RELATIONSHIPS BETWEEN TECHNOLOGICAL AND MATERIAL PARAMETERS DURING DENSIFICATION OF CHERRY TREE SAWDUST

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In this paper, we will present the research findings concerning relationships between technological and material parameters during densification of cherry tree sawdust. In general during in the biomass densification process technological and material variables influence this process and thus the final briquettes quality. The main goal of presented experimental research is to determine the impact and relationship between compression pressure and particle size. These variables are influencing lonely treatment, densification and also the combustion of final briquettes from cherry tree sawdust. The abovementioned impact of these variables can be observed during densification in the quality indicators. Experimental research findings were obtained using single-axis densification. The influence of the particle size interacting with compression pressure on the final density was determined. The experimental research findings presented here should prove the significance in briquette production and also in the engineering of densification machines.

KEYWORDS

biomass, densification, briquetting machine, briquettes density, compression pressure, particle size, moisture content

1 INTRODUCTION

Development and engineering of densification machines with effective production of solid biofuels is significantly influenced by knowledge about lonely densification process. On our department is the main area of interest about scientific research of important parameters influence during densification of biomass residues. Development of new machines is more effective if the information about lonely densification process is available. Requirements from the solid biofuels production are showing that other important fact is considering the possibility for variable change of pressed material. Each type of raw material requires an independent approach. Each densification machine should to produce solid biofuels to the required quality according to technical Standards [DIN 1976], but this is not so simply if the raw material is changed very often. Hence each type of raw material has its specific properties and chemical composition, each small change in the properties of raw material can influence the final biofuel quality. Different raw material properties cause different conditions during densification process and this causes that the final quality of biofuels is very different [Krizan 2015b]. For each raw material is necessary to find optimal parameters setting for densification. According to our experience and knowledge we know that parameters which are influencing the final biofuels quality can be divided into the three groups. There can be recognized raw material parameters which are related with the pressed material properties and with degree of raw material treatment. In this group are included type of raw material, material moisture content and material particle size. Second group of influencing parameters are related with the lonely densification technology as a process of final treatment before energy recovery. Here can be included compression pressure, pressing temperature, pressing speed, holding time, etc. Another group of parameters are related with the densification machine construction and the impact of some structural parameters is widely known. In this group can be recognized pressing chamber length, conicalness of pressing chamber walls, friction coefficient, pressing chamber diameter, etc.

Because we recognized many influencing parameters is necessary to proceed gradually – step by step. According to our experience and knowledge obtained also from many analyses most significant parameters are: type of raw material being pressed, raw material moisture content “w_r”, raw material particle size “L”, compression pressure “p” and pressing temperature “T”.

General purpose of this paper is to determinate the relationship between technological and material parameters and final quality of solid biofuels, namely briquettes from cherry tree sawdust. Initially, to evaluate if the briquettes fulfill the requirements established in the European Standards, a physical characterization of each densified briquette was performed. Subsequently, to determine the impact of material and technological factors, all related parameters were measured, and the densification according to designed experimental plan was executed. Finally, to better understand the impact of the material and technological factors, detailed data processing was done and mutual interactions of monitored factors were characterized. In this paper we would like to present findings regarding the impact of compression pressure and impact of particle size.

2 MATERIALS AND METHODS

2.1 *Experimental Pressing Stand*

Experimental research was realized for determination of technological and material parameters impact on final biofuels quality during densification. Briquettes quality, as a final output of densification process, was evaluated by its density [DIN 1976, EN ISO 2015b]. Briquettes were produced by vertical hydraulic press which was supplemented by experimental pressing stand. This equipment is representing vertical single-pressing densification. Experimental pressing stand consist of base frame, cylindrical pressing chamber with 20 mm diameter die, heating device with temperature sensor for temperature control and the backpressure plug. When the temperature into the chamber was reached the raw material was fed into the chamber and pressing by hydraulic piston was performed. Hydraulic press allowed setting the pressing pressure in the range from 31 MPa to 318 MPa.

2.2 *Raw Material Properties*

Sawdust of cherry tree (*Prumus avium*) originating from Southern Slovakia was chosen for this experiment and suitable raw material in sawdust form was obtained from wood processing company with 8 % of moisture content and without bark. Cherry tree planting is widespread in Slovakia especially in fruit orchards in Southern Slovakia. Cherry tree is deciduous tree and for its special colour and mechanical properties also very often used for furniture production. In following Tab. 1 can be seen some physical and mechanical properties of cherry tree. On the base of these parameters is cherry tree included to the hardwoods. Initially, the particle size distribution was analyzed by Retsch Vibrating Sieve Equipment AS 200. The raw material particle size distribution was determined, proportions by weight see in the Fig. 1. For the experimental research fraction sizes 0.5, 1.0, 2.0, 4.0 mm and unsorted mix was chosen (see Fig. 2) according to our possibilities.

