Effect of Particle Size on Surface Smoothness of Bio-Briquettes Produced from Agricultural Residues

Gürkan Alp Kagan Gürdil, Bahadır Demirel
Department of Agricultural Machineries and Technologies Engineering, Faculty of Agriculture, Ondokuz Mayıs University, Samsun, Turkey. Email: ggurdil@omu.edu.tr, bdemirel@omu.edu.tr

This study analyzed the surface smoothness of some fuel briquettes produced from hazelnut, corn and sunflower residues. The residues were briquetted with different particle sizes (PS: 2-5 mm and 7-10 mm) under 80 MPa and 160 MPa. The surface smoothness of them were analyzed by image analyze from their high quality photos. In conclusion, it's seen obviously that the smaller particle sized briquettes had smoother surface than the ones produced with bigger PS. Furthermore, they had better results of compaction, toughness and physical properties.

Keywords: Briquette, Image, Residue, Smoothness, Tumbler index

1 Introduction

Alternate fuel sources are being continuously searched [1]. Briquettes can be further used as fuel in furnaces, coal in power plants and many other industrial applications [2-3]. Briquetting is the process of densification of loose biomass to improve its fuel and handling characteristics. It increases the volumetric calorific value, and reduces transportation cost and storage space requirement as compared to raw biomass. Briquetting produces a uniform, clean and stable fuel [4]. By briquetting, bulk density of loose biomass can be increased from 40 to 200 kg·m^{-3} to 600–1200 kg·m^{-3} which would reduce the storage space requirement significantly [5]. Due to its uniform size, high density and improved fuel properties, it has secured its place in industries and domestic cooking applications as the renewable fuel of high demand. [6].

Briquettes can be produced from any ligno-cellulosic biomass. Densification of ligno-cellulosic biomass is a complex process and influenced by factors such as densification pressure, particle size, moisture content, temperature and type of biomass. Biomass briquettes from different types of biomass materials have varied widely (wodd dust, sawdust, wheat straw, olive refuse, peanut shell, coconut fibers, municipal solid waste, etc.) [6, 7]. One of possibilities of its meaningful utilization is the briquetting technology, which product are briquettes determined for energetic utilization [7].

Briquetting, one of the densification technologies, is a fundamental and promising method for conversion of the waste and purposely grown biomass into solid biofuels [8]. It is achieved by forcing loose particles together into a larger, more compact and shaped form, by application of mechanical force to create particle-to-particle bonding [9-10]. Effectiveness of the densification process is given by the quality of these inter-particle bonds [11].

Compactness is very important in order that at a common handling neither crumbling nor disintegration occur [12]. Compacting biomass can be a suitable alternative fuel in existing large-scale for agricultural residues. Also, due to their fibrous nature, raw biomass particles cannot be readily pulverized down. Thus, their grindability is an issue and improves grinding. The resulting biomass particle size, and even particle shape are important physical properties, which influence the fuel fluidization and combustion parameters of the particles [13-14]. Marinelli et al. [15] reported that grinding to very fine particle sizes increases the cohesive strength of the powder, which impedes fluidization. Grinding to fine sizes is also expensive as it requires a lot of energy. Whereas grinding of torrefacted biomass consumes a fraction of the energy requirement for grinding raw biomass [16, 17, 18]. Surface roughness is one of the most significant evaluation factor in metal machining operations. Surface roughness is one of the parameters with great importance considered for the functional behaviour of the mold or tool, moreover is widely used as a description of surface quality and as a technical requirement in most cases [19]

In this study mainly hazelnut husk, stalk of sunflower maize which are agricultural wastes and released intensely from agricultural areas in the Black Sea region were investigated and evaluated as a solid biofuel. The residues were briquetted with different particle sizes (PS: 2-5 mm and 7-10 mm) under 80 MPa and 160 MPa. The surface smoothness of them were analyzed by image analyze from their high quality photos. In conclusion, it's seen obviously that the smaller particle sized briquettes had smoother surface than the ones produced with bigger PS. Furthermore, they had better results of compaction, toughness and physical properties.

