BRIQUETTES FROM RECOVERED PAPER AND BOARD

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Abstract. Worldwide increasing energy demand is today permanently covered by a majority of non-renewable energy sources, namely by coal, crude oil and natural gas. This causes the rapid decline of their reserves and the time gets near when they will be run out. Therefore, in recent years the exploitation of renewable energy sources is permanently preferred. One of the alternative fuel forms is the fuel on the basis of paper waste. In this paper the results of tests are published, which were carried out using five sorts of recovered paper and board (group and grade 1.05, 1.06, 2.02, 2.05 and 3.05 according to ČSN EN 643), pressed in a form of briquettes. During the tests the following briquettes parameters were considered: moisture content, ash amount, length and diameter, weight, density, rupture force and mechanical durability. The results are presented in the form of tables and graphs. It was proved that briquettes made from recovered paper and board are compared with briquettes from wood waste of high density, high mechanical durability and for their rupture relatively high force is necessary. But at the same time they have high ash amount and low combustion heat.

Keywords: renewable energy sources, recovered paper and board, briquetting, properties of briquettes, mechanical durability.

Introduction

Today the comfortable life is paid with the expressive energy consumption in its all forms. The non-renewable energy source reserves are limited and they exhaust. Nevertheless, they supply about four fifths of energy. But in the last decades the renewable energy sources are preferred. One of the alternative forms of fuel, made from renewable sources, is the fuel on the basis of paper waste. First of all, it is recommended to recycle this raw material – to use it as a material. But in several last years it is paper waste surplus on the world market and therefore the interest of specialized firms in this raw material decreases. Besides, not every paper waste is apt for recycling. E.g., chancery paper, exercise-book paper, magazine paper, newspaper, boxes, cartoons or boards are suitable. E.g., wet, greasy or otherwise polluted paper or coverings from paper and another material (e.g., coverings Tetra-pak contain besides paper aluminum or polyethylene foil, too) are not suitable. Energetic use becomes an interesting alternative and it is certainly more suitable than the paper waste disposal. Besides, it is necessary to keep in mind that cellulose fibers progressively lose their original properties. Therefore, the paper recycling can be repeated only 5 or 6 times. Then the raw material is unusable.

Paper is a flexible, sufficiently consistent mass, made mostly from vegetable substances and finished in a form of thin sheets. Doubtless it is one of materials without which our everyday life is unimaginable. History of its production is old and at the same time interesting, too. Already more than 5000 years ago the parchment paper was produced in Egypt from medullas of cypress-grass (*Cyperus Papyrus* L.) stems. The production was relatively demanding and therefore the price was high. At the beginning of the 2nd century in China the paper production was significantly developed, as the rests of silk and hemp were used as the initial raw material. Later, cotton and flax waste was utilized. In the same way hand-made paper is produced up to the present day. The modern industrial paper production is a relatively complicated process. In principle two steps concur – the paper pulp production and the paper production.

The fuel briquettes are mostly of a circular section, eventually of a square, rectangular or hexagonal section with rounded corners. The briquette size depends above all on the used press type. Cylindrical briquettes are most often of 50 mm, 65 mm or 90 mm diameter; briquettes in a form of blocks are usually of 100 x 150 mm section. The briquette length is proportional to the material quantity in the press chamber. The length of cylindrical briquettes is most often 0.5 to 1.5 of their diameter, of block form briquettes about 65 mm [1-4].

Materials and methods

The briquette mechanical properties are very important. They influence expressively, e.g., the storage ability. By the author it was experimentally proved [5] that at storage the briquette mechanical properties decrease. The decrease depends above all on the storage conditions and storage time. The

adequate mechanical properties level influences also the possible handling from their production, packing and sale to the combustion at the final user.

In the Czech Republic the demands on the briquette properties are prescribed by the Directive of the Ministry of the Environment Nr. 14-2009 [6]. It requires the briquette minimum density of 900 $kg \cdot m^{-3}$. The briquette strength requirements are not prescribed. Nevertheless, for operational reasons the adequate compactness is very important in order that at a common handling neither crumbling nor disintegration occur. The briquette minimum gross calorific value must be 17 $MJ \cdot kg^{-1}$, the total moisture content max. 10 % by weight and the ash content max 1.5 %. But the above mentioned Directive applies to briquettes made from wood waste, alternatively to wood waste with maximum 20 % of vegetable waste. Although it is a case of different material, briquettes from paper waste are evaluated according to these technical requirements. In the Czech Republic special technical requirements for briquettes from paper waste still do not exist.