Material properties	Value	Chemical Element	Percentage of
Density at absolute dry state (kg.dm^{-3})	490	Carbon (%)	49
Density at w_r=12% (kg.dm^{-3})	570	Hydrogen (%)	6
Density at w_r=58% (kg.dm^{-3})	670	Oxygen (%)	44
Tensile strength (MPa)	45	Nitrogen (%)	0.1
Bending strength (MPa)	85		
Brinell hardness (MPa)	59		
Modulus of rupture (MPa)	103.3		

Table 1. Selected properties of cherry tree

The input particle size has a very interesting effect on the densification process because larger particle sizes increase the energy needed for densification. However, briquettes formed from large particle sizes have lower homogeneity and strength [Kaliyan 2009]. On the other hand, a large portion of fine particles allows for better material densification. The resulting briquette is uniform, of high quality, and reaches higher volumetric density [Krizan 2015d, Mani 2006]. When pressing, especially without additives, the surfaces of the grains must contact on the greatest possible area [Mani 2006, Krizan 2015a]. The size of this contacting area increases as the particle size becomes finer and higher compression pressures are applied. Particles exist in the material that, due to external forces, deform and load mainly the contact regions. In terms of densification, it is very important that the bonding forces are created between particles. The strength of the resultant bonds increases with decreasing particle size [Kaliyan 2009, Krizan 2015c]. However, the optimum particle size changes with respect to the densification technology employed and the raw material used. Therefore, it is important to investigate the effects of particle size on the resulting density of the briquette. Particle size is thus one of the parameters that we attempted to identify and verify through our experiments.

The moisture content of the raw material is in generally an important condition for the optimal densification of biomass and also for energy recovery [Mani 2006, Nielsen 2009]. The effects of moisture content on the material must be known to produce quality briquettes as defined by Standards [DIN 1976]. It is known from specific results from research discussed in the literature that density and strength depend on the moisture content of the pressed material, for example, in the case of pressing wood sawdust [Krizan 2015b, Kaliyan 2009, and Mani 2006]. If the moisture content of the pressed material is very low, or very high for that matter, the particles become inconsistently arranged, and the resulting briquette becomes unstable [Mani 2006, Nielsen 2009]. The mutual interaction between the material moisture, compression pressure, and pressing temperature is very interesting. However, if the pressed material has high moisture content, escaping water in the form of steam cracks the briquette. Optimal moisture level improves the compaction of the material by causing a degree of sintering which improves the unity of the briquettes particles.

