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Determination of physical, mechanical and burning characteristics of polymeric waste material briquettes

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Abstract. In this paper the study of recycling technology for production of refuse derived fuel (RDF) is described. Various types of wastes (wood, carton, paper, plastic and textile) were processed by two-shaft and single-shaft shredders to obtain the output product (1–2 mm), which is suitable for briquetting process. For samples manufacturing the briquetting equipment developed at Slovak University of Technology in Bratislava was used. Technological test showed that by briquetting of the municipal waste higher pressing temperature and compacting pressure should be applied. For quality evaluation of the manufactured briquettes the density and strength properties were determined. The mechanical strength of briquettes from RDF increased after mixing it with wood and paper wastes. The influence of different parameters (fraction size, moisture content, compacting pressure and temperature) to briquette quality was studied. To determine the calorific value of the briquetting stock the tests in the chemical laboratory of the Department of Thermal Engineering of TUT were performed.

Key words: recycling, municipal wastes, refuse derived fuels, briquetting technology.

1. INTRODUCTION

Environmental protection and material recycling are important matters today. For renewable energy resources utilization, the briquetting technology is used. Biomass-based fuels are utilized in many countries [1,2]. Briquettes are produced not only from biomass, but also from different type of wastes like milled paper, plastic and other combustible wastes [3]. Different types of briquetting equipment and its modifications are under development [4]. Alternative fuels like biomass are making breakthrough to energy sector for production of green energy [5]. Currently in Estonia as RDF mainly milled plastic packaging wastes are used in rotary cement kiln by blowing the milled compounded plastic particles (25 mm) into the combustion chamber. In the future these wastes could be grinded and briquetted for gasification in power stations. Before the waste briquetting, pre-conditioning of the material is necessary [6]. First step is processing of municipal waste by disintegrator mills for the size reduction. Smaller particle size enables to obtain better properties of the product by drying, mixing and briquetting. Mixing of milled plastic waste with biological materials (wood sawdust, paper, etc.) leads to better briquette pressing as well as to greater calorific value. Before briquetting, the moisture content of the material should be reduced by drying process. Lower moisture content improves the briquetting process.

Briquetting is the most known and widely spread technology of materials compacting. The technology uses mechanical and chemical properties of materials to compress them into compact shape (briquettes) without usage of additives or binders in the high pressure compacting process [7]. Briquetting is mostly used for compacting of biomass (sawdust, wood shavings, bark, straw, cotton, paper, etc.). The biomass undergoes the process of briquetting, while high pressure and temperature simultaneously act upon the mass, the cellular structures within the material release lignin, which binds individual particles into a compact unit – briquette. Briquetting, however, can be also used for compacting of compounded plastic waste or municipal waste etc.

Briquetting is executed by briquetting presses. The material is pressed into the pressing chamber with high compacting pressure and high pressing temperature.

For briquette quality control, the physical parameters, such as density, moisture content and compressive strength, were found to be the best indicators of the quality [6]. In this contribution the output of a briquetting technology is assessed.

2. EXPERIMENTAL STUDY

2.1. Size reduction of the wastes

The two-shaft and four-shaft shredders and their combination with single-shaft shredders are generally used for size reduction of different types of waste materials. The principle of mechanical size reduction process is very simple. Rotor blades of the one rotor rotate against cutting elements of the second rotor. Cutting elements of rotors are catching material and cut output fraction. Dimensions of the material before disintegration are hundreds of millimeters. The size of output fraction after first step of disintegration is tens of millimeters. Productivity of disintegration machines depends on the dimensions of the machine, rotation velocity and size and shape of the input fraction. Productivity can be hundreds to thousands kilograms per hour.

Disintegration in a single-shaft shredder follows after disintegration in two- or four-shaft shredders. A grinding process in the single-shaft disintegration machine takes place. Output fraction passes through the screen. Screen is mounted under rotor and it assures homogeneity of the output fraction. The size of the output product is 1–2 mm. This product is suitable for the briquetting process. Productivity of single-shaft shredders is from hundreds to thousands of kilograms per hour and it depends on the size of the openings in the screen, cutting wedges on the rotor, rotation velocity etc.