The properties of briquettes made from five different sorts of recovered paper and board were watched (according to ČSN EN 643), namely old corrugated containers (group 1, grade 05), unsold magazines (group 1, grade 06), and unsold newspapers (group 2, grade 02), sorted office paper (group 2, grade 05) and white woodfree letters (group 3, grade 05). Before briquetting all samples were shredded using a shredder of 3.9 x 50 mm cross cut.

Ahead of briquetting the moisture content (according to ČSN EN 14774-2), ash amount (according to ČSN EN 14775) and gross calorific value (according to ČSN EN 14918) were determined. Then the raw material was without other treatment briquetted using the briquetting press type "BrikStar 30-12" [7] of 50 mm press chamber diameter. From each material at least 50 pieces of briquettes were made, what makes possible to effect the measured values statistical evaluation.

The tests of briquette mechanical properties were carried out according to the method used by the author for several years for testing of briquettes made from different nonmetallic [8] and metallic [9] materials. The method of operation is relatively simple. Using the dial caliper the diameter and length of each briquette are measured. By weighing their weight is determined. Then the briquettes are placed between the plates of the universal tensile testing machine and continuously loaded till to the briquette rupture. The method of operation is presented in Fig. 1. The test is finished at the briquette rupture, which is accompanied with the rapid load decrease. From the load indicator the maximum load is noted down.

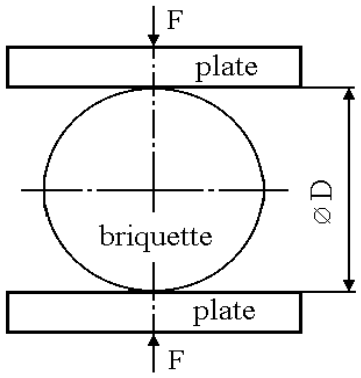

Fig. 1. **Method of the rupture test**

By the above mentioned method obtained values are mathematically evaluated. From diameter and length volume, next from volume and weight density and from length and force for rupture needed for destruction per unit of length are calculated. Using the unit of length the influence of briquette different length is eliminated.

The determination of the mechanical durability of briquettes (according to CSN EN 14961-1 and CSN EN 15210-2) was a part of the carried out tests.

Results and discussion

The results of the carried out tests are presented in the following tables and figures. Table 1 presents the properties of the tested papers ahead of briquetting. Table 2 presents the results of the

sizes and weight measurements. Table 3 contains the results of the calculated density and the rupture force. Fig. 2 presents the Gaussian curves of briquette length, Fig. 3 of briquette diameter, Fig. 4 of briquette weight, Fig. 5 of briquette density and Fig. 6 of rupture force.

From the results presented in Table 1 it follows that the moisture content at all tested materials ranged in the relatively low level, from 4.9 % (samples 2.05 and 3.05) to 6.0 % (sample 1.05). From the point of view of the ash amount between the five tested materials the significant differences exist. The lowest ash amount was determined at the sample 1.05 (7.7 %), the value of 11.1 % was determined at the sample 2.02. At the next two samples (2.05 and 3.05) the ash amount was higher than 20 %. The highest ash amount (34.7 %) was determined at the sample 1.06. The gross calorific value ranged from 14.1 (sample 2.05) to 17.4 (sample 2.02) $MJ \cdot kg^{-1}$.

