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Material waste paper recycling for the production of substrates and briquettes

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Abstract. This Article is focusing on recycling waste paper, which became one of the main collecting commodities for its widespread use in many economic regions. The introduction provides an overview of the development of a segment of waste paper in the EU. The article presents information about product options, new materials from processed waste and waste paper. The first part of the article describesthe situation in the Central Bohemia region both in terms of production and in terms of processing capacities. The next part of the article contains the practical information and value gained from the process of production of briquettes from waste paper and the description and analysis of technologies as well as description and analysis of achieved physical characteristics of manufactured briquettes. Another mentioned option for using waste paper is the application in substrate production technology as an input material with excellent physical properties, which could become an indispensable component in the production of high-quality substrates. The resulting values indicate a higher absorption capacity of fluids that are substrates of biodegradable materials. In both technologies there are present variations of the different samples and their ratios used to manufacture the final products and are shown in the resulting comparison.

Key words: biodegradable municipal waste, material recycling, composting, production of briquettes.

INTRODUCTION

Today the comfortable life is paid with the expressive consumption of energy in all its forms. The non-renewable energy source reserves are limited and they are to exhaust. Nevertheless, they supply about four fifths of energy consumption. In last decades, the renewable energy sources have been preferred. One of 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 (McKinney, 1995).

From the results of works published before (Brožek, 2013; Brožek & Nováková, 2013), it follows that compared to briquettes from wood waste, briquettes made from recovered paper and board are of low moisture content, high density, high mechanical durability and relatively high force is necessary for their rupture. But at the same time, they have high ash amount and low gross calorific value.

The constant industrial activity rise and world population growth are directly related to the increase of overall energy consumption, and it is estimated that in 2025, energy demand will surpass by 50% the current needs (Ragauskas et al., 2006).

Nowadays, almost 80% of the world's energy supply is provided by fossil fuels (Sims et al., 2007) with harmful impacts to the environment.

In the Czech Republic, 800,000 tons of waste paper is collected anually in average via separate sorting, but out of this amount only 315,000 tons is processed, and the rest, i.e. approx. 60% out of the mentioned total amount, is being exported abroad at the expense of the environment and the Czech economy. Although a paper consumption in the Czech Republic is estimated at 1.5 million tons, only 900,000 tons of paper is produced there. Out of this quantity, 700,000 tons is exported simultaneously, which means that it is necessary to import 1.3 mil. tons of new paper (Barták, 2010). These figures clearly confirm that 85% of the paper intended for consumption must be imported to the Czech Republic.

In recent years recorded, one of the most serious problems in the environmental field is an increased soil erosion and the associated degradation of the total agricultural land fund (Plíva et al., 2016). The paper presents two ways of secondary material recycling of waste paper in order to manufacture substrates, which are going to replace the loss of humus in the soil. Through application of produced substrates into the soil, other negative phenomenons, e.g. decreasing infiltration capacity of soil, can be prevented. Low infiltration results in poor water penetration into the deeper section and thus there is a constant destocking of groundwater.

The paper presents two ways of processing the waste paper and its consequent potential use. There are two groups of experiments that A) lead to the production of briquettes and determine their bulk density with a focus on the future use in the production of substrates as substitutes for e.g. behind wood chips, and B) lead to the production of the substrate in which the waste paper is going to be a high-quality irreplaceable commodity. During the production of the substrate, the sludge from sewage treatment plants (STP) is utilised at high extent, which brings another positive effect to recycling of problematic waste materials.

The experiments focus on the qualitative characteristics of the products produced. Both products are going to be applied to the soil in the next trial period and are going to be tested on their ability of rainwater retention in the soil profile. Based on the results, the before-mentioned primary experiments are going to be expanded with the content percentage adjustment in order to determine the optimum ratio of waste paper and added secondary waste materials that would ensure maximum dwell time of rainwater in the soil profile and would reduce risk of water erosion due to extreme precipitation.

MATERIALS AND METHODS

The goal of the research is the confirmation of waste paper usability, especially in the view of its low apparent density and high ability to bind water. In this paper, the primary results that deal with the verification of biodegradation properties and structural transformation of waste paper after shredding and crushing are presented.

A) Production of briquettes

The volume of shredded paper was determined using measuring cylinders of known volume and weight of the material. There were chosen 3 kinds of waste paper for the experiment:

- office paper shredded with the Fellowes MS 450Ms paper shredder,

- shredded paperboard (Fig. 3),
- shredded waste paper (a mixture of magazines, newspapers and other paper packaging), shredded using the HSM DuoShredder 5750 at WEGA recycling Ltd.

