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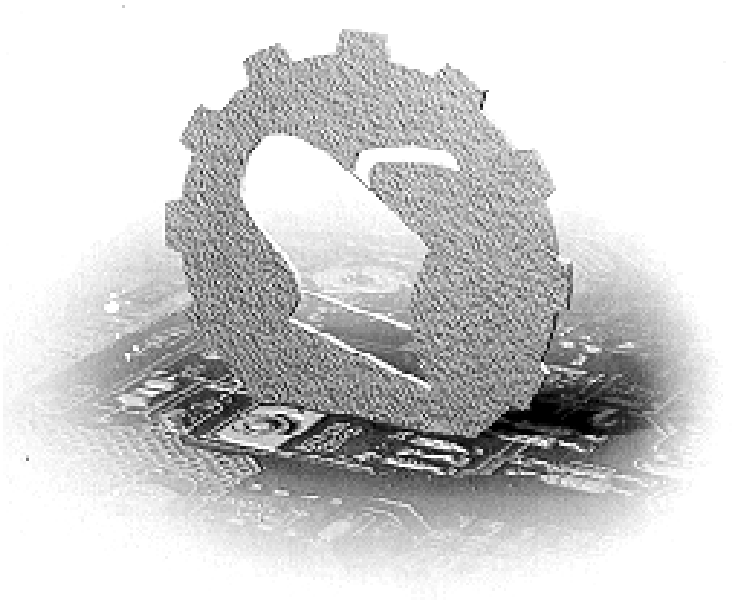

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EFFECT OF HEAT-TREATMENT UNDER CHANGEABLE APPLIED LOAD ON WEAR RESPONSE OF AGRICULTURAL GRADE MEDIUM CARBON STEEL: A MULTIPLE RANGE ANALYSIS

Dushyant Singh[*1], K.P. Saha[1], Dehi Pada Mondal[2]

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Abstract: Low alloy medium carbon steels have tremendous potential for agricultural application because of its low cost and obtaining excellent combination of various properties after heat treatment. In the present study abrasive wear response of medium carbon steel used for soil working components of agricultural implements i.e. rotavator blade, cultivator sweep, plough share etc. was studied under three heat treatment processes and three load conditions. Micro structural, mechanical, and tribological properties of medium carbon SAE-6150 steel were altered by annealing, inter-critical annealing and quenching and tempering heat-treatment processes. A rotating rubber wheel type test apparatus was used to measure the wear rate of heat-treated and control specimen at 75, 200 and 375 N loads. This technique of wear measurement is very similar to working condition of soil working components of agricultural implements. The study revealed that under low load (75 N) condition, both the inter-critically annealed and quenched and tempered SAE-6150 medium carbon steels gave identical wear resistance. However, inter-critically annealed material under medium load (200 N) condition and quenched and tempered material under high load (375 N) condition exhibited supremacy in terms of abrasive wear resistance.

Key words*: soil working components, mechanical properties****,*** *heat-treatment cycle, abrasive wear, DMRT*

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INTRODUCTION

Most of the fast wearing components of agricultural machines like plough share, cultivator sweep, rotavator blade, weeder blade, thresher pegs are made up of various grades of medium carbon steel. High strength and abrasive wear resistance is primary requirement for these components to overcome abrasive wear, fatigue and chemical reaction during operation. Micro-structural examination of various working components of agricultural machines revealed that most of these components were not properly heat-treated [10]. Formation of ferrito-martensitic structure and tempered martensitic structure in the steel during heat-treatment process provides extremely excellent combination mechanical as well as tribological properties [7-9]. Heat-treatment process especially quenching and tempering is a commonly used popular method to improve the wear resistance and hardness of agricultural implements [7,9]. Apart from different heat-treatment processes, various surface modification technologies such as diffusion processes like carburising, nitriding, boriding [2], coatings [4] as well as hard facing [1,3] and shot peening [6,7] have been tried by various researchers to alter the properties of the materials. All above-mentioned treatment changes the micro-structural constituents of the material, which leads to change in hardness that follows a linear relationship with the wear rate in most of the cases. Some of these surface modification techniques, used to overcome the wear situation in agricultural engineering application, are cheaper but these are effective up to a certain depth. As the effective depth is worn out, the specimen behaves like the parent specimen [7]. The medium carbon steel like SAE-6150 after application of heat-treatment gave better wear resistance in rotavator blades among other steels used for agricultural application in India which was also techno-economically viable [11]. Wear rate at the same time is highly influenced by the applied load and sand particle size used to induce abrasive wear on the specimen [5]. Soil working components of various agricultural machineries usually work under different soil conditions having variable soil resistance or draft. Hence, evaluation of influence of heat-treatment processes in medium carbon low-alloyed agricultural grade steel under different system of applied load is very crucial. This will be helpful to determine the appropriate heat treatment process to be given to the material of these components engaged in different farm operations exerting distinct load on them so that the cost incurred for heat treatment can be minimized.

MATERIAL AND METHODS

Present study was conducted at Central Institute of Agricultural Engineering (CIAE), Bhopal, India during 2009-10. In this study a low alloyed medium carbon steel (SAE-6150) most common used for fast wearing components of agricultural machinery containing 0.52% C, 0.22% Si, 0.70% Mn, 1.0% Cr, 0.17% V, 0.025% S and balance Fe was used. This steel was undergone three heat-treatment process at Indo-German tool room Indore. German made double chamber furnace was used for austening the specimen at 870^0C for two hours. In case of inter-critical annealing the specimens after socking two hours were shifted to second chamber at 777^0C for 30 minutes. For annealing the specimen were allowed furnace cooling and others were quenched in circulating water and 8% NaCl solution for uniform heat flow. Tempering of these

specimens was carried out at 250^0C for two hours in German made fluidized bed furnace for maintaining the uniformity of properties in the steel specimen. The hardness and mechanical properties of control and heat-treated specimens were measured using Vicker's hardness tester and universal testing machine. The control and treated specimens were examined for their micro-structural characterization using Scanning Electron Microscope (SEM) at Advanced Materials and Processes Research Institute, Bhopal as per standard procedure. Rotating rubber wheel (having 12.7 mm thickness and 177.8 mm diameter) type dry sand apparatus was used to study the wear behaviour of control and treated specimens of 76.2 mm X 25.4 mm X 8 mm size as per ASTM G-65 standard. Initially polished specimens were used and subsequent tests were conducted on pre worn surfaces of the specimens. This process was repeated to obtain steady state value of the wear rate. The specimens were tested using dry crushed silica sand particles of 212-300 μm at the rate of 370 g/min for abrasion on the stationary specimen's surface pressed against the rotating rubber wheel as depicted in Fig.1. During the testing the speed of rotating rubber wheel was maintained at 100 rpm (1.86 $m \cdot s^{-1}$ linear velocity) with three loads (75, 200 and 375 N). This test methodology is very similar to the working condition of soil engaging components of agricultural machinery.

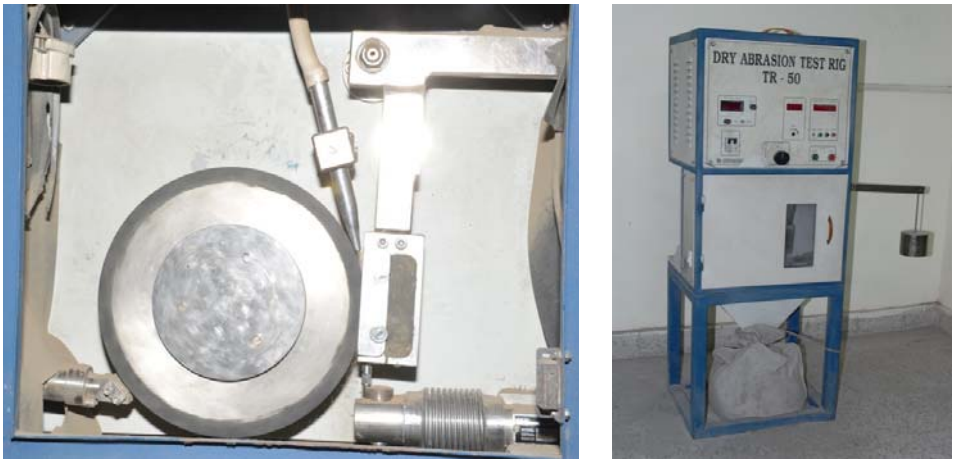

Figure 1. Rubber wheel /dry sand abrasion test apparatus

The experiment was laid out by following factorial completely randomized design with two factors namely, heat treatment process with four levels and applied load with three levels to find out the effect of heat treatment processes and applied load as well as their interaction on wear response of medium carbon steel for indicating the most suitable heat treatment process under different load regimes so as to minimize the cost incurred for heat treatment. Similar multi-factor analysis of variance technique to work out the least significant difference (LSD) was also adopted by [5] for finding the effect of individual as well as interacting factors influencing the grain yield of winter wheat. However, moving a step further we applied Duncan's Multiple Range Tests (DMRT) to the means to critically scrutinize the behaviour of different heat treated materials under varying load applied on them.

RESULTS AND DISCUSSION

The average hardness, ultimate tensile strength, percentage elongation and volume fraction of micro constituents of the examined steel i.e. Control and heat-treated is depicted in Tab. 1. These results indicate that the control and annealed specimen; inter-critically annealed and quenched & tempered steels have almost identical mechanical properties and microstructural constituents.

Table 1. Properties of SAE-6150 steel undergone various heat-treatment processes

Heat-treatment	*Phase %*	*Hardness (HV)*	*Ultimate tensile strength [N·mm^{-2}]*	*Percentage elongation*
Control	*86% pearlite and remaining ferrite*	*150*	*858*	*7*
Annealed	*80 % pearlite and remaining ferrite*	*130*	*785*	*11*
Inter-critical annealing	*85% tempered martensite and remaining ferrite*	*471*	*1390*	*6*
Quenching & tempering	*96 % Tempered martensites and remaining retained austenite*	*498*	*1450*	*4*

The micro-constituents of control and annealed specimens are 86% pearlite, 14 %ferrite and 80 % pearlite, 20 % ferrite respectively. These steels are almost identical only the percentage of ferrite is increased by about 6 % when the steel under gone annealed process as compared to control. Hardness of control and annealed steel is 150 HV, 130 HV respectively; the ultimate tensile strength and percentage elongation are also almost similar in these two specimens. On the other side inter-critical annealing and quenching & tempering also depict similar behaviours. The ICA steel contains 85% tempered martensite and 15 % ferrite, whereas QT condition depicted tempered martensites with 4-5% retained austenite. The martensitic structure is relatively harder in comparison to ferritic and pearlitic, so the hardness of the heat-treated specimen increases with increase the martensite content. After inter-critical annealing or quenching & tempering process the hardness of the specimen was 471 and 498 HV i.e. more than threefold of the hardness of the control specimen and ultimate tensile strength of the steel increased to three fold to the control and annealed specimen.

Effect of sliding distance, heat-treatment and applied load on abrasive wear

The wear rate of control as well as heat-treated specimen as a function of sliding distance at 375 N load is examined in Fig. 2(a). This figure depicts that the wear rate reduces in uniformity with the sliding distance due to continuous work hardening (plastic deformation) during the abrasion process and finally reaches to the stable value. Annealed steel has lower hardness but more capacity to work hardening due to releasing the residual stresses; it becomes more ductile than the control. It retains wear debris for long duration and the chips/flakes are not easily removed from the surface of the

specimen. The wear rate of control and annealed are comparable irrespective of the sliding distance; it is reduced substantially 60-75 % in case of inter-critical annealing and quenching & tempering process. This reduction is due to generation of harder phase of micro-structure i.e. ferrito-martensite or tempered martensite in case of inter-critical annealing or quenching and tempering process, which controls the penetration and scratching ability of the hard abrasive on the specimen surface. There structures exhibit excellent combination of strength and toughness to control the by the sand particles from the specimen surface. Similar trend is obtained when the specimens were tested at lower loads i.e. 75 and 200 N loads. The wear rate of differently heat-treated specimen as a function of applied load is depicted in Fig. 2(b).

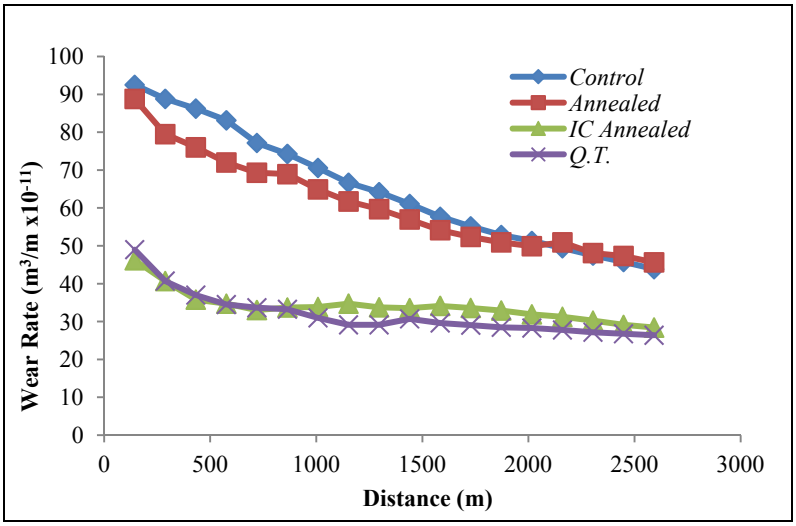

Figure 2(a). Wear rate as a function of sliding distance

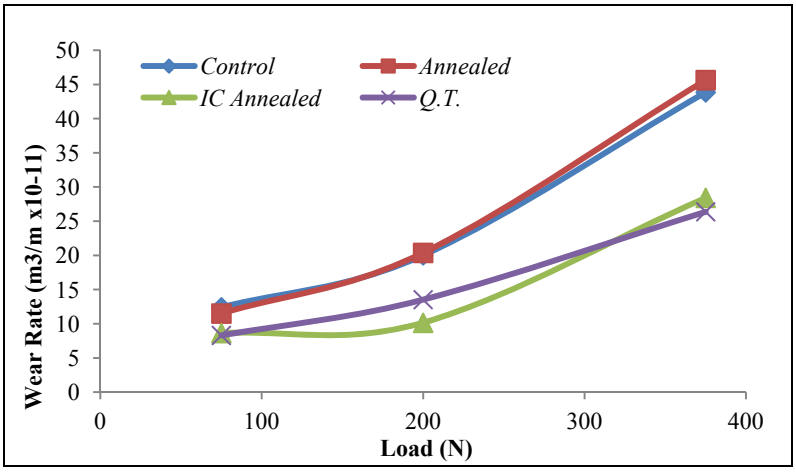

Figure 2(b.) Wear rate as a function of applied load

It is evident from this figure that wear rate increases with applied load irrespective of heat-treatment schedule. As explained earlier on the base of wear rates are these heat-treatments classified in two categories in formal category control and annealed specimen and in latter category inter critical annealed and quenching & tempering. The former category exhibits significantly higher wear rate than that of later category at all applied loads. This signifies that microstructure and mechanical properties have significant effect on wear behaviour of the steel specimens. This figure shows that at higher applied load the trend of wear rate changes i.e. the wear rate of quenched and tempered steel reduces than that of inter critical annealing because of transformation of retained austenite in to tempered martensitic structure because of generation of high heat due to fraction.

The effect of heat treatment and applied load on wear rate of medium carbon steel (SAE-6150) has been described in Tab. 2. It was observed that there was insignificant reduction in wear rate in annealed specimens as compared to control specimens. These two specimens have almost identical microstructure and mechanical properties. The hardness of annealed specimen is slightly lower than the control that is compensated by the removal of residual thermal stresses. However, the wear rate reduced significantly when the specimens were subjected to inter-critically annealing and quenching and tempering treatments, because of generation of harder phase during the heat-treatment process. But, the difference in wear rate between these two treatments was found again insignificant because in both the cases formation of ferrito-martensitic and tempered martensitic structure gives excellent combination of toughness and ductility, which reduces the penetration or scratching ability of the hard abrasives during the wear test.

Table 2. Effect of heat treatment and applied load on wear rate of SAE-6150 steel

Factors of experiment	*Wear rate*	*Least significant difference at 5% level of significance*	*Standard error of mean*
No heat treatment (Control)	*25.826*	*0.651*	*0.223*
Annealed	*25.414*		
Inter-critically annealed	*15.728*		
Quenched and tempered	*16.075*		
Under low load (75 N)	*10.213*	*0.564*	*0.193*
Under medium load (200 N)	*16.008*		
Under high load (375 N)	*36.061*		

Table 3. Analysis of variance for factorial experiment

Source of variation	*Sum of squares*	*Degree of freedom*	*Mean sum of squares*	*F-ratio*	*Coefficient of variation (%)*
Heat Treatment	*851.324*	*3*	*283.775*	*633.550****	*3.224*
Load	*4415.018*	*2*	*2207.509*	*4928.445****	
Heat Treatment x Load	*324.831*	*6*	*54.138*	*120.868****	
Residual	*10.749*	*24*	*0.448*	-	
Total	*5601.923*	*35*	-	-	

*** = Significant at 1% level

The analysis of variance for different factors and their combination influencing the wear rate of medium carbon steel (SAE-6150) showed that all the factors and their combinations were significantly controlling the wear rate in the material under study (Tab. 3). As shown in earlier table, the heat treatment processes exert a distinctive and polarized effect on wear rate because after heat-treatment the steel specimens depict two categories i.e. poor combination of microstructural and mechanical properties i.e. control and annealed specimen and excellent combination such as inter-critical annealing and quenching & tempering whereas; the applied load demonstrated a linear influence on wear rate because during abrasion testing, increase in applied load increases the depth of penetration which leads to more removal of material from the specimen i.e. more wear rate.

Table 4. Duncan's multiple range test for heat treatment under different load

Load condition	*Heat treatment*	*Wear rate*	*Rank obtained*	*Least significant difference at 5% level of significance*	*Standard error of mean*
Under low load (75 N)	*No heat treatment (Control)*	*12.404*	*fg*	*1.128*	*0.387*
	Annealed	*11.500*	*g*		
	Inter-critically annealed	*8.632*	*i*		
	Quenched and tempered	*8.317*	*i*		
Under medium load (200 N)	*No heat treatment (Control)*	*20.003*	*e*		
	Annealed	*20.360*	*e*		
	Inter-critically annealed	*10.140*	*h*		
	Quenched and tempered	*13.530*	*f*		
Under high load (375 N)	*No heat treatment (Control)*	*43.835*	*b*		
	Annealed	*45.618*	*a*		
	Inter-critically annealed	*28.412*	*c*		
	Quenched and tempered	*26.378*	*d*		

Duncan's Multiple Range Test (DMRT) was applied for distinguishing the treatment combinations according to their rank to identify treatments for maximum wear resistance. It was observed that under low load condition, both inter-critically annealing and quenching and tempering emerged out as the maximum wear resistance inducing treatments for medium carbon steel (SAE-6150). Both the steel specimen have excellent combination of microstructural and mechanical properties, which reduces the penetration of hard sand particles and during low load application, the force exerted on the sand particle for penetration or scratching also low that leads to minimum wear rate or maximum wear resistance. However, under medium load condition inter-critically annealing was the most desirable treatment for reduction of wear rate for the same

material showing a significant improvement in wear rate as compared to quenched and tempered steel.

Generation of ferrito-martensitic structure in intercritically annealed steel depicts excellent combination of toughness and ductility, whereas, martensitic structure of quenched and tempered steel is more brittle in comparison to ferrito-martensitic structure. This leads to more cutting and fragmentation from the specimen surface during wear. With further increase in applied load, the wear resistance behaviour in medium carbon steel showed significant transformation as the quenched and tempered steel showed the best wear resistance revealing significant improvement in reduction of wear rate as compared to inter-critically annealed steel. At higher applied load i.e. 375 N, due to higher fraction the surface temperature increases very high and its effect at the point of contact is again very high that leads to transformation of retained austenite to martensite and at high temperature the brittleness of the steel again reduces and lesser tendency for fragmentation contributes towards reduction in wear rate of quenched and tempered steel when tested at higher applied load.

Therefore, the study indicates that both the inter-critically annealed and quenched and tempered medium carbon steel can be selected as material for manufacturing the components which are subjected to soil resistance typically for conducting farm operations like deep ploughing in summer in heavy clay soils but inter-critically annealed material should be preferred for farm operations like deep trench making for irrigation. However, for farm operations involving very high draft like digging of well, using of quenched and tempered material is the only option for manufacturing of working components.

CONCLUSIONS

The process of heat-treatment applied to medium carbon steel determines its micro-structural, mechanical and tribological properties to a great extent. Treatments such as quenching and tempering as well as inter-critically annealing of medium carbon steel result into greater hardness with desirable mechanical properties which lead to superior abrasive wear resistance as compared to that of controlled and annealed steel. However, the heat-treatment process should be selected according to the load applied on the working components. Therefore, it is suggested that the soil working components of agricultural machinery may be appropriately heat treated for better resistance to abrasive wear and enhanced service life.

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UTICAJ TOPLOTNOG TRETMANA POD PROMENLJIVIM OPTEREĆENJIMA NA HABANJE RADNIH ORGANA OD SREDNJE UGLJENIČNOG ČELIKA: ANALIZA VIŠE OPSEGA

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2Institut za unapređene materijale i procesna istraživanja, Bhopal, India

Sažetak: Nisko legirani srednje ugljenični čelici imaju značajan potencijal za upotrebu u poljoprivredi zbog svoje niske cene i postizanja odlične kombinacije različitih svojstava posle toplotnog tretmana. U ovom istraživanju je proučavano abrazivno habanje srednje ugljeničnog čelika od koga su izrađeni radni organi priključaka za obradu zemljišta, kao što su nož roto sitnilice, motičica kultivatora, raonik pluga i sl., posle tri toplotna tretmana i u uslovima tri nivoa opterećenja. Mikro strukturne, mehaničke i tribološke osobine srednje ugljeničnog čelika SAE-6150 su izmenjene žarenjem, inter-kritičnim žarenjem sa naglim hlađenjem i toplotnim tretmanom površinskog kaljenja. Uređaj sa testiranje sa rotacionim gumenim točkom je

upotrebljen za merenje stepena habanja toplotno tretiranog i kontrolnog uzorka pod opterećenjima od 75, 200 i 375 N. Ova tehnika merenja habanja je veoma slična radnim uslovima u kojima se nalaze radni organi priključaka za obradu zemljišta. Istraživanje je pokazalo da pod malim opterećenjem (75 N) i inter-kritično žaren pa naglo hlađen i pogvršinski kaljen srednje ugljenični čelik SAE-6150 daje jednak otpor habanju. Ipak, inter-kritično žareni material pod srednjim opterećenjem (200 N) i hlađeni i kaljeni material pod visokim opterećenjem (375 N) pokazali su najveće otpore abrazivnom habanju.

***Ključne reči**: radni organi za obradu zemljišta, mehanička svojstva, ciklus toplotnog tretmana, abrazivno habanje, DMRT*

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COMPACTION CHARACTERISTICS OF SOME AGRICULTURAL SOILS IN NIGER STATE OF NIGERIA

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Abstract: The movement of farm tractors and other heavy duty machineries leads to soil compaction. The dry density, penetration resistance and hydraulic conductivity are seriously influenced as a result of this, thus affecting plant physiology. In this study, soil samples were collected from three locations in Niger state, Nigeria namely Gidan kwano, Maikunkele and Maizube farms. Particle size analysis showed the textural class of the soils as sandy clay loam, loamy sand and clay loam, respectively. Atterberg limits of the soils samples were determined using the consistency test. The soils were characterized for their compaction behavior using 5, 10, 15, 20 and 25 blows compactive efforts of a proctor hammer in the moisture range of 8 to 26% (wet basis). The results of the compaction test showed that dry density increased with increase in compactive efforts, and that loamy sand had the highest dry density with accompanying low moisture content at all compaction levels. The result of the consistency test revealed that the optimum moisture content required for machinery traffic occurred between the plastic and liquid limits for all the three soil samples. Consequently, the use of tractors in carrying out farming operations is better suited when the soils are not too wet, so that the soil can support the machinery and hence avoiding wheel skidding. Predictive equations were established to relate the dry density of the different compactive efforts with moisture content of the three soils.

Key words*: Compaction characteristics, agricultural soils, dry density, compactive effort, Nigeria*

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INTRODUCTION

Soil compaction is the process whereby soil particles are constrained to pack more closely together through a reduction in the air voids due to external pressure [1]. In agricultural field, the external force could be human, animal or machinery traffic. Compaction increases the strength properties of soils, namely bulk density and shear strength. Several authors have shown that soil moisture content is the most important factor in the compaction process and soil compatibility [2, 3]. A small increase in moisture content tends to increase the repulsion of particles and to facilitate their orderly arrangement. During the compaction process, additional application of water expels more air from the soil and increases the dry density of the soil until the optimum moisture content is attained. The maximum dry density of the soil coincides with optimum moisture content. When the water content exceeds the optimum value, the water pushes the soil grains apart, and because water is much more incompressible than the grain assembly and has no time to drain, the dry density starts to decrease.

According to [4], soil compaction varies with soil type: sandy soil have naturally higher bulk densities than clay soil due to the many small pores associated with clay. Several researchers have suggested ways of minimizing the effects of soil compaction. Increasing the soil resistance to compaction could be accomplished by increasing soil strength, thus enabling the soil to better withstand the compacting effects of applied loads. One method of increasing soil strength is to reduce soil moisture. A relatively dry soil may improve the soils ability to withstand compactive forces caused by vehicle traffic [4]. [5] observed that subsoil bulk density was unaffected by large axle loads when dry, but increased significantly when wet. [6] recommended that moderate compaction of the top soil may be beneficial to crop yield in a dry year, but to limit traffic and compaction to an absolute minimum level in wet years.

However, the control of soil moisture content during field machinery operations is a difficult task. According to [7, 8], knowing the change in soil compatibility with moisture content changes would assist farmers schedule farm trafficking and cultivation operations at the proper moisture content. [9] opined that the no-tillage system conserves energy, but results in lower yields, while conventional tillage with higher yields imparts compaction on the soil. Therefore, compaction studies must aim at striking a balance between yield and energy efficiency in order to optimize agricultural production and productivity. [10] stated that a soil moisture content lower than the plastic limit (pl) is desirable for cultivation. This desirable condition, however, is a function of the soil type [11].

