INTERNATIONAL
Agrophysics
www.international-agrophysics.org

Int. Agrophys., *2012, 26, 279-284*
doi: 10.2478/v10247-012-0040-8

Pelletization process of postproduction plant waste*

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Received March 2, 2011; accepted May 6, 2011

A b s t r a c t. The results of investigations on the influence of material, process, and construction parameters on the densification process and density of pellets received from different mixtures of tobacco and fine-grained waste of lemon balm are presented. The conducted research makes it possible to conclude that postproduction waste *eg* tobacco and lemon balm wastes can be successfully pelletized and used as an ecological, solid fuels.

K e y w o r d s: pelletization, waste, tobacco, lemon balm, pressure densification

INTRODUCTION

The food, grain, and herbal industries as well as other types of industries which process plant materials, generate huge amounts of post-production waste *eg* buckwheat hulls obtained during the production process of groats in grain processing plants, rapeseed pomace obtained in rapeseed oil production, or potato pulp left over after producing potato starch. These types of waste are not utilized to a great extent and they are a serious problem.

One type of industrial waste of plant origin, classified as noxious waste, is tobacco waste which is obtained at different stages of tobacco and cigarette production. The waste is most often used as fertilizers (Piotrowska-Cyplik, 2008), a component in manufacturing light construction concrete (Öztürk and Bayraklı, 2005) or it is densified (Obidziński, 2011).

Another type of post-production waste generated during sorting and packaging herbs is lemon balm fine-grained waste. This waste is usually sold by the company for small sums or even given away for the price of transport (Obidziński, 2010). The most common method of managing herbal waste is using it as fodder additives (Hańczakowska, 2007; Paschma, 2004). Besides that, herbal waste is also used to a small extent in the confectionery industry, and as gardening mulch (Hańczakowska, 2007).

The last few years have observed a significant growth and development of applying biomass waste for energy purposes in the form liquid fuel as a form of their utilization *ie* frying rape oil as fuel biocomponent (Szmigielski *et al*., 2008) or using fruit and kernel of *Thevetia peruviana* as a potential biofuel plant (Sahoo *et al*., 2009) or biomass waste as a substrate for biogas production (Prochonow *et al*., 2009).

One of the methods of converting biomass (including waste biomass) into energy is producing solid fuels in the form of pellets or briquettes through pressure agglomeration. It has been confirmed by numerous examples of experimental research carried out by many scientific centres on densification of energetic plants like barley straw (Serrano *et al*., 2011), corn stover and switchgrass (Mani *et al*., 2006a,b), reed canary grass (Larsson *et al*., 2008), wheat straw and grass (Gilbert *et al*., 2009), willow and virginia mallow biomass (Stolarski *et al*., 2005), poplar wood (Shaw, 2008), wood residues of neem (Sotannde *et al*., 2010).

Pellets are also produced form waste materials from the agricultural-food industry like palm oil biomass (Nasrin *et al*., 2008), rice straw and rice bran (Chou *et al*., 2009a, b), grape pomace (Miranda *et al*., 2009), palm kernel cake (Razuan *et al*., 2011), timothy hay (Ghazanfari *et al*., 2007) extracted rape meal (Laskowski and Skonecki, 2006) and other biomass waste (Kaliyan and Morey, 2009; Skonecki and Potręć, 2010), or mixing of different types of waste products of plant origin with other additives (also of plant origin) which constitute natural adhesives (for example different

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*The work was financed from the budget for science in Poland, project N N504 488239 (G/WM/4), 2010.

mixtures of vine shoots and cork (Mediavilla *et al.*, 2009)). Other example of using post-production waste formed in different food processing industries is an attempt to manage such waste as pellets from grain waste *ie* off-quality grain combined with oak sawdust and waste generated in the process of producing apple juice (Stolarski, 2006).

Attempts were also made at applying biomass for energy purposes in which fuels were used in the form of pellets made of waste biomass mixed with *eg* coal (Poskrobko *et al.*, 2010) or with non-biomass additives of *eg* plastics (Wandrasz and Wandrasz, 2006) too high concentration of which in the newly created fuel is undesirable due to unfavourable effects of burning this fuel. Tobacco is an example of waste which are not utilized to a great extent and they often constitute a serious problem to particular processing plants. Densification of postproduction waste like tobacco and lemon balm waste to form a densified, homogeneous and durable product (pellets), which is under the main scope of this work, is of great importance because it allows to utilization, simplify handling, transport and storage of this type of waste. Another advantage of tobacco and lemon balm waste densification can also be an effective solution and can reduce material waste and will allow its better implementation.

The aim of the present paper is to analyze the usability of mixture of tobacco waste and fine-grained lemon balm post-production waste as a densified, ecological solid fuel (pellets).