Table 1

Properties of tested papers

Sample designation	Moisture content, %	Ash amount, %	Gross calorific value, $MJ \cdot kg^{-1}$
1.05	6.0	7.7	16.1
1.06	5.1	34.7	15.4
2.02	5.9	11.1	17.4
2.05	4.9	21.2	14.1
3.05	4.9	23.0	14.6

Table 2

Briquette size and weight

Sample designation	Briquette length, mm	Briquette diameter, mm	Briquette weight, g
1.05	49.9 ± 6.7	50.9 ± 0.3	115.6 ± 16.2
1.06	49.8 ± 6.7	51.3 ± 0.3	116.9 ± 16.5
2.02	45.3 ± 7.8	51.1 ± 0.3	98.5 ± 16.7
2.05	32.0 ± 8.8	50.6 ± 0.2	74.1 ± 21.4
3.05	30.8 ± 5.8	50.6 ± 0.1	72.2 ± 14.2

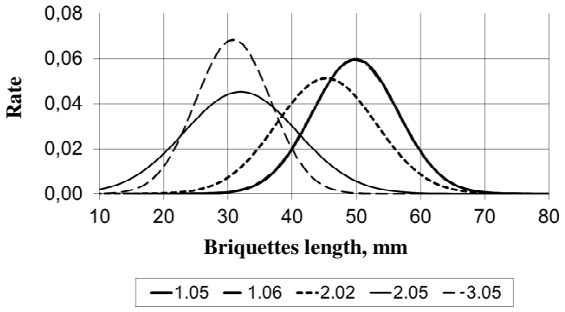

Fig. 2. **Briquette length**

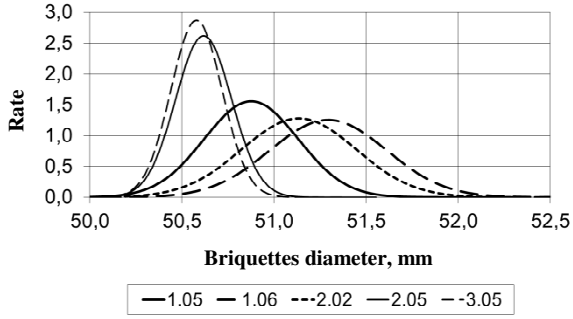

Fig. 3. **Briquette diameter**

From the results published in Tab. 2 and Fig. 2 it is evident that the average length of the briquettes made from all five sorts of paper waste is in the relatively wide range from 30.8 mm (sample 3.05) to 49.9 mm (sample 1.05).

From the results published in Tab. 2 and Fig. 3 it is evident that the briquettes made from all five tested materials enlarged their diameter compared to the diameter of the press chamber diameter. The enlargement was relatively small and for all materials it ranged from 0.6 mm (samples 2.05 and 3.05) to 1.3 mm (sample 1.06).

From the results published in Table 2 and Fig. 4 it is evident that the briquette weight ranged relatively widely from 72.2 g (sample 3.05) to 116.9 g (sample 1.06). From the results it also follows that the weight of the samples 1.05 and 1.06 was practically identical.

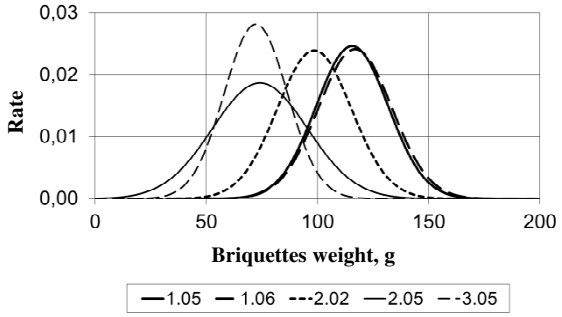

Fig. 4. **Briquette weight**

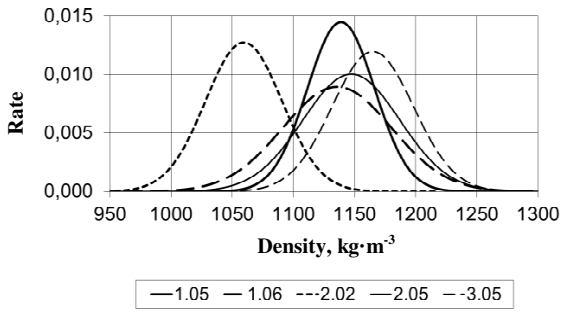

Fig. 5. **Briquette density**

Table 3

Briquette density, rupture force and mechanical durability

Sample designation	Density ρ, kg·m^{-3}	Rupture force F, N·mm^{-1}	Mechanical durability, DU %
1.05	1138.9 ± 27.5	178.8 ± 39.2	99.4
1.06	1135.8 ± 44.6	105.6 ± 27.4	98.8
2.02	1059.4 ± 31.1	116.6 ± 28.7	99.1
2.05	1147.4 ± 39.8	236.6 ± 47.7	99.7
3.05	1164.9 ± 33.4	275.2 ± 56.9	99.3

From the results published in Table 3 and Fig. 5 it is evident that the briquette density ranges relatively widely from 1059 kg·m^{-3} (sample 2.02) to 1165 kg·m^{-3} (sample 3.03). The density of the samples 1.05, 1.06 and 2.05 is similar, about 1140 kg·m^{-3}.