The material was scattered into a 1,000 ml measuring cylinder. The material was not compacted, just sprinkled into the measuring cylinder of the same height. Subsequently, the material was sprinkled on a scale and the weight of the material was measured in [g]. There were 10 measurements performed for each material and the mean value was determined, from which the specific weight of input shredded material was calculated.

Other devices:

- the measuring cylinder with a volume of 2,000 ml,
- laboratory scale KERN PFB 2000-2 with weighing range up to 2,000 g with a 0.01 g accuracy.

The material was inserted into the reservoir of briquetting machine BrinkStar CS25 with a matrix of 65 mm, and three types of briquettes were produced depending on a waste paper. Maximum operating pressure of the briquetting machine was 18 MPa (180 bar). Materials for pressing had to meet the following conditions: moisture content from 8 to 15%, dimensions smaller than 15 mm and bulk density of at least 70 kg m^{-3}. Briquette height was measured in two spots and the average value was calculated. Using the matrix diameter 65 mm, the height and the weight of the briquettes, the resulting bulk density was calculated. The briquettes were also analyzed to obtain a combustion heat and heating value according to ISO 1928. According to the manual of the briquetting machine, the briquettes should have had a shape of a cylinder of diameter 65 mm, length from 30 to up to 50 mm, and the heating value from 15 to 18 MJ kg^{-1}. The compression coefficient was calculated as the ratio between the density of the material prior to entering the briquetting machine and the density of the resulting briquettes.

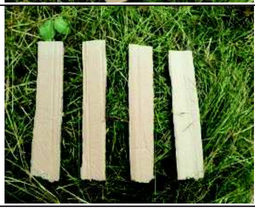
B) Production of substrate using waste paper

The aim of the experiment was to verify the possibility of processing raw material composed of cardboard and of sludge from sewage treatment plants in a high percentage share by technology of composting in order to verify the material degradation, and to produce a substrate.

In order to create piles for substrate production, composters showed in Fig. 1 were stocked with the raw materials listed in Table 1. Formation of raw materials was carried out according to the standard EN 14 045.

Figure 1. Establishment of piles of row material.

Table 1. The parameters of individual components and of the total

Sample No.	Sample photo	Material used	Volume [m^3]	Weight [kg]	C:N [-]
1.		sludge from STP	0.325	229.474	8.3:1
		cardboard (2x2) [cm]	0.114	3.911	150:1
		fresh grass matter	0.311	89.364	30:1
		total	**0.75**	**322.746**	**14.4:1**
2.		sludge from STP	0.325	229.474	8.3:1
		cardboard (10x10) [cm]	0.114	3.911	150:1
		fresh grass matter	0.311	89.364	30:1
		total	**0.75**	**322.746**	**14.,4:1**
3.		sludge from STP	0.325	229.474	8.,3:1
		cardboard (3x25) [cm]	0.114	3.911	150:1
		fresh grass matter	0.311	89.364	30:1
		total	**0.75**	**322.746**	**14.4:1**

Due to the fact that the piles had the same weight of individual components, the speed and quality of gradual decomposition of waste paper according to its original sample size could have been observed during the prosess. In the middle of the experiment, i.e. after 30 days, observations of the decomposition were carried out according to norm ČSN EN 14045. After the decomposition assesment, substrate production was accomplished under the conditions of autumn outdoor temperatures.

The temperature during decomposition was measured using electronic thermometers Testo 175 able to record measured data (Pliva et al., 2016). Upon entering the experiment, the thermometer recorders were programmed to measure hourly the temperature at the end of the probes (inside the pile), and also ambient air temperature. Thermometers were placed in the composters for the whole duration of the experiment, with the exception of compost rearrangement.

The oxygen content was measured by an electrochemical method using the Testo 327 with a penetration probe, and an electric gas pump.

For the detection of density, a method weightigh the known volume of raw materials was used. From the weighted value, the values in desired units [kg m^{-3}] were calculated. The standard scale of up to 30 kg was used for weighting as well as a vessel with calibrated volume. The procedure for determining materials' bulk density (Plíva et al., 2016) was as follows:

1) A sample of the raw material was chosen for determination of bulk density.

2) After filling the measuring vessel with a defined volume of 0.038 m^3, the container with the material was weighed, and the weight of the measuring vessel was subtracted from the detected value afterwards.

3) The weighing was carried out for a total of three samples taken from the total amount of raw material.

4) The detected density in kg m^{-3} was calculated with the following formula (1):

$$\overline{m_v} = k \cdot \frac{m_1 + m_2 + m_3}{3} \quad [\text{kg m}^{-3}] \qquad (1)$$

where: k – conversion coefficient [m^{-3}]; m_n – sample weight [kg].

