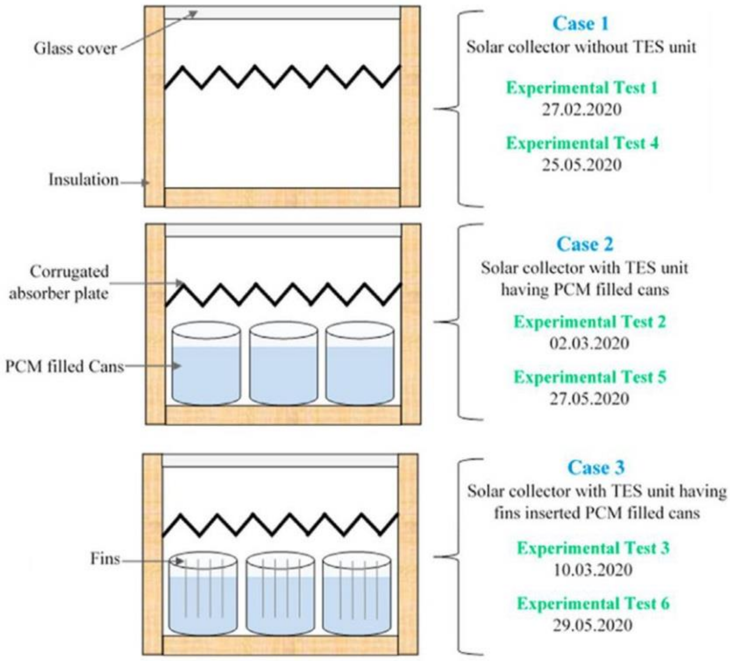


Fig. 5 Schematic representation of experimentation plan 15.

Lakshmi et al. 25. developed two types of solar dryers (mixed mode and indirect mode) integrated with an energy storage system based on paraffin wax. The TES is made up of galvanized iron sheet (shell and tube heat type). The air passes through the tubes of TES from the collector to the drying chamber. In the heat exchanger was poured 38 kg of Paraffin wax. During the experiment, 30 kg of black pepper from an initial moisture content of 3.46 (d b) to a moisture content of 0.14 (d b) was dried. In the first case, the upper part of the dryer is transparent and the product receives thermal energy from solar air heaters as well as through the upper transparent cover (mixed mode). In the second case, the upper part of the chamber is completely insulated and the dried product receives heat only from solar air heaters (indirect mode). In the first case, the drying process was completed after 14 h, in the second case after 23 h, while open sun drying took 59 hours. The first case proved to be a better solution due to the higher overall dryer efficiency of 53.1% compared to the second case of 42.5%. Medicinal qualities attributes (TPC, TFC, and anti-oxidants) of dried black pepper are found to be better in the first case.

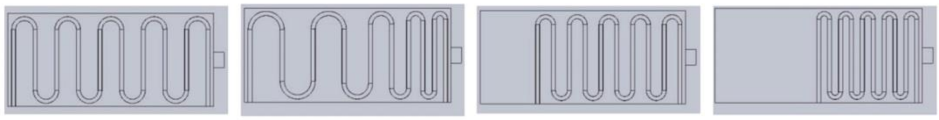


Fig. 6 PCM positions inside the collector 24.

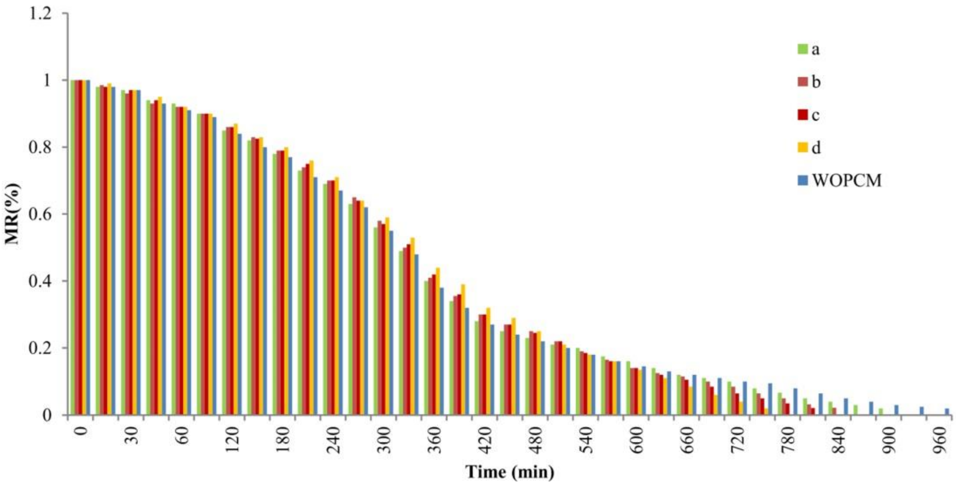


Fig. 7 Variations of drying process vs. drying time at various PCM conditions (a, b, c, d and WOPCM). 24.