Research has shown that compaction has the potential to depress crop yields, since extremely dense soil impedes root growth thereby limiting water consumption by plants [12]. Thus, farm managers must design strategies to manage soil compaction in order to minimize its detrimental effects. In this regard, researchers have adopted modeling approach to simulate soil compaction in order to address the problem [13, 14].

The extent of soil compaction worldwide from vehicular traffic is estimated to be 68 million hectares of land [15]. In recent years, the need to achieve food security for the teeming population in Nigeria has led to the massive importation of agricultural machinery for increased mechanization. According to [16] increased use of power machinery system particularly heavy machines with high wheel load is one of the major reasons for compaction of subsoil layers in agricultural fields. They further opined that

during the last two decades, mechanization level has increased manifold in developing countries. Citing India as a typical example, [17] reported that the production of tractors with matching power in the category of more than 45 kW increased because of the increased use of heavy machinery. The situation in Nigeria is akin to that of India and other developing countries. Over 83% of the tractors imported into Nigeria and tested at the National Centre for Agricultural Mechanization (NCAM), Ilorin from 2005 to date come from Asian countries, namely India and China. Seventy two (72) percent of these tractors exceed 45 kW (60 hp) capacity with weights of over 35 kN which exceeds the limit set for soils resistant to compaction [18, 19]. Severely compacted soil impedes root growth and development and restricts plants ability to utilize soil water and nutrients by reducing the soil volume utilized by roots. The resultant effect is reduced crop yield and low financial returns to the farmer.

[16] noted that compaction phenomenon in the field due to machine passage and its impact on crop growth is site-specific and also influenced by edaphic, climatic and environmental factors. Taking into cognizance that there is not yet a country-wide study on compaction of agricultural soils of Nigeria as previous studies were limited to Northeastern and Southwestern Nigeria [20, 21, 22], it becomes imperative to investigate the compaction characteristics of soils of Niger state of Nigeria.

The objectives of the study was:

1. to determine the optimum moisture content and maximum dry density at different compactive efforts of three major soils of Niger state, Nigeria; and
2. to establish the most suitable moisture content for each soil type for field machinery operations.

MATERIALS AND METHODS

Study Area

The study sites fall under Minna senatorial zone of Niger State, North-central Nigeria (Fig. 1). The sites are Maizube Farms (Lat. 9°37'N and Long. 6°30'E); Gidan Kwano (Lat. 9°32'N and Long. 6°28'E) and Maikunkele (Lat. 9°42' N and Long. 6°28' E). Maizube Farms is a large-scale mechanized farm. Gidan Kwano houses the Federal University of Technology, Minna Research Farm; while Maikunkele is the headquarters of Bosso local government area of Niger State where in addition to mechanized farming, the traditional farming system is prevalent. Niger state falls within the Southern Guinea Savannah vegetation of Nigeria. The zone has distinct dry and rainy season with a mean annual rainfall of about 1200 mm. The rainy season usually commences in April or May and ceases in October with a five (5) month dry period which extends from November to March. The average minimum and maximum temperatures of the area are 23 and 35°C, respectively. The soils of Niger State are sharply divided between the two geographical formations of the state: the soils of the Basement Complex rocks and those of the sedimentary Nupe Sandstone. The Nupe sandstones dominate the sites of study and consist mainly of the semi-consolidated coarse grits, conglomerates, fine grained sandstone.

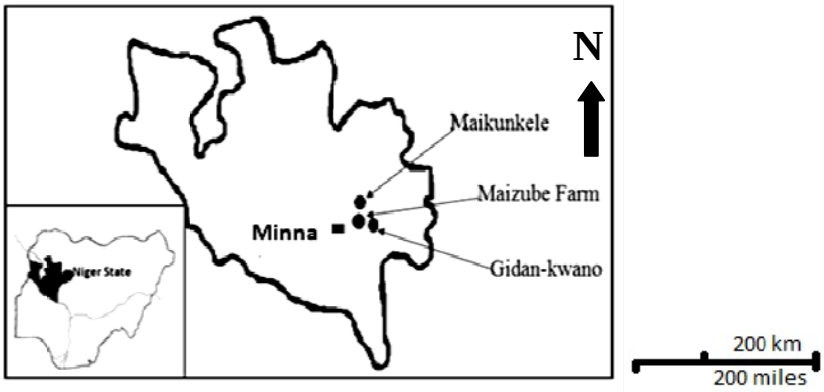

Figure 1. Map of Niger State indicating the study sites

Methodology

Soil samples were collected in three replicates within 0-30 cm depth. The soils were characterized for their physical properties- particle size distribution, moisture content (MC), liquid limit, plastic limit and plasticity index using standard procedures as specified in BS 1377 part 2 [23]. The compaction test was done for the three (3) soils using Proctor test procedures. The particle size distribution and consistency limits of the three soils are given in Tab. 1.

Table 1. Particle size distribution and consistency limits of the three soil types

Soil Characteristics	*Soil texture*		
	Gidan kwano Sandy-clay loam	*Maikunkele Loamy sand*	*Maizube farms Clay loam*
Particle size distribution (%)			
Sand	*66.12*	*78.00*	*39.32*
Silt	*7.00*	*12.50*	*26.50*
Clay	*26.88*	*9.50*	*34.18*
Consistency limits (%)			
Liquid limit	*20.20*	*20.00*	*32.40*
Plastic limit	*15.76*	*0.00*	*22.88*
Plasticity index	*4.24*	*0.00*	*9.52*

Sample Preparation

A homogeneous sample was obtained from each soil after thorough mixing. The initial moisture content of the three soil samples were 7.10%, 7.03% and 7.92% (w. b.) for sandy clay loam, loamy sand and clay loam, respectively. These moisture contents were brought to eight moisture levels in the range of 8 to 26% (w.b.). Each soil type was subjected to 5, 10, 15, 20 and 25 blows of a proctor hammer in a cylindrical mould with internal diameter of 10.15 cm, internal effective depth of 11.7 cm and a capacity of 944 cm^3. The mould consists of a detachable base plate, collar 5 cm in effective height, and

rammer 2.5 kg in mass falling through a height of 30.5 cm. The average dry density of three replicates for the compacted soils corresponding to each moisture level was computed.

Statistical analysis

The optimum moisture content and maximum dry density were correlated with soil components using simple and multiple correlation and regression analysis.

RESULTS AND DISCUSSION

The liquid limits, which were found to be highest in clay loam and least in loamy sand, were used to determine the moisture range for the compaction test of the soil samples (Tab. 1). The plastic limit was highest in clay loam and gave zero value in loamy sand. The low silt and clay content of the loamy sand could be reason for its non-plastic behaviour. It is possible to roll clay loam owing to its high plasticity index into a crumbling thread of 3 mm when the water level of the soil is increased beyond the plastic limit. However, if the water level is less than the plastic limit, the soil thread will crumble at a diameter more than 3 mm. The optimum moisture contents of the three soil samples occurred below the liquid limit and between plastic and liquid limits. Similar studies were conducted by [7] and [21] for soils of North and South western Nigeria, respectively. In their respective studies, they found the soils to be well below the liquid limits. Consequently, farm tractors are better suited when the soil is not too wet, so that the machinery can be supported and skidding can be avoided [24].

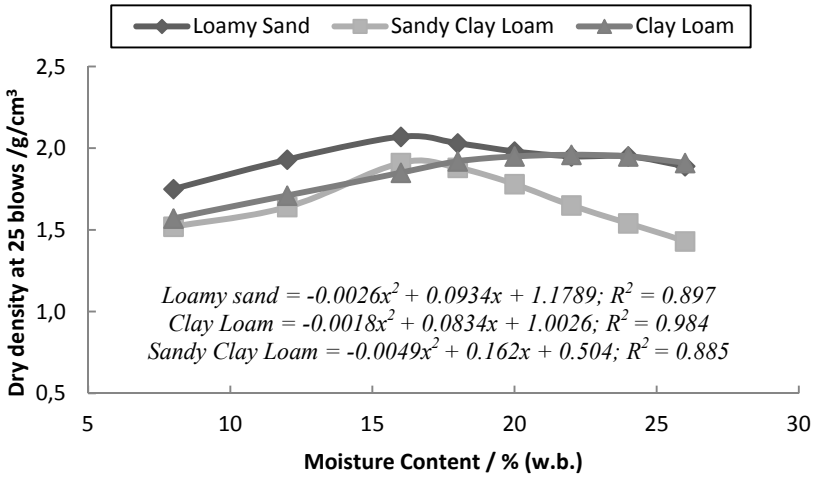

Figure 2. Moisture content Vs Dry density at 25 blow compactive effort

Figs. 2 to 6 show the results of the dry density of the three soils with respect to moisture content at 25, 20, 15, 10 and 5 blows, respectively. The bulk density was found

to increase with increase in compactive effort, from 5 to 25 blows, on the soils. The dry density at 25 blows compactive effort increased from 1.52 to 1.91 g·cm^{-3}, 1.57 to 1.96 g·cm^{-3}, 1.75 to 2.07 g·cm^{-3} and decreased to 1.88 g·cm^{-3}, 1.95 g·cm^{-3}, 2.03 g·cm^{-3} with further increase in moisture content from 8 to 26% (w.b.) for sandy loam, clay loam and loamy sand, respectively.

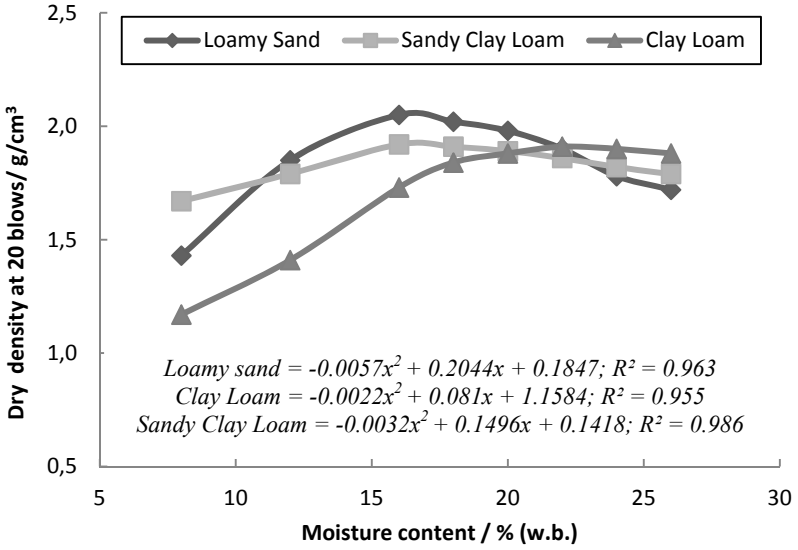

Figure 3. Moisture content Vs Dry density at 20 blows compactive effort

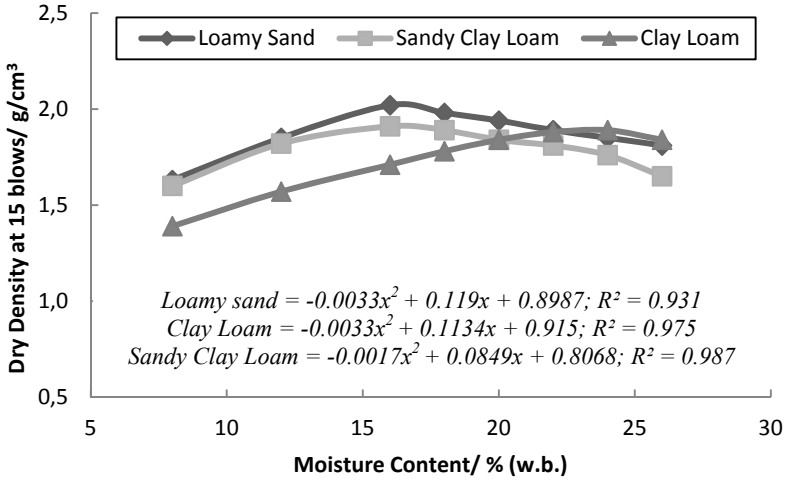

Figure 4. Moisture content Vs dry density at 15 blows compactive effort

Similar trend were observed in the variations of dry density with moisture content at all other compactive efforts. The increase in dry density for all three soils samples at all compaction levels were expected because the higher the number of blows, the more air is expelled and the higher the mass per unit volume. The structural disparity associated with the three soil samples in terms of their classification as sand, silt or clay explained why there were small differences in the values of their dry densities.

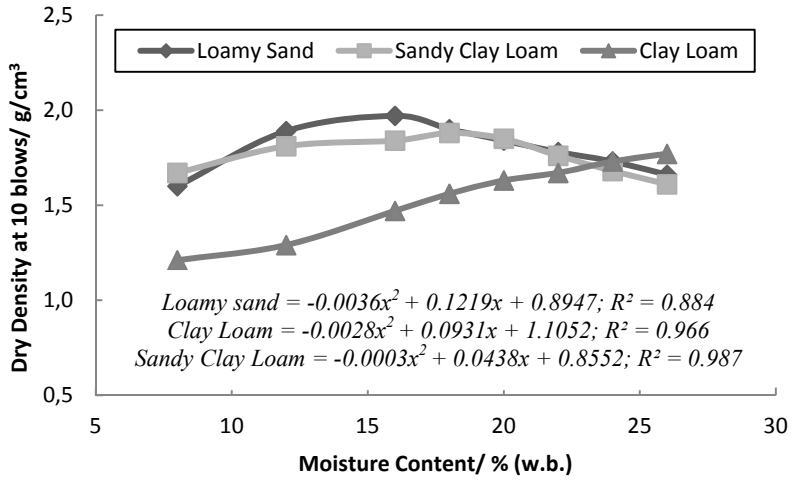

Figure 5. Moisture content Vs Dry density at 10 blows compactive effort

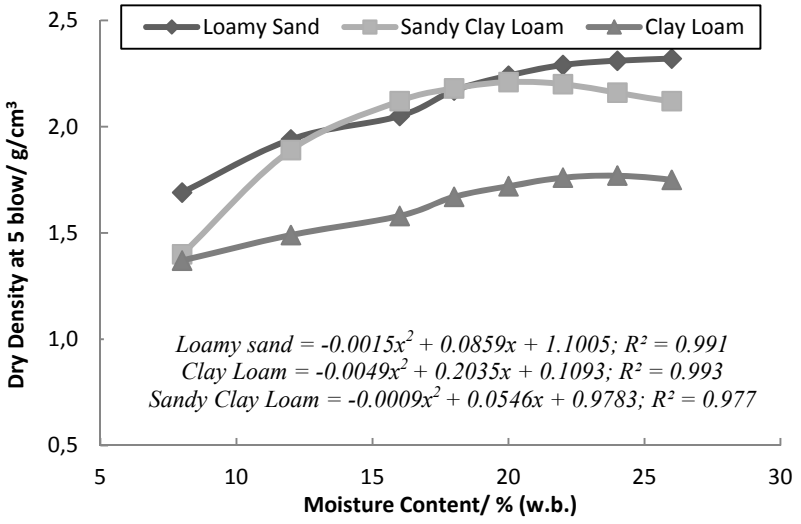

Figure 6. Moisture content Vs dry density at 5 blows compactive effort

CONCLUSIONS

The soils obtained at Gidan kwano, Maikunkele and Maizube farms in Minna, Niger state Nigeria are generally sandy in particle size composition and this seemed to have an overriding influence on their compaction characteristics. Classifying the soils revealed that the soils are sandy clay loam, loamy sand and clay loam with respect to the three locations. The maximum and minimum dry densities occurred at 25 and 5 blows compactive efforts, respectively. The dry density of the soil at traffic increased with increasing moisture content up to a predetermined level, which was below the liquid limit, and thereafter decreased as moisture content increased. The optimum moisture content required for machinery traffic occurred between the plastic and liquid limits. Consequently, the use of tractors in carrying out farming operations is better when the soils are not too wet, so that the soil can support the machinery and wheel skid is avoided. Predictive equations were established to relate the dry density of the different compactive efforts with moisture content of the three soils. The moisture content of the soils affected compaction behavior. Hence, the degree of compaction is a function of mass, moisture and soil type. Developing specifications for the limit of compactness required for mobility of farm machineries in the field is suggested.

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KARAKTERISTIKE SABIJENOSTI NEKIH POLJOPRIVREDNIH ZEMLJIŠTA U DRŽAVI NIGER U NIGERIJI

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Sažetak: Kretanje poljoprivrednih traktora i drugih teških mašina uzrokuje sabijanje zemljišta. Zapreminska težina, otpor penetracije i hidraulična provodljivost su pod značajnim uticajem sabijanja, što ugrožava i fiziologiju biljaka. U ovom istraživanju sakupljeni su uzorci zemljišta sa tri lokacije u državi Niger u Nigeriji, farme: Gidan kwano, Maikunkele i Maizube farms. Analiza dimenzija čestica pokazala je da teksture zemljišta pripadaju klasama peskovito-glinovita ilovača, pesak i glina ilovastog sastava, redom. Atterberg granice uzoraka ovog zemljišta određene su testom konzistentcije. Uzorci zemljišta su bili karakterisani koristeći intervale za sabijanje od 5, 10, 15, 20 i 25 udaraca Proctor čekića u opsegu vlage od 8 do 26% (mokra osnova). Rezultati testa sabijanja pokazuju da se zapreminska težina suvog uzorka povećava sa povećanjem broja udaraca i da frakcija ilovasti pesak ima najveću gustinu koja prati nizak nivo vlage na svim nivoima sabijanja. Rezultat testa konzistencije je pokazao da je optimalna vlažnost potrebna za saobraćaj mašina bila između plastične i tečne granice za sva tri uzoraka zemljišta. Shodno tome, upotreba traktora u obavljanju poljoprivrednih radova je bolje prilagođena kada zemljišta nisu prevlažena, tako da zemljište može da izdrži opterećanje mašina, a da pri tome bude izbegnuto proklizavanje točka. Postavljene su jednačine za predviđanje odnosa zapreminske težine suvog uzorka za različit broj udaraca čekića sa sadržajem vlage kod tri uzorka zemljišta.

Ključne reči*: karakterisitke sabijanja, poljoprivredna zemljišta,suva zapreminska težina, udarac Proctor čekića, Nigerija*

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DEVELOPMENT AND EVALUATION OF METERING MECHANISM FOR MULTI-CROP PLANTER FOR HILLY REGIONS

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Abstract: Inclined plate seed metering device was designed and evaluated in laboratory for singulation and uniform placement of maize and soybean seeds at three different cell shapes and sizes. The performance parameters like average spacing, multiple index, quality of feed index and precision were measured. Among the combinations of design variables, the seed metering plate with semi-circular cell shape having cell size 7 mm diameter was found to be the optimum for metering maize seed. Average spacing, quality of feed index, multiple index, miss index and precision were 17.48 cm, 79.33 %, 18.67 %, 2 % and 10.5 %, respectively. Likewise, the seed metering plate with semi- circular cell shape having cell size of 12 mm diameter was found to be optimum for metering soybean seed. Average spacing, quality of feed index, multiple index, miss index and precision were 9.65 cm, 77.33 %, 14.33 %, 8.34 % and 18.73 %, respectively. Therefore, considering all the performance parameters, inclined plate metering device with semi-circular shape of cell diameters 7 mm and 12 mm were selected for maize and soybean seeds, respectively.

Key words*: Maize, soybean, NEH region, inclined plate metering device, performance indices, semi-circular cells*

INTRODUCTION

The ultimate objective of planting using improved sowing equipment is to achieve precise seed distribution within the row for its proper growth. It is necessary for seeds to

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be placed at required distance apart within rows. Various seed drill and planters with different metering mechanisms have been developed, evaluated and reported by various researchers in literature, i.e. [3] [4] [5] [8] [11] [15] [16] [17]. In manual seeding with conventional practice, the higher and non-uniform plant population adversely affect grain yield of different crops [14]. The seed spacing majorly depends on the machine technical variables such as the type of seed pickup mechanism, machine operating speed, overall gear ratio between drive wheel and seed plate, and also on seed quality to some extent. Further, a number of others factors affect the spacing of plants. The device may pick and drop multiple seeds resulting in small spacing between seeds [13]. The proper design of a seed metering mechanism is essential for satisfactory performance of any seed planter. Besides, seed tube design and soil conditions along with other factors determine the final placement of seed. Although there are many planters having different seed metering mechanisms, the application of single seed metered plate mechanisms (inclined plate) has increased rapidly due to better seeding performance than that of other mechanical rotors.

Performance of single seed planter is related to the sowing uniformity of the distribution pattern along the length of the row. Under field conditions, direct measurement of seed placement is very difficult. Therefore, measurement of the spacing between plants after they emerge is an alternative. Much of the variability in spacing could be removed by evaluating planters under laboratory conditions. The assessment of plant spacing and seed rate as provided by the planters is also crucial in analyzing its performance. A variety of methods have been evolved to assess the performance of planter metering mechanism. Measuring the spacing between germinated plants after planting with machine is most common method. When examining the spacing between the plants once they emerge, considerable variability often exists in the plant-to-plant distance. The second most prevalently used method is the grease belt test rig under laboratory conditions, which is unaffected by crop and soil conditions. The main aim is to quantify the observed variability in a way that will allow one to make meaningful comparisons between single seed metering devices.

[12] designed and developed an inclined plate type metering unit having metering plates with cells of proper size and shape for maize seeds. The plates were made of cast aluminum 120 mm diameters. They had eight L-shaped cells at the periphery. The number of cells on the plate depended on the plant-to-plant spacing in a row and on the transmission ratio between the ground wheel and the metering plate. The seed plate was mounted at an angle of 60º with the horizontal so that the extra seed dragged along were dropped before reaching the seed outlet of the hopper. [10] developed a three-row bullock drawn multi-crop inclined plate planter at for sowing different type of crops. The plant population was found 10-12 plants per square meter.

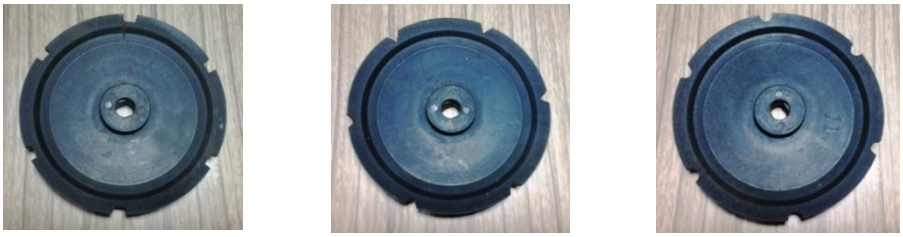
[9] tested and compared the widely used measures; mean, standard deviation, quality of feed index, multiple index, miss index and precision. Those measures were based on the theoretical spacing (Xref), specified in ISO 7256-1 standard (1984) and gave a good indication of the spacing distribution. It was also concluded that the mean and standard deviation of seed spacing didn't offer an appropriate evaluation of planter performance on seed distribution. The final selection of metering device also depends on multiple index and miss index.

A large number of planter designs are available for plains areas, but very little information is available on planters with their suitable metering mechanisms which can be used for planting crops such as maize, soybean etc., in the hilly region particularly, NEH region which have different physical characteristics than those used for the plains. Physical and engineering properties of commonly available local varieties of maize and soybean have also not been studied earlier. Therefore, the objectives of study were to determine physical and engineering properties of seeds to develop and evaluate seed metering plate for maize and soybean crops, and recommend the optimum metering devices both for maize and soybean seeds from laboratory investigation.

MATERIAL AND METHODS

Metering System

Mechanical seed metering devices in planter usually have cells on a moving member to have positive seed metering. Commonly recommended metering systems on planters are horizontal plate, inclined plate, vertical rollers with cells, and cups over the periphery [2]. The seeds are handled gently by the inclined plate in comparison to other devices. The plates and outer cells are machined accurately to provide uniform cell size for precision planting of seeds. Since the risk of crushing unevenly sized seeds is greater, horizontal plate metering device is not considered. Laboratory experiment was thus conducted with inclined plate cell type metering mechanism having cells of different shapes and sizes for metering of maize and soybean seeds locally used in NEH region (Figs. 1-2). Details of the metering plates are shown in Fig. 3.



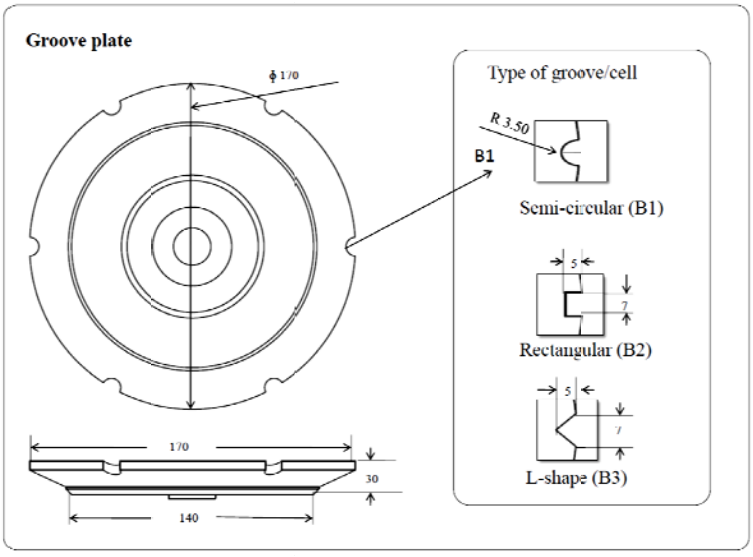
a. Rectangular shape *b. L-shape* *c. Semi-circular*

Figure 1. Metering plate with different cell shapes used for metering maize seed

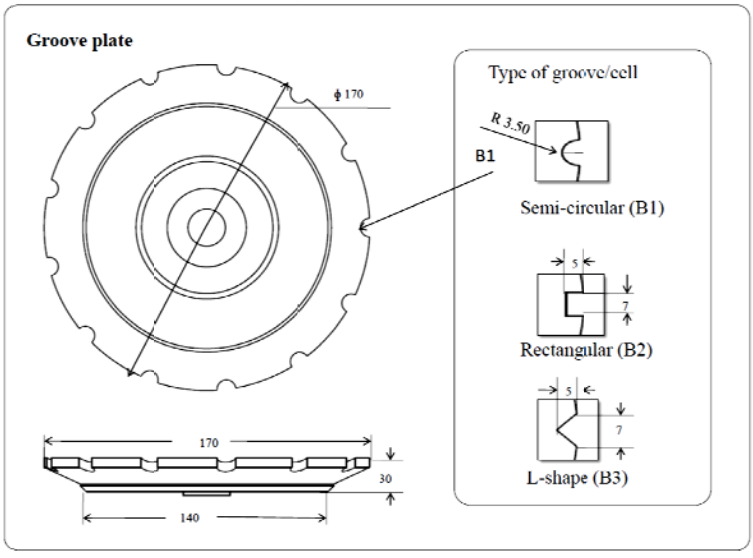
a. Rectangular shape *b. L-shape* *c. Semi-circular*

Figure 2. Metering plate with different cell shapes for metering soybean seed

The types of maize (Murli Makai) and soybean (Raus 5) seeds used for the study are shown in Fig. 4. Tab. 1 showed that roundness and sphericity of both the types of seeds were close to one. The average angle of repose for the both the crops were 27º and 26º, respectively. The slope of the hopper walls, which was required to be more than the angle of repose of the seed, was selected as 30º considering standard deviation.



a.



b.