2 Materials and Methods

A Hydraulic type briquetting machine with a horizontal pressing course, designed and constructed in Turkey of Samsun was used for briquetting the hazelnut husk residues. Briquetting pressure range of this machine is adjustable from 0 to 320 MPa by a manometer on it. Piston and cylinder of the machine is bedded horizontally thus the briquetting is done in a horizontal course. The pump of the machine has a tank of 25 L capacity of hydraulic oil with a 1.2 m^3·s^{-1} flow rate. Stroke of the piston is 310 mm and the velocity of the stroke is adjusted to 10 mm.s^{-1} at 160 MPa briquetting pressure. Machine dimensions are 1280x1155x740 (AxBxC) mm. Operation of the machine is controlled by a start-stop button embedded on it. Hydraulic pump functions by a 15 kW powered 3-phase electrical engine with a star delta starter. The mold for the briquette was not heated. As a support block for the pressing a rectangle shaped metal plate is placed at the end of the course having 125x105x30 mm dimensions. Movement of this plate is done manually. Main parts are given in Fig. 1, the mold in Fig. 2.

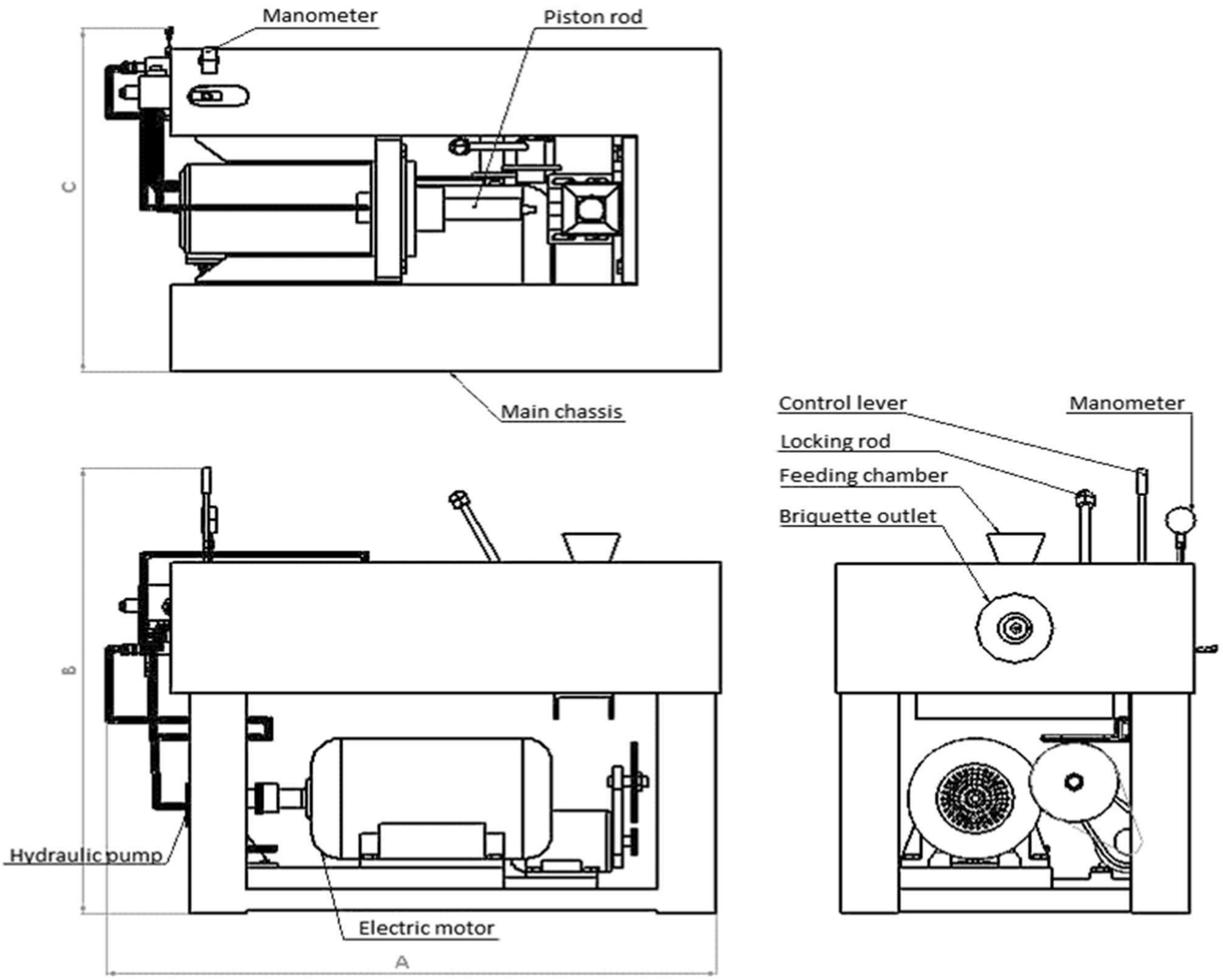