Ananno et al. 26. performed a numerical analysis of a hybrid geothermal PCM flat plate solar collector dryer. The analysis showed that this hybrid system has much higher efficiency than the existing stand-alone systems. The air outlet temperature from the hybrid geothermal PA-FPSC dryer is 18.79-16.55 °C higher than the ambient temperature during 5 h after sunset and 15.9-13.4 °C higher during 12 hours after sunset. In theory, a hybrid system can achieve 20.5 times greater efficiency than a flat solar collector, or 6% more efficiency than a v-corrugated solar air heater when drying food for 20 hours a day.

Atalay and Cankurtaran in 27. developed a large solar dryer with implemented PCM (paraffin wax) as an energy storage medium. During the experiment, 5, 10, and 15 kg of strawberries were dried. The drying rate was 0.953, 1.834, and 2.391 kgw/h, and the total drying time was 225, 261, and 300 min respectively. In the experiment that was conducted for three days during the day and night, the highest and lowest energy efficiency were 70% and 76%, and exergy efficiency were 69.59% and 62.80%, which is a significantly high result. The results showed that the change in the amount of product to be dried does not greatly affect the energy and exergy efficiency. Fans were found to have the highest exergy destruction cost of $ 0.2286/h and the lowest exergy efficiency of 55.96% and therefore those components needed to be improved the most. It is calculated that the CO_2 mitigation for the expected service life of the system is 99.60 tons.

5. CONCLUSION

The use of solar dryers for drying products contributes to large energy savings and reduction of harmful gas emissions. Improvements of solar dryers can be achieved by integrating PCM and due to its characteristics, paraffin wax is the most commonly used PCM. The integration of PCM in the solar dryer allows it to work for several hours after sunset, which greatly reduces the time required for the product to dry. Also, the integration of PCM reduces the temperature fluctuation in the drying chamber, which results in a dried product of much better quality. It is necessary to carefully choose the place of installation of PCM because its position has a significant effect on the drying rate, thermal efficiency, and total drying efficiency. The overall efficiency of a solar dryer with PCM can be further increased by the additional use of sensitive energy storage or an additional source of renewable energy (geothermal, photovoltaic, biomass). Although the initial investments in solar dryers with PCM are large, the operating costs are small and the saving rate will grow with the increase in energy costs.

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FINANCIAL ASPECTS OF WATERMELON PRODUCTION ON FAMILY FARMS IN THE REPUBLIC OF SERBIA

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Abstract: *Vegetable production in the Republic of Serbia accounts for about 3.5% of total crop production, within which there is a constant trend of declining areas where vegetables are grown, primarily due to the great need for hiring labor, which is decreasing. One of the most common vegetable crop grown in the Republic of Serbia is watermelon, which according to the Republic Statistical Office, along with quince, was grown on 5,700 hectares in 2019, while the largest areas under these vegetables were recorded in 2017 when they amounted to about 8,300 acres. The aim of this paper is to present the economic and financial aspects of watermelon production on farms in the Republic of Serbia in the period between 2015 and 2019, based on data from Statistical Office of the Republic of Serbia and the income and expense survey on the family farms, which represents calculations based on variable costs, conducted by the Institute for the Application of Science in Agriculture. Sensitivity analysis shows the price and yield influence on gross margin amounts in watermelon production. The obtained results indicate a variation in the amount of gross margin in watermelon production in the analyzed period, due to changes in prices, yields and variable costs. Data obtained on sensitivity analysis, determinate that changes in price and yield have a significant impact on the amount of gross margin in watermelon production.*