Figure 3. Details of metering plate used for: a. maize seed, b. soybean seed metering

a. b.

Figure 4. Seeds used for the study: a. maize, b. soybean

Table 1. Physical and engineering properties of maize and soybean seed for design of metering mechanism

Properties	Unit	Type of seed	
		Maize	Soybean
Length	[mm]	6.49±0.43	8.88±0.55
Breadth	[mm]	5.94±0.49	6.46±0.36
Thickness	[mm]	5.17±0.51	4.68±0.00
Sphericity	[-]	0.89±0.05	0.73±0.22
Roundness	[-]	0.86±0.07	0.66±0.02
Bulk density	[kg·m^{-3}]	754.00±7.04	749.50±1.59
1000 seeds weight	[g]	137.80±1.83	177.55±3.04
Angle of repose	[°]	26.60±3.15	25.82±1.88

Source: [7]

Laboratory Test

The performance of cells of different shapes was evaluated using a sticky belt test rig under laboratory condition by varying cell size of the metering device for both maize and soybean seeds (Tab. 2). The sticky belt mechanism consisted of 4 m long endless canvass belt mounted on two endless rollers spaced 100 cm apart along with a seed hopper and power transmission unit of belt pulley system with reduction gear and driving roller driven by a 4 kW motor. Observations were taken on the spacing between two adjacent seeds over the greased belt. Based upon the in-between spacing of 50 seeds, five measures of performance parameters viz. average spacing, multiple index, miss index, quality of feed index and precision were determined [9].

Table 2. Plan of experiments on metering device

Sl. No.	System variable	Levels of variable
1	Seed	Maize (S1), Soybean (S2)
2	Cell shape	Semi-circular (B1), Rectangular (B2), L-shape (B3)
3	Cell size	Maize: 7 mm (C1), 8 mm (C2), 9 mm (C3) Soybean: 10 mm (C4), 11 mm (C5), 12 mm (C6)

Table 3. Cell dimensions of seed metering plate

Cell dimension	*Unit*	*Type of cell/groove*					
		Maize seed			*Soybean seed*		
		Semi-circular	*Rectangular*	*L-shape*	*Semi-circular*	*Rectangular*	*L-shape*
Lenth	*[mm]*	-	*7, 8, 9*	*7, 8, 9*	-	*10, 11, 12*	*10, 11, 12*
Height	*[mm]*	-	*5*	*5*	-	*5*	*5*
Diameter	*[mm]*	*7, 8, 9*	-	-	*10, 11, 12*	-	-
Thickness	*[mm]*	*5*	*5*	*5*	*5*	*5*	*5*

Performance Parameters

Multiple index (*D*) is an indicator of more than one seed dropped within a desired spacing. It is the percentage of spacing that is less than or equal to half of the theoretical spacing:

$$D = \frac{n_1}{N} \tag{1}$$

Where:

n_1 [-] - number of spacings in the region ≤ 0.5 times of theoretical spacing,

N [-] - total number of observations.

Thus, it is an indication of more than one seed being dropped within a desired spacing.

Quality of feed index (*A*) is the percentage of spacings that are more than half, but not more than 1.5 times the theoretical spacing. It is the measure of how often the seed spacing's were close to the theoretical spacing. The quality of feed index is mathematically expressed as:

$$A = \frac{n_2}{N} \tag{2}$$

Where:

n_2 [-] - number of spacings between 0.5 and 1.5 times of the theoretical spacing.

Miss index (*M*) is an indicator of how often the seed skips the desired spacing. It is the percentage of spacing greater than 1.5 times the theoretical spacing.

$$M = \frac{n_3}{N} \tag{3}$$

Where:

n_3 [-] - number of spacing in the region ≥ 1.5 times the theoretical spacing.

Precision (*C*) is a measure of the variability in spacing after accounting for variability due to both multiples and skips. The precision is the coefficient of variation of the spacing that is classified as singles. Lower the value of coefficient of variation in singles better is the performance of metering mechanism It is mathematically expressed as:

$$C = \frac{S_2}{X_{ref}} \tag{4}$$

Where:
S_2 [-] - sample standard deviation of the n_2 observation,
X_{ref} [-] - theoretical spacing.

Statistical Analysis. Using factorial RBD design the data analysis was done to see the effect of seed and machine parameters and their interactions. Then, the performance parameters were statistically analyzed using SAS software.

RESULTS AND DISCUSSION

Performance Indices of metering device for maize seeds

Average spacing was influenced by all combinations of design variables of the study at 5 % level of significance. Average seed spacings obtained with cell shape B1 and cell size C1, C2 and C3 were 17.48 cm, 16.28 cm, and 15.79 cm, respectively. For cell shape B2 and cell size C1, C2 and C3, average seed spacings were 15.57 cm, 14.72 cm and 14.46 cm, respectively. Similarly, average spacings with cell shape B3 and cell size C1, C2 and C3 were 37.31 cm, 32.20 cm and 21.43 cm, respectively. However, the performance was also influenced by other indicators as miss index, multiple index, and quality of feed index and precision of the metering device. Hence, only the average seed spacing could not draw any conclusion regarding selection of metering device.

Multiple index was influenced by cell shape and cell size of the metering device at 5 % level of significance. The cell shape of metering device influenced the multiple index the most, followed by cell size as indicated by the F-values, Tab. 4. Fig. 6 shows the performance indices of various combinations of design variables. It was found that multiple index was higher in case of semi-circular (B1) and rectangular (B2) shape cells of all sizes as compared to L-shape cells. The least multiple index was 5.67 % in case of seed metering plate with L-shape cells of size 8 mm (C2).

Miss index was influenced highly by all the design variables of study at 5 % level of significance. Cell shape influenced the most, followed by cell size as indicated by the F-values, Tab. 4. Fig. 6 indicates that seed metering by plate with L-shape cells resulted in more missing. The least miss index was 1.33 % for rectangular cell shape (B2) of cell size 9 mm (C3).

Quality of feed index **(***QFI*) was highly influenced by cell shape, followed by cell size as indicated by F-values, Tab. 4. QFI decreased with increase in miss index, multiple index, or both (Fig. 6). QFI was highest for semi-circular shape seed metering plate and the maximum value was 79.33 % cell shape B1 of cell size C3.

Precision was most influenced by cell shape, followed by cell size at 5 % level of significance as indicated by F-values, Tab. 4. Fig. 7 shows that precision was lowest for semi-circular shape cells and the least value was 10.5 % for seed metering plate with cell size of 7 mm.

Table 4. F-values for performance parameters of maize seed metering mechanism

Source	F-value				
	Average spacing	Miss index	Multiple index	Quality of feed index	Precision
R	0.16	0.65	0.45	2.28	0.79
B	51.29*	554.36*	79.56*	123.74*	11.85*
C	7.15*	65.93*	20.77*	8.57*	0.85*
B*C	4.45*	42.20*	4.68*	13.86*	1.17*

** Significant at 5 % level of significance. R=Replication; B=Shape of cell; C=Size of cell*

Table 5. F-values for performance parameters of soybean seeds metering mechanism

Source	F-value				
	Average spacing	Miss index	Multiple index	Quality of feed index	Precision
R	1.73	0.32	0.45	2.51	0.17
B	175.05*	361.72*	79.56*	253.04*	15.44*
C	94.94*	117.78*	20.77*	69.57*	4.75*
B*C	32.72*	31.99*	4.68*	45.27*	8.01*

** Significant at 5 % level of significance. R=Replication; B=Shape of cell; C=Size of cell*

Selection of Metering Mechanism

Final metering system for maize seed was selected taking into account different performance parameters discussed above. Average seed spacing of maize was close to the theoretical seed spacing of 20 cm for NEH region for the plate with cell shape B1 and cell size C1 as compared to the remaining cell shapes and sizes. The highest quality of feed index observed was 79.33 % for semi-circular cell shape and cell size 7 mm diameter. The least value of precision was 10.50 % for cell shape B1 of size C1. It could thus be seen that semi-circular cell of 7 mm size gave highest precision. Hence, considering all the performance parameters among the combinations of design variables, inclined plate metering device with semi-circular cell shape having cell size of 7 mm and 5 mm deep was found optimum and was selected for metering maize seed.

Performance indices of metering device for soybean seeds

Average speed spacing was influenced by all combinations of design variables of the study at 5 % level of significance. Average seed spacings obtained with cell shape B1 and cell size C4, C5 and C6 were 41.20 cm, 19.44 cm and 9.65 cm, respectively. For cell shape B2 and cell size C4, C5 and C6, average seed spacings were 8.38 cm, 8.85 cm and 7.72 cm, respectively. Similarly, average spacings with cell shape B3 and cell size C4, C5 and C6 were 36.51 cm, 29.87 cm and 21.12 cm, respectively. As in case for maize seeds, cell shape and cell size highly influenced the performance parameters for soybean seeds as also average seed spacing, multiple index, miss index, quality of feed index and precision. Cell shape of metering plate influenced the average seed spacing the most, followed by cell size as indicated by F-values, Tab. 5. However, only the average seed spacing could not draw any conclusion regarding selection of metering device as the performance is influenced by other indicators discussed above.

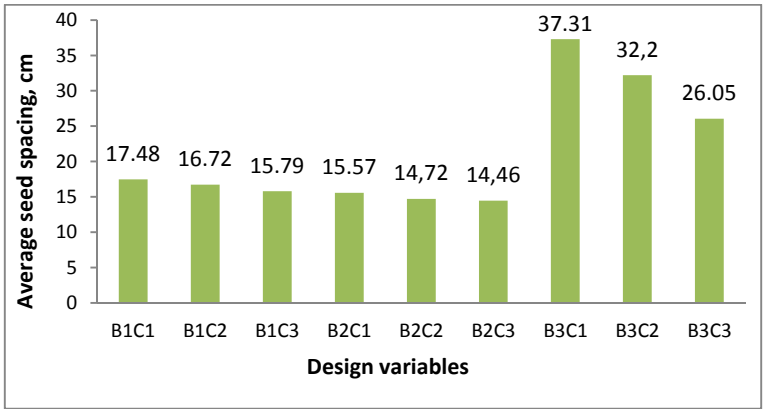


Figure 5. Average seed spacing of metering device with different cell types for maize seeds

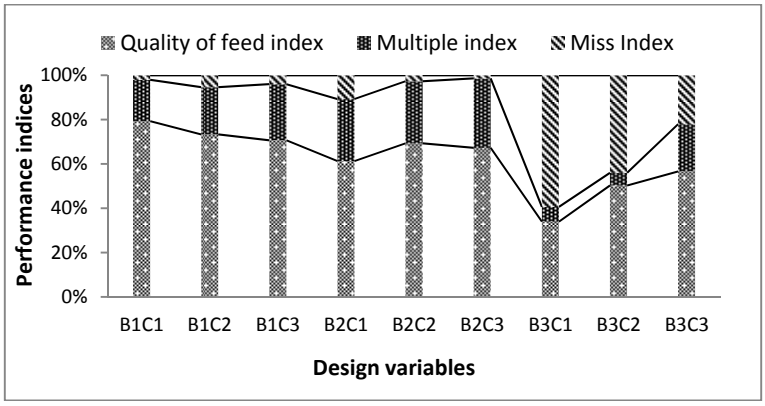


Figure 6. Performance of metering device for maize seeds

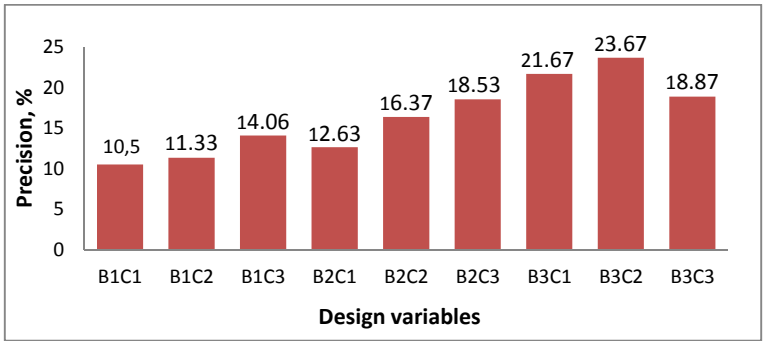


Figure 7. Precision of metering device for combinations of design variables for maize seeds

Multiple index was influenced by cell shape and cell size of the metering device at 5 % level of significance. The cell shape of metering device influenced the multiple index the

most followed by cell size as indicated by the F-values, Tab. 5. Fig. 9 showed the performance indices of various combinations of design variables. For soybean seed, multiple index was irregular. There was no multiple for semi-circular cell of size 10 mm diameter (C4). The maximum multiple index was 28.67 % for rectangular cell shape and cell size C6.

Miss index was highly influenced by all the design variables of study at 5 % level of significance. Cell shape influenced the most, followed by cell size as indicated by the F-values, Tab. 5. Fig. 9 showed that seed metering by plates with semi-circular (except cell size C3) and L-shape cells resulted in more missing. The least miss index was 8.34 % for cell shape B1 of cell size 12 mm (C6).

Quality of feed index **(***QFI*) was highly influenced by cell shape, followed by cell size as indicated by F-values, Tab. 5. QFI decreased with increase in miss index, multiple index or both (Fig. 9). Quality of feed index was highest for semi-circular cell shape with maximum value of 77.33 % for semi-circular cell shape (B1) and cell size 12 mm diameter (C6).

Precision was influenced by cell shape the most followed by cell shape at 5 % level of significance as indicated by F-values, Tab. 5. The least value of precision was 18.16 % for L-shape cell of size C5. It was also found that precision values for semi-circular shape cells were also close to the least value, Fig. 10.

Selection of Metering Mechanism

As in case of maize seed, final metering system for soybean was also selected taking into account different performance parameters discussed above. Average soybean seed spacing of 9.65 cm was close to the theoretical seed spacing of 10 cm for the plate with semi-circular cell shape (B1) and cell size of 12 mm diameter (C6).

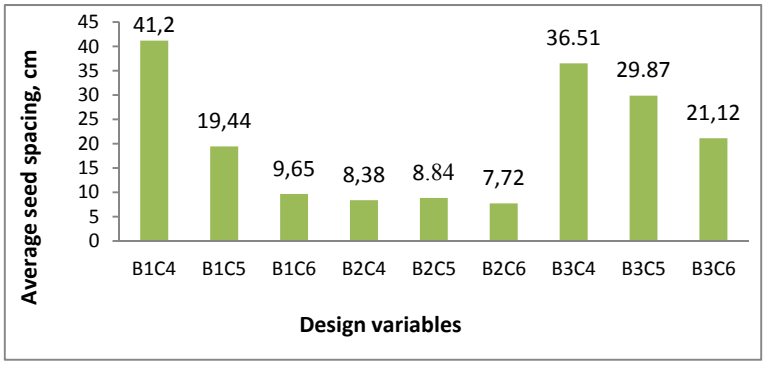


Figure 8. Average seed spacing of metering device with different cell types for soybean seeds

The highest quality of feed index observed was 77.33 % for semi-circular cell shape (B1) and cell size of 12 mm (C6). The least miss index was 8.34 % for cell shape B1 of cell size C6. Hence, considering all the performance parameters, inclined plate metering device with semi-circular cell shape having cell size 12 mm and 5 mm deep was found optimum and was selected for metering soybean seed.

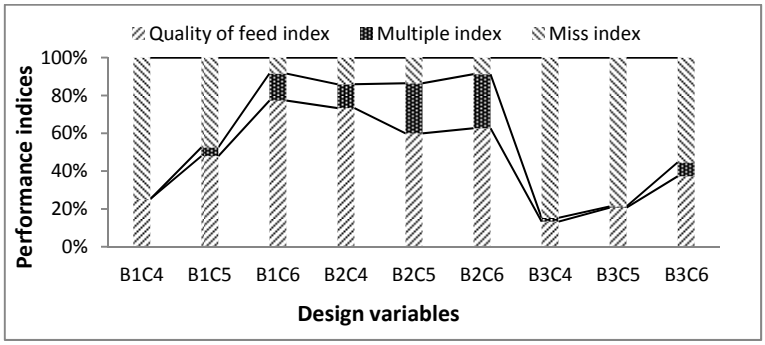


Figure 9. Performance of metering device for soybean seeds

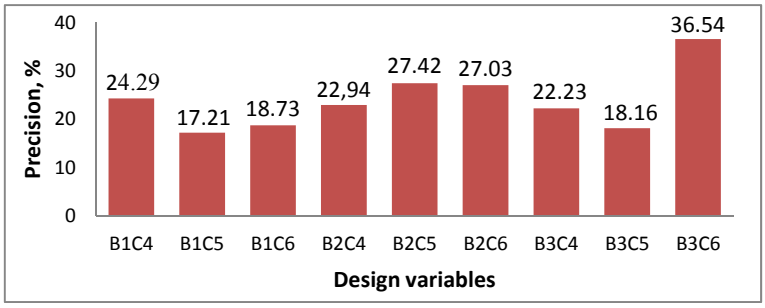


Figure 10. Precision of metering device for combinations of design variables for soybean

CONCLUSIONS

The average seed spacing, quality of feed index, multiple index and precision of the distribution of maize and soybean seeds along the length of the row were significantly influenced by cell shape, cell size and seed type. Inclined metering plate with semi-circular cell of 7 mm diameter and 5 mm deep gave average spacing, quality of feed index, multiple index, miss index and precision for this combinations were 17.48 cm, 79.33 %, 18.67 %, 2 % and 10.5 %, respectively for maize indicating best performance. For soybean seed, the seed metering plate with semi-circular cell shape having cell size of 12 mm and 5 mm deep was found to be optimum providing average spacing, quality of feed index, multiple index, miss index and precision for this were 9.65 cm, 77.33 %, 14.33 %, 8.34 % and 18.73 %, respectively.

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RAZVOJ I OCENA RADA MERNOG MEHANIZMA ZA ŠIROKOREDNU SEJALICU NA BRDSKIM TERENIMA

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Sažetak: Merni uređaj sa kosom pločom za merenje izbacivanja zrna konstruisan je i ispitivan u laboratoriji. Ispitivani su pojedinačno polaganje i ujednačenost polaganja semena kukuruza i soje sa tri različita oblika i veličine ćelija. Mereni su parametri kao što su: srednje rastojanje, index umnožavanja, indeks kvaliteta punjenja i preciznost.

Među kombinacijama promenljivih veličina u konstrukcijama, merna ploča sa polukružnim ćelijama i prečnikom ćelije od 7 mm bila je optimalna za merenje izbacivanja semena kukuruza. Srednje rastojanje, indeks kvaliteta punjenja, index umnožavanja, indeks greške i preciznost iznosili su 17.48 cm, 79.33 %, 18.67 %, 2 % i 10.5 %, redom. Merna ploča sa polukružnim ćelijama i prečnikom ćelije od 12 mm bila je optimalna za merenje izbacivanja semena soje. Srednje rastojanje, indeks kvaliteta punjenja, index umnožavanja, indeks greške i preciznost iznosili su 9.65 cm, 77.33 %, 14.33 %, 8.34 % i 18.73 %, redom. Imajući u vidu sve parametre, merni uređaji sa kosim pločama sa polukružnim ćelijama prečnika 7 mm i 12 mm bili su izabrani za setvu semena kukuruza i soje, redom.

***Ključne reči**: kukuruz, soja, NEH region, merni uređaj sa kosom pločom, performanse, polukružne ćelije*

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RESULTS OF RESEARCH OF ELECTRICAL RESISTANCE OF MAIZE SEED GERMS AFTER THEIR PRE-SOWING ELECTROMAGNETIC TREATMENT

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Abstract: A pre-sowing electromagnetic treatment of maize seeds was carried out.

A laboratory setup was designed for measuring the resistance of maize seed germs at signal frequency 10 kHz. The setup is appropriate for use in the process of student training.

The resistance values were determined for the seed germs of French maize hybrid LG 34.75, treated and untreated in an electromagnetic field.

The parameter S, expressing the ratios of measured resistance values of electromagnetically treated to untreated seeds, was analyzed.

The resulting values for the parameter *S*, after a 14-day rest of the seeds, were closest to and smaller than 1. This correlated with the time limit determined from practical experience for sowing the seeds following their electromagnetic treatment.

It was established that for the seeds of the French maize hybrid LG 34.75, the parameter S values were more dispersed around the value 1 in comparison to the values obtained by other authors. This could be attributable to the genetic specifics of the examined maize hybrids.

Key words*: maize seeds, pre-sowing electromagnetic treatment, resistance of a seed germ*

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INTRODUCTION

New technologies of pre-sowing seed treatment are used to satisfy the population's growing food demand [7]. They aim to increase the yields [4] [7] while reducing energy costs [8]. Questions are therefore raised with regard to the reasons for increasing the yields once new technologies of pre-sowing seed treatment have been applied.

In [3] [6] a possibility has been established for research on the conductivity (resistance) and dielectric permittivity of maize seeds. In [5] it has been demonstrated that a maize seed may be considered to be a dielectric object. In the same paper it has been noted that, under certain conditions during the pre-sowing electromagnetic treatment, the electric field generated in the seed has its greatest-magnitude component in the direction of the germ. The latter is the living object in the surrounding nutrient medium in which no vital processes take place.

The objective of the research was to establish the electrical resistance of maize seed germs of the French hybrid LG 34.75.

MATERIAL AND METHODS

The object of research was the resistance of germs undetached from the maize seeds of the French hybrid LG 34.75, a mid-early cultivar from FAO 480 group, which were provided by the company Safari-M of Ruse, Bulgaria.

The seeds were subjected to a pre-sowing electromagnetic treatment with the setup [2] under applied voltage between the electrodes U=1,65 kV and duration of impact τ=10s. The seeds were not disinfected before the treatment.

The measurements of the germ resistance were carried out on the 1st, 7th, 14th and 60th day after the treatment of the seeds. The pre-sowing electromagnetic treatment was carried out on 24.07.2013, at the following times: for option No. 1 at 7:00, for option No. 11 at 12:00, and for option No. 12 at 19:00.

From the preliminary laboratory examinations, it had been proven sufficient to measure the electric resistance of 20 seed germs in each experiment. Each seed was measured only once. The measurements in the above mentioned days after the treatment were carried out with new batches of 20 seeds each.

The analysis of the size and structure of the maize seeds provided grounds to bring forward the following requirements to the laboratory setup for measuring the resistance of maize seed germs:

The resistance must be measured using electrodes made of chemically inert steel, such as nickel-chrome steel. They must be needle-type electrodes in order to allow easier penetration in the seed germ. The electrodes must be inserted in the maize seed germ at a certain distance from one another. To this end, micrometer screws installed upon swivel-type movable stands must be used. To improve the accuracy of attaching the electrodes to the germ it is necessary to use a microscope and appropriate lighting. Each single seed must be positioned upon a glass slide by means of a micrometer ruler and a fixing mechanism.

The setup for measuring maize seed germs resistance, developed according to the specified requirements, is shown in Fig. 1.

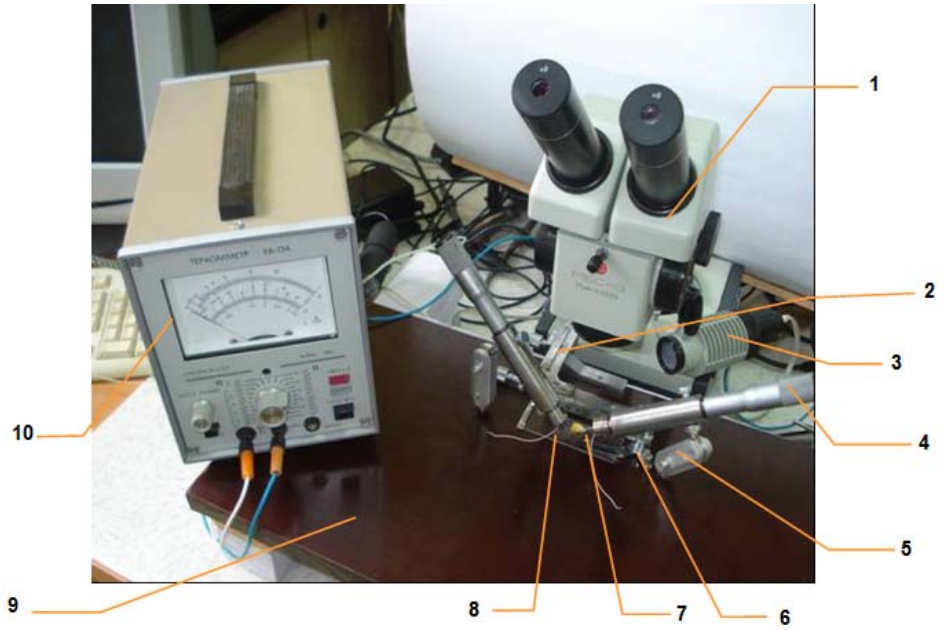

Figure 1. Experimental setup for measuring the electric resistance of a seed germ: 1. microscope, 2. micrometer ruler, 3. light source, 4. micrometer screw, 5. swivel-type movable stands, 6. fixing mechanism, 7. nickel-chrome electrodes, 8. glass slide, 9. insulation base plate, 10. teraohmmeter

From the preliminary studies carried out, the following sequence of actions was determined to operate the measurements setup: The light source 3 is turned on. The glass slide 8 is fixed immovably through the fixing mechanism 6. The tested seed is positioned upon the glass slide with the use of the micrometer ruler. The nickel-chrome electrodes 7 are brought in contact with the seed thus positioned. They are electrically insulated from the micrometer screws 4 and, in view of the length of the maize seed germ, are positioned at a distance of 3 mm from one another. This is possible owing to the swivel-type movable stands 5 and the microscope 1. Once in contact, the electrodes are inserted in the seed at a depth of 2 mm by making use of the micrometer screws 4. After the electrodes have penetrated to the required depth, the teraohmmeter is switched on and the germ resistance is measured. The frequency of the measurements is 10 kHz.