***Fig. 1** Main Parts of the Briquetting Machine*

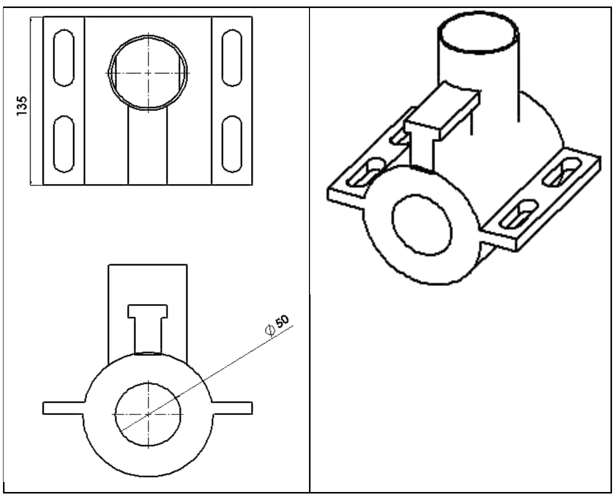


***Fig. 2** The Mold*

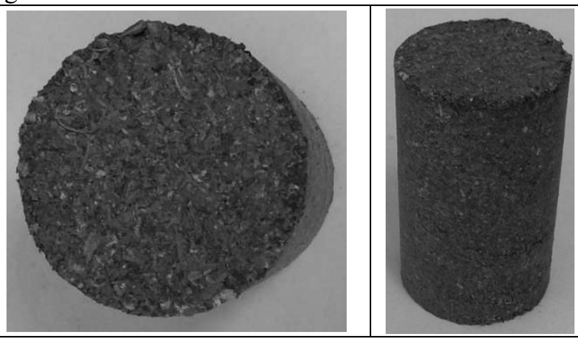
The residues were first dried in normal conditions under the sun and their moisture contents were decreased down to 13-15 % (M15). Then the dried material was grinded by a knife-hammer mill till the required particle sizes were obtained (2-5; 7-10 mm). The grinding process is the main process in the production of solid cutting tools to obtain the required geometry of the cutting tool [20]. Their moisture contents were con-trolled again and they were briquetted under 160 MPa briquetting pressures.

Mechanical durability of the briquettes were determined by tumbling the test sample for 3 minutes at 40 r·min^{-1}. The covering shall be 12.5 mm mesh hardware cloth applied taut to the outside of the frame. Interior projections, such as screw heads, should be kept to a minimum and should be well rounded. The box shall be mounted on a diagonal axis (2 planes) with 2 stub shafts terminating at the exterior of the angle iron frame. There is a hinged triangular door 300 × 300 × 430 mm on each end. The axis of rotation is horizontal.