Keywords: *gross margin, watermelons, farms, Serbia*

1. INTRODUCTION

In the Republic of Serbia, vegetables are grown evenly in all regions, but at a higher percentage in an open field than in enclosed space 1.. Vegetable production is one of the most intensive branches of crop production, resulting in high yields per unit area, generated income and net revenue, but with significant labor engagement 2, 3.. Watermelon is a vegetable crop originating from central and southern Africa, and spreading across European countries from the Mediterranean 4.. It is grown all across Europe, and the most famous watermelon-growing countries are Greece, Northern Macedonia, Italy and Spain. In the Republic of Serbia there is a vast assortment and diversity of watermelon genotypes, making watermelon production quite successful 5.. It is cultivated up to 600 m altitude, although at that altitude only early cultivars can be grown. Watermelon production is most common in Vojvodina, where the largest quantities of this crop come from, most famous of which is “sremska” watermelon. The areas under watermelon have been on a similar level for years, amounting to about 7,000 ha. Watermelon yields have been slightly declining, probably due to several dry years, averaging about 30 t/ha, whereas until 2015 yields were higher for about 5 t/ha 6..

2. MATERIALS AND METHODS

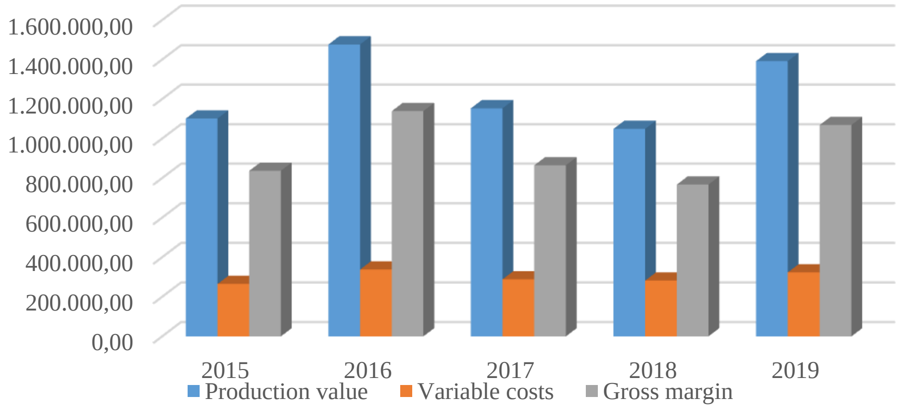
This research paper contains the data from a survey on gross margins conducted by the Institute of Science Application in Agriculture 7.. For the purpose of this paper, 90 survey questionnaires were analyzed, all collected from family farms on which watermelon production is a dominant type of production.

Financial indicators are the universal indicators of profitability of every production. For family farms, which are the subject-matter of this analysis, calculations based on variable costs are mostly used when determine the optimal scope and structure of farm production, and the indicators obtained from such calculation can be a good financial instrument for making business decisions on a farm 8.. Using a calculation based on variable costs, the following basic financial business indicators are determined: the value of production, variable costs and gross margin. The business result is expressed as a gross margin, which is a difference between the value of production and variable costs 9.. A gross margin is a quick and efficient indicator for comparing different lines of production on a family farm and choosing the most profitable one 10, 11.. The aim of this paper is to show financial indicators of watermelon production by calculating them based on variable costs.

3. RESULTS AND DISCUSSION

Given the calculations based on variable costs of watermelon production on family farms in the Republic of Serbia in the period 2015-2019, the average annual value of production, variable costs and gross margin were calculated.

The movement of financial indicators of watermelon production based on variable cost calculations in the period 2015-2019, calculated for 1 ha is shown in Chart 1.



Source: Authors' analysis based on the data from the selected family farms surveyed by the IPN

Chart 1: Movement of financial indicators of watermelon production, based on a variable cost calculation in the period 2015-2019 (calculated per 1 ha)

Given the Chart 1, it can be seen that the highest value of production, variable costs and gross margin were achieved in 2016. The lowest value of production and gross margin were recorded in 2018, whereas the lowest variable costs were achieved in 2015.