Due to the specifics of the setup described above, seeds of approximately the same size must be used for the tests.

RESULTS AND DISCUSSION

In Tab. 1 are presented the averaged results from the measured resistances of the maize seed germs and the calculated values of the variability ratio and the parameter *S*.

It was established, that the average values of the resistance *Z* for the different treatment options vary within the range of 1,96 to 5,36 GΩ. From Tab. 1. can be

concluded that a correlation exists between the length of rest of the seeds after the treatment and the measured resistance values. The low resistance values were obtained 7 days after the treatment, while the high ones –60 days after the treatment.

An assessment of the dispersion of the obtained results was done through the variability ratio [1]. The calculated values (Tab. 1) are in the range of 12,081 to 27,905%. This shows a comparatively small dispersion of the measured quantity.

Table 1. Averaged resistance values of the germs of maize seeds LG 34.75

Treatment options – hour of taking the measurement	*Number of days after the treatment of the seeds*					
	1			*7*		
	Z, GΩ	*V, %*	*S*	*Z, GΩ*	*V,%*	*S*
No.1- 07:00	*2,66*	*18,201*	*0,779*	*2,30*	*24,285*	*1,191*
No. 2- 12:00	*3,22*	*24,798*	*0,658*	*2,20*	*12,531*	*1,245*
No. 3- 19:00	*3,92*	*18,843*	*0,541*	*1,96*	*18,139*	*1,398*
c- untreated	*2,12*	*12,081*	*1,000*	*2,74*	*27,076*	*1,000*
Treatment options – hour of taking the measurement	*Number of days after the treatment of the seeds*					
	14			*60*		
	Z, GΩ	*V,%*	*S*	*Z, GΩ*	*V,%*	*S*
No.1- 07:00	*3,40*	*13,542*	*0,682*	*5,36*	*27,856*	*0,527*
No. 2- 12:00	*2,54*	*27,905*	*0,926*	*5,14*	*26,493*	*0,560*
No. 3- 19:00	*2,26*	*24,008*	*1,027*	*2,70*	*24,343*	*1,067*
c- untreated	*2,32*	*19,160*	*1,000*	*2,88*	*22,331*	*1,000*

For the comparison of the obtained results given in Tab. 1, and in similarity to [6], the parameter *S* was introduced:

$$S = \frac{Z_c}{Z_{tr}} \tag{1}$$

Where:

Z_c [Ω] - averaged resistance value of the seed germs from the control batch

Z_{tr} [Ω] - averaged resistance value of the seed germs from the treated batch.

Other authors [6] who have carried out studies of the resistance of Bulgarian maize hybrids state in their works that the parameter *S* is a number smaller or larger than, but in any case close to 1 (0,9 - 1,1).

From the data contained in Tab. 1 it can be concluded that the parameter *S* takes values within the range of 0,527 to 1, 398. These values, regardless of their higher dispersion around the value 1, correlate with the results obtained in [5]. The dispersion of the values of the parameter *S* can be accounted for by the genetic differences between Bulgarian and French hybrids.

CONCLUSIONS

1. A laboratory setup was designed for measuring the resistance of maize seed germ.
2. The resistance values of the germs of maize seeds of the French maize hybrid LG 34.75, treated and untreated in an electromagnetic field, were determined.
3. The calculated variability ratio values were within the range of 12,081 to 27,905%, showing a relatively small dispersion of the measured value.
4. A parameter *S* was used to express the ratio between the measured resistance values *Z* of the seeds untreated in an electromagnetic field and the treated seeds.
5. The obtained values for the parameter *S* after a 14-day period of rest of the seeds were closest to and less than 1. This correlates with the time limit determined from practical experience for sowing the seeds following their electromagnetic treatment
6. It was established that for the seeds of the French maize hybrid LG 34.75, the values of the parameter *S* have a higher dispersion around the value one in comparison to the findings of other authors. This could be accounted for by the genetic specifics of the studied maize hybrids.

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REZULTATI ISPITIVANJA ELEKTRIČNOG OTPORA KLICA SEMENA KUKURUZA POSLE ELEKTROMAGNETNOG TRETMANA PRED SETVU

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Sažetak: U ovom istraživanju je izveden elektromagnetni tretman semena kukuruza pre setve.

Laboratorijski uređaj je postavljen tako da meri otpor klica semena kukuruza na signalnoj frekvenciji od 10 kHz. Ovako podešen uređaj se može koristiti i za obuku studenata.

Vrednosti otpora su merene na klicama semena kukuruza francuskog hibrida LG 34.75, sa i bez tretmana u elektromagnetnom polju.

Analiziran je parametar *S*, koji izražava odnose merenih vrednosti otpora tretiranog prema netretiranom semenu.

Rezultujuće vrednosti parametra *S*, posle 14 dana odmora semena, bile su najbliže i manje od 1. Ovo je bilo u korelaciji sa vremenskim ograničenjem određenim na osnovu praktičnog iskustva za setvu semena posle elektromagnetnog tretmana.

Ustanovljeno je da su za seme kukuruza francuskog hibrida LG 34.75 vrednosti parametra *S* bile više rasute oko vrednosti 1 u poređenju sa vrednostima dobijenim kod drugih autora. Ovo može biti karakteristično za genetičke specifičnosti ispitivanih hibrida kukuruza.

Ključne reči*: seme kukuruza, elektromagnetni tretman pre setve, otpor klice semena*

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PRODUCTION OF EMISSIONS DURING COMBUSTION OF VARIOUS BIOFUELS

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***Abstract*:** Biomass, or more precisely biofuel, nowadays increasingly substitutes for fossil fuels in the process of heating. It is used for heating of the drying medium as well. The paper is focused on the evaluation of the heat source during combustion of various kinds of solid biofuels. The heat source in question is the boiler VIGAS 25 with controller AK 2000 for home heating. The device TESTO 330-2LL was used for the measurement of gaseous emissions. Tested biofuels included bark briquettes and hardwood briquettes. The results of experimental measurements of gaseous emissions production for two fuels are processed in tabular and graphic form in dependence on the boiler output and the combustion time. Monitoring of surface temperature of the boiler was carried out by the means of the thermal imaging camera Flir.

***Key words**: heat source, solid biofuel, emissions, briquette, firewood*

INTRODUCTION

Considering its wide application, biomass is the most significant alternative to fossil fuels. Its energy can be converted by direct combustion into thermal energy, by means of

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which it is possible to heat houses and flats, or it can be further converted into electrical energy. As regards industry, all types of biomass can be utilized. In Slovakia it is primarily used in solid form for heating in the urban heating plants. Similarly, the operation of crop dryers considerably relies on agricultural waste, which is an easily available and affordable source of energy [1], [2] and [3].

On the other hand, combustion of biomass also has its drawbacks. In recent years, so-called clean fuels have become quite preferred, mainly in the form of pellets and briquettes. However, the price of these biomass-based fuels, calculated with regard to calorific value, nowadays approaches the cost of natural gas. Apart from energetic and economic points of view, the role of environmental aspects in the characterization and evaluation of biofuels gains considerable importance. Numerous analyses and measurements of emissions arising from the combustion of biofuels indicate that flue gas contains, apart from the main products of the oxidation of carbon and hydrogen - CO_2 and H_2O, also other aliphatic and aromatic hydrocarbons, CO and nitrogen oxides [4], [5]. For this reason, the idea of so-called ecological harmlessness of heat production from wood and wood waste should be abandoned, while further attention shall be paid to the development and improvement of technological procedures of biofuel combustion in the furnaces of heat generators [6], [7].

The article introduces the results of measurements of concentration of gaseous emissions performed on the heat source for home heating which combusts wood biomass.

MATERIAL AND METHODS

Production of flue-gas emissions was observed on the hot water gasification boiler VIGAS 25 with controller AK 2000, which is designed particularly for firewood combustion and is used for home heating [8].

Boiler parameters are as follows: manufacturer VIMAR, nominal output 25 kW, output range 5 - 31 kW, efficiency 85,49 %, max. operational pressure 0,3 MPa, chimney draft 15 - 20 Pa, firebox capacity 120 dm^3, max. electrical input 70 W, noise level 45,5 dB [9]. This boiler is made for combustion of firewood with appropriate moisture content up to 20 %. The manufacturer recommends the following alternative fuels: wood briquettes, woodchips, sawdust and wood shavings, provided that they are burned together with larger pieces of wood (logs).

The fuel is dried and gasified in the firebox, from which the produced wood gas flows through a refractory concrete nozzle to the combustion chamber. There it burns with the help of the secondary air. Flue gas is intensively cooled in the exchanger. Unburned residue is swept out of the combustion chamber. In order to start up the boiler, the lighting up valve controlled by a draw-bar in the front part of the boiler is used. To meet the requirements of simple operation, the device contains the control unit AK 2000 placed in the upper part of the boiler. This control system enables very efficient combustion of various types of biofuels. In case of long-term power outage or automatic regulation failure it is possible to heat by opening the flue baffle and leaving the lower door ajar. This method of heating requires more frequent checks of the water outlet temperature and smaller amounts of fuel to refill, because loading the firebox to the maximum may cause overheating of the boiler [8].

For the purpose of the experiment, two types of biofuels were used- bark briquettes and hardwood briquettes. These fuels were selected in order to provide comparison of the emissions arising from the combustion of fuel which the boiler is designed for (i.e. firewood) in contrast to alternative fuels or the ones which were not recommended by the manufacturer.

The device Testo 330-2 LL was used for the measurement of emissions. It is a flue gas analyser, which can measure various quantities and save the obtained values to the memory.

During the experiment, the following quantities were observed: O_2 %, CO ppm, CO_2 %, T_s (flue gas temperature) °C, T_v (ambient air temperature) °C, *qA* (chimney loss) %, η (efficiency) %, λ (air surplus) -, NO ppm, NO_x ppm, chimney draft Pa.

In order to start the measurement of the emission production, it is necessary to choose the option *Flue gas measurement* on the device and confirm the choice. In case the type of the fuel was not selected yet, it has to be submitted in the settings prior to the measurement.

During the experiment, the flue gas probe of the device was placed approximately 900 mm from the flue outlet of the boiler. At the same time, to ensure the most accurate results possible, the end of the probe was set approximately in the middle part of the flue.

Moisture content of selected biofuels was determined by the means of the laboratory oven Memmert UFE 400 and calculated as an average of several measurements. Weight of the samples was measured by the scales KERN EG 420 with 0,001 g resolution. The samples were dried at the temperature of 105°C to a constant weight.

Moisture content from the obtained weight of the samples was calculated according to the following relation:

$$w = \frac{m_1 - m_2}{m_1} 100 \tag{1}$$

Where:
w [%] - moisture content,
m_1 [g] - initial weight,
m_2 [g] - dry matter weight.

This relation was used to determine carbon monoxide content in the emissions:

$$CO_e = \frac{21\% - O_{2ref}}{21\% - O_2} 1{,}25\, CO \tag{2}$$

Where:

CO_e	[mg·m^{-3}]	- carbon monoxide content in the emissions,
21	[%]	- concentration of oxygen in the air (*const.)*,
O_2	[%]	- measured concentration of oxygen,
O_{2ref}	[%]	- reference oxygen content (depending on the fuel),
1,25	[mg·m^{-3}·ppm^{-1}]	- conversion factor (ppm → mg·m^{-3}),
CO	[ppm]	- measured concentration of carbon monoxide content.

This relation was used to calculate nitrogen oxides content in the emissions:

$$NO_{xe} = \frac{21\% - O_{2ref}}{21\% - O_2} 2{,}05\, NO_x \quad (3)$$

Where:

NO_{xe}	[mg·m^{-3}]	- nitrogen oxides content in the emissions,
2,05	[mg·m^{-3}·ppm^{-1}]	- conversion factor (ppm → mg·m^{-3}),
NO_x	[ppm]	- measured concentration of nitrogen oxides content.

Surface temperature of the boiler was monitored by the thermal imaging camera Flir T-335.

RESULTS AND DISCUSSION

The first measurement of selected emissions and other quantities for given fuel was carried out approximately 30 minutes after loading of the boiler. Following measurements were performed in 30-minute intervals in order to point out the differences at varying output of the boiler. Measured values for bark briquettes and hardwood briquettes are presented in Tab. 1 and Tab. 2, respectively. Corresponding values of boiler output for each measurement are provided. At 100% of the boiler output, chimney draft was also measured. It reached the value of -18 Pa at maximum flue gas temperature of 80,9°C.

Table 1. Results of measurements of emissions during combustion of bark briquettes

	O_2	CO_2	CO		T_S	T_V	qA	η	Λ
	[%]	[%]	[ppm]	[mg·m^{-3}]	[°C]	[°C]	[%]	[%]	[-]
1.	15,4	7,06	1284	2866,1	76,55	26,0	3,8	96,2	2,23
2.	19,1	1,84	1378	9065,8	33,20	26,2	3,3	96,7	11,10
3.	17,9	3,00	550	2217,7	58,30	27,0	6,2	93,8	6,96
4.	19,8	1,16	777	8093,7	45,50	26,3	11,6	88,4	18,00
5.	17,4	3,43	1165	4045,1	62,40	25,8	8,7	91,3	5,97
6.	14,4	6,38	585	1108,0	104,00	25,6	9,7	90,3	3,34
7.	17,5	3,39	780	2785,7	67,40	25,7	7,9	92,9	6,08
8.	16,8	5,42	1111	3306,5	72,90	25,7	8,2	91,8	4,83
	NO		NO_x		Boiler output				
	[ppm]	[mg·m^{-3}]	[ppm]	[mg·m^{-3}]	[%]				
1.	100	366,1	105	384,4	100				
2.	12	129,5	12	129,5	0				
3.	94	621,6	98	648,1	30				
4.	16	273,3	16	273,3	10				
5.	98	558,1	103	586,5	70				
6.	101	313,7	106	329,2	100				
7.	54	316,3	57	333,9	40				
8.	95	463,7	101	493,0	70				

Three six-piece (6 kg) packs of block-shaped briquettes made from tree bark were used in the experiment. Their size was 15 x 7 x 10 cm (*w* x *h* x *l*) and average moisture content reached 4,7 %. Briquettes were put into the firebox with embers for easier start up. After loading and closing of the firebox door, control measurement of carbon monoxide concentration around the boiler was performed. The results indicated slightly increased concentration, reaching 286 ppm. The next measurement after 20 minutes showed significant decrease to 56 ppm. During the following measurement after 30 minutes, no considerable change in CO concentration was observed. From the short-term point of view it remained within the safe limits.

Fig. 1 shows the dependence of oxygen, carbon dioxide and carbon monoxide levels in the flue gas on the boiler output and chimney loss at given output during the combustion of bark briquettes.

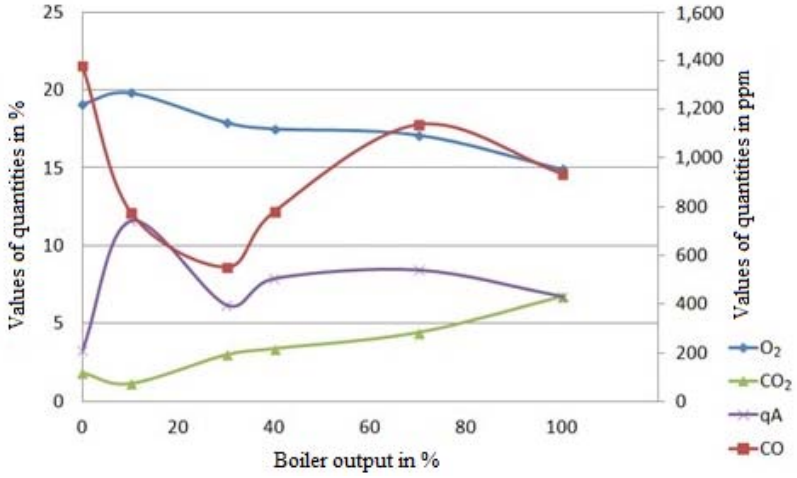


Figure 1. Dependence of oxygen, carbon dioxide, carbon monoxide levels in the flue gas on the boiler output and chimney loss at given output

Fig. 2 demonstrates the dependence of nitrogen oxides and nitric oxide emission levels in the flue gas on the boiler output, the dependence of flue gas temperature on the boiler output as well as course of ambient air temperature during the measurement. The graph depicts average values of two measurements which were performed at 100% and 70% of the boiler output.

The graph in the Fig. 1 shows decrease in carbon monoxide emissions at boiler output in the range 10-40% with a minimum reached at 30% of the boiler output. On the other hand, Fig. 2 indicates rise in nitrogen oxides emission level at 30% of the boiler output. This growth may be explained by the fact that bark briquettes are primarily intended to keep the embers burning once the boiler is turned off, rather than to be used for heating.

Fig. 3 presents dependence of efficiency and air surplus on the boiler output. From the graph we can see that efficiency significantly dropped at 10% of the output. This decline may be similarly attributed to the purpose of bark briquettes.

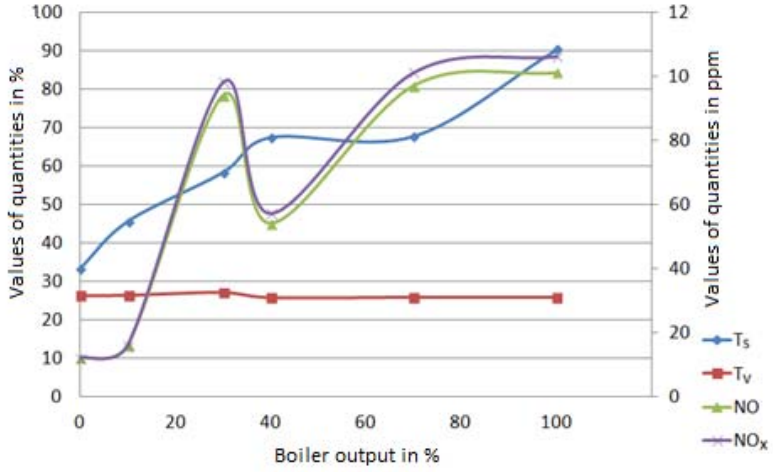


Figure 2. Dependence of nitrogen oxides and nitric oxide emission levels in the flue gas on the boiler output, dependence of flue gas temperature on the boiler output, and course of ambient air temperature during the measurement

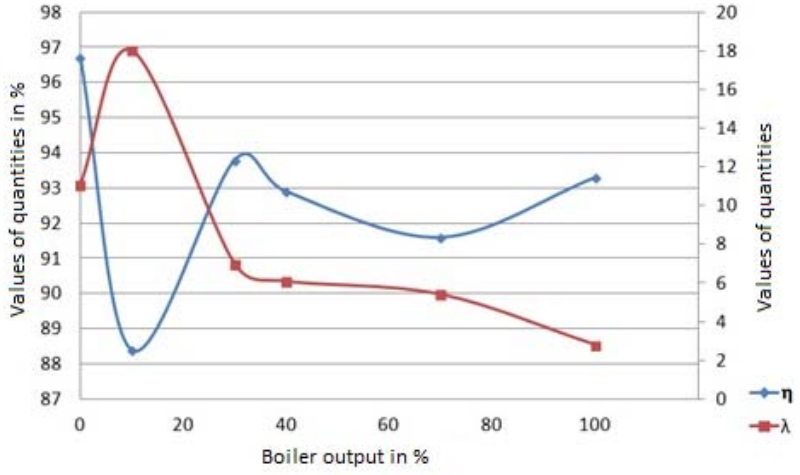


Figure 3. Dependence of efficiency and air surplus on the boiler output

In the following experiment, three five-piece (10 kg) packs of cylinder-shaped hardwood briquettes were used. Their length was 26 cm, diameter 9,5 cm and average moisture content reached 6,0 %. In order to ensure easier start up, embers from firewood were set up prior to loading of the firebox with briquettes.

The first measurement was performed approximately 30 minutes after loading of the boiler with the new fuel. Emissions and other quantities were measured in 30-minute intervals with respect to the boiler output. Results are shown in Tab. 2 with

corresponding values of boiler output at which they were obtained. Similarly to the previous measurements, chimney draft was measured at full boiler output. It reached the value of -12 Pa at maximum flue gas temperature of 76,7 °C.

With respect to the scope of the article, graphic dependences are not provided. Nevertheless, significant decrease in carbon monoxide emissions at 30-70% of the boiler output was observed. This decline may be attributed to the appropriate combustion parameters for this kind of fuel in the given boiler output range. During combustion of hardwood briquettes (and firewood as well), production of nitrogen oxides emissions depends on the fuel gas temperature.

Table 2. Results of measurements of emissions during combustion of hardwood briquettes

	O_2	CO_2	CO		T_S	T_V	qA	η	Λ
	[%]	[%]	[ppm]	[mg·m^{-3}]	[°C]	[°C]	[%]	[%]	[-]
1.	15,7	5,15	1590	3750,0	87,6	25,7	11,6	88,4	4,88
2.	13,8	7,01	1256	2180,6	99,9	25,5	9,8	90,2	2,90
3.	16,8	4,06	321	955,4	73,9	25,6	12,2	87,8	6,47
4.	17,0	3,86	170	531,3	85,4	26,3	31,6	68,4	6,25
5.	17,3	4,64	155	523,6	71,9	25,3	7,9	92,1	6,84
6.	15,1	5,41	1358	2877,1	103,4	25,8	10,7	91,2	4,13
7.	19,6	1,40	1200	10714	33,3	27,0	3,8	96,2	17,50
8.	19,3	1,65	741	5448,5	45,8	27,4	4,7	95,3	16,20
	NO		NO_x		Boiler output				
	[ppm]	[mg·m^{-3}]	[ppm]	[mg·m^{-3}]	[%]				
1.	60	232,1	63	243,7	100				
2.	44	125,3	46	131,0	90				
3.	53	258,7	56	273,3	70				
4.	42	215,3	44	225,5	50				
5.	41	227,2	43	238,2	30				
6.	57	198,1	60	208,5	100				
7.	14	205,0	15	219,6	0				
8.	16	192,9	17	205,0	10				

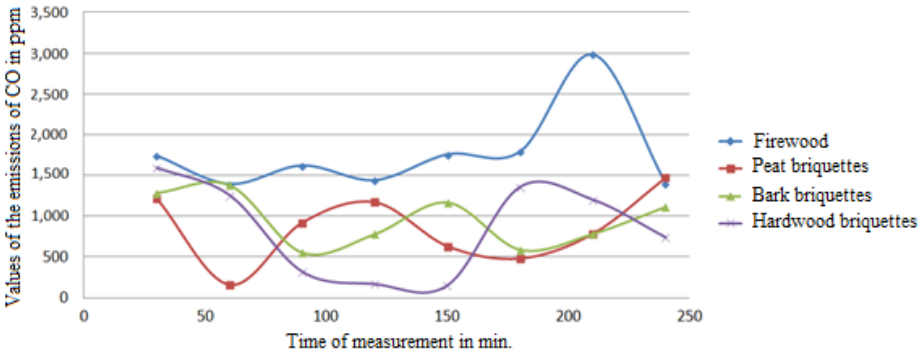
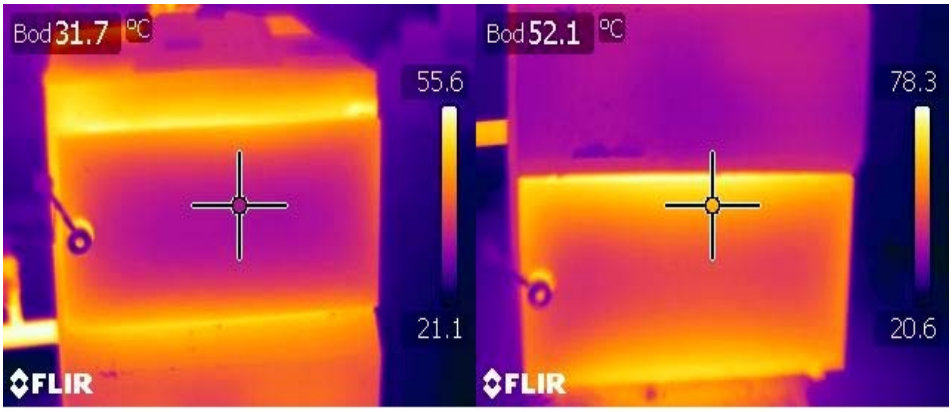


Figure 4. Dependence of production of carbon monoxide emissions on the time of measurement

In order to provide comparison of the tested biofuels, Fig. 4 shows the dependence of carbon monoxide emissions level on the time of measurement. It is apparent that the emissions reached a peak during combustion of firewood. However, the course of the emissions remained stable, except the measurement at 80% of the boiler output. Other kinds of fuel were characteristic of considerable variability in production of carbon monoxide emissions, as regards dependence on the time of measurement and on boiler output as well.

Fig. 5 shows the boiler monitored by the means of the thermal imaging camera. Thermograms depict upper part with the firebox door and lower part with the combustion chamber door. Increased temperature on the outer edges indicates so-called thermal bridge, when the heat conduction in the door frame causes warming of the surface panels. The boiler is not suitably designed in this part.



a. *b.*

Figure 5. Thermogram of the boiler surface
a. firebox door, b. combustion chamber door

According to [10], combustion of biomass, as far as carbon dioxide (CO_2) emissions are concerned, may be considered as neutral. Various authors [11], [12] and [5], [7], hold the same views and present biomass as a neutral source of energy. This article is in line with this theory, although the results of the measurements indicate relatively high levels of emissions, especially when using a biofuel the tested heat source was not designed for. Differences in flue gas temperature were also observed. The analysis of the course of boiler wall temperature is dealt with in the following paper [13].

According to [1], measurements at the heat source for a housing estate showed that combustion of biomass produces considerably higher amount of air pollutant emissions than combustion of natural gas. For example, approximately 19 times more emissions of particulate matter arise. Despite the fact that the device has a whirl separator, CO emissions are nearly 13 times higher and NO_x emissions are 9 times higher than comparable heat production from natural gas generates. This situation implies higher fees for air pollution. However, some advantages may be also pointed out, such as economic profitability and regional employment support.

The operating staff may have negative impact on the production of emissions by using of the inappropriate type of fuel for the given device, using of the fuel with higher moisture content and by the amount and frequency of loading of the device with fresh fuel.