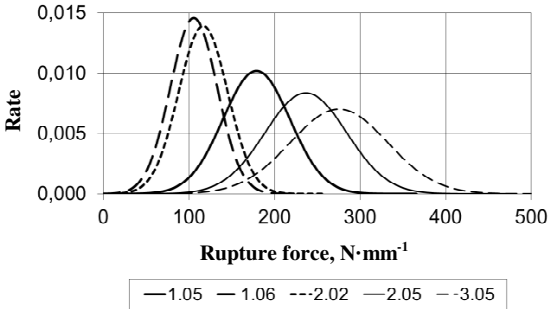

Fig. 6. **Rupture force for briquette destruction**

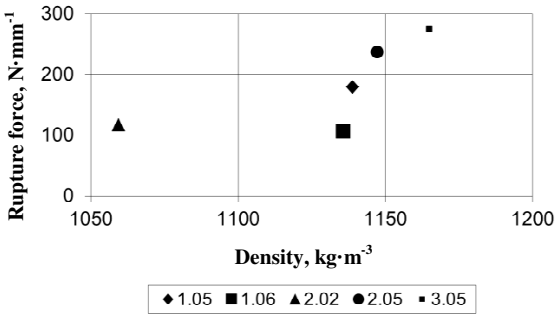

Fig. 7. **Relationship between rupture force and density**

From the results published in Tab. 3 and Fig. 6 it is evident that the rupture force of the briquettes made from paper ranges relatively widely from 106 (sample 1.06) to 275 N·mm^{-1} (sample 3.05). From this point of view the briquettes were not similar.

As it follows from Tab. 3 the mechanical durability of all briquettes is very high. The value just below 99 % was determined at the sample 1.06; the values over 99 % were found at all next samples.

The graphical representation of the briquette rupture force and density is shown in Fig. 7. It is evident that the highest density was determined at briquettes made from the sample 3.05 (white woodfree letters). The briquettes showed the highest rupture force, high ash amount and low gross calorific value. On the contrary, the briquettes made from unsold newspapers (sample 2.02) were of the lowest density, the rupture force being the second lowest. But the ash amount was low and the gross calorific value the highest.

The comparison of the obtained results with other works is in this case difficult. The author actually knows only one work [10] studying the properties of briquettes made from paper waste. For briquetting the cuttings of two different sorts of newspaper were used (dimensions: width about 3 to 10 mm, average length about 300 mm), and common shredded chancery paper, made using two types of shredders (longitudinal cut 3 x 300 mm and cross cut 3 x 30 mm). For briquetting the press type

"BrikStar 50" [7] of the press chamber diameter 65 mm was used. From the published results it follows that the briquettes made from shredded chancery paper are of higher mechanical properties (density about 1045 $kg \cdot m^{-3}$, rupture force at the use of longitudinal cut about 126, at the use of cross-cut 172 $N \cdot mm^{-1}$) than the briquettes made from newspaper shavings (density about 790 $kg \cdot mm^{-3}$, rupture force about 45 $N \cdot m^{-1}$). By the results comparison we find that at the use of the briquetting press of a smaller press chamber diameter the briquette density and rupture force increase considerably.

Other works, studying the briquette properties, exist, too. But they engage in other materials than paper waste, primarily in briquettes made from wood waste [11-13], from energy plants [14-16], or from alternative fuels [17]. Their authors concentrate primarily on the energy properties, but not on the mechanical properties. Therefore, the comparison of their results gained at the use of briquettes from paper waste is not possible owing to the tested materials dissimilarity.