Fraction size has also very high influence on the briquetting process. For the briquetting of coarser fraction a higher compacting power is needed. Briquette has lower homogeneity and stability. With increasing the fraction size, the binding forces inside the material are decreasing which results in faster decay by burning (briquette burns faster and that is a disadvantage). The enlargement of fraction size raises the compacting pressure and decreases briquette quality. Smaller fraction size is also an advantage in the drying process. The drying process ends faster and better drying quality is achieved. Therefore the waste material should be grinded into a suitable fraction size and dried to a certain moisture content before the briquetting process.

2.2. Briquetting equipment and parameters

Briquetting is executed by briquetting presses. Compacting process of the plastic and municipal waste into the briquette is not as simple as it is in the case of briquetting of biomass waste, because municipal waste (plastics, textiles, etc.) does not contain a great amount of biological materials and therefore does not contain lignin – which is a natural binder. For briquetting of the municipal waste, a higher pressing temperature and compacting pressure should be applied.

Density is an important parameter, which characterizes the briquetting process. If the density is higher, the energy/volume ratio is higher too. Hence, high-density products are desirable in terms of transportation, storage and handling [6]. The density of biowaste briquettes depends on the density of the original biowaste, the briquetting pressure and, to a certain extent, on the briquetting temperature and time. The density of the briquette is calculated as

$$\rho_N = \frac{m_N}{V_N}, \tag{1}$$

where V_N is the briquette volume and m_N is briquette weight. The compression strength of briquettes in cylindrical shape is determined by cleft failure (Fig. 1). Briquette is placed between round dies of the press where it is equally compressed by increasing the compression force till the cleft fracture. Testing by axial pressure is shown in Fig. 2. For testing only the compacted and intact briquettes should be used. Maximization of the applied force leads to the increase of stresses inside briquettes until the specimen failure by cleft. Determined maximum value specifies briquette compression strength. The ratio of the maximal applied compression force and the briquette length is the indicator of the compression strength.

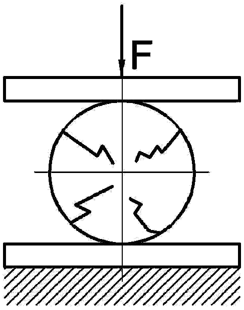

Fig. 1. Testing of the briquette compression strength in cleft failure conditions.

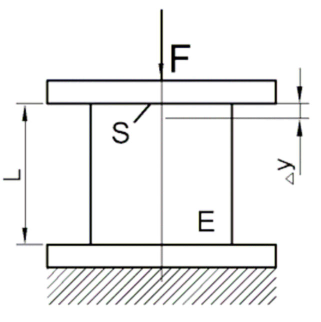

Fig. 2. Testing of briquette compression strength in axial pressure conditions.

Briquettes' strength in cleft and axial pressure are very important from the point of view of briquettes transportation, manipulation and storage.

3. RESULTS AND DISCUSSION

The briquettes were made from various compounded materials. For manufacturing the samples the briquetting press, developed at Slovak University of Technology in Bratislava, was used. Several tests to estimate the influence of compacting pressure to briquette quality were performed. Briquettes from the same type of material (wood sawdust) with the same fraction size and with the same moisture content were experimentally manufactured at the same pressing temperature by changing only one parameter – the compacting pressure.

3.1. Technological tests with briquettes

The briquettes manufactured at lower pressures (30–60 MPa) fall to pieces. Briquettes produced at higher pressures (150–250 MPa) are consistent and compact. The briquette density is also higher at higher compacting pressures.

Therefore the wood and paper wastes are to be added to the plastic and municipal waste. These materials contain lignin and help to bind the particles together into the briquette. Lignin acts also as stabilizer of cellulose molecules in the cell wall. The more lignin the material contains the more of it can be released to produce briquettes with higher quality. Higher concentration of the lignin assures better briquette strength. High pressing temperature is needed also for plastic and municipal waste plastification. Briquetting presses are mainly manufactured without the heating equipment. Therefore it is recommended to attach the heating equipment to the briquetting press for briquetting of plastic and municipal waste. It will increase the quality of the briquette.

The briquettes were pressed from 5 different samples of compounded material containing plastic, carton, textile, wood and other types of waste material. The following samples were investigated:

– Sample 1: RDF from mixed municipal waste consisted of 38% wood chips from soft wood, 45% disintegrated carton waste, 11% disintegrated PET bottles, 6% textile waste (MMW);
– Sample 2: RDF with an addition of 20% of disintegrated carton waste (80/20 – MP);
– Sample 3: RDF with an addition of 4% of cement (4 C);
– Sample 4: RDF with an addition of 20% of wood sawdust (20 WS);
– Sample 5: RDF without any additions (RDF–MP);
– Sample 6: RDF with an addition of 50% disintegrated carton waste (50/50 – HP);
– Sample 7: RDF without any additions (RDF–HP).