CONCLUSIONS

The results have shown that firewood is the most suitable fuel for this type of boiler. During the combustion of firewood, the lowest levels of emissions (except CO emissions) and the highest combustion efficiency (η = 91,9÷94,6%) were measured. Other kinds of biofuels were characteristic of higher amounts of air pollutants. Variability in the emission levels was observed in bark briquettes, as regards dependence on the time of measurement and on boiler output as well. Combustion of bark briquettes also generated the highest amounts of NO_x emissions (106 ppm) and NO emissions (101 ppm).

The data supported the recommendation of the manufacturer to use firewood as a primary biofuel and wood briquettes as an alternative fuel for this boiler type. As regards long-term operation, it is not possible to draw any conclusions for another fuel from this experiment. Thermogram of the boiler surface from the front indicated increased temperature on the outer edge of the firebox door and combustion chamber door. This problem should be addressed by the manufacturer.

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EMISIJE GASOVA TOKOM SAGOREVANJA RAZLIČITIH BIOGORIVA

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***Sažetak*:** Biomasa, ili tačnije rečeno biogorivo, danas sve više zamenjuje fosilna goriva za grejanje. Takođe, koristi se i za zagrevanje fluida pri sušenju. Ovaj rad je usmeren na ocenu izvora toplote tokom sagorevanja različitih vrsta čvrstih biogoriva. Izvor toplote koji je ispitivan je bojler VIGAS 25 sa kontrolerom AK 2000 za kućno grejanje. Za merenje gasovitih emisija je korišćen uređaj TESTO 330-2LL. Testirana biogoriva bili su briketi od kore drveta i briketi od tvrdog drveta. Rezultati eksperimentalnih merenja produkcije gasova ova dva goriva su predstavljeni u tabelarnoj i grafičkoj formi, u zavisnosti od izlaznih parametara bojlera i vremena sagorevanja. Površinska temperatura bojlera je praćena termovizijskom kamerom Flir.

***Ključne reči**: izvor toplote, čvrsto biogorivo, emisije, briketi, ogrevno drvo*

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SOLAR: A SOFTWARE TOOL FOR METEOROLOGICAL DATA PROCESSING

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Abstract: The current standards for solar components and systems testing (SRB, EN, ISO, DIN, etc.) imply the determination of the system relevant parameters at the monitored locality. In this regard, it is necessary to prepare all the input data for the selected location in order to determine the standard values, such as: thermal collector performance, factor changes in incident angle of radiation, heat capacity, pressure values and various quality tests. The parameters collected with appropriate measuring instruments are necessary for defining the state of atmospheric moisture air (temperature, relative humidity), air movement (speed and wind direction), ambient characteristic at given location (clouds, precipitation, etc.) and parameters that describe the energetic potential of the Sun (total, direct and diffusion radiation). A software tool for meteorological data processing (SOLAR) is designed and constructed so that the collected data of experimental measurements can be effectively and easily processed, with the possibility to present the results in a number of ways. The basic software components are subroutines for data filtering (extracting the minimum, maximum and average values in the selected time interval of observation), data processing (calculation of unknown characteristic values that are based on experimentally measured values), and visualization of results (graphical representation results).

Keywords*: software tool, data processing, data filtering, moisture air, solar radiation, energy.*

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INTRODUCTION

The sudden development and availability of computer technology has enabled fast and efficient manipulation with large databases. There are a number of software that similarly processed data, however, it may be noted that even in similar areas of research there is no strict unification of software input and output variables. An obvious example is a software package called „Climate Consultant“ [1, 2] developed at University of California, Los Angeles, whose primary task is filtering and visualization of meteorological files (extension *.epw). The data are adjusted to the standardized forms defining the parameters of comfort when people stay indoors as the California Energy Code Comfort Model (2008), ASHRAE Handbook of Fundamentals Comfort Model (2005) and ASHRAE Standard 55-2004 Model. The use of software in which one of the modules deals with similar issues, is widespread in practice. For example, the program „TRNSYS - Transient System Simulation Program“ [3], whose primary function is the simulation of the system work and performance, has a separate module to read and recognize a variety of meteorological data base format (*.dat, *.tmy, *.tmy2, etc.). In a similar way „EnergyPlus program - Energy Simulation Software“ [4], intended to simulate the energy demand of buildings, has a module for processing all the relevant size of a typical meteorological year (*.iwec), aggregate data about the weather conditions for the given location (*.stat) and information about the outside design conditions for a given location according to ASHRAE standards (*.ddy).

While TRNSYS is commercial software written only for Microsoft Windows, Climate Consultant (from the version 3.0) and EnergyPlus are free software compatible with all operating systems. Although TRNSYS and EnergyPlus are both written in FORTRAN, TRNSYS is extendable through any programming language able to compile Windows Dynamic Link Libraries (C, C++, FORTRAN, PASCAL…) and EnergyPlus is extendable only via FORTRAN. Climate Consultant is developed in Java and cannot be extended by user. All described tools are fast, highly graphic and easy to use, understand and maintain. Each has a built in demonstration and automatic install routine.

Based on the analysis of existing similar software solutions, it can be noted that there is no universal format in which the input data is prepared for processing, and that there is no universal way of formatting the results obtained and processed data. Therefore, this approach leaves the possibility to freely accessed creation of algorithms for the creation of databases and their treatment, according to the needs arising from their own research.

MODEL

Data processing involves modeling the new thermomechanical parameters and variables by using familiar formulas of various complexities whose implementation is significantly simplified by the use of appropriate software routines.

A software tool for meteorological data processing – SOLAR, handles [5] experimental data stored in the database. The format of software database must be such that it contains the INPUT data for $n=1\div15$ pre-defined experimental parameters and according to those values calculates $n=16\div35$ additional variables as the results (Table 1). The input values $n=1\div7$ are placed in database (experimental measurement results),

and values $n=8\div15$ are entered by software main window interactive menu. The software calculation procedure is based on Eq.1 to Eq.20.

Table 1. Software database input/output parameters and variables

n	In / Out		Parameter / Variable	Unit	Description	Equation number
1	Input	Database	T_{db}	°C	Dry-bulb temperature	n/a
2			RH	%	Relative humidity	
3			I_H	Wh/m^2	Total solar radiation on horizontal surface	
4			$I_{DIF,H}$	Wh/m^2	Diffuse radiation on horizontal surface	
5			P_a	Pa	Atmospheric pressure	
6			w	m/s	Wind speed	
7			WD	$0\div360°$	Wind direction	
8		Interactive menu	M	$1\div12$	Month of the year	
9			D	$1\div31$	Day of the month	
10			N	$1\div365$	Day of the year	
11			H	$1\div24$	Hour of the day	
12			ρ_g	$0\div1$	Reflectance of the foreground	
13			LAT	degrees	Latitude	
14			ψ	$0\div360°$	Surface azimuth	
15			Σ	$0\div90°$	Tilt angle	
16	Output		p_{ws}	Pa	Water vapor saturation pressure	1
17			p_w	Pa	Water vapor partial pressure	2
18			W_s	kg_w/kg_{da}	Air humidity ratio of saturated air	3
19			W	kg_w/kg_{da}	Air humidity ratio	4
20			h	kJ/kg	Enthalpy of the moist air	5
21			T_{wb}	°C	Wet-bulb temperature	6
22			T_d	°C	Dew-point temperature	7
23			δ	$0\div90°$	Declination	8
24			$\angle H$	$0\div90°$	Hour angle	9
25			β	$0\div90°$	Solar altitude	10
26			ϕ	$\pm90°$	Solar azimuth	11
27			γ	$0\div90°$	Surface-solar azimuth	12
28			Θ	$0\div90°$	Angle of incidence	13
29			Θ_Z	$0\div90°$	Zenith angle	14
30			R_b	-	Geometric factor	15
31			$I_{D,H}$	Wh/m^2	Direct radiation on horizontal surface	16
32			$I_{D,T}$	Wh/m^2	Direct radiation on tilted surface	17
33			$I_{DIF,T}$	Wh/m^2	Diffuse radiation on tilted surface	18
34			$I_{r,T}$	Wh/m^2	Reflected radiation from the foreground	19
35			I_T	Wh/m^2	Total solar radiation on tilted surface	20

When determining a number of moist air properties (the saturation humidity ratio primarily), the water vapor saturation pressure p_{ws} is required. The Eq.1 is created by fitting the curve (with coefficient of determination value r^2=0.9999076) to data presented in Table 2, where equation constants are C_1=-0.51429817, C_2=1.076863162 and C_3=-20.1577755.

$$p_{ws} = C_1 + C_1 \cdot e^{\left(\frac{-T_{db}}{C_3}\right)} \tag{1}$$

Table 2. The water vapor saturation pressure dependence of dry-bulb temperature [6, 7]

T_{db}	°C	0	10	20	30	40	50	60	70
p_{ws}	kPa	0.61	1.23	2.34	4.24	7.37	12.33	19.92	31.17

The water vapor partial pressure p_w is the product of the relative humidity RH and the water vapor saturation pressure (Eq.2) [8].

$$p_w = (RH/100) \cdot p_{ws} \tag{2}$$

Saturation humidity ratio W_s is the humidity ratio of moist air saturated with respect to water (or ice) at the same temperature and pressure (Eq.3). Humidity ratio W of a given moist air sample is defined as the ratio of the mass of water vapor to the mass of dry air contained in the sample (Eq.4).

$$W_s = (M_w/M_a) \cdot [p_{ws}/(p_a - p_{ws})] \tag{3}$$

$$W = (M_w/M_a) \cdot [p_w/(p_a - p_w)] \tag{4}$$

where equation constants are M_w=18.016 *kg/kmol*, M_w=28.964 *kg/kmol* and P_a=101325 *Pa*.

The enthalpy of a mixture of perfect gases equals the sum of the individual partial enthalpies of the components. Therefore, the enthalpy of moist air can be written by Eq.5.

$$h = c_{p,a} \cdot T_{db} + W \cdot (r_o + c_{p,w} \cdot T_{db}) \tag{5}$$

where equation constants are $c_{p,a}$=1.004 *kJ/kgK*, r_o=2500 *kJ/kg* and $c_{p,w}$=1.805 *kJ/kgK*.

The value of wet-bulb temperature T_{wb}, which satisfies Eq.(6) for given values of T_{wb}, W and W_s is calculated by using the assumption-iteration method.

$$W = \frac{(2500 - 2.381 \cdot T_{wb}) \cdot W_s - (T_{db} - T_{wb})}{2500 - 1.805 \cdot T_{db} - 4.186 T_{wb}} \tag{6}$$

Dew-point temperature t_d is the temperature of moist air saturated at the same pressure p, with the same humidity ratio W as that of the given sample of moist air. It is defined as the solution $t_d = t_d(p, W)$ of the Eq.7 [8].

$$W_s(p,t_d)=W \tag{7}$$

To find the solar altitude β and the azimuth φ when the hour angle $\angle H$, the latitude *LAT*, and the declination δ are known, the following Eq.8 to Eq.11 may be used.

$$\delta = 23.45\cdot\sin\left[360°(284+N)/365\right] \tag{8}$$

$$\angle H = 15\cdot H - 180° \tag{9}$$

$$\sin\beta = \cos\left(\mathrm{LAT}\right)\cdot\cos\delta\cdot\cos\left(\angle\mathrm{H}\right)+\sin\left(\mathrm{LAT}\right)\cdot\sin\delta \tag{10}$$

$$\cos\phi = \frac{\sin\beta\cdot\sin(LAT)-\sin\delta}{\cos\beta\cdot\cos(LAT)} \tag{11}$$

The surface-solar azimuth γ is the angular difference, described in Eq.12, between the solar azimuth ϕ and the surface azimuth ψ.

$$\gamma = \phi - \psi \tag{12}$$

For a surface with a tilt angle Σ (measured from the horizontal), the angle of incidence θ between the direct solar beam and the normal to the surface is given by Eq.13. All previously used solar angles with respect to a tilted surface are described on Fig.1.

$$\cos\Theta = \cos\beta\cdot\cos\gamma\cdot\sin\Sigma+\sin\beta\cdot\cos\Sigma \tag{13}$$

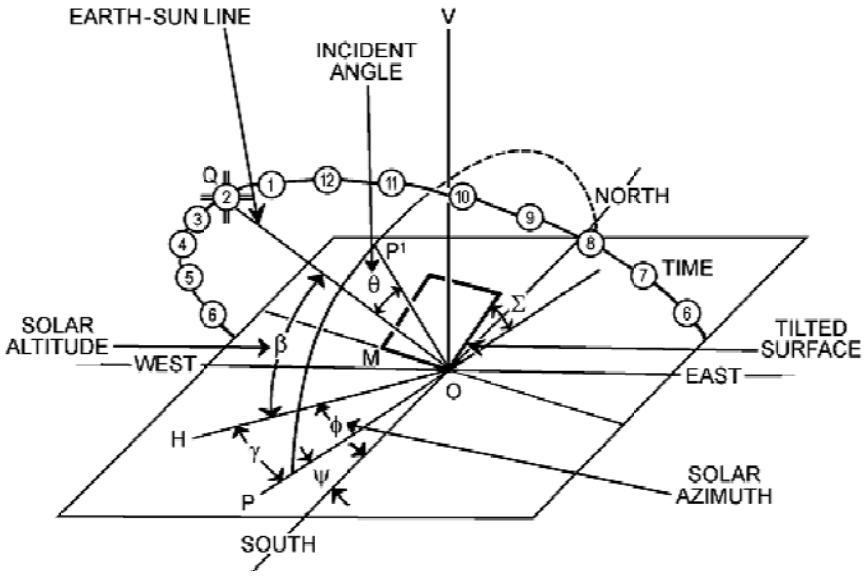

Figure 1. Solar Angles with Respect to a Tilted Surface [9]

Zenith angle θ_Z defined with Eq.14 and geometric factor R_b calculated from Eq.15 are used for calculating the value of the intensity of the direct normal radiation $I_{D,T}$, at the terrestrial surface of any orientation and tilt with an incident angle θ on a clear day.

$$\Theta_Z = 90 - \beta \tag{14}$$

$$R_b = \cos\Theta / \cos\Theta_Z \tag{15}$$

The intensity of the direct normal radiation $I_{D,H}$, at the terrestrial horizontal surface, can be calculated from the Eq.16.

$$I_{D,H} = I_H - I_{DIF,H} \tag{16}$$

The intensity of the direct normal radiation $I_{D,T}$, at the terrestrial surface of any orientation and tilt with an incident angle θ on a clear day, can be calculated from the Eq.17.

$$I_{D,T} = I_{D,H} \cdot R_b \tag{17}$$

The intensity of the diffuse radiation $I_{DIF,T}$, at the terrestrial surface of any orientation and tilt with an incident angle θ on a clear day, can be calculated from the Eq.18.

$$I_{DIF,T} = I_{DIF,H} \cdot \left[\left(1 + \cos\Sigma\right)/2\right] \tag{18}$$

The reflected radiation I_r from the foreground, when the reflectance ρ_g is known, is given by the Eq.19.

$$I_R = I_H \cdot \rho_g \cdot \left[\left(1 - \cos\Sigma\right)/2\right] \tag{19}$$

The intensity of the total solar radiation I_T, at the terrestrial surface of any orientation and tilt with an incident angle θ on a clear day, can be calculated from the Eq.20. [18]

$$I_T = I_{D,T} + I_{DIF,T} + I_{R,T} \tag{20}$$

SOFTWARE CHARACTERISTICS

SOLAR is portable, flexible, secure, scalable and easy-to-use software freely available as a web application requiring no download or installation. Software architecture followed by brief description of software implementation and usage is given below.

Software architecture

Software architecture involves the components of a software system and the relationships between those elements [10]. In the case of web-based software modules, databases and web servers are the components of system and mechanisms of information exchange between system components are described with relationships among them [11]. In order to create and maintain the software architecture, structure of a system has to be specified and standard design practices have to be followed.

A multi-tier architecture is architectural pattern used to divide functionality of a system into a number of layers [12]. This architecture is widely used for development of different web-based applications because it enhances reusability, scalability and flexibility of application [13].

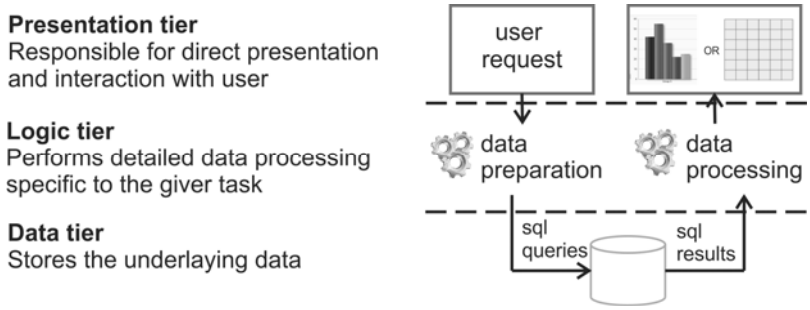

Figure 2. SOLAR architecture

For example, module for parsing and processing CSV (Comma Separated Values) files created for one application can be reused in other applications. SOLAR web-based software has three tiers with architecture detailed in Fig. 2.

Software implementation

SOLAR is built on open source and platform independent solutions, with Apache HTTP Server 2.2 and MySQL 5.6 at the back end and PHP 5.3 [14, 15], HTML [16], CSS [17] and JavaScript at the front end. This software is available online through any Web browser at http://solar.mas.bg.ac.rs/software.html.

With interactive and user-friendly graphical interface, SOLAR is easy to use for all users. Also, user guide is available as a PDF, downloadable from manual section[1]. Software can work with default database entries but user can provide its own file with appropriate data in suitable format (template is available for download from manual section) to fill the database. Software-provided data are available for any user while user-provided data are available only for the user who provides it. After the user chooses a type of filtering (minimum, maximum and average), time interval (hourly, daily and monthly or arbitrarily specified interval in specific format), parameters (given in Table 1) and result representation (graphical, tabular), the software prepares data for further use based on selected constraints.

[1] http://solar.mas.bg.ac.rs/manual.html

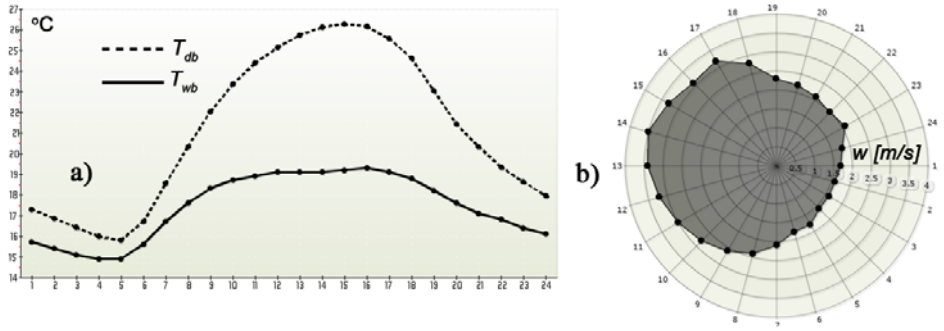

Figure 3. Air properties graphs: a) Dry-bulb and wet-bulb temperatures; b) Wind speed

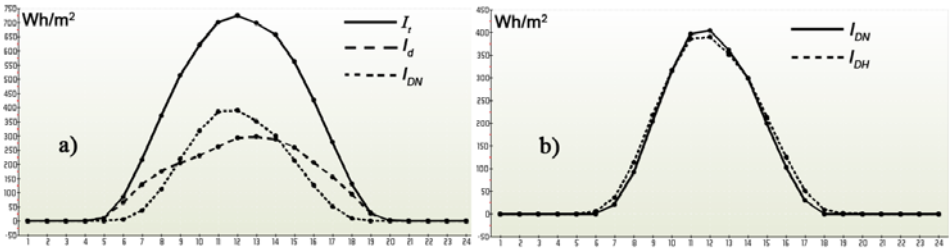

Figure 4. Surface radiation graphs: a) Total solar, Diffuse and Direct radiation; b) Direct radiation on surface of any orientation and tilt angle and Direct radiation on horizontal surface

Then, corresponding values are read from the database and new ones are calculated according to formulas given in previous section. All values are standardized, normalized and grouped depending on selected result representation. Finally, obtained results are submitted to user in one of two formats – tabular format and graphical format. Results are available for download as PNG file for graphical representation and as CSV file for tabular representation.

The examples of graphical representation of the results are presented in Fig. 3 and Fig. 4. Fig. 3 illustrates the simple visualization of hourly averaged input database data, during the selected period 1st June – 30th August. Software is reading the input values of dry-bulb and wet-bulb temperatures (Fig. 3a) and wind speed (Fig. 3b) from the database, calculates average values and draws the graphs. The input data and calculated variables could be combined on the same graph. For example, it is possible to present total solar radiation (from database), diffuse radiation (from database) and direct radiation (calculated variable) in a same graph (Fig. 4a). However, if there is a need to explore database in more details, there is a software possibility for selecting additional criteria from interactive menu. For example, the direct radiation on surface (South orientation) with tilt angle (45 degrees) and with included reflectance of foreground (0.10) could be presented along with direct radiation on horizontal surface in a same graph (Fig. 4b), despite the fact that all values are calculated.

The practical application of SOLAR is possible within solving and calculation of various ranges of different problems. For example, this type of data processing could bring great benefit in the analysis and simulation of greenhouses performances [19],

energy consumption for different greenhouse constructions [20, 21], exploring possibilities for renewable energy storage [22], or dealing with different solar energy related problems and applications [23, 24], etc.

CONCLUSIONS

Based on current scientific knowledge in the field of applied thermodynamics, a software application for processing data collected by experimental measurements was developed. The software contains modules for data filtering, data processing and data visualization. The software significantly shortens the time needed for problem analysis, trend monitoring changes in relevant process parameters or extract characteristic values of the observed desired intervals. Developed software is easy to use and supported by accompanying documentation, maintenance and training, with the possibility of module extension according to the user demands. The implementation of such a computer program that automates the calculation and provides a graphical picture of the changes observed parameters can enable rapid implementation of numerous analyses which are based on multi-criteria basis. The possibility of exporting the fitted values in the new - an updated database, gives this application a special importance, especially for displaying the data obtained in the so-called “user friendly" format, that is accepted by the huge number of applications that are used in mathematical and statistical analysis of data.

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SOLAR: SOFTVER ZA FILTRIRANJE, OBRADU I VIZUELIZACIJU PRIKUPLJENIH METEOROLOŠKIH PODATAKA

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Sažetak: Aktuelni standardi za ispitivanje solarnih komponenata i sistema (SRB, EN, ISO, DIN i drugi) podrazumevaju određivanje svih relevantnih parametara rada instalacije na posmatranom lokalitetu. S tim u vezi, neophodno je pripremiti sve ulazne podatke za odabranu lokaciju radi određivanja standardom definisanih veličina, kao što su: toplotni učinak kolektor, faktor promene upadnog ugla zračenja, toplotnog kapaciteta, padova pritisaka i raznih testova kvaliteta. Veličine koje su od značaja za proračun se mere odgovarajućim mernim instrumentima i neophodne su za definisanje stanja vlažnog atmosferskog vazduha (temperatura, relativna vlažnost), kretanja vazduha (brzina i pravac strujanja vetra), ambijentalnih karakteristika atmosfere na posmatranoj lokaciji (oblačnost, količina padavina, i slično) kao i veličina koje oslikavaju energetski potencijal Sunca na posmatranoj lokaciji (ukupno, direktno i difuzno zračenje). Softver za filtriranje, obradu i vizuelizaciju prikupljenih meteoroloških podataka - SOLAR, osmišljen je i izrađen tako da prikupljene podatke eksperimentalnih merenja efikasno i jednostavno procesuira, a dobijene rezultate potom predstavi korisniku. Osnovne komponente softvera su subrutine za filtriranje podataka (izdvajanje minimalnih, maksimalnih i prosečnih vrednosti u željenom vremenskom intervalu posmatranja), za obradu podataka (izračunavanje nepoznatih karakterističnih veličina koje su od značaja za posmatrani proces na osnovu eksperimentalno merenih veličina) i vizuelizaciju rezultata (grafičko predstavljanje rezultata sa mogućnošću uporednog prikazivanja srodnih veličina i mogućnošću eksportovanja u druge formate pogodne za dalju analizu).

Ključne reči: *softver, obrada podataka, filtriranje podataka, vlažan vazduh, Sunčevo zračenje, energija.*

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UNAPREĐENJE KONSTRUKCIJE MAŠINE K2S POMOĆU DINAMIČKE ANALIZE STABLA OTKAZA

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Sažetak: Mašina K2S je mašina koja služi za klasiranje i pakovanje krompira. Dosadašnja eksploatacija ove mašine ukazala je na neke njene nedostatke. Mašina K2S se sastoji od jednog trakastog transportera koji služi za dodavanje i dva oscilatorna transportera koja služe za klasiranje krompira. U ovom radu je korišćenjem dinamičke analize stabla otkaza napravljen predlog revizije mašine u cilju povećanja njenih kapaciteta, otkalanjanja nedostataka i produžavanja radnog veka. Dinamička analiza stabla otkaza je izabrana pored ostalih metoda pouzdanosti zbog njene mogućnosti za uračunavanje redosleda događaja otkaza. U radu su dati prikazi stare mašine, dinamička analiza stabla otkaza sistema za pobudu oscilacija kao i predlog revizije mašine. Na kraju rada izvršena je diskusija postignutih rezultata i dati su pravci mogućeg daljeg unapređivanja ove mašine.

Ključne reči*: mašina, klasiranje, pakovanje, pouzdanost, dinamička analiza stabla otkaza*

UVOD

Pri projektovanju pouzdanosti mašinskih sistema najrasprostranjenija je Analiza stabla otkaza, *Failure tree analysis – FTA*, metoda [1]. Analiza stabla otkaza je deuktivna metoda koja se zasniva na vršnom događaju koji predstavlja otkaz sistema. Ovaj vršni događaj se dalje razvija na događaje nižeg reda koji dovode do vršnog događaja. Praktično, analiza stabla otkaza predstavlja metodu koja tehnički sistem sa aspekta otkaza pretvara u logički dijagram [2, 3].