Table 1 Financial indicators of watermelon production in the period 2015-2019 (calculated for 1 ha)

Year	2015	2016	2017	2018	2019
Value of production (RSD)	1,101,333.33	1,476,375.00	1,153,000.00	1,048,750.00	1,391,600.00
BI* (%)	-	134.05	104.69	95.23	126.36
CI**(%)	-	134.05	78.10	90.96	132.69
Variable costs (RSD)	264,673.90	337,704.38	288,400.36	281,750.31	323,408.50
BI* (%)	-	127.59	108.96	106.45	122.19
CI**(%)	-	127.59	85.40	97.69	114.79
Gross margin (RSD)	836,659.43	1,138,670.62	864,599.64	766,999.69	1,068,191.50
BI* (%)	-	136.10	103.34	91.67	127.67
CI**(%)	-	136.10	75.93	88.71	139.27
Share of gross margin in the value of production (%)	75.97	77.13	74.99	73.13	76.76

*BI – base indices
**CI – chained indices
Source: Authors' analysis based on the data from the selected family farms surveyed by the IPN

Table 1 shows the most significant financial indicators from a variable cost calculation of watermelon production in the period 2015-2019 (calculated for 1 ha). The highest value of production was recorded in 2016, amounting to 1,476,375.00 RSD/ha, whereas the lowest value was recorded in 2018, and it amounted to 1,048,750.00 RSD/ha. Given the indicators calculated based on base and chained indices, it can be seen that in 2016 the value of production increased by 34.05% compared to 2015, which is the highest increase in the value of production in the period in question. In 2017, the value of watermelon production was 4.69% higher than in the base year, but 21.90% lower than in the previous year. In 2018, the value of production decreased further more, about 4.77% compared to the base year and 9.04% compared to the previous year. In 2019, the value of production was at the similar level as in 2016, i.e. it was 26.36% higher than in the base year and 32.69% higher than in the previous year.

The movement of the variable costs has shown a similar tendency. The lowest variable costs were recorded in 2015, amounting to 264,673.90 RSD/ha, whereas the highest variable costs were recorded in the following year (2016), amounting to 337,704.38 RSD/ha. As the indicators calculated from base and chained indices have shown, the biggest changes happened in 2016, when the variable costs were 27.59% higher than in the previous year. In 2017, the variable costs were 8.96% higher than in the base year, but 14.60% lower than in 2016. In 2018, the similar amount of variable costs was recorded, slightly lower than in the previous year (2.31%). Furthermore, in 2019, the variable costs were 22.19% higher than in the base year and 14.79% higher than in the previous year.

The highest gross margin was generated in 2016, amounting to 1,138,670.62 RSD/ha, when also the highest value of watermelon production was achieved. The lowest gross margin was generated in 2018, amounting to 766,999.69 RSD/ha. The indicators obtained from a calculation of base indices have shown that the gross margin mostly increased over the analyzed years, except in 2018, when it was 8.33% lower than in the base year. In 2016, the gross margin was 36.10% higher than in the base year. The gross margin in 2017 was 3.34% and in 2019 it was 27.67% higher than in the base year. The indicators obtained from a calculation of chained indices have shown that in 2016 the gross margin increased 36.10% compared to the previous year and in 2019 it increased 39.27% compared to 2018. In the last two years there was a decrease in gross margin compared to the previous years, by 24.07% in 2018 and 26.87% in 2018.

The indicator of farm profitability expressed as the share of gross margin in the value of production did not change significantly over the analyzed period (2015-2019), averaging about 75%. The highest share was in 2016 (77.13%) and lowest in 2018 (73.13%). Accordingly, it can be concluded there are no significant changes, i.e. the value of production increase at the same rate as variable costs so the share of gross margin in the value of production is similar in each analyzed year.

The sale price for watermelon has shown some minor oscillations. It ranged from 21.13 to 27.13 RSD/kg. The lowest price was recorded in 2015 and 2018 (21.13 RSD/kg), and highest in 2016 (27.13 RSD/kg). In 2017 and 2019, watermelon price averaged to 22.86 RSD/kg, and 25.80 RSD/kg, respectively.

The sensitivity analysis of gross margin in watermelon production in the Republic of Serbia in the period 2015-2019 shows how gross margin changes when watermelon price and yield change. The sensitivity analysis took into consideration absolute changes in watermelon price and yield if those parameters change for 10% and 20%.