Samples 1–5 were manufactured by mechanical press and samples 6–7 by hydraulic press. From each group of the samples 1–7 the quality of seven briquettes was evaluated. Briquettes must be equal in composition; cracks and fine particles separation are not acceptable. The diameters and lengths of each briquette were measured before testing. Briquettes with higher density have longer burning time.

The results of the briquettes testing are presented in Fig. 3.

As it follows from the test results, the mechanical strength of the briquettes obtained from only RDF wastes was quite low. Mixing the municipal waste with wood and paper waste increases both tested parameters of the briquettes.

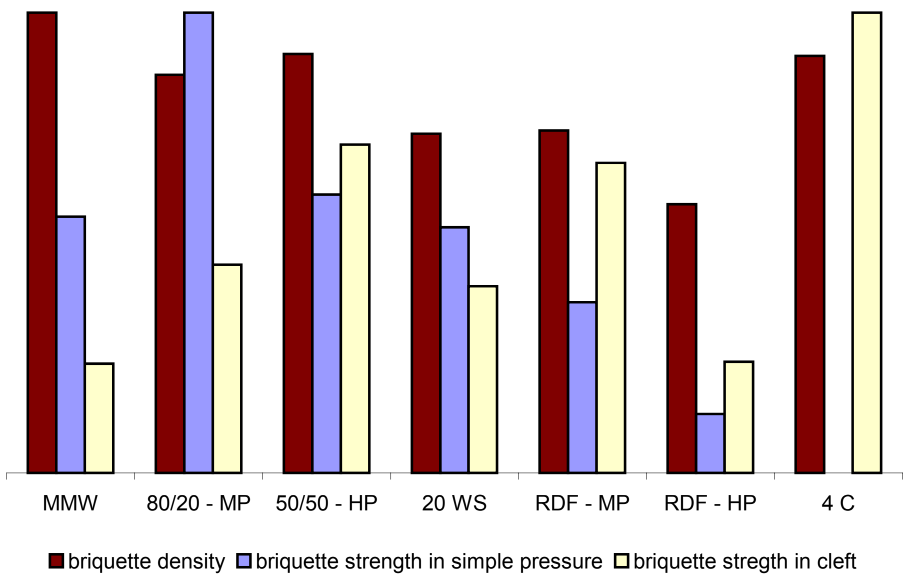

Fig. 3. Physical and mechanical properties of the tested briquettes.

3.2. Evaluation of the physical parameters in briquetting process

One of the important factors is pressing temperature, which has significant impact on the briquette quality and strength. This parameter influences the excretion of lignin from the cellular structure of wood. Lignin plays very important role in the compacting process; it has the function of joining the fibres of the pressed material. In Fig. 4 the dependence of the briquette strength on the pressing temperature is shown. As it appears from the graph, it is not necessary to use the highest pressing temperature. The optimal pressing temperature is in that part of the curve where the maximum briquette strength properties are achieved. When the temperature is lower than the optimal value, the briquette is unstable and has lower strength, which causes faster crumble by burning. Also the briquette burns shorter time and less heat is generated in the process. By increasing the pressing temperature the volatile compounds can be burned out from the pressed material. Usage of higher compacting temperatures will cause the escape of volatile compounds or pressing material can begin to burn.

With increasing the pressing temperature when the compacting pressure is constant, higher values of the briquette strength could be achieved, but only to some extent.

Second important factor, which influences mainly briquette strength, is compacting pressure. Briquettes strength increases with the increase of the pressure. Briquette strength can be increased only to the strength limit of the compacting material. Briquette strength has impact on the briquette durability, because when the strength increases the absorption of atmospheric humidity decreases. Compacting pressure is a very interesting and complicated parameter. Compacting pressure can be affected by various parameters, e.g., the type of the pressing material, temperature in the pressing chamber, temperature, dimensions (length,