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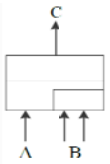
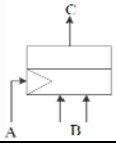
Kod klasične anlize stabla otkaza postoje i određeni nedostaci. Glavni nedostatak ove metode je izostavljanje uticaja vremena jednog događaja u odnosu na drugi. Mnogi događaji su uslovljeni jedan drugim kao lančana reakcija. Uvođenjem zavisnosti između vremena odvijanja događaja metoda analize stabla otkaza se transformiše u dimaičku analizu stabla otkaza, *Dynamic fault tree – DFT*. U radu [4], autroi su detaljno objasnili prednosti ove metode u odnosu na klasičnu analizu stabla otkaza. Takođe, razvlili su i matematički model procene pouzdanosti sistema na osnovu dinamičke analize stabla otkaza. U radovima [5-8] autori su u kombiniciji metode dinamičke analize stabla otkaza sa metodama *Markov*-ih lanaca i simulacione metode *Monte Carlo* ispitivali konkretne sisteme. Rezultati ispitivanja ovim metodama se u mnogome razlikuju od ispitivanja klasičnom metodom analize stabla otkaza. U radu [9] autori su koristili strukturne funkcije za razvijanje dinamičkog stabla otkaza. U ovom radu je dat i matematički model prevođenja strukturne funkcije u dinamičko stablo otkaza. U radu [10] je dat *Weibull*-ov pristup koji je prilagođen dinamičkoj analizi stabla otkaza.

U ovom radu je izvršena dinamička analiza stabla otkaza sistema za pobudu oscilacija mašine za pakovanje krompira K2S. Analiza je izvršena u cilju sveopšteg unapređivanja mašine pre izrade prve revizije. Nakon analize izvedeni su zaključci i dat je predlog revizije.

DINAMIČKA ANALIZA STABLA OTKAZA

Logičke kapije koje se koriste u dinamičkoj analizi stabla otkaza su date i u Tab. 1.

Tabela 1. Logičke kapije kod dinamičke analize stabla otkaza

Naziv kapije *Gate name*	Izgled simbola kapije *Symbol appearance*	Opis kapije *Gate description*
Uslovna kapija I *Conditional gate AND*		Uslovna kapija I označava kapiju kod koje je uslovljeno da se prvo dogodi događaj A, pa tek onda događaj B, dok njihovo dešavanje izaziva događaj C. *AND gate means event A happens before B. Both events triggers event C.*
Kapija sa rezerviranjem *Spare gate*		Kapija sa rezerviranjem znači da u slučaju događaja A, system može da se osloni na komponentu koja predstavlje događaj B. Tek kad ne postoji rezerviranje pokreće se događaj C. *Spare gate means that when event A happens, system is using B component. When all spares is gone event C is starting.*
Kapija sa uzrokujućim događajem *Trigger event gate*		Kapija sa uzrukujućim događajem označava da se nakod događaja A, pokreću togađaji B, što na kraju uzrukuje događaj C. *Trigger event gate means that before A, the event B is triggered, which causes event C.*

Simbli koji označavaju vršne, nearzvijene, bazične i ostale događaje identični su i u dinamičkoj analizi stabla otkaza i u klasičnoj analizi stabla otkaza. Simboli događaja su dati u Tab. 2.

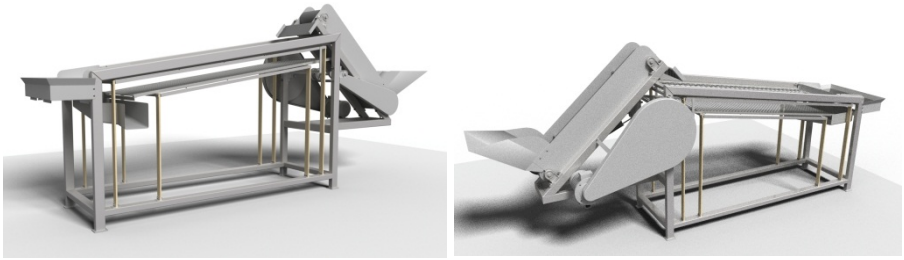
Dinamička analiza stabla otkaza predstavlja transformisanu klasičnu analizu stabla otkaza u zavisnosti od vremena. U zavsnosti od potrebne dubine dinamičke analize stabla otkaza moguće je i uvođenje vremnske matraice, koja sadrži sve događaje. Razlika u odnosu na klasičnu analizu stabla otkaza nalazi se u logičkim kapijama.

Tabela 2. Simboli događaja kod klasične i kod dinamičke analize stabla otkaza

Naziv događaja *Event name*	Izgled simbola događaja *Event symbol appearance*	Opis događaja *Event description*
Vršni događaj *Top event*		Pravougaonik označava događaj na izlazu iz logičke kapije (vršni ili posredni), koji se javlja kao posledica logičke kombinacije ulaznih događaja. *Fault event resulting from the logical combination of the input events, which are operating through the logic gate.*
Bazični događaj *Basic fault event*		Krug označava bazični inicirajući događaj koji ne zahteva dalje razvijanje. *Circle to mark a basic initiating fault requiring no further development.*
Nerazvijeni događaj *Undeveloped event*		Romb označava događaj koji nije razvijen do sopstvenih uzroka zbog nedostatka potrebnih informacija, ili malog značaja posledica, ili izbegavanja paralelnosti analize. *Fault event which is not developed up to its own cause, either because of absence of required information's, or because the low level of risk, or because of avoiding duplication of the analysis.*

RAZVIJANJE DINAMIČKOG STABLA OTKAZA MAŠINE K2S

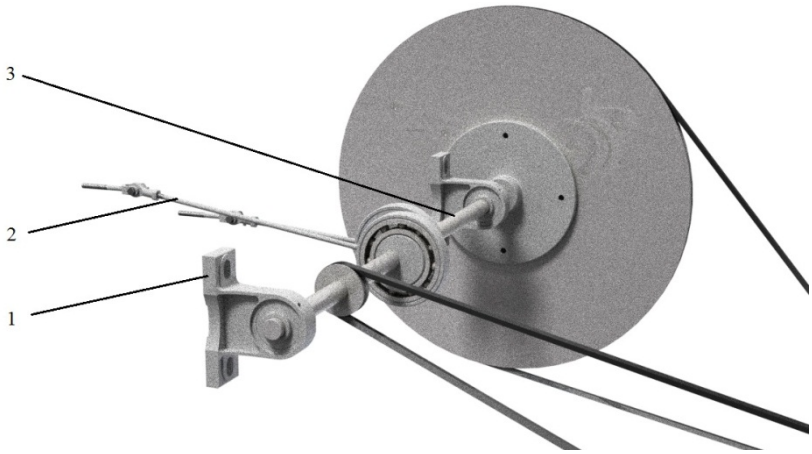
Mašina za klasiranje krompira K2S sastoji se iz jednog trakastog transpotera koji služi za doziranje i transport krompira do osciltarnih transportera, koji služe za sortiranje krompira. Oscilatorni transpoteri se nalaze jedan ispod drugog i razdvajaju krompir na klasu jelovnih i na klasu semenskih krompira. Svi transporteri su spojeni u celinu preko rama mašine. Prenos snage od elektromotora do oba transportera ostvaren je remenim kaišnim prenosom. Remeni kaišni prenosnici su zaštićeni oblogama od tankog lima radi postizanja bezbednosti u radu. Promena broja obrtaja vratila koje služi za pogon obe vrste transportera se vrši preko frekventnog regulatora napona. Dodatno pojačavanje ili smanjivanje doziranja krompira moguće je izmenama na traci transportera, montažom ili demontažom profila za povlačenje krompira. Dodatno ubrzanje ili usporenje kretanja krompira kroz oscilatorni transporter moguće je promenom nagiba mašine, koja se vrši produženjem ili skraćenjem prednjih stopa mašine. Izgled mašine za klasiranje i pakovanje krompira K2S dat je na Sl. 1.



Slika. 1 K2S mašina za klasiranje i pakovanje krompira

Figure 1. The design of K2S machine

Njakritičniji deo mašine K2S je sistem za pobudu oscilacija i prenos snage na trakasti transporter. Sistem je konstruisan tako da su kretanja transportera sinhronizovana preko pogonskog vratila, svi pogonski elementi se nalaze na jednom vratilu. Ovakvo izvođenje sistema podrazumeva srazmernu promenu obrtaja svih elemenata na vratilu u odnosu na promenu obrtaja pogonske remenice. Sistem za pobudu oscilacija dat je na Sl. 2.



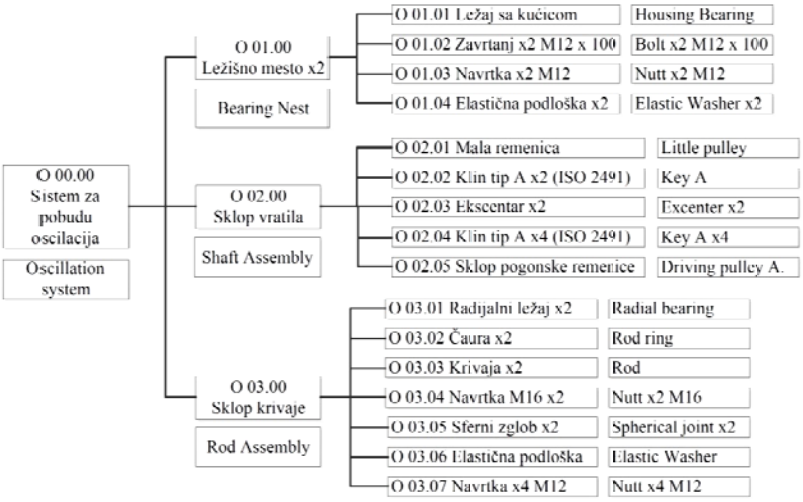
Slika 2. Sistem za pobudu oscilacija: 1. ležišno mesto; 2. sklop vratila; 3. sklop krivaje

Figure 2. The oscillation sytem: 1. bearing nest; 2. shaft assembly; 3. rod assembly

Sistem za pobudu oscilacija se sastoji od tri sklopa. Prvi je sklop ležišnih mesta koji vezuje ovaj sistem za ram mašine. U ovom sistemu postoje dva ležišna mesta. Drugi je sklop krivaje ze pobudu oscilacija. Sistem za pobudu oscilacija takođe sadrži dva sklopa krivaje da bi oba ocilatorna transportera mogla biti opslužena. Treći je sklop vratila. Sklop vratila povezuje sve ove elemente u celinu.

Pre prevođenja sistema za pobudu oscilacija na logički dijagram dinamičkog stabla otkaza potrebno je definisati njegovu strukturu sa svim sastavnim delovima sistema. Kako se ovaj sistem sastoji od tri sklopa, njegova struktura se širi u tri grane, koje se

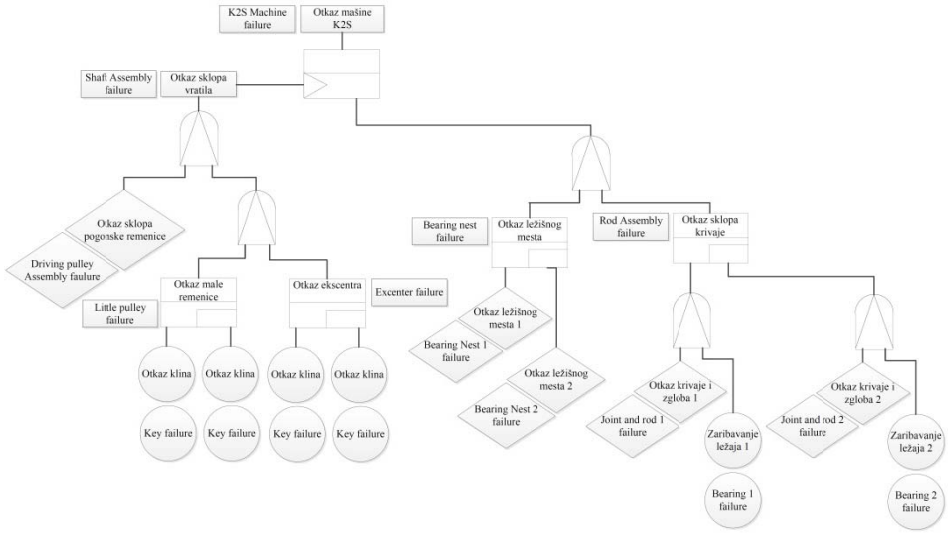
zatim šire na sastavne delove sklopova. Struktura sistema za pobudu oscilacija data je na Sl. 3.



Slika 3. Struktura sistema za pobudu oscilacija

Figure 3. The oscillation sytem structure

U logičkom dijagramu dinamičke analize stabla otkaza uvedena je vremenska zavisnost događaja. Ova zavisnost mora da prati i mogućnosti otkaza i način funkcionisanja mašine. Razvijeno dinamičko stablo otkaza sistema za pobudu oscilacija dato je na Sl. 4.



Slika 4. Dinamičko stablo otkaza sistema za pobudu oscilacija

Figure 4. The oscillation system dynamic fault tree

Vršni događaj dinamičkog stabla otkaza je otkaz mašine. Sa Sl. 4 se vidi da se ovo stablo otkaza deli na tri grane. Događaj koji uzrukuje ostale događaje na prvoj kapiji je otkaz sklopa vratila. On se posle deli uslovnom kapijom na otkaz pogonske remenice koji je primarni i kaskadno sa ostalim elemntima sklopa vratila, koji su sekundarni događaji. Otkaz pogonske remenice je predstavljen kao nerazvijeni događaj, zbog pojednostavljena analize. Otkaz pogonske remenice automatski znači permanentni otkaz mašine. Kaskadno podeljeni sekundarni događaji koji se uslovno dešavaju nakon otkaza pogonske remenice su otkazi male remenice, koja služi za pogon trakastog transportera, i otkaz ekscentara. Pošto je otkaz male remenice za pogon trakastog transportera po funkciji stariji u odnosu na otkaz ekcentara, on je primarni u kaskadnoj kapiji. Za oba otkaza napravljeno je preventivno rezerviranje u vidu od po dva klina po elementu koji su postaljeni pod 180^0 jedan u odnosu na drugi. Događaji otkaza klinova su predstavljeni kao bazični događaji.

Druge dve grane otkaza su otkaz ležišnog mesta i otkaz sklopa krivaje koji su respekticno podeljeni uslovnom kapijom. Primarni je otkaz ležišnih mesta koji je stariji po funkciji. On je zbog pojednostavljenja analize predstavljen kao nerazvijen događaj. Kod otkaza ležišnog mesta takođe postoji rezerviranje u vidu dva ležišna mesta. Kada bi se događaj otkaza ležišnog mesta razvio, to bi bilo u pravcu zaribavanja ležaja i slabljenja ili pucanja zavrtanjske veze sa ramom.

Sekundarni događaj u uslovnoj kapiji koja odvaja druge dve grane dinamičkog stabla otkaza je otkaz sklopa krivaje. Otkaz sklopa krivaje prolazi kroz kapiju sa rezerviranjem, zbog toga što postoje dva identična sklopa. Otkaz ovog sklopa se deli uslovnom kapijom na otkaz ležaja, koji je predstavljen kao bazični događaj, i na otkaz podsklopa zgloba krivaje koji je predstavljen kao nerazvijeni događaj. Otkaz sklopa krivaje je predstavljen kao nerazvijeni događaj, takođe zbog pojednostavljenja analize.

DISKUSIJA DINAMIČKOG STABLA OTKAZA I PREDLOG REVIZIJE K2S MAŠINE

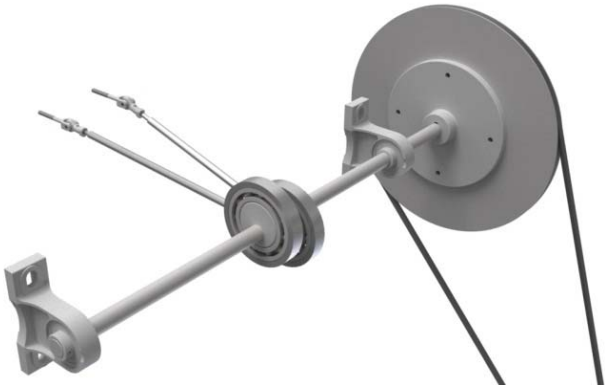
Na osnovu dinamičkog stabla otkaza mašine za klasiranje i pakovanje krompira K2S i njegovog opisa može se zaključiti da funkcije koje obalja ova mašina dolaze obrnutim redosledom (Sl. 2.) :

1. pobuda oscilacija na donjem oscilatornom transporteru;
2. pobuda oscilacija na gornjem oscilatornom transporteru i
3. prenos snage i broja obrtaja na preko remenog kaišnog prenosnika na trakasti transporter.

Da bi se povećali efikasnost, kapaciteti i pouzdanost mašine K2S potrebno je da se izmeni redosled funkcija mašine. Ovakva izmena bi dovela do znatnog pojednostavljenja dinamičkog stabla otkaza. Međutim, ovakva operacija promene konstrukcije mora biti izvedena tako da u najmanjoj meri utiče na promenu cene mašine kao i na mogućnost efikasnog rukovanja njome i održavanja. Dakle, funkcije koje mašina obalja moraju da dolaze sledećim redosledom, tj. onako kako se dešavaju u radu mašine:

1. prenos snage i broja obrtaja na preko remenog kaišnog prenosnika na trakasti transporter;
2. pobuda oscilacija na gornjem oscilatornom transporteru i
3. pobuda oscilacija na donjem oscilatornom transporteru.

Da bi se postigao ovakav redosled funkcija, na mašinu mora biti dovedena još jedna pogonska jedinica, ili se mora promeniti redosled elemenata na sklopu vratila. Na predlogu revizije odlučeno je da se pogon mašine razdvoji na dve pogonske jedinice, zbog jednostavnije montaže i održavanja. Takođe je napravljena i promena redosleda ekscentara, tako da prvo dobija snagu ekscentar koji pobuđuje oscilacije na gornjem oscilatornom transpoteru, a tek onda ekscentar koji pobuđuje oscilacije na donjem oscilatornom transporteru. Predlog revizije sistema za pobudu oscilacija dat je na Sl. 5.



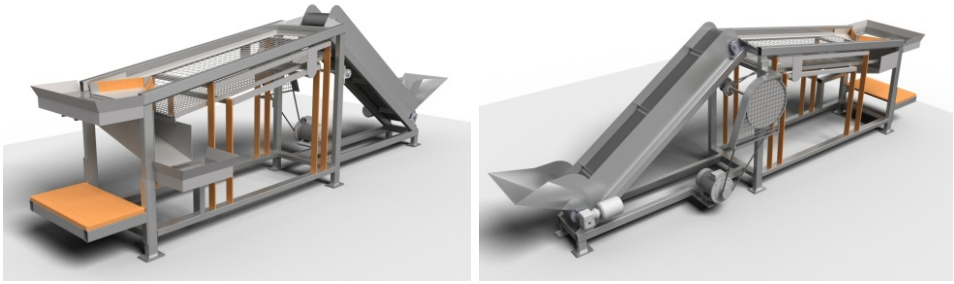
Slika 5. Predlog novog sistema za pobudu oscilacija

Figure 5. Proposal of the oscillation sytem

Pored promena na sistemu za pobudu oscilacija napravljene su još neke izmene u predlogu revizije mašine:

1. trakasti transporter je produžen i spušten do poda radi lakšeg opsluživanja mašine;
2. dodati su radni stolovi i za jelovne i za semenske krompire i
3. oscilatorni transporteri su skraćeni zbog samnjenja vremena klasiranja.

Kompletan predlog revizije mašine K2S dat je na Sl. 6. Sa Sl. 6 se vidi da je u predlogu revizije mašine data samo jedna zaštitna obloga za veliku remenicu na vratilu. Druga zaštitna obloga, kao i kaišni prenos nisu potrebni na reviziji mašine zbog ugradnje još jedne pogonske jedinice.



Slika 6. Predlog revizije K2S mašine

Figure 6. Proposal of the K2S design revision

ZAKLJUČAK

Korišćenjem dinamičke analize stabla otkaza daleko se brže dolazi do zaključaka u odnosu na klasičnu analizu stabla otkaza, kako u fazi projektovanja mašinskih sistema tako i u fazi eksploatacije. Najveća prednost ove metode u odnosu na klasičnu metodu analize stabla otkaza je uzimanje u obzir vremena i uslova za razvoj pojedinih događaja.

Na osnovu dinamičke analize stabla otkaza sistema za pobudu oscilacija napravljen je predlog revizije mašine za klasiranje i pakovanje krompira K2S. Revizija je u odnosu na osnovnu verziju mašine poboljšanja:

- sa aspekta povećanja pouzdanosti mašine u radu napravljeno je pobljšanje tako što su funkcije koje mašina vrši dovedene u redosled koji ispunjava operacijski redosled od ulaza ka izlazu. Povećanje sa aspekta pouzdanosti se ogleda u pojednostavljenju dinamičkog stabla otkaza;
- sa aspekta povećanja kapaciteta mašine izvršeno je poboljšanje koje se ogleda u spuštanju trakastog transportera prema podu i skraćenju oscilatornih transportera radi bržeg klasiranja krompira i
- sa aspekta pobljšanja mogućnosti rukovanja mašinom napravljen je pomak koji se ogleda u uvođenju još jedne pogonske jedinice, tako da kretanja trakastog i oscilatornih transportera ne zavise direktno jedno od drugog, kao što je to bio slučaj u osnovnoj verziji.

Međutim, sva ova poboljšanja u funkcionisanju mašine imaju određeni kontraefekat u podizanju osnovne cene koštanja izrade mašine. Zbog toga se vodilo računa o uštedi materijala, npr. kod skraćivanja oscilatornih transportera.

Mogući dalji pravci istraživanja naa ovu temu bili bi zasnovani na izradi prototipa revizije mašine, kod kog bi bili praćeni kako predviđeni uzroci otkaza, tako i eksploatacijeske karakteristike u odnosu na osnovnu verziju mašine.

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IMPROVING K2S MACHINE DESIGN ACCORDING TO DYNAMIC FAULT TREE ANALYSIS

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Abstract: The K2S is machine for sorting and packing potatoes. Exploitation of this machinery so far point to some weakness of it. The K2S machine consists of one belt conveyer, which is used to transport potatoes to oscillating transporter, and two oscillation transporters, which is used for sorting potatoes. This paper presents using of dynamic fault tree method in order to make revision proposal of K2S. Revision of K2S should provide incision of the capacity, removing the weaknesses, and prolonging of the machine life cycle. The dynamic fault tree method is chosen among other methods because of its ability to put events in time order. This paper also shows old design, dynamic fault tree of the oscillation system and proposal of the machine revision. Paper concludes with the discussion of the achieved results. At the end of the paper other possible directions of improving machine design are given.

Key words: *machine, sorting, packing, reliability, dynamic falut tree*

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IMPORTANT ENGINEERING PROPERTIES OF PADDY

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Abstract: Engineering properties of paddy is essential for designing of storage bin. The physical properties of paddy (ADT-43) namely, size, shape, thousand paddies mass, aspect ratio, surface area, volume, bulk density, true density and porosity at moisture contents ranging from 11.86 to 23.61% d.b. were determined using standard techniques and these effects on storage chamber design ware evaluated. In the case, thousand paddy mass, surface area and volume increased from 18.24 to 24.07 g, 28.91 to 31.82 mm^2 and 17.55 to 20.52 mm^3, respectively, with an increase in moisture content from 11.86 to 23.61% d.b. Equivalent diameter, sphericity, aspect ratio and bulk density increased from 3.22 to 3.39, 0.41 to 0.42, 30.55 to 31.91% and 568 to 613 $kg \cdot m^{-3}$, respectively, with an increase in moisture content from 11.86 to 23.61% d.b. Porosity and true density decreased from 46.82 to 38.27% and 1069 to 994 $kg \cdot m^{-3}$ respectively, with an increase in moisture content from 11.86 to 23.61%.

Key words*: paddy, ADT-43, moisture content, physical properties, aspect ratio, equivalent diameter, porosity*

INTRODUCTION

Paddy is one of the stable and leading food crops in India. About 70% of the paddy produced in India was stored at farm level. ADT 43 is the most popular paddy variety grown in all the parts of Tamil Nadu, the reason behind that of ADT 43 are resistant to stem borer and gall midge, high tillering and fine rice. Food grain storage technology

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whether at farm level or commercial level does not fulfill the technical requirements. Food grains are stored in different types of storage structures such as godowns and silo for certain periods till they reach the consumers which play an important role in the proper preservation of food grains. Temperature and moisture content of the grain provide the basis for extension of storage period, alternatively upon further processing of grain. According to the Food and Agriculture Organization of the United Nations (FAO), more than 20% of the world's harvested grain is spoiled every year. The major part of this loss is caused by insects and mould activity [1]. It indicates the inefficient design of the storage bin. Comprehensive information on physical properties of these materials are most importance for increasing economic importance of food materials, together with the complexity of modern technology for their production, handling, storage processing, preservation, quality evaluation and utilization [2]. The knowledge of some important physical properties of different grains is necessary for the design of various processing equipments and storage chamber [3]. Principal axial dimensions of paddy grains are useful in selecting sieve separators and in calculating power during the rice milling process. They can also be used to calculate surface area and volume of kernels which are important during modeling of grain drying, aeration, heating and cooling [4].

Physical properties of paddy have been investigated and reported by some researchers [4-5]. However, there is a need for a comprehensive study of the engineering properties of paddy is essential for designing of storage bin for ADT-43. Hence the present study was conducted to determine the important engineering properties of paddy viz., shape and size (axial dimensions, equivalent diameter, aspect ratio and sphericity), volume, surface area, true density, bulk density and porosity at five moisture content levels and also to determine how these properties interconnect with moisture content. Paddy as a function of moisture content in the range of 11 to 23% (d.b.) during harvesting to storage operations, which can facilitate in the design of storage bin for whole unit operations.

MATERIAL AND METHODS

Raw Material

Paddy (ADT-43) was obtained from centre farm, located in Tamil Nadu Agricultural University, India and used for the study. The paddy was cleaned manually to remove all foreign materials such as dust, dirt, chaff and immature paddy.

Moisture content determination and sample preparation

The initial moisture content of the paddy was determined using hot air oven at 130˚C for 14-16 h [6]. The initial moisture content of paddy was found to be 11.86 % (d.b.). In order to achieve the desired moisture levels for the study, paddy samples were conditioned by adding calculated quantity of water. The moisture contents of the samples were equilibrated to 11.86, 14.63, 17.51, 20.93 and 23.61% (d.b.) as per the procedures outlined in AOAC (1995) [6]. The required quantity of sample was withdrawn and equilibrated at room temperature (30±2°C) before conducting different tests [7].