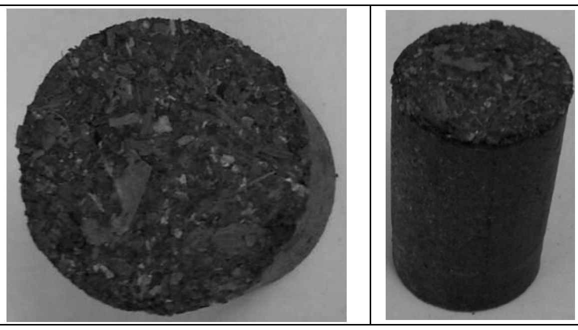
The briquetting pressure was chosen as 160 MPa showed that the briquettes were enough solid and durable both physically and in shape. This working pressures also matches with the studies defined in Krizan et al [21], Zhang & Guo [22] and Sun et al. [23]. Feeding of material was done batch wise during the briquetting pro-cess in order to avoid occlusion. The material prepared for briquetting was poured into the cylindrical mold and they were squeezed by a piston in the mold and the briquettes were obtained. Pressing process continued 20 seconds more after the completing of squeezing in order to avoid expansion in the produced briquettes. Full cylindrical shape briquettes having 50 mm diameter and 80 to 110 mm varying lengths were produced by this process.

3 Results and Discussion

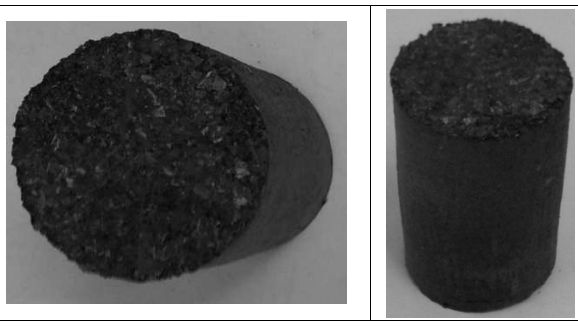
Top and front view of the produced briquettes are in Fig. 3-5 below.



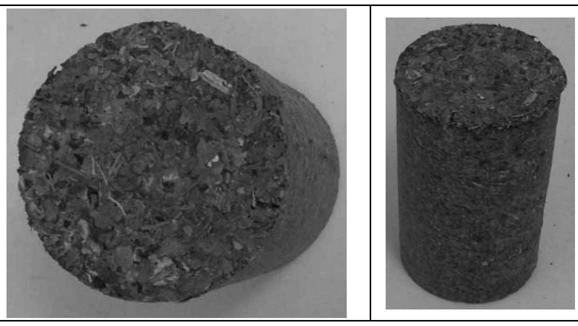
PS: 5mm – 80 MPa



PS: 10mm -80 MPa

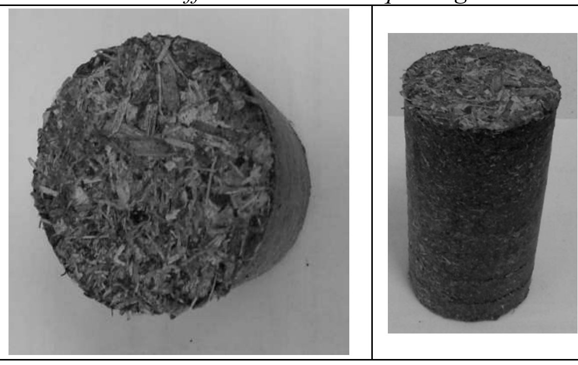


PS: 5mm – 160 MPa

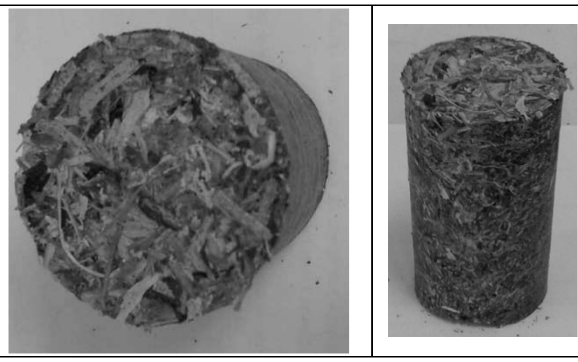


PS: 10mm – 160 MPa

Fig. 3 *Top and Front View of Hazelnut Husk Briquettes Produced with Different PS and Briquetting Pressures*