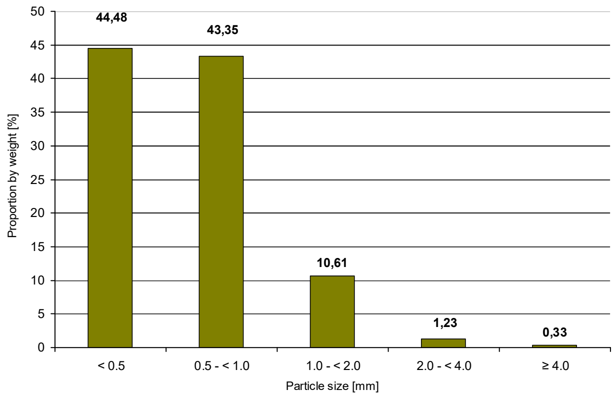

Figure 1. Raw material particle size distribution

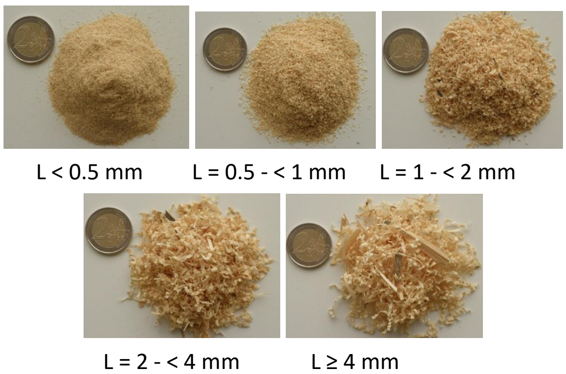

Figure 2. Cherry tree sawdust particle sizes

Behavior and properties of cherry tree sawdust in various moisture conditions are also very helpful for the densification. It helps when choosing the treatment technologies and when setting the optimal values of densification according to the current status of raw material. Therefore we realized simple experiment with humidifying and drying in laboratory conditions. Because we got raw material sawdust with 8 % of relative moisture content it was needed to use only the humidification. For our experiment is this moisture content level suitable. But in practice is this moisture content level unreachable due to expensive drying technology. Knowledge about moisture properties of cherry tree sawdust is therefore very important. To a various weight of sawdust sample was added various amount of water and we determined the moisture content in various time periods [EN ISO 2015a]. Humidified sawdust was deposited in a bulky form in our laboratory for various time periods. Results are listed in Fig. 3. There can be seen dependence of moisture content on time period at various amount of added water.

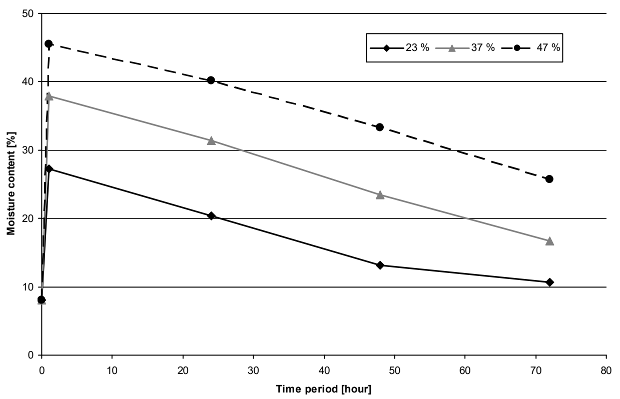

Figure 3. Dependence of moisture content on time period at various amount of added water

2.3 *Experiment Conditions*

According to experimental plan for each experiment setting 5 briquettes was produced. This number was chosen according to requirements of standard mathematical and statistical methods for experiments evaluation [Krizan 2015a, Krizan 2015b]. Described hydraulic press with pressing stand allowed experimental settings in wide range of compression pressure and temperature. Densification of cherry tree sawdust was executed gradually in order to achieve correct results. Briquettes density was calculated by means of the ratio between briquettes weight and its volume. The weight, length and diameter of each briquette were measured by a digital caliper and an electronic balance. The volume of briquettes was calculated as the volume of a cylinder with dimensions (length and diameter), according to EN ISO 17829 [EN ISO 2015b]. The average density was calculated for each sample briquettes. All results in this phase were interpreted by graphical dependencies, as seen in following figures. The results of this experimental research are applicable at densification machines dimensioning and gave a comprehensive overview of the parameters behaviors during the densification process.

3 RESULTS AND DISCUSSION

3.1 *Effect of Compression Pressure*

Effect of compression pressure on final briquettes density can be seen on the Figure 4. With increasing of compression pressure also increases the briquette density. This dependence also shows how important is also briquette stabilization time. Briquette stabilization time is the time interval during which dilatation occurs; it is also the time interval during which the briquette stabilizes [Krizan 2015b, Krizan 2015c]. Briquette stabilization time takes approximately 24 hours according to the type of the pressed material and densification technology used but it can also take longer. Standard DIN 52182 [DIN 1976] describes the conditions and process for detecting briquette density after stabilization time. After densification, the briquettes had to be placed into stable climate conditions. From time to time the briquette diameter, length and weight were measured. During this stabilization time the briquette dimensions was measured often and its weight and density was evaluated. If during the last 24 hours briquette weight had changed by a maximum of 0.1 %, the briquette wad considered stable [DIN 1976]. Briquette dilatation is an effect during which the briquettes dimensions and weight are changing (diameter, length and weight). These changes come from the internal parameters of the briquette material and also external parameters of the densification technology. Dilatation directly influences the briquette density because density was calculated from the aforementioned briquette dimensions. The dilatation effect is generated when the compression pressure was released and, due to the relation of mutual interactions with pressing temperature, material moisture and input particle size.