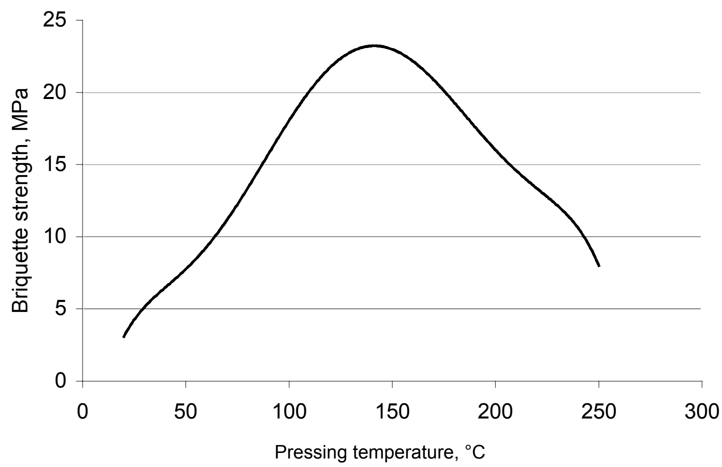

Fig. 4. Dependence of the briquette strength on the pressing temperature [8].

diameter) and shape of the pressing chamber and the compacting procedure. Compacting procedure has an impact on the layers distribution in the briquette and on the briquette strength. In Fig. 5 the dependence of the briquette density on the compacting pressure is depicted. The difference of compacting a warm material (200 °C) and a material at room temperature (20 °C) is pointed out. The pressing at high temperature enables to obtain the briquettes with higher densities at lower pressures. Briquettes have uniform shape and volume without visible cracks and scratches.

The third important factor is the moisture content, which depends on the material type and its specific properties.

Several experiments were carried out to measure the influence of the material moisture content at the briquetting process. From Fig. 6 it follows that the optimal material moisture content is in the interval from 10% to 18%. These values are also given in scientific papers about suitable values of material moisture content for briquetting.

As it follows from the graph, briquettes with moisture content lower than 10% or higher than 18% are not suitable for subsequent combustion process. If material moisture content is very low or very high (it means out of the interval 10%–18%), the elements are not consistent and briquette is falling to pieces. When the material moisture content is very high, the vaporization of surplus water tears the briquette to pieces. When the material moisture content is very low (fewer than 10%), for briquette quality the higher pressures should be used and it is very expensive and uneconomic. Therefore material moisture content should be reduced before briquetting by the drying process. Lover moisture content improves briquette quality.

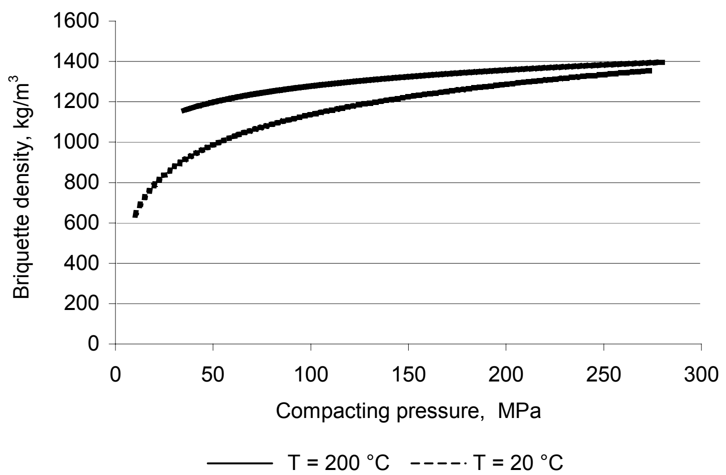

Fig. 5. Dependence of the briquette density on the compacting pressure and temperature [9].

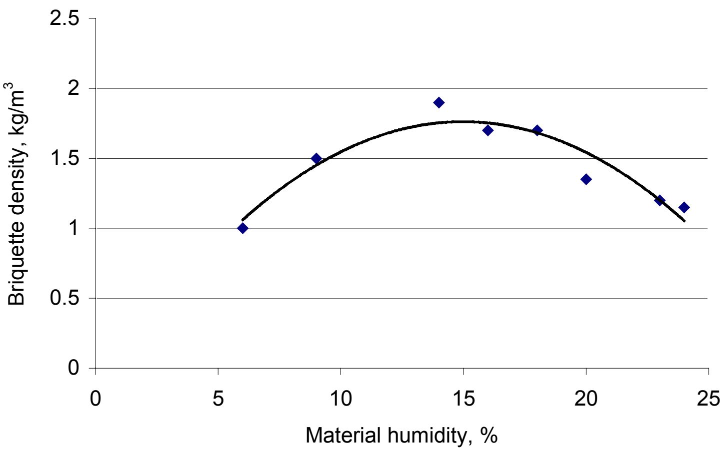

Fig. 6. Dependence of the briquette density on the humidity [8].