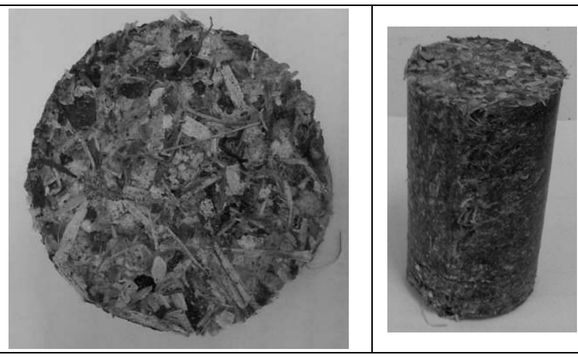


PS: 5 mm – 80 MPa



PS: 10 mm – 80 MPa

PS: 5 mm – 160 MPa



PS: 10 mm – 160 MPa

Fig. 4 *Top and Front View of Sunflower Residue Briquettes Produced with Different PS and Briquetting Pressures*

As obvious from the pictures it's observed that smoother surfaces were obtained at smaller PS and in the same manner this was valid for the higher briquetting pressures. As stated before, the size of the particles significantly affects the physical and mechanical properties as well as burning characteristics of briquettes [11, 12, 16, 22, 24, 25]. Particle size has a great impact on the compressibility of a bulk input material and the durability of the final briquettes [9, 12, 25, 26]. Usually, with the smaller particle size, the density, mechanical strength, hardness, mechanical durability, impact resistance and the burning time of densified briquettes are increased [22, 25, 27, 28, 29], however very fine grinding is undesirable due to the increased cost of briquette production [12] and the longer fuel ignition time [30].

Tumbler Indexes of the produced briquettes from different residue materials are given below (Tab. 1, Tab. 2).

As a result of statistical evaluation performed separately for each material, the difference between the Tumbler Indexes of the briquettes obtained under 2 different compression pressures of 80 and 160 MPa was found to be significant (P<0.01) (Tab. 1). The pressure reduces the distance between the material particles and allows them to approach each other and increase the contact ratio of the surfaces. According to the results, it was determined that the briquettes obtained under compression pressures of 160 MPa were higher than the briquettes obtained under the pressure of 80 MPa in three different materials. The briquettes obtained from the hazelnut husks had lower Tumbler Indexes than the briquettes obtained from corn and sunflower residues. This is because sunflower and corn residues have a fibrous structure and therefore can be compressed better under the same pressure than the hazelnuts.

As a result of separate statistical evaluation for each material, the difference between the Tumbler Indexes of the briquettes obtained at 2-5 mm and 7-10 mm particle sizes was found to be significant (P<0.01) (Tab. 2). The Tumbler Indexes of sunflower and corn briquettes increased as the particle size increased. This is because that they have a fibrous structure, which is why the larger particle size materials can bind each other better. Since the hazelnut husks has a woody structure so, had the exact opposite situation.