Table 2 Sensitivity analysis of gross margin in watermelon production on changes in watermelon price and yield

Yield (kg/ha)		Price (RSD/kg)				
		-20%	-10%	Average	+10%	+20%
		18.89	21.25	23.61	25.97	28.33
-20%	38,843.77	522,328.57	614,038.70	705,748.84	797,458.98	889,169.11
-10%	43,699.24	614,038.70	717,212.61	820,386.51	923,560.41	1,026,734.32
Average	48,554.71	705,748.84	820,386.51	935,024.18	1,049,661.85	1,164,299.52
+10%	53,410.18	797,458.98	923,560.41	1,049,661.85	1,175,763.29	1,301,864.72
+20%	58,265.65	889,169.11	1,026,734.32	1,164,299.52	1,301,864.72	1,439,429.93

Source: Authors' analysis based on the data from the selected family farms surveyed by the IPN

Based on the survey questionnaires on gross margins in the period 2015-2019 collected from farms with prevailing watermelon production, the researchers calculated the average price, average yield and average gross margin in watermelon production. The average watermelon price in this five-year period was 23.61 RSD/kg, average yield was 48,554.71 kg/ha, whereas the average gross margin amounted to 935,024.18 RSD/ha. If watermelon price and yield decreased by 20%, it would lead to a significant decrease in gross margin (for about 44%), while an increase of 20% in watermelon price and yield would result in an increase of about 54% in gross margin. It can be concluded that changes in watermelon price and yield significantly affect gross margin in watermelon production.

4. CONCLUSION

Watermelon production has been carried out on more-less similar acreages (about 6,000 hectares), with minor annual oscillations. On the other hand, although the acreage of the areas under watermelon do not oscillate, the total production of watermelon has significantly varied over years due to great changes in average yields. The highest average yield was achieved in 2015 (35.40 t/ha), and lowest in 2019 (28.60 t/ha). This difference of almost 7 t/ha significantly affected the total production of watermelon in certain analyzed years. The gross margin in the analyzed period oscillated. In three years (2015, 2017 and 2018) it amounted to about 800,000 RSD/ha, whereas in 2016 and 2019 it achieved highest amounts of about 1,100,000 RSD/ha. These two years were also the years when the sale price for watermelon was highest. The watermelon price in 2015, 2017 and 2018 was about 21 RSD/kg, and in 2016 and 2019 it was about 26 RSD/kg. The sensitivity analysis shows that an increase in watermelon price and yield of 20% would also increase gross margin by 54%, whereas a decrease in price and yield by 20% would decrease gross margin by 44%. When it comes to the structure of variable costs in watermelon production, the largest portion comprise seed costs (38.64%) and fertilizer costs (23.26%).

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OFFICINAL PLANTS: AN OPPORTUNITY FOR SOCIO-ECONOMIC DEVELOPMENT IN BASILICATA

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Abstract: *For some years, consumers have been buying more genuine and healthy products and they are more attentive to environmental protection, therefore they are more likely to use natural products, including Officinal Plants (OP), for nutritional, aesthetic and therapeutic purposes.*
Also in Basilicata, a region of southern Italy, there is a growing attention towards OPs. In the last ten years, implementing the European policy objectives, the Rural Development Plans of Basilicata have activated innovative processes aimed at increasing the competitiveness and sustainability of the supply chains and at increasing and enhancing production. The transnational cooperation project MEdicinal PLAnts in a SUstainable Supply chain. Experience of land use practices (MEPLASUS) fits into this logic of sustainability, it involves the production of OPs according to innovative supply chain models and circular economy able to promote competitiveness, including the economic and social aspects, of OP producers and processors, through the creation of full integration between the world of research and the world of production.

Key words: *minor crops, sustainable supply chain, circular economy, energy efficiency, competitive production, quality products*

1. INTRODUCTION

The change in the lifestyle of consumers, for over a decade oriented towards the consumption of genuine and healthy products and more attentive to environmental sustainability, has led to the rediscovery of knowledge, traditions and ancient flavours like Officinal Plants (OP).

The Italian binomial "officinal plants" identifies a multitude of botanically very different plant species, being **arboreal** plants, such as laurel, lemon or eucalyptus, **shrubby**, such as rose or juniper, and, as in most cases, **herbaceous** (chamomile, iris, balm-mint, valerian, verbena, lavender, saffron, etc.) (see Photo 1), and, consequently, also different from an agronomic point of view. For this particularity, the OPs are included in a transversal class and it is estimated that it includes between 20,000 1. and 100,000 2. botanical species 3.. These are spontaneous and/or cultivable plants, but all united by having substances with sensory, biological and pharmacological properties.

The officinal plant as such is to be considered a "primary product" art. 2, paragraph 1, letter b) - Reg. (EC) No. 852/2004. therefore, with the exception of aromatic plants sold fresh for consumption, they must be adequately processed to be used 4, 3..