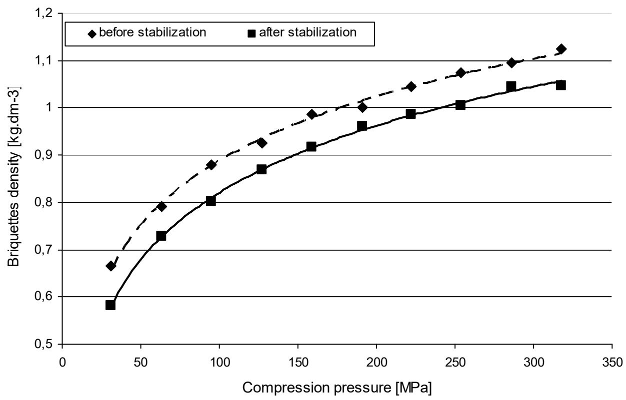

Figure 4. Dependence of briquette density on compression pressure (w_r=8%; L=2 mm)

In Fig. 4 can be seen two dependences, one for densities evaluated immediately after briquettes released the pressing chamber it means before stabilization and the second for densities evaluated after stabilization time. Briquettes density changed significantly and dilatation in this case negatively influenced the briquette density.

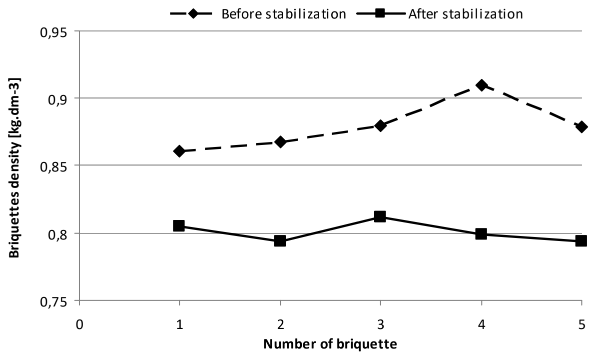

Figure 5. Briquette density values at compression pressure 95 MPa (w_r=8%; L=2 mm)

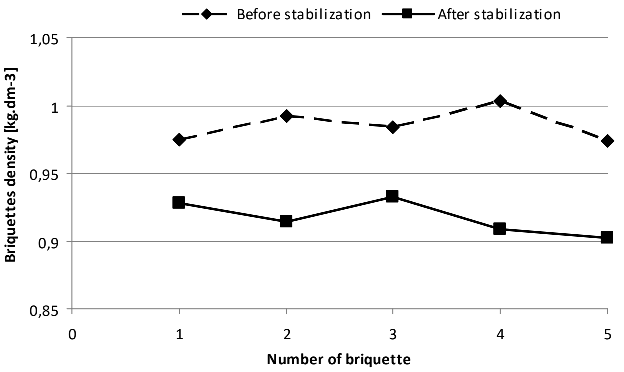

Figure 6. Briquette density values at compression pressure 159 MPa (w_r=8%; L=2 mm)

This effect can significantly distort the results of the experiment. Briquette density is important in the point of view of material particle cohesion. During densification, lignin is releasing from the biomass which acts as a natural glue. If the briquette isn't created in optimally adjusted conditions, dilatation of the briquette can also significantly influence the absorption of moisture from surroundings. In practice, the stabilization time can be decreased by cooling. On the Fig. 5, 6 and 7 can be seen that each briquette from the same setting and also from another setting was during stabilization time subjected by dilatation. Size of dilatation depends on investigated parameters. On these figures you can see separately the situation during pressing at three values of pressures (at 95 MPa, at 159 MPa and at 254 MPa). Different size of dilatation was observed. This difference was observed between briquettes produced under the same conditions. Besides the impact of pressure on dilatation, also the material parameters and amount of pressed raw material is influencing the dilatation.

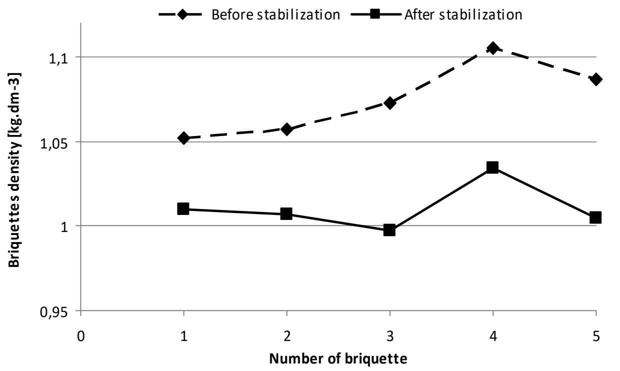

Figure 7. Briquette density values at compression pressure 254 MPa (w_r=8%; L=2 mm)

Increasing of compression pressure positively affects the size of dilatation; it is mean dilatation is decreasing. We can see that differences between lonely briquettes density values before and after stabilization are decreasing with increasing of compression pressure. In Fig.9 the graphical dependence of differeing density before and after stabilization on the compression pressure can be observed. This dependence clearly proves the impact of compression pressure on briquette dilatation and means that with increasing compression pressure, briquettes dilatation is decreasing. Also the Fig.8 proves this fact where can be seen dimensional change of briquettes depending on different acting compression pressure.