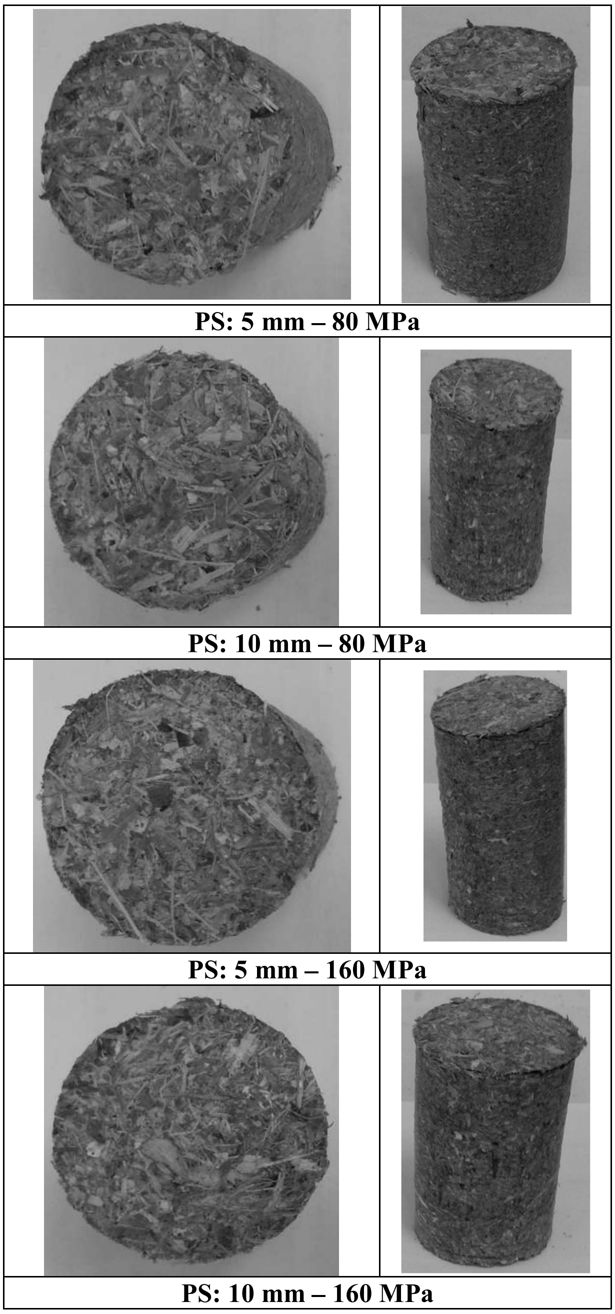


***Fig. 5** Top and Front View of Corn Residue Briquettes Produced with Different PS and Briquetting Pressures*

***Tab. 1** Tumbler Indexes of Briquettes at Different Briquetting Pressures*

	Tumbler Index (%) $\bar{X} \pm S_{\bar{x}}$		
P (MPa)	Hazelnut residue	Sunflower residue	Corn residue
80	64.84 ± 1.11	95.66 ± 0.20	96.38 ± 0.19
160	87.31 ± 1.00	96.27 ± 0.26	97.61 ± 0.09
Sig.	**<0.01**	**<0.01**	**<0.01**

***Tab. 2** Tumbler Indexes of Briquettes at Different Particle Sizes*

	Tumbler Index (%) $\bar{X} \pm S_{\bar{x}}$		
PB (mm)	Hazelnut residue	Sunflower residue	Corn residue
2-5	78.92 ± 3.57	95.39 ± 0.24	96.84 ± 0.25
7-10	73.23 ± 3.16	96.54 ± 0.09	97.14 ± 0.22
Sig.	**<0.01**	**<0.01**	**<0.01**

4 Conclusions

Surface smoothness is assumed as an important indicator in briquettes. In this study the effect of PS and briquetting pressure on surface smoothness of bio briquettes produces from hazelnut, corn and sunflower harvesting residues are investigated. Smoother surfaces were obtained with smaller PS and also with the higher briquetting pressures. Surface smoothness shows the quality of the briquettes especially for commercial purposes. These kinds of studies can be helpful for the agricultural engineers, farmers and academicians working on similar topics.

References

[1] SINGH, R.N., BHOI, P.R., PATEL, S.R. (2007). Modification of commercial briquetting machine to produce 35 mm diameter briquettes suitable for gasification and combustion. In: *Renewable Energy*, Vol. 32, No. 3, pp. 474 – 479.