MATERIALS AND RESEARCH METHODS

Tobacco waste generated in the process of producing cigarettes in the British-American Tobacco Factory, Augustów, Poland, and fine-grained lemon balm post-production waste generated at sorting and packaging of this herb in the Herbapol S.A., Białystok, Poland, was used.

In the tobacco waste, fractions of 0.5 mm were dominant (62% of the total mass), fraction with particle sizes of 1 mm was 16%, and the fraction of 0.25 mm – 16%. Lemon balm waste is a material of low bulk density which does not exceed 300 kg m^{-3}. The particles of size of 0.125 mm (42.28% of the mass content) and particles of size of 0.25 mm (34.65%) were dominant fractions. The humidity of both materials was 12%. Durring the research, of fine-grained lemon balm post-production waste at concentrations of 10, 20, and 30%, respectively, were introduced into the tobacco waste.

The tests were carried out on an SS-3 test stand (Obidziński, 2010) which was partly modernized by using the heating band joint with the temperature regulator. This allows for regulating the temperature of the process (even above 100°C), which simplifies the construction of stand and accelerates the (conducting of) investigations considerably.

The research on the densification process consisted of three stages:

– preparing the raw material before pelletization (refining the tobacco waste from filters and cigarette paper, wetting the waste in order to reach the pre-set humidity, preparing samples of the defined content of lemon balm waste and specified masses, heating the matrix and the samples up to the pre-set temperature);
– densification (pelletization) of the prepared material samples (20 samples for each position of the adopted plan of the experiment) in the open chamber (of 9 mm in diameter), and recording the results;
– determining the density of the obtained pellets (after the pellets had left the chamber, the density of the obtained pellets was established through measuring the heights and diameters of fifteen granules exact to ±0.02 mm, using slide callipers, and through determining their mass with laboratory scales exact to ±0.001 g. The density of the agglomerate was calculated as the ratio of the mass of the granules to the total sum of their volumes).

Tests on granulating the waste under research were performed on an SS-3 test stand according to the Hartley PS/DS-P experiment plan. The choice of this experiment plan resulted from the need to reduce the cost of research and time for its implementation. A three-level Hartley PS/DS-P experiment plan with four variables offers relatively high accuracy of prediction despite the limited number of the required experiments and it allows to conduct estimates of the uncorrelated main effects and two-factor interactions.

The experiment plan matrix (Table 1) with N-17 plan positions had been generated with the STATISTICA 9.0 application.

The input quantities were the material, process, and construction parameters of the tool-in-use system, whose values were determined on the basis of the performed initial tests:

- $x_1 = z_m$ – lemon balm waste contents (10, 20, and 30%),
- $x_2 = t_w$ – temperatures of the waste and the tool-in-use system (40, 60, and 80°C),
- $x_3 = l_m$ – lengths of the matrix holes (37, 42, and 47 mm),
- $x_4 = m_p$ – mass of densified portions (0.3, 0.6 and 0.9 g).

Before the densification process started (before the measurements were taken), the densification chamber had been heated up to the desired temperature appropriately earlier. During the tests, 20 samples were densified for each position of the adopted plan of the experiment, and the particular densifying pressures obtained in the granulation process were recorded. The density of pellets and maximum densifying pressures were determined as mean values on the basis of 20 tests for each position of the adopted experiment plan.

RESULTS AND DISCUSSION

The received results of investigations according to the Hartley PS/DS-P: Ha4 plan of the experiment were introduced in (Table 1).

Table 1. The matrix of the Hartley PS/DS-P: Ha4: experiment plan with the adopted real values of the studied parameters and the received results of investigations

No.	z_m (%)	t_w (°C)	l_m (mm)	m_p (g)	Max. densifying pressures (MPa)	Density of pellets (kg m^{-3})
1	30	40	37	0.3	2.06	659.34
2	10	80	37	0.3	1.62	650.47
3	10	40	47	0.3	0.81	634.12
4	30	80	47	0.3	11.23	1 293.81
5	30	40	37	0.9	1.62	737.77
6	10	80	37	0.9	11.64	1 097.04
7	10	40	47	0.9	11.36	916.50
8	30	80	47	0.9	23.37	1 317.57
9	10	60	42	0.6	1.70	734.96
10	30	60	42	0.6	1.14	768.13
11	20	40	42	0.6	3.93	982.43
12	20	80	42	0.6	13.11	1 260.51
13	20	60	37	0.6	0.90	967.77
14	20	60	47	0.6	22.14	1 270.19
15	20	60	42	0.3	0.47	660.31
16	20	60	42	0.9	8.41	1 052.13
17	20	60	42	0.6	0.85	733.64

On the basis of the performed experiments it was concluded that both increasing the mass of the sample of the densified mixture from 0.3 to 0.9 g, and increasing the content of lemon balm waste in the densified mixture from 10 to 30% led to a large increase in the densifying pressures (Fig. 1a).