Figure 8. Briquettes from cherry tree sawdust produced with different acting pressures (w_r=8%; L=2 mm). /Used pressures description - upper figure from left to right side: 31, 63, 95, 127 and 15 MPa; lower figure from left to right side: 191, 222, 254, 286, 318 MPa/

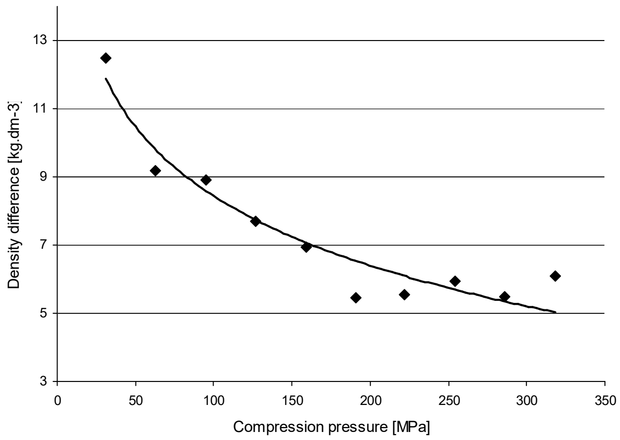

Figure 9. Density difference, dependence of the compression pressure (w_r=8%; L=2 mm)

3.2 *Effect of Particle Size*

Important part of experimental research was dedicated to studying the effect of raw material particle size on briquette density. Dependence of particle size on briquettes density (see Fig. 10) has shown that, decreasing the particle size positively influences the increase in briquette density. As we can see with increasing of compression pressure also can be positively influenced briquette density.

In the figure, can be seen that with increasing of particle size, briquette density changes. Also it's important to notice, that for these results, the measurement was performed while pressing without any increase in temperature during the process and at 3 levels of compression pressure. On Fig. 11 are illustrative views of produced samples from various particle sizes. Here can be very easily recognized different structure of briquettes due to dimensional difference of raw material particles.

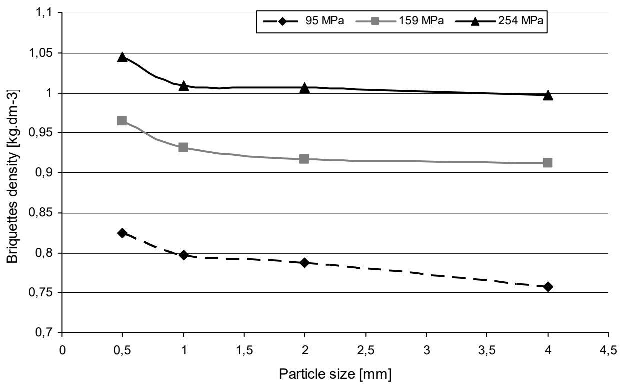

Figure 10. Dependence of briquette density on particle size (w_r=8%; T=25°C)

In the case of particle size the cherry tree sawdust compressibility factor is an important parameter. The compressibility factor characterizes one of the basic properties of disintegrated sawdust – compression. The sawdust compression is defined as the tendency of bulk sawdust to change volume under the effect of an external force. This means, that the magnitude of this compressibility or compression factor, is affected by the acting pressure. The results of the experiments show that increasing the compression pressure for cherry tree sawdust of equal fraction size increases the briquettes density (see Fig. 12). Also it was proven that by increasing the particle size the briquette density decreases. The listed results imply that important parameters affecting the compression factor are the pressure acting and the particle size.

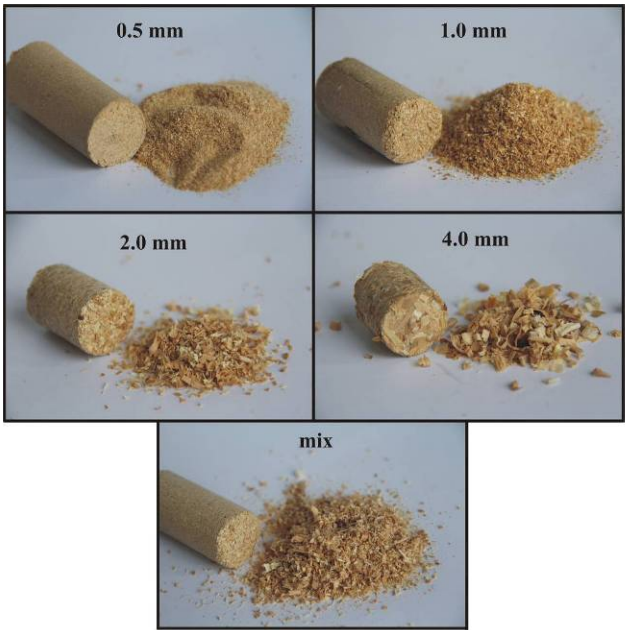

Figure 11. Comparison of cherry tree briquettes from various particle sizes (w_r=8%; T=25°C)