The term "officinal", in fact, commonly adopted in Italy, derives from the Latin *officina*, which means laboratory, indicating the room in which the plants were processed (dried, ground, macerated, pressed for the extraction of the essences, etc.); this definition, however, is not reflected either in official statistics or in the terminology used in other Countries where, on the basis of their main uses, these plants are classified as medicinal, aromatic and perfumed. The same classification is officially valid also in Italy (law n.99 of January 6, 1931). In particular, the Italian National Institute of Statistics (ISTAT) in the censorship of agricultural data refers to a single category that includes aromatic plants, medicines, spices and condiments.

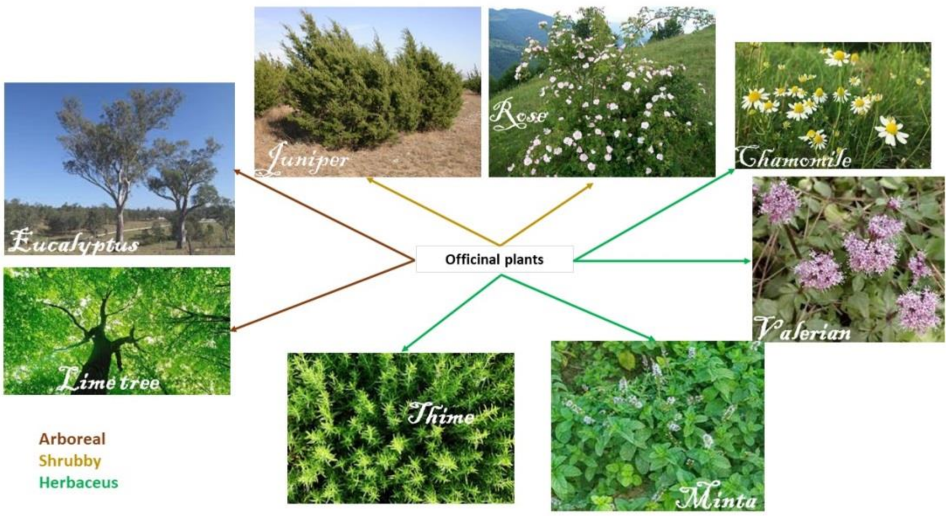


Photo 1 Some Officinal Plant species

In 1980 in Beijing, the World Health Organization defined a medicinal plant as any vegetable that contains, in an organ, or in several organs, substances that can be used for therapeutic purposes or that are the precursors of chemo-pharmaceutical hemisynthesis 5.. The Italian Official Pharmacopoeia and the European Pharmacopoeia, with the term medicinal plant, on the other hand, generally refer to whole, fragmented or cut plants, parts of plants, algae, fungi, lichens in the untreated state, generally in dried form, but sometimes fresh.

The recent legislative decree n. 75 of 21 May 2018 - The Consolidated Law on the cultivation, harvesting and first processing of medicinal plants introduced new rules for the cultivation, harvesting and first processing of OPs, considered to all intents and purposes agricultural activities, and it provided for the establishment a "Register" listing the varieties admitted to marketing.

OPs are very important from an ecological point of view as they participate in the conservation of plant and animal biodiversity; during the flowering period their showy colouring (see photo 2) attracts numerous pollinating insects, such as bees and bumblebees which, in turn, play an irreplaceable role in maintaining the environmental balance and agricultural production itself. From medicinal plants we obtain a wide range of products (fresh and dried herbs, fruits, flowers, essential oils, extracts, etc.) that can be used in or as food, food supplements, liqueurs, cosmetics (currently Italy is the first user of medicinal herbs for this sector 6.) drugs, feed and veterinary products, products for the dyeing and tanning industry, crop protection products and household products.

Photo 2 Lavender field (left), saffron field (right)

Besides Italy, the major producers in the Mediterranean basin of medicinal and aromatic cultivable plants are: Albania, Bulgaria, France, Croatia, Greece, Bosnia-Herzegovina and Montenegro (up to internal Serbia), Slovenia, Spain, Turkey, Egypt, Morocco and Tunisia 7..

Italy is in the Top-5 of European producers of medicinal plants, in a ranking where Poland, Bulgaria and France stand out from all other areas 6.. In fact, since the beginning of the millennium, Italy has tripled the production and export of some medicinal plants while it has doubled the import of other medicinal plants and the trade in spices and aromatic plants. It is estimated that the national market for medicines alone - over 120 cultivated species, 300 traded ones, including imports - is worth around 750 million. Amount that exceeds 6 billion dollars on a global scale 6..