3.3. Basic combustion properties of the stock of briquettes

For determining the structure and combustion parameters of briquette samples, tests in the chemical laboratory of the Department of Thermal Engineering of Tallinn University of Technology were performed. Mostly two different types of raw material RDF plus carton and paper (disintegrated cellulosic fiber) were analysed. First sample of the RDF briquette consists mainly of plastics, paper, carton and textiles (MSW). Two another sample briquettes were pressed from RDF and besides paper and carton additives were used. Test results of different samples are presented in Table 1.

The comparison of the burning characteristics and some elements in the briquette material shows that the composition of samples varies considerably. Notably different is sample 2 (Table 1) that consist 50% of hygroscopic and

Table 1. Results of RDF briquette analysis

Parameters	Unit	Test samples			Standard
		1	2	3	
Moisture	%	3.2	6.9	3.4	CEN/TS 15414
Ash (for dry matter)	%	8.3	11.3	9.5	CEN/TS 15403
Sulfur (for dry matter)	%	0.14	0.05	0.05	CEN/TS 15407
Chlorine (for dry matter)	%	0.40	0.14	0.46	CEN/TS 15408
Nitrogen (for dry matter)	%	0.25	0.07	0.28	CEN/TS 15407
Gross calorific value, dry	MJ/kg	28.90	17.34	26.79	CEN/TS 15400
Net calorific value	MJ/kg	26.14	14.72	24.08	CEN/TS 15400

% Gives the percentage by mass.

ash rich paper. The moisture content of sample 2 is approximately twice higher than average moisture of other samples, probably due to the high concentration of paper (50%) that is able to absorb ambient humidity. High ash content of the fibre material (paper and carton) that was added to RDF increases ash content of the mixed briquettes up to 36% (sample 2). Due to higher moisture and ash content, the net calorific value of the briquettes material is lower than that of those containing only RDF material.

It is interesting to mention that the content of corrosion aggressive elements like chlorine and sulfur in sample 2 is many times lower as compared to other samples. This property of sample 2 makes it from the combustion and boiler operating aspect better fuel for combustion equipment in comparison with the RDF briquettes and RDF + 20% carton ones. The compounds of chlorine and sulfur have essential corrosive effect to heating surfaces of boilers and the emission of sulfur oxide has levy taxes. Further expenditures and technical problems for consumers of briquettes made of 50% RDF and 50% carton (sample 2) will cause about 36% higher ash content as compare to only RDF briquettes.

4. CONCLUSIONS

The mechanical strength of the briquettes obtained from only RDF wastes was quite low. Therefore the wood and paper wastes have to be added to the plastic and municipal waste. When wood and paper wastes are mixed with municipal wastes and then this mix is briquetted, the briquette strength increases for 1.5–4.5 times. Material warming at the briquetting process leads to the reduction of the compacting pressure without lowering the qualitative properties of the product. Therefore it is recommended to attach the heating equipment to the briquetting press for briquetting plastic and municipal waste.

The comparison of the burning characteristics and some elements in the briquette material shows that the composition of samples varies considerably. The sample 2 had highest moisture content, althought it had about 36% higher ash content as compare to only RDF briquettes. The concentration of corrosion-aggressive elements as chlorine and sulfur in sample 2 is many times lower than in other samples, which is an important property from the combustion and boiler operating aspect. That makes sample 2 a better fuel for combustion equipment than the other tested briquettes.

The briquettes from municipal wastes (RDF) or compounded plastic wastes can be used by gasification technology for obtaining heat.

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Polümeersetest jäätmetest pressitud brikettide füüsikalis-mehaaniliste ja põlemiskarakteristikute määramine

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On käsitletud polümeersete jäätmete ümbertöötlemist. Võimaliku lahendusena jäätmeprobleemile on esitatud jäätmete briketeerimise tehnoloogia. Katselisel teel määrati kindlaks tahketest jäätmetest valmistatud brikettide füüsikalis-mehaanilised omadused. Brikettide kütteväärtuse ja keemiliste elementide sisalduse määramiseks viidi läbi põletamiskatsed.