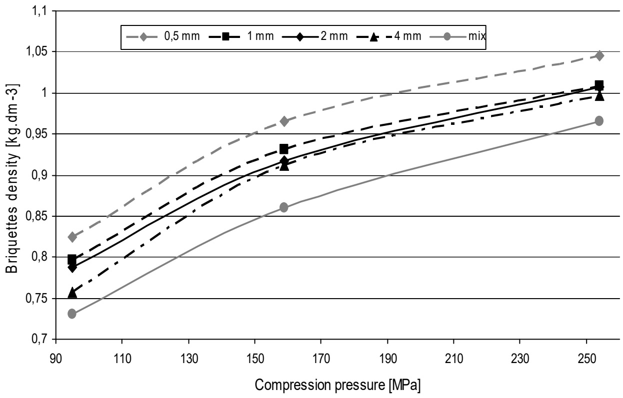

Figure 12. Dependence of briquette density on compression pressure for different particle size (w_r=8%; T=25°C)

Interesting comparison is also comparison of briquette density changes for different particle sizes separately and with no separated sawdust - mix. At this given particle size distribution the briquettes produced from mixed sawdust had lowest densities. Highest densities were achieved by producing from sawdust with 0.5 mm particle size. This was caused by creating of stronger bonds between smaller particles. Very similar or no major changes between densities from fractions 1.0, 2.0 and 4.0 mm were observed. These research findings should be very helpful at economical calculation and design of treatment (disintegration), especially the degree of disintegration. Finer sawdust increases the briquettes production price.

From economical calculation and also from briquettes final quality points of view are very interesting and helpful research findings on Fig. 13. This figure shows the density difference as dependence of compression pressure for different particle sizes. These results prove that at this particle distribution is most suitable 0.5 mm particle size. Briquettes produced from this particle size were influenced by dilation less than others. We can say that bonds created between raw material particles influences also the briquettes dilatation.

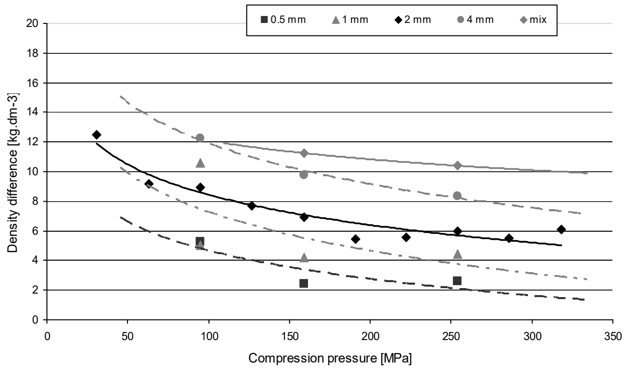

Figure 13. Density difference, dependence of the compression pressure for different particle sizes (w_r=8%; T=25°C)

4 CONCLUSIONS

Research of cherry tree sawdust densification as a wood waste was investigated in this research. The main conclusions that can be withdrawn from this study are as follows:

• Both of the investigated parameters are significantly affected the final briquettes density. With increasing of compression pressure and decreasing of particle size, cherry tree briquettes density increases.

• At this given particle size distribution the briquettes produced from mixed (no separated) sawdust had lower densities in comparison with briquettes produced from separated fractions (0.5, 1.0, 2.0 and 4.0 mm).

• Density value which is given by technical Standard (1.14 $kg.dm^{-3}$) [DIN 1976] under the given experiment conditions (in the absence of a higher pressing temperature) wasn't obtained. On the base our experience we can expect that briquettes density values will be increase only under the active pressing temperature [Krizan 2015a, Nielsen 2009].

• The both of investigated parameters (particle size and compression pressure) are significantly affected also the briquettes dilatation. Increasing of compression pressure and decreasing of particle size positively influences the dilatation. It means at these conditions were achieved lower dilatation.

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