Growing attention to OPs is also recorded in Basilicata, a region that boasts over 400 species of indigenous medicinal herbs 8., cultivated and spontaneous herbs, which characterize many landscapes, represent good productive realities and are an essential element of food and gastronomic local traditions, linking to the history and culture of numerous places.

Already in the decade 2000-2010 (ISTAT) 9., following the national trend, also in Basilicata there was a decrease of 83.3% in the number of companies (more than -29% at national level) to which contrasts with the 51.9% increase in dedicated area (+ 216.3% national data) which indicates a significant increase in the average area per farm, from 0.26 to 2.36 hectares, just below the national average (equal to 2.45 ha / farm).

Attention to OPs continues to grow as shown by the monitoring data carried out by Lucanian Development Agency for Innovation in Agriculture (ALSIA Basilicata) in 2019 (pending the data collected by ISTAT with the 7th Agricultural Census of the year 2020) which highlighted a positive trend by estimating significant increases both in the number of farms (over 400%) and in the cultivated area (about 239%).

Furthermore, the Lucanian OP market is constantly evolving to respond to request of various kinds (protection of biodiversity, nutrition, sustainability, multi functionality, pharmaceuticals, etc.); it follows diversified development paths to produce plants for fresh consumption or spices or essences for the preparation of liqueurs or essential oils for cosmetics. In many cases the raw material is produced according to organic farming practices and this is a further input that gives an interesting economic impact to the farms involved. The knowledge of the energy efficiency of a production cycle, instead, it would be a further strength on behalf of the environmental sustainability.

2. THE LUCANIAN OP MICRO-CHAIN

The reconstruction of the regional OP chain was carried out on desk on the basis of the databases prepared by the research bodies involved. The Authors referenced to the regional monitoring and evaluation documentation of the RDP 2007-13 and 2014-2020, to the in-depth studies on biodiversity and innovation with telephone checks and virtual meetings with numerous subjects who operate in the sector in order to reconstruct the activities and aggregative processes in progress.

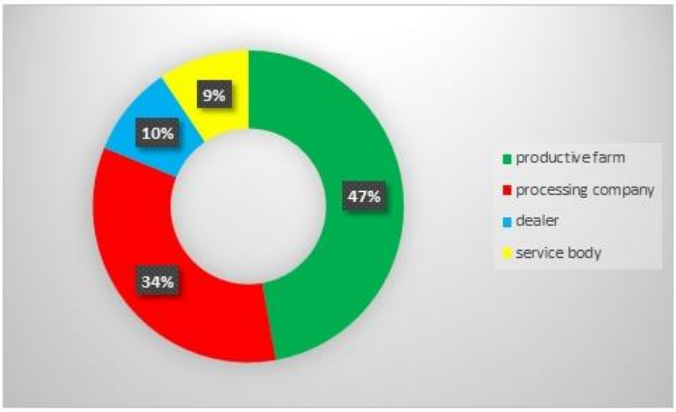
The involvement of Lucanian farmers in the development of the drug supply chain is linked to their knowledge and to the synergistic action carried out by national and regional research bodies operating both in the field of experimentation and research. Among these the Council for Agricultural Research and Economics - Research Centre for Agricultural Policies and Bioeconomy (CREA-PB), the ALSIA and the University of Basilicata – Department of Science which have enabled the Lucanian micro-chain from a production, technological and organizational point of view, in agreement with the National OP Table.

Over the last few years, the multiplicity of development actions and investment projects (in individual and aggregate form) of a regional and national nature has allowed the OP sector to respond, with the necessary quality, to the various requests coming from the markets.

In Basilicata there are 10.:

- the Sud-Officinale Cooperative of Irsina (province of MT), with 16 hectares of irrigated land in the Bradano river plain at about 120 meters above sea level; it is the national leader in the production of medicinal plants from certified organic and biodynamic agriculture. The plants grown by Sud Officinale are processed (extraction of essential oils) and marketed by the Bioplanta company;