When determining the humidity of raw material, a sample of about g was taken and was subsequently spread on a mat, and larger lumps were broken down. Dividing the sample reduced it to 500 g, and it passed then through a sieve having a mesh size of 5 mm. After this adjustment, 20 g of compost was collected from the original sample (accuracy of ± 0.05 g) into weighed dry containers and the sample was dried at 105 °C to a constant weight. After cooling in a desiccator, the sample was weighed and the moisture content was calculated in % (Plíva, et al., 2016).

The gravimetric moisture content was calculated using the formula (2):

$$x = \frac{m_1 .100}{m} \quad [\%] \qquad (2)$$

where: m_1 – sample weight loss by drying [g]; m – weight of the sample before drying [g].

RESULTS AND DISCUSSION

A) Production of briquettes

In the first part of the research, the density of selected materials was calculated, and it was found out that the cardboard had the highest density. It is due to a higher proportion of pulp after multiple recycling that the cardboard containes compared to other types of waste paper.

In the next part of the experiment, the production of briquettes of cylindrical shape with a diameter of 65 mm (Fig. 2) using a briquetting press was performed. The tested waste material was continuously inserted into the reservoir, and after the briquettes had been produced, the entire reservoir was cleaned before being used again for another tested material.

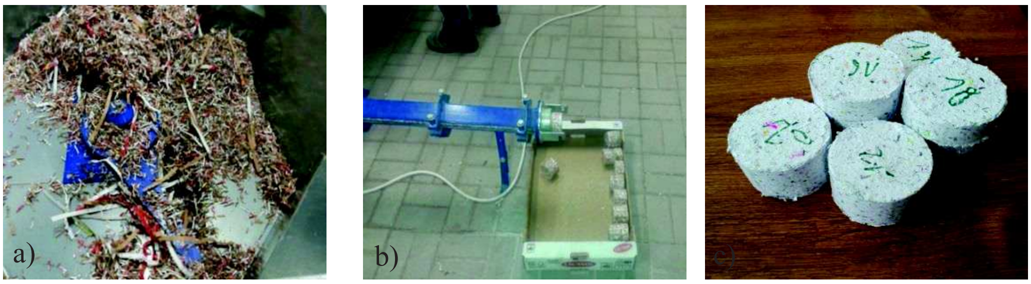


Figure 2. Briquette production process: a) a container with the material; b) conveyor of the briquettes; c) briquettes produced.

Twenty pieces of produced briquettes were tested for each measured type of the waste paper. Each briquette was measured at two spots to calculate the height and its average value. Furthermore, the volume of the briquettes was calculated, as was their weight and their bulk density. At the end, the compression ratio of the mentioned types of waste paper was calculated (Table 2).

Table 2. Calculation of compression ratio of measured types of waste paper

Input material	Bulk density of input material [kg m^{-3}]	Bulk density of briquettes [kg m^{-3}]	Compression ratio [-]
separate paper	66.322	278.343	4.20
cardboard	76.202	252.322	3.31
office paper	55.622	258.126	4.64

The briquettes were analyzed to obtain a combustion heat and heating value according to ISO 1928 (Table 3). The heating value of briquettes made of paper fell bellow the interval indicated by the manual of the briquetting machine. The cardboard briquettes demonstrated the highest heating value, probably because of the content of chemical binders.

Table 3. Chemical analysis, heating vaue and combustion heat of the briquettes

Materials	Humidity	Ash	C	H	N	S	O	Combustion heat	Heating value
	gravimetric %							MJ kg^{-1}	MJ kg^{-1}
office paper	4.13	12.628	36.175	5.107	0.060	0.041	44.146	12.941	11.821
separate paper	4.225	20.408	35.305	4.769	0.086	0.032	37.221	13.194	12.152
cardboard	4.820	11.580	39.348	5.408	0.135	0.050	41.183	14.717	13.535

The aim of the experiment where briquettes were produced by pressing three types of waste paper was to assess quality of the compression and possibility of further material use after its shredding. It is well known that there is a large amount shredded waste paper in office buildings that is according to current practice disposed of mainly together with a mixed municipal waste to a landfill. The briquettes produced can be used both in the process of energy production via combustion, and in the compost production process where they can significantly reduce the cost of transportation thanks to the compression ratio. This is going to be the subject of further reflection and experimentation. The size of manufactured briquettes is in accordance with data reporting the size of wood chip material from various wood chippers (Epstein et al., 1997), and corresponds to the commonly used sizes exploited in composting plants as mentioned by Soucek & Burg (2009).