Conclusion

In the paper the results of briquette mechanical properties are published. The briquettes were made from five sorts of recovered paper and board (according to ČSN EN 643), namely old corrugated containers (group 1, grade 05), unsold magazines (group 1, grade 06), unsold newspapers (group 2, grade 02), sorted office paper (group 2, grade 05), white woodfree letters (group 3, grade 05). These materials were pressed without any admixtures.

Ahead of briquetting the paper properties (moisture content, ash amount and gross calorific value) were determined. For briquetting the briquetting press type "BrikStar 30-12" of the press chamber diameter 50 mm was used. The briquettes were judged from several standpoints – length, diameter, weight, density, mechanical durability and rupture force using the rupture test.

After evaluation of all measured values it is possible to say that all briquettes made from five sorts of recovered paper and board are from the user's view suitable. The briquette technical parameters were objectively determined using the above mentioned tests, borrowed from the methods for testing of briquettes made from wood waste. Compared with the briquettes from wood waste the briquettes from paper waste are of considerably higher density, mechanical durability and rupture force. But the combustion heat of all sorts of paper waste is lower than the combustion heat of wood waste and contemporarily the ash amount is many times higher.

References

1. Basore C. A. Fuel Briquettes from Southern Pine Sawdust. Auburn: Alabama Polytechnic Institute, 1929. 30 p.
2. Brožek M. Briketování nekovového odpadu (Briquetting of non-metallic waste). In.: XIV. Didmattech 2001. Radom: Politechnika Radomska, 2001. pp. 84-87. (In Czech).
3. Brožek M. Briketování kovových odpadů (Briquetting of metal waste). In.: Trendy technického vzdělávání 2001. Olomouc: Univerzita Palackého, 2001. pp. 38-41. (In Czech).
4. Brožek M. Study of briquette properties at their long-time storage. Journal of Forest Science, 59, 2013, pp. 101-106.
5. Brožek M., Nováková A., Kolářová M. Quality evaluation of briquettes made from wood waste. Research in Agricultural Engineering, 58, 2012, pp. 30-35.
6. Kakitis A, Nulle I., Ancans D. Durability of the arranged structure biomass briquettes. In.: Engineering for rural development. Jelgava: Latvia University of Agriculture, 2010. pp. 285-289.
7. Kolářová M. Vlastnosti pelet a briket pro energetické využití (Properties of pellets and briquettes for energy use). PhD thesis. Prague, CULS, 2011. 144 p. (In Czech).
8. Nováková A., Brožek M. Briquettes from paper waste. In.: Ecology and farming technologies: Agro-engineering approaches. Saint-Petersburg-Pavlovsk: Russian academy of agricultural sciences et al. 2011, pp. 219-225.
9. Plíštil D., Brožek M., Malaťák J., Heneman P. Heating briquettes from energy crops. Research in Agricultural Engineering, 50, 2004, pp. 136-139.
10. Plíštil D., Brožek M., Malaťák J., Roy A., Hutla P. Mechanical characteristics of standard fuel briquettes on biomass basis. Research in Agriculture Engineering. 51, 2005, pp. 66-72.

11. Sheridan E. T., Berte V. C. Fuel-briquetting and Packaged-fuel Plants in the United States that Reported. Washington, U. S.: Government Printing Office, 1959. 7 p.
12. Tymich J. Sběrový papír a jeho využití (Waste paper and its use). Papír a celulóza. 66, 2011, pp. 20-23. (In Czech).
13. Tymich J., Lešikar J. M. Sběrový papír a jeho využití. 2. část. (Waste paper and its use. Part 2.) Papír a celulóza. 66, 2011, pp. 52-54. (In Czech).
14. Directive of Ministry of Environment No. 14–2009: Brikety z dřevního odpadu (Briquettes from Wood Waste). Prague, Ministry of Environment of the Czech Republic. (In Czech).
15. Papír (Paper) [online] [21. 04. 2012] Available at: http://cs.wikipedia.org/wiki/Pap%C3%ADr (In Czech).
16. Historie výroby papíru (History of paper production) [online] [21. 04. 2012] Available at: http://www.rucnipapir.com/rucni-papir/historie-vyroby/ (In Czech).
17. Briketovací lis (Briquetting press) BrikStar 30, 50, 70 [online] [21. 04. 2012] Available at: http://www.briklis.cz/briketovaci-lis/30-50-70/ (In Czech).