[2] FONT, R., CONESA, J.A., MOLTÓ, J., MUÑOZ, M. (2009). Kinetics of pyrolysis and combustion of pine needles and cones. In: *Journal of Analytical and Applied Pyrolysis*, Vol.85, No. 1, pp. 276 – 286.

[3] PANWAR, V., PRASAD, B., WASEWAR, K.L. (2011). Biomass residue briquetting and characterization. In: *Journal of Energy Engineering*, Vol. 137, No. 2, pp. 108 – 114.

[4] GRANADA, E., LÓPEZ GONZÁLEZ, L.M., MÍGUEZ, J.L., MORAN, J. (2002). Fuel lignocellulosic briquettes, die design and products study. In: *Renewable Energy*, Vol. 27, No. 4, pp. 561 – 573.

[5] ADAPA, P., TABIL, L., SCHOENAU, G. (2009). Compaction characteristics of barley, canola, oat and wheat straw. In: *Biosystems Engineering*, Vol. 104, No. 3, pp. 335 – 344.

[6] MANDAL, S., KUMAR, G.V.P., BHATTACHARYA, T.K., TANNA, H.R., JENA, P.C. (2018). Briquetting of Pine Needles (Pinus roxburgii) and Their Physical, Handling and Combustion Properties. In: *Waste and Biomass Valorization*, https://doi.org/10.1007/s12649-018-0239-4, pp. 1-10.

[7] BROŽEK, M. (2015). Briquettes made from wood residues. In: *Manufacturing Technology*, Vol. 15, No. 2, pp. 126 – 130.

[8] HOOVER, A.N.; TUMULURU, J.S.; TEYMOURI, F.; MOORE, J.; GRESHAM, G. (2014). Effect of pelleting process variables on physical properties and sugar yields of ammonia fiber expansion pretreated corn stover. In: *Bioresource Technology*, Vol.164, pp. 128 – 135.

[9] KALIYAN, N.; MOREY, R.V. (2010) Natural binders and solid bridge type binding mechanisms in briquettes and pellets made from corn stover and switchgrass. In: *Bioresource Technology*, Vol. 101, pp.1082 – 1090.

[10] KARUNANITHY, C.; WANG, Y.; MUTHUKUMARAPPAN, K.; PUGALENDHI, S. (2012). Physiochemical characterization of briquettes made from different feedstock. In: *Biotechnology Research International*, Vol. 2012, pp. 1 – 12.

[11] KALIYAN, N.; MOREY, R.V. (2009). Factors affecting strength and durability of densified biomass products. In: *Biomass Bioenergy*, Vol. 33, pp. 337 – 358.

[12] BROŽEK, M. (2018). Briquettes properties after four years storage. In: *Manufacturing Technology*, Vol. 18, No. 1, pp. 11 – 15.

[13] SOUZA-SANTOS, M. (1999). A feasibility study of an alternative power generation system based on biomass gasification/gas turbine concept. In: *Fuel*, Vol. 78, No. 5, pp. 529 – 538.

[14] KIM, Y.D., YANG, C.W., KIM, B.J., KIM, K.S., LEE, J.W., MOON, J.H., YANG, W., TAE, U.Y., DO LEE, U. (2013). Air-blown gasification of woody biomass in a bubbling fluidized bed gasifier. In: *Applied Energy*, Vol. 112, pp. 414 – 420.

[15] MARINELLI, J., CARSON, J.W. (1992). Solve solids flow problems in bins, hoppers, and feeders. In: *Chemical Engineering Progress*, Vol. 88, pp. 22 – 28.

[16] TUMULURU, J.S., WRIGHT, C.T., HESS, J.R., KENNEY, K.L. (2011). A review of biomass densification systems to develop uniform feedstock commodities for bioenergy application. In: *Biofuels Bioproducts & Biorefining*, Vol. 5, pp. 683 – 707.