- the Lucana Officinali Society Cooperative, established in 2016, has about 70 hectares of surface, located mainly in the protected area of the Pollino National Park, certified according to the ISO 22005 standard for traceability of the supply chain which provides for the application of integrated agriculture;
- the company EVRA Italia srl, of Lauria (province of PZ) works both cultivated and spontaneous plants. Here, active ingredients are extracted and thirty species of OP are transformed into products of good quality, in some cases rewarded, with positive effects on the farmers who supply the product. Currently EVRA transforms the whole production of the Lucana Officinali Soc. Coop.;
- the F.L.E.O. partnership (53 partners, 3 of which are public) (Graph 1) aims to stimulate and encourage the creation of a stable network among companies that produce, process and transform medicinal herbs, operating throughout the entire region, above all into Lagonegrese-Pollino area. The partnership operates along two distinct lines, the first involves the production and transfer of the OPs to the company Lucano 1894 s.r.l., producer of the well-known Amaro Lucano whose recipe includes the presence of numerous Lucanian officinal herbs. The companies that follow the second line, on the other hand, produce seasoning plants and deliver them to the SpeSì distribution centre which, after processing, also carried out thanks to machinery purchased with financing (PSR Basilicata 2014-2020 Measure 4.2), brings them to the market through small and medium distribution with the SpeSì brand;
- the Orti Lucani Piante Officinali business network (O.L.P.O.) was born in 2017, thanks to the aggregation of about 270 companies; its aim is to provide incentives for cultivation of OPs and to increase the innovative and competitive capacity of the participating companies through their collaboration, the sharing of information, the carrying out of joint activities, the exchange of services and the joint exercise of one or more activities.



Graph 1 F.L.E.O. partnership

Source: Authors' elaboration on project data

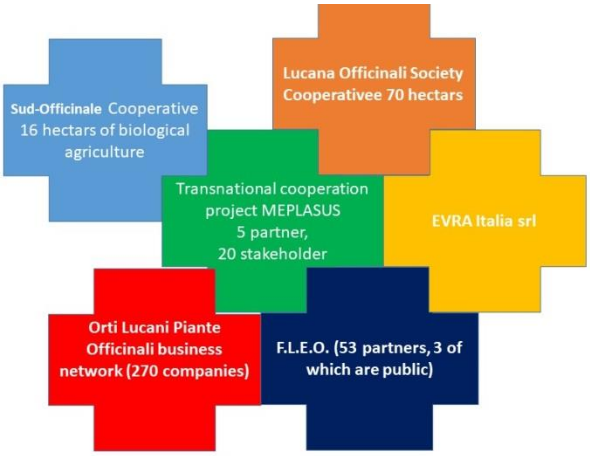


Figure 1 The components of the Lucanian OP micro-chain

In order to strengthen the reality of the OPs, the networks have been expanded by involving Serbian and Greek partners (research bodies) and stakeholders (farms and processing companies) to the exchange on knowledge on research, technological innovation and digitalization of the economy. Italian, Serbian and Greek stakeholders are involved along the entire micro-chain value chain trough the exchange of good agricultural practices and knowledge also in the production of new commercial products. This new network is called MEPLASUS, a transnational cooperation project on MEdicinal PLAnts in a SUstainable Supply chain - Experience of land use practices, approved by the Basilicata Region in December 2020. MEplasus foresees the enhancement of the OP supply chain according to innovative models including circular economy and reuse of production and processing waste (development of new "green" products, practices, processes and technologies). Therefore, all productive inputs, collected and classified as renewable and non-renewable energy inputs, of some medicinal plant species will be analysed from a sustainability perspective.

3. CONCLUSION

The OPs characterize many Mediterranean landscapes. In Basilicata region the OP market has been growing, in the last decade, certainly thanks to the increased demand for products by consumers to satisfy the health and well-being sphere. In fact, there is the rediscovery of ancient flavours, knowledge and traditions that induce consumers to use natural products, including PO, for food purposes, because they are present in local gastronomic traditions, but also for therapeutic and aesthetic purposes, binding themselves to history and the culture of the places.

The Lucanian OP sector still occupies a niche place, but the various research projects, the bottom-up actions and the exchange of experiences can bring out and enhance all the existing potential and develop an important sustainable supply chain capable of impacting the economy regional, and beyond. A sustainable production according to circular economy models and energy efficiency analysis lets to generate new jobs and therefore the economic and social growth of various regional inner areas. Moreover, the possibility of offering, in the field of rural tourism and/or agri-tourism, innovative services such as walks among the PO flowerbeds (aromatherapy, chromatic therapy), herbal tea tasting or treatments for wellness, relaxation and body care with cosmetics, also based on oils and/or OP extracts, would be a source of further economic development.

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