The bulk density of the paper briquettes is up to 4 times lower than the density of briquettes made from herbaceous phytomass, and there is no problem of increased level of nitrogen that is generated by energy utilization of herbal phytomass as indicated by e.g. Theerarattananoon et al. (2011), Hutla (2012), or Zajonc & Frydrych (2012).

B) Production of substrate using wastepaper

Measurement of gradual decomposition of waste paper in the pile

The controlled microbial decomposition in composters was used as for a technology of substrate production. All the raw materials were measured for determining their humidity, weight and density. Table 4 showes the resulting values. During the composting process, important indicators, i.e. temperature and oxygen content, were monitored. Bulk density and humidity were measured also in the final compost. Input material and the resulting compost were subjected to chemical analysis in an accredited laboratory. The effectiveness of sanitation was assessed, and quality parameters were specified.

Table 4. Raw materials for the production of substrate from waste paper, and from sludge of sewage treatment plants

Material	Weight of the samples of given volume 0.038 m^{-3} [kg]				Density [kg m^{-3}]	Humidity [%]
	1	2	3	Average		
cardboard	1.22	1.19	1.50	1.30	34.30	1.60
grass	10.50	11.20	10.90	10.87	286.97	40.51
sludge (STP)	27.60	26.20	26.80	26.87	707.02	79.80

Based on the photographs (Fig. 3), it can be stated that sample No. 3 with cardbord size of 3 x 25 cm demonstrated the fastest decomposition process. It showed signs of the highest decomposition of the superficial layer, and of disintegration into three parts. The reason seems to be the largest contact area with the other compost components, and thus absorbtion of the highest amount of moisture from the surrounding environment.

Figure 3. The gradual disintegration of waste paper in the compost after 30 days of composting (from left to right samples No. 1, 2, 3).

Measurement of temperature

The temperatures in individual composters didn‘t show any abnormal differences, thus Fig. 4 presents the measured and recorded temperatures of only one of them. The curve of air temperature has large aberrances, because three daily measurements are plotted. Accordingly, the temperature fluctuates compared to the temperature in the compost piles where only one average value per day is charted. Eight digovers are crearly discernible in the graph. Due to autumn period, temperatures were relatively low.

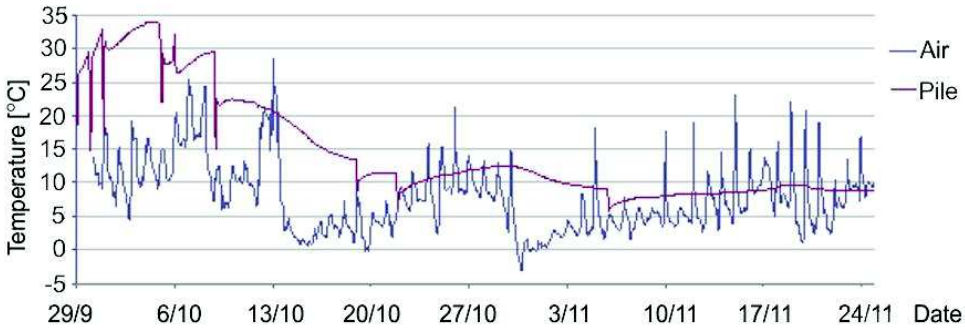


Figure 4. Graph of the temperature development in the composter in autumn 2015.

Measurement of oxygen content

Concerning oxigen content, data retrieved from the composters No. 1 to 3 are shown in an abbreviated form in Fig. 5. Eight digovers were performed. After each digover, the amount of oxygen in the compost increased.

Figure 5. Measuremens of the average oxygen content in the piles in autumn 2015.

Aerating the substrate and securing aerobic conditions are the key requirements material decomposition through composting technology. Microorganisms that transform organic matter have high demand of aerial oxygen. The technology has to enable an exchange of gasses between the maturing substrate and its environment, so that there is enough fresh air containing oxygen in the pile. Oxygen content in the aerial pores of maturing compost should reach at least 6% (Laurik et. al., 2011; Dubský & Kaplan, 2012 etc.). As the measured values plotted in Fig. 5 show, the development of the oxygen content in the piles was optimal. At the beginning of the process, it did not decrease below the threshold of 6.8%, and at the end, it continuously approached common level of aerial oxygen, i.e. 20.9%.

Evaluation of the substrate produced

The quality of the substrate produced was evaluated from the perspective of CSN 64 5735 in an accredited laboratory. Overall characteristics and heavy metal content were assessed. Basic quality characteristics of sludge input were also established. The results are shown in Table 5.