Size

The dimensions of paddy such as length (*L*), width (*W*) and thickness (*T*) were measured in mm at five levels of moisture content with the help of a digital vernier caliper having a least count of 0.01 mm. A sample of 100 kernels ware randomly selected from each sample lot having various levels of moisture content from 11.86 to 23.61% d.b. The equivalent diameter (D_p) in mm was calculated through the following expression [8]:

$$D_P = \left[4L\left(\frac{W+T}{4} \right)^2 \right]^{\frac{1}{3}} \tag{1}$$

Surface area and volume

The volume (*V*) and surface area (*S*) of paddy was calculated by using the following relationship:

$$V = 0.25\left[\left(\frac{\pi}{6} \right) L(W+T)^2 \right] \tag{2}$$

$$S = \frac{\pi B L^2}{2L - B} \tag{3}$$

Where:

$$B = \sqrt{WT} \tag{4}$$

Aspect ratio

The aspect ratio (R_a) is used for classification of paddy shape and it was calculated as [8].

$$R_a = \frac{W}{L} \tag{5}$$

Shape

Shape of paddy can be expressed in the terms of sphericity (ϕ). It is defined as the ratio or the surface area of sphere having the same volume as that of the paddy to the surface area of the paddy was determined as [8].

$$\phi = \frac{(LWT)^{\frac{1}{3}}}{L} \tag{6}$$

Thousand paddies mass

In order to determine mass of thousand paddies approximately 1 kg of paddy sample was roughly divided into 4 equal portions and then 1000 numbers of paddies were randomly picked from each portion and weighed on a digital electronic balance with an accuracy of 0.01 g. The measurement was repeated for 3 times and the mean value was taken as weight of 1000 seeds.

Bulk Density

The bulk density is the ratio of mass of the paddy to its total (bulk) volume. It was determined by filling a circular container of known volume with paddy.

$$\rho_b = \frac{M}{V} \tag{7}$$

Where:

ρ_b [kg·m^{-3}] - bulk density,
M [kg] - mass of the paddy sample
V [m^3 - volume of the container.

True Density

The true density (ρ_t) is the ratio of mass of the paddy to its true volume. It was determined using Toluene displacement method. Toluene (C_7H_8) was used in place of water because paddy absorbed toluene to a lesser extent.

Porosity

The porosity (ε) of the paddy is the ratio of the volume of internal pores in between the paddy to its bulk volume. It was determined using following relationship [8]:

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right) * 100 \tag{8}$$

Where:

ε [%] - porosity,
ρ_b [kg·m^{-3}] - bulk density,
ρ_t [kg·m^{-3}] - true density.

Data analysis

The data were analyzed statistically using SPSS software and regression equation using Microsoft Excel software.

RESULTS AND DISCUSSION

Size distribution pattern and dimension

Per cent distributions of paddy dimensions at storage moisture content of 11.86% (d.b.) measured. About 94 % of paddy has a length from 7.78 to 7.80 mm, about 91 % of paddy has a width ranging from 2.37 to 2.39 mm and about 89% of paddy has a thickness ranging from 1.75 to 1.78 mm. Minimum, maximum and mean values of the three principal dimensions of paddy at different moisture contents are presented in Table 1. The data indicated that size of the paddy increased with an increase in moisture content. The length increased from 7.79 to 7.99 mm ($P<0.01$); the width from 2.38 to 2.55 mm ($P<0.01$) and thickness from 1.77 to 1.88 mm ($P<0.05$), respectively, with an increase in moisture content from 11.86 to 23.61% d.b. Corresponding value of the IR-36 were the length, width and thickness increased from 9.81 to 9.97 mm, 2.47 to 2.62 mm and 1.93 to 2.05 mm, respectively, with an increase in moisture content from 8.40 to 28.28% d.b. [5]. This data shows ADT-43 variety was smaller than IR-36. A greater increase was found in width (6.66%) and thickness (5.85%) then in length (2.50%). The changes in the size of paddy with increase in moisture content may be due to hygroscopic nature. Tab. 2 shows the regression analysis of the experimental data showed a linear correlation between length, width and thickness with moisture content at high coefficient of determination (R^2).

Table.1. Minimum, maximum and mean values of axial dimensions of paddy (ADT-43) at different moisture contents

M.C. (d.b.)	*Length [mm]*				*Width [mm]*				*Thickness [mm]*			
	Min	*Max*	*Mean*	*SD*	*Min*	*Max*	*Mean*	*SD*	*Min*	*Max*	*Mean*	*SD*
11.86	*7.78*	*7.80*	*7.79*	*0.01*	*2.36*	*2.39*	*2.38*	*0.02*	*1.73*	*1.78*	*1.77*	*0.02*
14.63	*7.80*	*7.83*	*7.81*	*0.02*	*2.38*	*2.43*	*2.41*	*0.03*	*1.75*	*1.80*	*1.79*	*0.06*
17.51	*7.83*	*7.87*	*7.85*	*0.04*	*2.44*	*2.49*	*2.47*	*0.11*	*1.78*	*1.83*	*1.82*	*0.04*
20.93	*7.88*	*7.94*	*7.91*	*0.03*	*2.48*	*2.52*	*2.50*	*0.09*	*1.81*	*1.86*	*1.84*	*0.01*
23.61	*7.97*	*8.01*	*7.99*	*0.10*	*2.49*	*2.58*	*2.55*	*0.04*	*1.84*	*1.93*	*1.88*	*0.13*

**M.C-Moisture content *S.D-Standard deviation*

Equivalent diameter

The variation in equivalent diameter of paddy at different moisture contents is shown in Fig. 1. The increase in moisture content from 11.86 to 23.61% (d.b.) increased the equivalent diameter of paddy from 3.22 to 3.39 mm ($P<0.01$), respectively. From the figure, it is seen that equivalent diameter of paddy increased with increase in moisture content and established a linear relationship and followed a regression equation of the form as shown in Tab. 2. High coefficient of determination ($R^2 > 0.98$) shows the best fit of models to describe the change in equivalent diameter of paddy within the experimented moisture range.

Aspect ratio

From the Fig.1, it is seen that aspect ratio of paddy increased from 30.55 to 31.91% (P<0.05) with increase in moisture content from 11.86 to 23.61 per cent (d.b.). Thus, the lower values of the aspect ratio indicate a difficulty in getting the kernels to roll than that of spheroid grains [9]. However, it slides on their flat surfaces. This tendency to either roll or slide should be necessary in the design of hoppers for storage bin. The increase in aspect ratio with increase in moisture content was reported by [9] for rice. This confirms the findings of present study. The relation between moisture content and aspect ratio is linear (Tab. 2.).

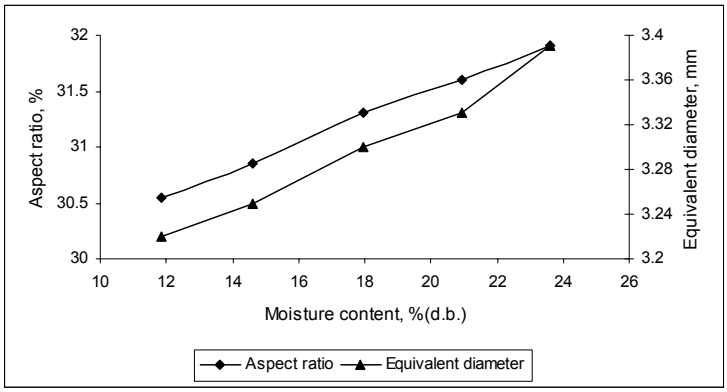

Figure 1. Effect of moisture content on equivalent diameter and aspect ratio of paddy

Shape and thousand grain mass

From the Fig.2, it is seen that sphericity and thousand paddy mass increased from 0.4109 to 0.4218 (P<0.01) and 18.24 to 24.07 g (P<0.01), respectively, with increase in moisture content from 11.86 to 23.61 per cent (d.b.).

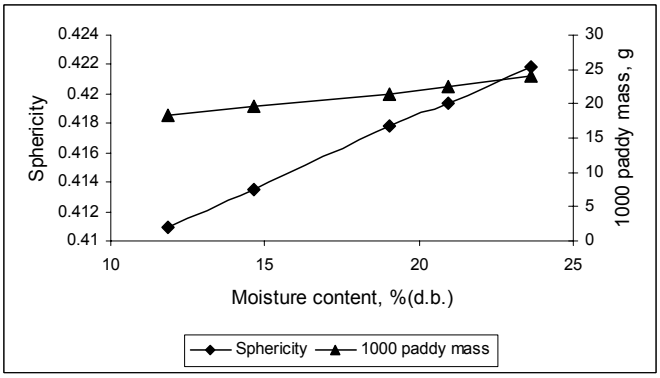

Figure 2. Effect of moisture content on sphericity and thousand mass of paddy

According to [4] considered the grain as spherical when the sphericity value was more than 0.70. Obtained results from this study, ADT 43 should be treated as an equivalent sphere. The changes in the shape of paddy and 1000 grains mass with increase in moisture content may be due to increase of the main paddy dimensions. The increase in sphericity and thousand grain mass with increase in moisture was reported by [2, 4]. This confirms the findings of present study. From the Tab. 2, it is seen that a linear relationship exists between shape and thousand grain mass of paddy with respect to moisture content.

Surface area

The value for surface area of paddy obtained for different moisture content is graphically represented in Fig. 3. The values of paddy surface area increased from 28.91 to 31.82 mm^2 with increase in moisture content from 11.86 to 23.61% (d.b.) and followed a linear regression equation of the form given in Table 2. High R^2 value shows the best fit of equation to the experimental values. The changes in the surface area of paddy with increase in moisture content may be due to increase in dimensions of paddy with increase in moisture content. Similar trends were reported by [10] for hemp seeds, respectively. These findings confirmed the results of present study.

Volume

The experimental results of volume of paddy at different moisture levels are depicted in Fig. 3. The volume of paddy increased from 17.55 to 20.51 mm^3 as the moisture content increased from 11.86 to 23.61% (d.b.). Similar results were reported by [11] reported an increase in volume with increase in moisture content for soybean and barnyard millet grain. The relationship exists between moisture content and volume followed a regression equation form shown in Table 2. High R^2 value indicates the best fit of model to the experiment results.

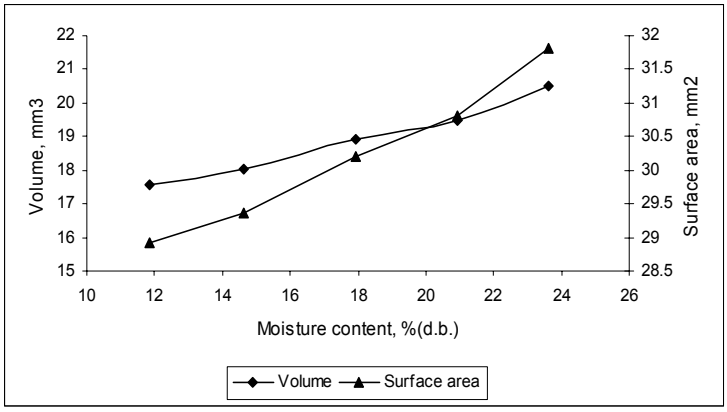

Figure 3. Effect of moisture content on surface area and volume of paddy

Densities

The bulk and true densities of paddy at different moisture contents are shown in Fig.4. Regression analysis shows that bulk density is linearly dependent on moisture content and it is positively correlated. High R^2 value (0.97) shows the best fit of equation to experimental values. The bulk density increased with the increase in moisture content. It increased from 568.51 to 613.68 kg·m^{-3} with an increase in moisture content from 11.86 to 23.61% (d.b.). That is, 49.76 per cent increase in moisture content resulted in 7.36 per cent increase in bulk density. The effect of moisture content on bulk density of paddy grains showed a significant increase (P<0.01) with increasing moisture content. The increase in bulk density with an increase in moisture content is mainly due to the increase in paddy volume was less than the corresponding increase in paddy mass of the material. It facilitates the same weight of material to occupy less volume of the cylinder thus increasing the bulk density. Similar results were reported by [12] for onion seeds and [13] for *Telfaria Occidentalis* seeds. This confirmed the findings of present study.

True density of paddy decreased with increase in moisture content. It decreased from 1069.03 to 994.13 kg·m^{-3} with an increase in moisture content from 11.86 to 23.61% (d.b.). That is, 49.76 per cent increase in moisture content resulted in only 7 per cent increase in true density. Increasing moisture content had a significant effect (P<0.05) on true density of paddy. The decrease in true density is due to an increase in volume of the kernel (more than weight increase) at higher moisture content levels. Regression analysis shows (Tab. 2) that true density is negatively correlated and depicts the linear dependency of true density on moisture content.

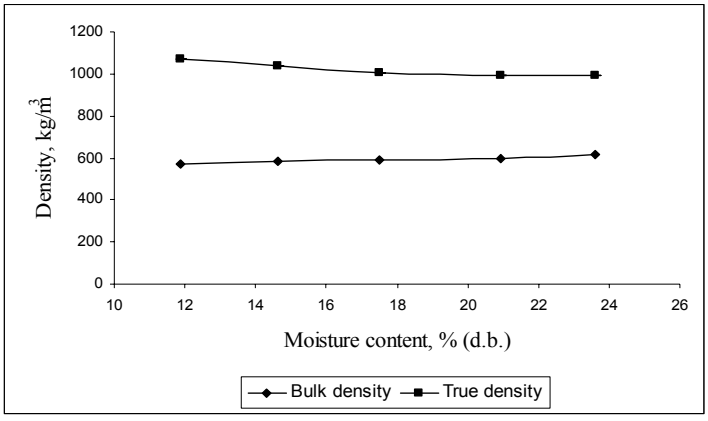

Figure 4. Effect of moisture content on densities of paddy

Porosity

The effect of moisture content on porosity of paddy is shown in Fig. 5. From the figure, it is observed that the porosity of paddy decreased from 46.82 to 38.27 %, when the moisture content was lowered from 23.61 to 11.86 per cent, (d.b.). The reason for this, as the paddy gains moisture increase, its volume increases, thus the number of

grains in a fixed volume decreases. Since the number of grains per unit volume decreases, the porosity, i.e. the percent pore space between the particles also decreases [5]. From the results, it is seen that for 49.76 per cent increase in moisture content, the porosity increased by 18.26 per cent. Among the three important physical properties studied namely, bulk density, particle density and porosity, for a unit change in per cent moisture content, the highest percentage change was observed in porosity followed by bulk density and particle density. The porosity of paddy followed a linear relationship with moisture content as given in Table 2. Similar trend was observed in onion seeds [12] and *Telfaria Occidentalis* seeds [13]. This confirmed the results of present study.

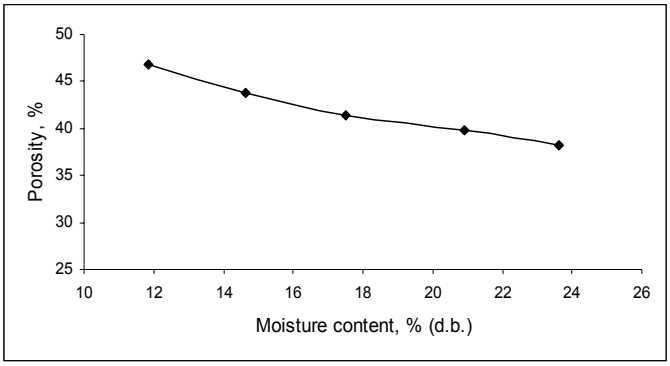

Figure 5. Effect of moisture content on porosity of paddy

Table.2. Engineering properties of paddy (ADT-43) as a function of moisture content

Engineering properties	*Unit*	*Relationship with moisture content*	*Coefficient of determination (R^2)*
Length	*[mm]*	*0.0168M + 7.5726*	*0.9502*
Width	*[mm]*	*0.0144M + 2.2072*	*0.986*
Thickness	*[mm]*	*0.0090M + 1.66*	*0.9806*
Equivalent diameter	*[mm]*	*0.0141M + 3.0477*	*0.9836*
Aspect ratio	*[-]*	*0.1162M + 29.173*	*0.9994*
Thousand grain weight	*[g]*	*0.4893M + 12.527*	*0.9928*
Sphericity	*[-]*	*0.0009M + 0.4001*	*0.9982*
Surface area	*[mm^2]*	*0.2431M + 25.897*	*0.9830*
Volume	*[mm^3]*	*0.2476M + 14.489*	*0.9840*
Bulk density	*[$kg \cdot m^{-3}$]*	*3.5533M + 527.5*	*0.9753*
True density	*[$kg \cdot m^{-3}$]*	*-6.3838M + 1133.1*	*0.8775*
Porosity	*[%]*	*-0.7034M + 54.492*	*0.9707*

**M-Moisture content, % (d.b.)*

CONCLUSIONS

The information on engineering properties of paddy (ADT-43) which may be useful for designing of equipment for paddy storage bin and processing equipments. Moisture

content of paddy is one of the most important factors influence the maintenance of paddy quality. At the moisture content of 11.86% (d.b.), the average length, width and thickness of paddy (ADT-43) were 7.79, 2.38 and 1.77 mm, respectively. The thousand grain weight of the paddy increased from 18.24 to 24.07 g with an increase in moisture content from 11.86 to 23.61% (d.b.). The bulk density increased from 568 to 613 $kg \cdot m^{-3}$ with an increase in moisture content from 11.86 to 23.61% (d.b.). The true density decreased from 1069 to 994 $kg \cdot m^{-3}$ with an increase in moisture content from 11.86 to 23.61% (d.b.). Porosity decreased from 46.82 to 38.27% with an increase in moisture content from 11.86 to 23.61% (d.b.). From the results obtained that all the physical properties of paddy are dependent on the moisture contents.

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ZNAČAJNE TEHNIČKE KARAKTERISTIKE ZRNA PIRINČA

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Sažetak: Tehničke karakteristike pirinča su osnove za konstruisanje skladišta. Fizičke osobine pirinča (ADT-43), koje čine: veličina, oblik, masa hiljadu zrna, odnos širine i dužine zrna, površina, zapremina, gustina rasute mase, gustina zrna i poroznost, pri sadržaju vlage od 11.86 do 23.61% , određene su standardnim tehnikama, a zatim su ocenjeni njihovi uticaji na skladišnu komoru. U ovom slučaju, masa hiljadu zrna, površina i zapremina porasle su sa 18.24 na 24.07 g, 28.91 na 31.82 mm^2 i 17.55 na 20.52 mm^3, redom, sa povećanjem sadržaja vlage sa 11.86 na 23.61%. Ekvivalentni prečnik, sveričnost, odnos širine i dužine i gustina rasute mase porasli su sa 3.22 na 3.39, 0.41 na 0.42, 30.55 na 31.91% i 568 na 613 $kg \cdot m^{-3}$, redom, sa povećanjem sadržaja vlage sa 11.86 na 23.61%. Poroznost i gustina zrna smanjile su se sa 46.82 na 38.27% i 1069 na 994 $kg \cdot m^{-3}$, redom, sa povećanjem vlage sa 11.86 na 23.61%.

Ključne reči*: pirinač, ADT-43, sadržaj vlage, fizičke osobine, odnos širine i dužine, ekvivalentni prečnik, poroznost*

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GUIDING ACCURACY OF THE AGRICULTURAL NAVIGATION WITH RTK CORRECTION ON SPRING SOWING

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Abstract: They are carried out two comparative experiments for determining the real guiding accuracy of a seed drill during spring sowing an earth-up crop. At the first one the seed drill is running with circle turns. The juxtaposition is made for the guiding accuracy by conventional disk markers and by agricultural navigation with RTK correction. At the second experiment the seed drill is running with stretch turns. The guiding accuracy of both navigation without RTK and RTK navigation are compared. The agricultural navigation with RTK ensures better statistical estimations, better qualitative indices for the boundary row distance and higher operational indices of the tractor with a seed-drill during sowing of the earth-up crop.

Key words*: seed drill, agricultural navigation, sowing*

INTRODUCTION

Many field operations require precise farm machinery guiding [4, 5]. Nowadays this leads to wide usage of different kinds of agricultural navigation systems, which ensure various levels of the accuracy guiding. The common GPS has a nominal accuracy of 10" (25,4 cm), whereas for GPS with RTK (Real Time Kinematic) it is ten times higher and equals to 1" (2,54 cm) [3]. The purpose of the investigation is to determine the real effect of two types agricultural navigations - the common one and navigation with RTK correction on guiding accuracy of a seed drill during the spring sowing.

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MATERIAL AND METHODS

There are carried out two comparative experiments for determining the real guiding accuracy of a seed drill during spring sowing an earth-up crop.

At the first one the seed drill is running with circle turns as it is shown on Fig. 1. The juxtaposition is made for the guiding accuracy by conventional disk markers and by agricultural navigation with RTK correction.

At the second experiment the seed drill is running with stretch turns as it is shown on Fig. 2. It is compared the guiding accuracy of both navigation without RTK and RTK navigation.

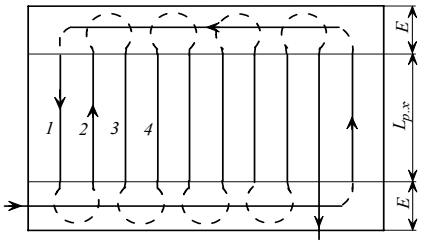


Figure 1. Seed drill running way with circle turns

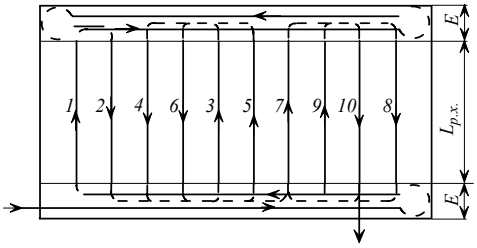


Figure 2. Seed drill running way with stretch turns

It is measured the durations of both every working runs and every turn at the ends of the field. After crop sprouting it is measured the distance between two boundary rows of the neighbor drill tracks, shortly *boundary row distance*. The measurements are implemented in three replications on different drill tracks at both experiments. Thereby are formed enough samples each one with more than 100 measurements along the working run. They are used for calculating statistical estimations, indices for process quality evaluation, operational indices, as well as for drowning autocorrelation functions [1, 2].

The experiments are carried out with seed-drill Monoseed - RABE 8230 linked to tractor Jon Deer DJ-6530 at sunflower sowing. At a navigation guiding mode the tractor is driven by built-in FarmSight™ equipment.

RESULTS AND DISCUSSION

In the Tab. 1. are shown descriptive statistics for the boundary row distance at the running circle turns way. The difference between the assigned and the mean value is 3,57 % for the markers guiding and 2,64 % for RTK navigation. The standard deviation - σ for markers guiding is 4,53 times more, which evidences for significantly more stable guiding by RTK navigation. This result is due not only to the way of guiding, but also to the difference of the driving precision of both autopilot and the tractor driver. For this reason the navigation guiding with autopilot causes more rectilinear rows than the markers guiding.

In Tab. 2. are presented descriptive statistics of the boundary row distance for the stretch turns running way. The difference between assigned value and the mean $\overline{x}$ is 26,2 % for navigation without RTK guiding and 5,9 % for RTK navigation. The standard

deviation - σ for RTK guiding is 2,20 times less than navigation without RTK. This is due to the lower level of guiding accuracy of navigation without RTK.

Table 1. Descriptive statistics of the boundary row distance for running way with circle turns

Indices	Unit	Tractor and seed-drill guiding way	
		by markers	by RTK navigation
Assigned value	[cm]	70	70
Mean value, $\bar{x}$	[cm]	67,50	68,15
Minimal value, x_{min}	[cm]	25,0	56,5
Maximal value, x_{max}	[cm]	84,1	76,5
Standard deviation, σ	[cm]	17,8024	3,9319

Table 2. Descriptive statistics of the boundary row distance for running way with stretch turns

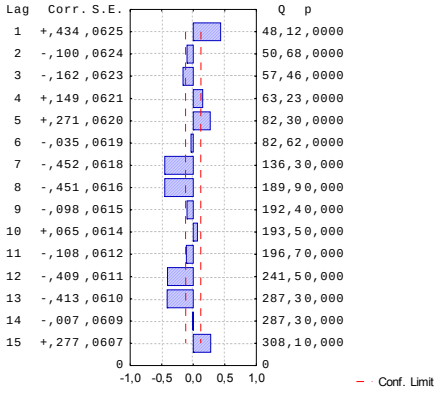
Indices	Unit	Tractor and seed-drill guiding way	
		by navigation without RTK	by RTK navigation
Assigned value	[cm]	70	70
Mean value, $\bar{x}$	[cm]	88,34	74,16
Minimal value, x_{min}	[cm]	77	67,0
Maximal value, x_{max}	[cm]	110	81,1
Standard deviation - σ	[cm]	6,6731	3,0321

Autocorrelation functions for the boundary row distances for the circle turns running way are given on Fig. 3. Obviously, the function for marker's guiding comes out the confidential interval very often. While the function for RTK guiding gets quiet very fast and all values are in the confidential interval, which means stable seed-drill guiding.

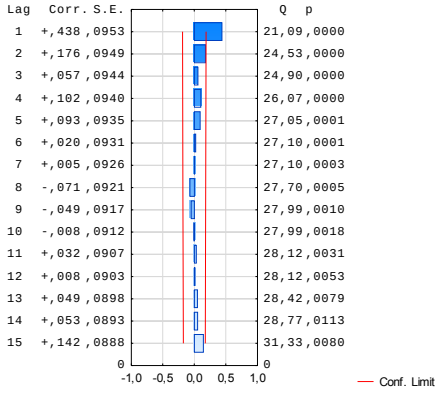
Autocorrelation functions for the stretch turns running way evidences for a significant influence of the RTK navigation on the variation of boundary row distance (Fig. 4). The function values do not come out confidential limit, therefore this type of guiding ensures stable boundary row distance. Obviously, this is the most suitable guiding for stretch turns running way, which is the only possible for large-size farm machinery in many cases. While, the navigation without RTK assists mainly to more sustainable way of seed-drill guiding, but the real precision is not enough [1].

The coefficient C_p is widely used indicator of the capability of an investigated process [1, 2]. For the circle turns running way and RTK guiding its value is 10,9 % higher than for the markers guiding (Tab. 3). The investigated processes are not centered, because the lower and upper potential capability C_{pl}, C_{pu} values are not identical each other. The demonstrated excellence value - $C_{pк}$ for RTK navigation guiding is 1,96 times higher than for the markers guiding. Thus the navigation guiding has better qualitative capability for the circle turns running way.