[17] ANDERSON, N., CHUNG, W., LOEFFLER, D., JONES, J.G. (2012). A productivity and cost comparison of two systems for producing biomass fuel from roadside forest treatment residues. In: *Forest Products Journal*, Vol. 62, No. 3, pp. 222 – 233.

[18] BERGMAN, P.C., KIEL, J.H. (2005). Torrefaction for biomass upgrading. In: *14th European Biomass Conference*, pp. 17–21. Paris, France.

[19] BÍLEK, O., PATA, V., KUBIŠOVÁ, M., ŘEZNÍČEK, M. (2018). Mathematical methods of surface roughness evaluation of areas with a distinctive inclination. In: *Manufacturing Technology*, Vol. 18, No. 3, pp. 363 – 368.

[20] BAKSA, T., SCHORNIK, V., ADAMEK, P., HRONEK, O., ZETEK, M. (2018). Effects of grinding conditions and strategy on the quality of the cutting edge. In: *Manufacturing Technology*, Vol. 18, No. 1, pp. 3 – 7.

[21] KRIŽAN, P., ŠOOŠ, L., MATÚŠ, M., BENIAK, J., SVÁTEK, M. (2015). Research of significant

densification parameters influence on final briquettes quality. In: *Wood Research*, Vol. 60, No. 2, pp. 301 - 316.

[22] ZHANG, J., GUO, Y. (2014). Physical properties of solid fuel briquettes made from caragana korshinskii kom. In: *Powder Technology*, Vol. 256, pp. 293 – 299.

[23] SUN, B., YU, J., TAHMASEBI, A., HAN, Y. (2014). An experimental study on binderless briquetting of chinese lignite: effects of briquetting conditions. In: *Fuel Processing Technology*, Vol. 124, pp. 243 – 248.

[24] GUO, Q.; XUELI, C.; HAIFENG, L. (2012). Experimental research on shape and size distribution of biomass particle. In: *Fuel*, Vol. 94, pp. 551 – 555.

[25] SUTRISNO, T., ANGGONO, W., SUPRIANTO, F.D., SIAHAAN, I.H. (2017). The effects of particle size and pressure on the combustion characteristics of cerbera manghasleaf briquettes. In: *ARPN Journal of Engineering and Applied Sciences*, Vol. 12, No. 4, pp. 931 – 936.

[26] GENASEN, V., ROSENTRATER, K.A., MUTHUKUMARAPPAN, K. (2008), Flowability and handling characteristics of bulk solids and powders—A review with implication for DDGS. In: *Biosystem Engineering*, Vol. 101, pp. 425 – 435.

[27] NDINDENG, S.A., MBASSI, J.E.G., MBACHAM, W.F., MANFUL, J., GRAHAM-ACQUAAH, S., MOREIRA, J., DOSSOU, J., FUTAKUCHI, K. (2015). Quality optimization in briquettes made from rice milling by-products. *Energy for Sustainable Development*, Vol. 29, pp. 24 – 31.

[28] MISSAGIA, B., GUERRERO, C., NARRA, S., SUN, Y., AY, P., KRAUTZ, H.J. (2011). Physicomechanical properties of rice husk pellets for energy generation. In: *Energy Fuels*, Vol. 25, pp. 5786 – 5790.

[29] MITCHUAL, S.J., MENSAH, K.F., DARKWA, N.A. (2013), Effect of species, particle size and compacting pressure on relaxed density and compressive strength of fuel briquettes. In: *International Journal of Energy and Environmental Engineering*, Vol. 4, No. 4, pp. 1 – 6.

[30] DAVIES, R.M., ABOLUDE, D.S. (2013). Ignition and burning rate of water hyacinth briquettes. In: *Journal of Scientific Research and Reports*, Vol. 2, No.1, pp. 111 – 120.

10.21062/ujep/170.2018/a/1213-2489/MT/18/5/742