Table 5. Quality parameters of the input sludge and the resulting substrate and evaluation of concentration of hazardous elements in the input sludge and in the substrate produced

Quality parameters	Sludge	Substrate	Limits	Unit
humidity	79.80	59.89	min. 40.0; max. 65.0	[%]
combustibles in dry sample	54.72	34.5	min. 25	[%]
C*	27.36	17.3	-	[%]
N*	3.30	1.28	min. 0.60	[%]
C:N Ratio	8.29	13.5	max. 30:1	[-]
pH	-	7.47	from 6.0 to 8.5	[-]
Cd*	0.7	0.93	max. 2	mg kg^{-1}
Pb*	34	28	max. 100	mg kg^{-1}
As*	6.7	12	max. 20	mg kg^{-1}
Cr*	25	33	max. 100	mg kg^{-1}
Cu*	62	57	max. 150	mg kg^{-1}
Ni*	15	21	max. 50	mg kg^{-1}
Hg*	2.4	0.93	max. 1	mg kg^{-1}
Zn*	410	360	max. 600	mg kg^{-1}

** in dry matter*

The production of substrates of sewage sludge was already covered by a number of authors, for example by Laurik et al. (2011) and Dubský & Kaplan (2012). The effect of quality of the substrate on the growth of some crops was observed by Wilson et al. (2002); Dubský & Šrámek (2008) and Carlile (2008). In the Czech Republic, the sewage sludge is added commonly into substrates, but forms generally only 20% of their weight. Sludge contains a high level of nitrogen. Therefore in the case of its higher share in the substrates, it is necessary to adjust the C:N ratio by adding the raw material with a sufficient carbon content. The fresh grass mass doesn't affect the ratio too much. Wood chips are more suitable from this respect. According to Raclavská (2008), the ratio of dewatered sewage sludge to wood chips should amount to 60:40.

The results of the experiment, where the experimental raw mix consisting of fresh grass cuttings, sewage sludge in a high share (71% of the total compost weight), and of the addition of structural material in the form of small pieces of cardboard underwent decomposition, confirmed the ability to combine these materials and showed partly favorable results. Quality characteristics of the finished substrate resulting from the conversion of the raw materials met the requirements of the standard CSN 46 5735 'Industrial substrate'. The prescribed temperature was reached during the process, though the temperature of 55 °C required by standards for the treatment of sludge from sewage treatment plants was not. Apparently, the narrow C:N ratio achieved caused this. It did not constitute a major problem, because the experiment was focused on possibility of decomposition of waste paper mixed with high amount of sewage sludge, and further utilization of the resulting substrate was not presumed in an agricultural fielda at this stage of the experiment. The fact that the decomposition was attained even at the lower temperatures and that the temperature of the processed material increased after each digover can be assessed as positive. Chemical risk assessment of the elements contained in the compost showed below-threshold concentrations of tracked elements (Table 5).

CONCLUSIONS

Concerning the experiment of briquette production, the cardboard waste that had undergone several recycling processes attained the lowest compression ratio, and thus pressing had the lowest effect. The highest compression ratio and therefore the highest pressing efficiency were achieved with the paper of higher quality, i.e. the paper from primary production, or once only recycled at most, which when shredded, disintegrated into smaller particles compared to shredded cardboard. Properties of the briquettes with the lower compression ratio can be exploited for example in the mentioned composting technology where it can lead to a faster decomposition of the briquettes used. The briquettes can serve as a substitute material in order to adjust the C:N ratio and moisture during composting as was reported by Souček & Burg (2009) and Plíva et al. (2016).

The results of the experiment, where the experimental raw mix consisting of fresh grass cuttings, sewage sludge in a high share (71% of the total compost weight), and of the addition of structural material in the form of small pieces of cardboard were processed, confirmed the ability to combine these materials. The tested paper waste could substitute wood chips. It demonstrates a sufficiently high percentage of carbon. If prepared at a high quality with regard to the desired particle size, it can serve also as a structural material. In the basis of the experimental substrates, only a small amount of cardboard was used (about 1.5% of the total substrate weight). Starting moisture also did not reach optimal values. Smaller water content and a more appropriate ratio of carbon to nitrogen substances would have most likely ensure better results of the process of substrate production. It is possible to continue the experiment in this area with testing higher mass loads of waste paper even with the presumption that the higher amount of waste paper will form a problem when attaining the desired substrate moisture. But this can be modified during the composting process more easily than in the case of excessive moisture.

Based on the previous, the further research is going to be focused on an analysis of physical properties of substrate made from waste paper in relation to the higher ability to retain water in the soil. This could help e.g. during intensive precipitation, and in general to protect soil against erosion.

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