Qualitative indices for the stretch turns running way also evidence better process quality for RTK guiding (Tab. 4). Its values for C_p and $C_{pк}$, are higher 6,6 % and 43,5 % accordingly. More over the investigated process for RTK guiding is more centered.

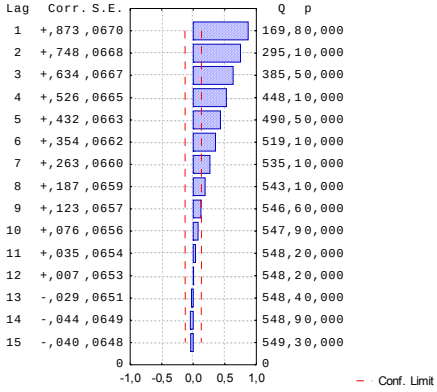


a) guiding by markers

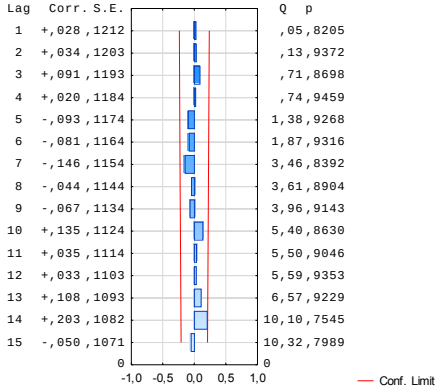


b) guiding by RTK navigation

Figure 3. Autocorrelation functions of the boundary row distance for the circle turns running way



a) guiding by navigation without RTK



b) guiding by RTK navigation

Figure 4. Autocorrelation functions of the boundary row distance for the stretch turns running way

Table 3. Qualitative indices of the boundary row distance for the circle turns running way

Sample Indices	*Tractor and seed-drill guiding way*	
	by markers	*by RTK navigation*
Potential capability - C_p	*0,805*	*0,892*
Upper potential capability - C_{pu} for different samples	*0,36 ÷ 3,68*	*2,470*
Lower potential capability - C_{pl} for different samples	*0,36 ÷ 0,68*	*1,490*
Demonstrated excellence - C_{pk}	*0,76*	*1,490*

Table 4. Qualitative indices of the boundary row distance for the stretch turns running way

Sample Indices	*Tractor and seed-drill guiding way*	
	by navigation without RTK	*by RTK navigation*
Potential capability - C_p	*1,202*	*1,281*
Upper potential capability - C_{pu} for different samples	*0,42 ÷ 2,82*	*0,55*
Lower potential capability - C_{pl} for different samples	*0,42 ÷ 0,65*	*0,63*
Demonstrated excellence - C_{pk}	*1,08*	*1,55*

In Tab. 5 are presented the operational indices for both running ways at an approximately equal length of the working runs and with RTK navigation guiding. The results show that the tractor with a seed-drill has 27,8 % higher productivity W_h when it applies the stretch turns running way. This is due to the turning speed $v_{n.x}$, which is 53,5 % higher than the speed at the circle turns. The average working speed $v_{p.x}$ is also higher at the stretch turns running way, because of the loss of time for the tractor acceleration after each turn, despite it runs in one and the same gear. The other operational indices do not differ considerably for both running ways.

Obviously, the agricultural navigation with RTK ensures better statistical estimations, better qualitative indices for the boundary row distance and higher operational indices of the tractor with a seed-drill during sowing of the earth-up crop. The received results give us an assumption that the seed-drill which is guided by RTK navigation can works with reduced protection zone and increased working speed during the earth up field operations. Of course this assumption should be investigated.

Table 5. Operation indices of tractor and seed-drill with RTK navigation

Indices	*Unit*	*Seed-drill running way*	
		First (Fig. 1)	*Second (Fig. 2)*
Average length of the working run	*[m]*	*492,67*	*493,5a*
Average length of the turn	*[m]*	*25,17*	*33,16*
Portion of working runs φ	*[-]*	*0,95*	*0,94*
Productivity W_h ,	$[ha \cdot h^{-1}]$	*60,64*	*77,52*
Portion of working time, τ	*[h]*	*0,90*	*0,89*
Average working speed $v_{p.x}$,	$[m \cdot s^{-1}]$	*2,24*	*2,89*
Average turning speed $v_{n.x}$,	$[m \cdot s^{-1}]$	*0,99*	*1,52*

CONCLUSIONS

1. At the experimental conditions and runs with stretch turns, the guiding accuracy of RTK navigation achieves 5,9 % (4,16 cm) average deviation from the assigned boundary row distance. It means that the real guiding accuracy is 63 % lower from the nominal accuracy of the RTK navigation. The real guiding accuracy of the navigation without RTK is 4,4 times lower than of the RTK navigation.

2. When the seed drill runs with circle turns, the guiding accuracy of the agricultural navigation with RTK correction does not differ significantly from the markers guiding.

3. When the seed-grill runs with stretch turns and is guided by the RTK navigation it's productivity is higher than compared with the runs with circle turns. This is due to 53,5 % higher turning speed, which increases the average machinery speed of the machinery. This inference is important for large size machinery, because the run with stretch turns is the only possible in many cases.

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TAČNOST NAVOĐENJA POLJOPRIVREDNE NAVIGACIJE SA RTK KOREKCIJOM U PROLEĆNOJ SETVI

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Sažetak: Sprovedena su dva komparativna ogleda za određivanje stvarne tačnosti vođenja sejalice tokom prolećne setve. Sejalica se u prvom ogledu kretala sa kružnim okretima. Tačnost navođenja pri slaganju prohoda je određivana korišćenjem konvencionalnih diskosnih markera i poljoporivrednom navigacijom sa RTK korekcijom. U drugom ogledu sejalica se kretala sa produženim okretima. Poređena je tačnost navođenja kod obe navigacije, sa i bez RTK. Poljoprivredna navigacija sa RTK obezbeđuje bolje statističke procene, bolje kvalitativne pokazatelje za ivični prohod i više operativne pokazatelje agregata traktora sa sejalicom tokom setve.

Ključne reči*: sejalica, poljoprivredna navigacija, setva*

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PLASMA RESTORATION AND HARDENING OF ELEMENTS OF TILLAGE TOOLS

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Abstract: The solution of the problem of creating competitive technologies of elements restoration and hardening considerably depends on impartial assessment of their technical level. This assessment is especially necessary at the stage of new technological processes development. Particularly at this stage of technological processes designing of elements restoration and hardening the right assessment of its technical level will influence the economic results during serial assimilation.

Key words*: plasma-jet surfacing, elements restoration and hardening, powered alloys, tillage tools.*

INTRODUCTION

At worn elements restoration the number of manufacturing operations is reduced in 5-8 times in comparison with manufacturing new ones. At that durability of restored elements can reach the level of new, but their cost corresponds to 40-70 % from new elements prize [1-3]. To use this reserve is necessary to develop efficient and accessible for wide application of innovative technologies. It follows therefore that the problem of extension of operating life of tillage tools elements is of vital importance in economic as well as resource saving aspect.

Promising direction of this problem solution is restoration of elements working surfaces by wide-layered plasma-jet surfacing of coatings (up to 1,3 mm on the side)

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with wear resistant powered hard alloys. At the same time is important to choose the surfacing mode that allows surfacing coatings with minimum penetration depth of base material. In this case thin layer of coating retains its original physical and mechanical properties.

RESULTS AND DISCUSSION

At plasma-jet surfacing there are many factors that to a variable degree influence the depth of penetration. Effort to sum up the results of single-factor experiments and to give general analysis and numerical estimate to the phenomenon sometime is problematic because of the considerable number of dependences having a particular value. Single-factor experiments do not allow taking into consideration synergy of several factors.

We turn our attention to technological parameters and peculiarities of plasma-jet surfacing technology; one should pay attention to some of them at restoration of quick wear elements of tillage tools and equipment. In general, coating obtained by plasma-jet surfacing is characterized with technological parameters presented in Tab. 1.

Table 1. Technological parameters of plasma-jet surfacing

Technological parameters	*Designation*
Current rate of plasmotron arc	$J_к$
Plasmotron arc voltage	U
Plasma-jet hard-surfacing rate	$V_н$
Amplitude of plasmotron oscillations	A
Frequency of plasmotron oscillations	f
Powder granulation	d
Powder application rate	$G_п$
Consumption of plasma supporting gas	$q_{пл}$
Consumption of carrier gas	$q_{тр}$
Consumption of protective gas	$q_З$
Distance from plasmotron to an element	h
Diameter of internal plasma nozzle	$d_{вн}$
Diameter of external plasma nozzle	$d_н$
Preheat temperature of an element being surfaced	$T_{под}$

The spheres of application of plasma methods of hardening and restoration of elements are defined with the following characteristics:

- Application of powders as filler; this gives the opportunity to mechanize the surfacing of wear resistant, heat resistant and other high alloys from which is difficult or practically impossible to produce electrode wire;
- Small penetration depth of base metal, which allows obtaining the required content of the deposited metal even at the first layer in spite of its thickness, and refuse from multiple layer deposition in many cases; as a result, consumption of surfacing materials and time of surfacing;
- Excellent formation of deposited beads, stability and good reproducibility of their dimensions, as a result the expenditures for machining of the deposited

elements are reduced; small allowances for machining is also one of the ways of economy of surfacing materials;
- Possibility to change in a wide range of technological parameters of modes, many of them are independent from each other, it gives great flexibility to the plasma-jet surfacing process and allows depositing small elements that require several grams of alloy, as well as large items on which the deposited metal mass can correspond to tens of kilograms;
- Easiness of deposition process automation.

One of the main advantages of plasma-jet surfacing with hard powder alloys is the possibility to provide a fairly small penetration of base metal [4-6], and also it is acknowledged with the results of experimental tests [7].

Besides the applied meaning, these tests allow understanding the formation mechanism of the deposited coating at plasma-jet surfacing.

Current rate of plasmotron arc of direct action J_n produces maximum effect on the base metal in the deposited metal, which is most noticeable at surfacing with powder application rate to 2 $kg \cdot h^{-1}$. At increase of powder application rate it is ma manifested in a less degree and a range of current rate providing admitted penetration of base metal is extended.

Current rate of plasmotron indirect arc J_k practically does not influence to base metal penetration that corresponds well to the results of calorimetric tests. But it is marked that at too low J_k *the plasmotron operation stability decreases*. At high values of J_k thermal loading on plasma-forming nozzle is increased greatly. From this point of view there is some optimal value of current rate of indirect arc which is equal to J_k = 70 - 100 A, it should be taken into consideration in production activity.

The influence of *consumption of plasma supporting gas* $q_{n\pi}$ on penetration of base metal is mainly connected with plasma arc pressure on the molten metal zone, because arc heat input at the change of $q_{n\pi}$ in the investigated limits is changing only by 10 - 15%. At the same time plasma flow rate in an arc increases more than twofold. Obviously, consumption of plasma supporting gas at surfacing must be supported low as far as possible. Its value should be selected according to the conditions of providing arc stability and stability of the surfacing process (according to the experimental data $q_{n\pi}$ = 1 - 2 $l \cdot min^{-1}$).

Consumption of carrier gas q_{mp} in the limits of 4 - 9 $l \cdot min^{-1}$ influences on the part of the base metal in the deposited bead γ_0 similar to plasma supporting gas but obviously weaker. Further increase of q_{mp} does not result in penetration increase. Comparing these data with the results of measurements of plasma flow rate in an arc at different consumptions of carrier gas it is easy to prove that in this case also there is full correspondence between the influence of consumption of plasma supporting gas on plasma rate and value γ_o.

With increase of consumptions of carrier gas the powder consumptions grow as the result of increase of particles initial rate and worsening of the conditions of their heating in the arc. At consumptions of carrier gas 3 - 4 $l \cdot min^{-1}$ plasma-jet surfacing is failed often because of plasmotron channels obstruction with powder. Consumptions of carrier gas is considered as optimal in the limits of 6 - 9 $l \cdot min^{-1}$. In the field or other specific conditions at the failure of supplies of protective gases, application of hot hydrocarbons of internal combustion engine with consumption of 10 - 14 $l \cdot min^{-1}$ is allowed for powder carriage and protection of coating being deposited.

Amplitude and frequency of plasmotron oscillations in the studied range (A = 2,5 - 16 mm, f = 8 - 87 min^{-1}) influence on base metal penetration insufficiently. Thus, at oscillations amplitude changes in the range of 2 - 16 mm value γ_o changes in the range of 12 - 17%. For this reason oscillations amplitude of plasmotron should be selected according to the required width of deposited bead, taking into consideration that bead width exceeds value A by 5 - 8 mm. Oscillations frequency must be coordinated with deposition rate so that oscillations interval will correspond to 2 - 5 mm.

When *distance from plasmotron to an element h* changes in the range of 7 - 22 mm base metal penetration remains practically constant that is the important advantage of plasma jet-surfacing.

Taking into consideration that with the increase of distance h molten metal protection is getting worse and powder losses are increasing it is recommended to support it equal to 8 - 15 mm.

The portion of base metal in deposited bead γ_o depends significantly on *powder consumption* G_n (at constant values of the rest of the technological process parameters). In practice powder application is selected simultaneously with surfacing rate $V_н$ that is why it is advisable to examine the influence of these two factors simultaneously.

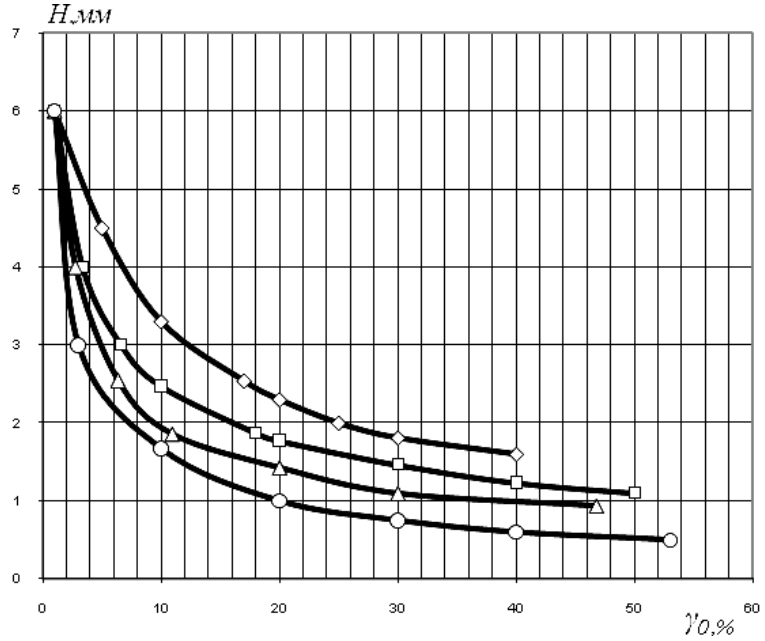

Figure 1. Dependance of coating being deposited from the base metal portion:
○ – productivity of plasma-jet surfacing 1 kg·h^{-1}; Δ – productivity of plasma-jet surfacing 2 kg·h^{-1};
□ – productivity of plasma-jet surfacing 4 kg·h^{-1};
◊ – productivity of plasma-jet surfacing 6 kg·h^{-1}

At increase of *surfacing rate* $V_н$ in the interval 1,7 - 32 m·h^{-1}, which value depends on current rate of plasmotron, powder application rate and amplitude of oscillations, the portion of base metal remains almost constant, and then decreases. At increase of

surfacing rate $V_н$ to keep thickness of deposited coating constant is necessary to increase powder application rate G_n. In this case to provide melting of more powder is necessary also to increase current rate of plasmotron arc of direct action J_n. As a result of simultaneous increase of $V_н$, G_n and J_n (at the condition of keeping deposited coating thickness), value γ_o increases too. Thus implies that the productivity of surfacing of a certain thickness is limited with permissible value γ_o.

The connection between deposited coating thickness, portion of base metal in the deposited one and surfacing productivity is illustrated with Fig. 1.

The analysis results show that the surfacing with thickness of 1,0 - 1,5 mm can be done with the productivity of 1,0 - 1,5 kg·h^{-1}, if value γ_o should not exceed 15%. The depositing of beads with the thickness more 3 mm can be done with the productivity more than 6 kg·h^{-1} at $\gamma_o < 10\%$.

From the given data it follows that the choice of optimal modes of plasma-jet surfacing at restoration of quick wear elements of tillage machines results in general determining of current rate of arc of direct action J_n, powder application rate G_n and surfacing rate $V_н$. The values of the rest parameters of mode (J_k, $q_{пл}$, q_{mp}, h) should be supported constant in the mentioned above limits. Amplitude of plasmotron transverse oscillations A is maintained depending on the required width of bead being deposited, and oscillations frequency f is defined depending on surfacing rate $V_н$.

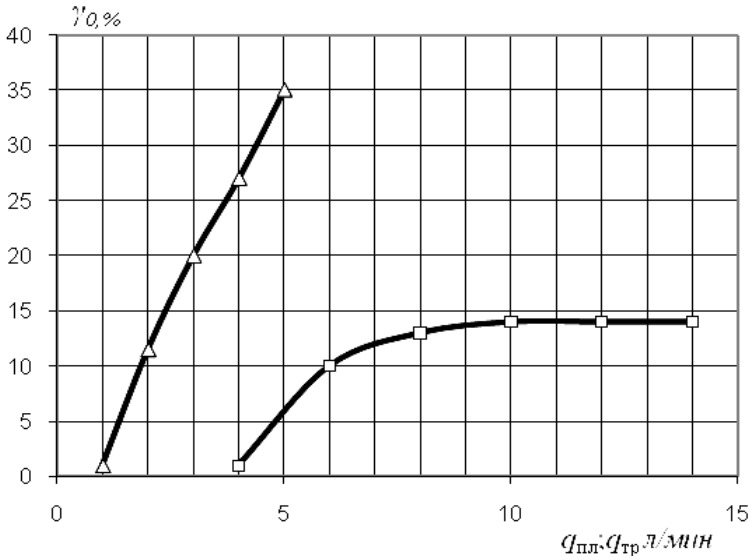

Figure 2. Dependence of the base metal portion in the deposited metal from consumption of plasma-supporting and carrier gases: Δ – plasma-supporting gas; □ – carrier gas

For selection of values $V_н$, G_n и J_n the following method is recommended. Depending on the preset thickness of the deposited coating and permissible value γ_o surfacing productivity is defined, it means that powder application rate value G_n, and then according to graphics $J_n = f(G_n)$ or $\gamma_o = f(J_n)$ at $G_n = const$ (Figs 2 and 3) the required current rate value is defined. The obtained value J_n is true for depositing of

beads with width up to 20 mm.

In case of depositing of beads with large width current rate of plasmotron is defined according to the following equation:

$$J_n = J_{20} + k\,(B - 20) \tag{1}$$

Where:

B [mm] - width of the deposited bead,
J_{20} [A] - current rate value, found graphically (for B = 20 mm);
k [A·mm^{-1}] - empirical factor (k = 3,5 - 4,0 A·mm^{-1}).

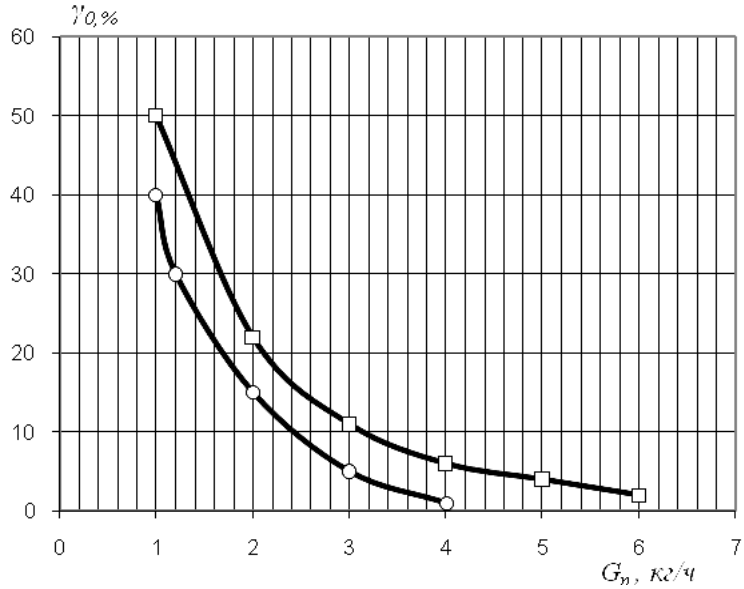

Figure 3. Dependence of the base metal portion in the deposited metal from powder application rate: ○ – at current rate of plasmotron arc J_n = 150 A; □ – at current rate of plasmotron arc J_n = 170 A

At the known productivity and preset bead dimensions surfacing rate can be defined by the following dependence:

$$V_H = \frac{G_n}{\rho \cdot \mu \cdot B \cdot H} \tag{2}$$

Where:

G_n [g·s^{-1}] - mass rate of powder application,
ρ [g·cm^{-3}] - density of the deposited metal,
μ [-] - bead completeness ratio (at plasma-jet surfacing μ = 0,8 - 0,85);
B [cm] - width of deposited bead,
H [cm] - height of deposited bead.

The observed method of surfacing modes selection is based on usage of empirical

dependences between current rate, powder application and a portion of base metal in the deposited coating from power hard alloys on nickel and iron base. These empirical dependences are defined by the heat and physical characteristics of the deposited material. At surfacing modes selection for other alloys it is necessary to take into consideration their heat and physical characteristics [7, 8].

Typical modes of plasma-jet surfacing of elements of different dimensions and form are given in Tab. 2.

If form and dimensions of the deposited element do not limit current rate of plasma-jet surfacing then productivity of plasma-jet surfacing of coatings with the width more than 3 mm is limited only with maximum permissible working value of current rate of plasmotron and maximum possible powder application, it means such application during which the plasmotron channels and nozzles are not obstructed. For example, for plasmotron of co-design with CJSC Scientific Production Association "Technoplasma" these values correspond to 350 A and 6,5 $kg \cdot h^{-1}$.

Thin coatings deposition productivity considerably depends on the permissible dilution of molten metal with base metal. At that, the thinner the coating and the less the preset value γ_o, the lower the productivity defined with the deposited metal mass per unit time.

Table 2. Plasma-jet surfacing modes for hardening and restoration of elements of tillage tools

Parameters	*Unit*	*Tillage tools elements*			
		Cutter ЭТЦ-1609	*Auger ПБУ-50М*	*Moldboard blade ДЗ-122А*	*Moldboard blade ДЗ-27*
Current rate	*[A]*	*80-110*	*120-140*	*140-180*	*140-180*
Consumption of plasma supporting gas (argon)	*[l·min^{-1}]*	*2-3*	*1,5-2*	*1,5-2*	*1,5-2*
Consumption of carrier gas (argon)	*[l·min^{-1}]*	*7-8*	*5-6*	*5-6*	*5-6*
Consumption of protective gas	*[l·min^{-1}]*	*18*	*15*	*15*	*18*
Amplitude of oscillations	*[mm]*	*7*	*3*	*10*	*15*
Deposition rate	*[mm·min^{-1}]*	*30-50*	*280*	*200*	*350*
Deposition productivity	*[kg·h^{-1}]*	*1,4*	*2,2*	*3,0*	*5,0*

Powder losses. Not all powder particles moving peripherally of plasmotron arc column get into the zone of metal melting. Those of them which get on the deposited surface in front or sidewise of the metal melting zone, as a result of elastic recoil from this surface, are lost permanently. Powder losses will be less if the metal melting zone "leaks" under arc. This is observed at good moistening of base material with metal of the molten coating at low deposition rate, at deposition on down grade, at large thickness of deposited bead and etc.

It is necessary to stress that powder losses increase, if plasmotron is located or periodically approaches close to the edge of deposited element, if base width is smaller that plasmotron nozzle diameter and etc. Thus, powder losses depend on many mode parameters (J_n, $V_н$, G_n, $q_{пл}$, $q_{тр}$, $d_{вн}$, $d_н$, etc.), determining movement character and intensity of powder melting in plasma arc, dimensions of the metal melting zone and the

presence of molten metal layer under arc. But from the above mentioned parameters, current rate J_n and consumption of carrier gas q_{mp} mostly influence on powder losses. At optimal modes of plasma-jet surfacing they do not exceed 5 - 8%.

Dimensions and form of deposited beads are defined mainly by powder consumption, amplitude of plasmotron transverse oscillations, deposition rate and arc current of direct effect. The rest parameters influence is inconsiderable

According to the investigations bead thickness at one layer deposition does not exceed 5 - 6 mm, otherwise flanges and incomplete fusions along its edges appear. Minimum thickness of the deposited coating at $\gamma_o \leq 10\%$ corresponds to 0,5 mm about. If relatively large penetration of base metal is permitted then plasma-jet surfacing with small reinforcement of bead is not a problem.

Plasma-jet surfacing is done with plasmotron transverse oscillations, that is why bead width is determined by oscillation amplitude and reaches 55 - 60 mm. At deposition without oscillations bead width corresponds to 3 - 6 mm depending on the diameter focusing nozzles and plasmotron current rate.

CONCLUSIONS

1. The suggested rational modes of plasma-jet surfacing establish interaction between factors influencing the coating process. This allows defining optimization criterion value according to the selected factors or factors according to other selected parameters and the preset optimization criterion, and also providing wear resistant coatings deposition with necessary and sufficient strength of coating adhesion with base and minimum depth of penetration.

2. On the ground of the obtained results considering economic, ecological and resource saving peculiarities the technological processes of hardening and restoration of tillage tools with plasma methods providing high wear resistance and increase of deposited coatings resources of elements with the preset quality parameters are developed and implemented into production. Implementation of resource saving plasma technologies allows to decrease labor, material and energy costs and also to increase labor productivity and technique repair efficiency.

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PLAZMA ZA OBNAVLJANJE I OTVRDNJAVANJE ELEMENATA ORUĐA ZA OBRADU ZEMLJE

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Sažetak: Rešenje problema određivanja kompetitivnih tehnologija za obnavljanje i otvrdnjavanje elemenata značajno zavisi od nezavisne procene njihovog tehničkog nivoa. Ova procena je posebno potrebna pri razvoju novih tehnoloških procesa. Na ovom nivou postavljanja tehnoloških procesa obnavljanja i otvrdnjavanja posebno je važna pravilna procena njihovog tehničkog stanja i uticaja na ekonomske rezultate u serijskoj primeni.

Ključne reči*: nanos mlazom plazme, obnavljanje i otvrdnjavanje elemenata, pogonske legure, oruđa za obradu.*

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