This increase in the densifying pressures when the mass of the sample increases is caused by increasing the amount of mixture undergoing the densification process in the open chamber, which influences an increase in friction resistance occurring between the densified mixture and the chamber walls.

The observed increase in the densification pressures alongside with increasing the content of lemon balm waste in the densified mixture was in turn caused by a significant increase in the amount of the fine-grained fraction in the mixture (the mean size of the lemon balm particles was much smaller than that in the tobacco waste), which affects a significant increase in energy expenditures required for densifying such a mixture in connection with an increase of the specific surface of contact between particles of such a mixture with the area of the wall of the matrix hole, and hence leads to an increase in the densification pressures.

According to the obtained test results, raising the process temperature (the temperature of the densified waste and that of the working chamber) from 40 to 80°C, and increasing the lengths of the matrix holes from 37 to 47 mm, result in increased maximum densification pressures obtained during the process of densifying the mixture of tobacco and lemon balm waste.

The increase of the pressures along with increasing the temperature (Table 1, Fig. 1b) was caused by adhesion of the densified material to the chamber walls during the densification process, which in turn led to increasing resistances

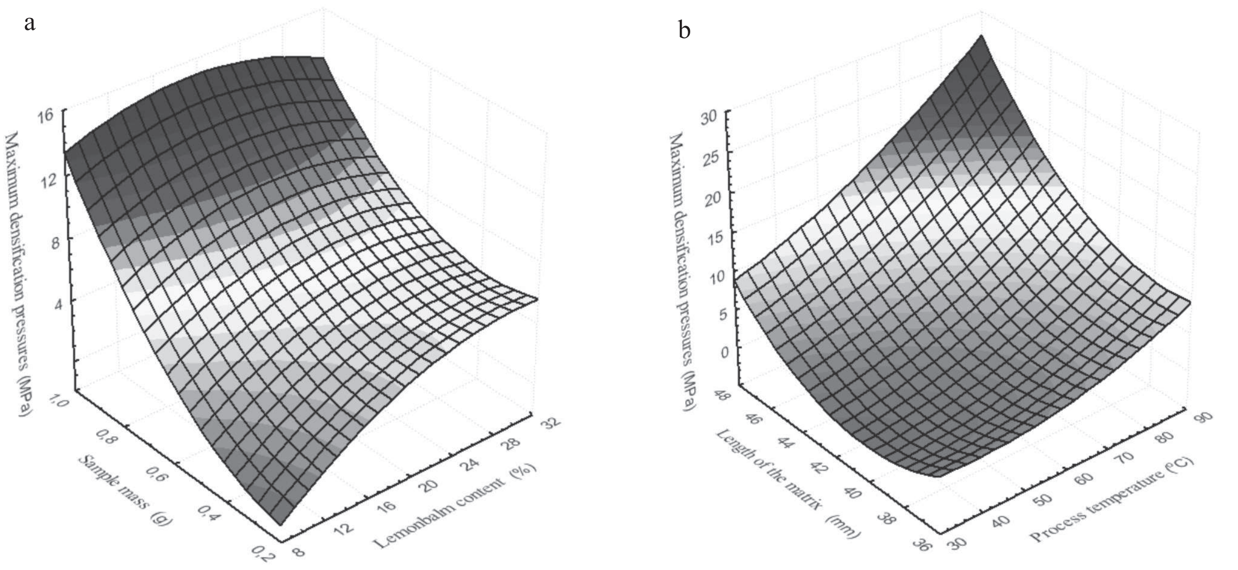

Fig. 1. The influence of material, process, and construction parameters on the value of maximum densification pressures in the densification process of lemon balm and tobacco waste mixture in the open chamber: a – the influence of lemon balm content and the sample mass of waste: ■> 14 MPa, ■< 10 MPa, ■ < 6 MPa, ■ < 2 MPa, b – the influence of the process temperature and the length of the matrix: ■> 24 MPa ■< 12 MPa, ■< 0 MPa.

of forcing through the material and at the same time to increasing the values of the densification pressures. It was particularly apparent at the temperatures of 60 and 80°C. The increase in the maximum densification pressures along with increasing the matrix length results from increasing the surface of friction between the particles of the densified mixture and the chamber walls. This influences a significant growth of the resistance to friction between the mixture particles and the surface of the densification chamber and thus an increase in the densification pressures.

As a result of the research described above, it was also observed that both increasing the mass of the sample of the densified mixture from 0.3 g to 0.9 g, as well as increasing the content of lemon balm waste in the densified mixture from 10 to 30%, resulted in an increase in the density of the obtained pellets (Fig. 2a).

The growth in the density of the obtained pellets along with the increased lemon balm content is caused by increasing the degree of densification *ie* packing of particles in the densified mixture due to increasing the content of fine-grained particles in the mixture along with increasing the content of fine-grained lemon balm waste, whereas the increase in the density of the produced pellets along with the increase of the mass of the sample undergoing the densification process is connected with higher and higher resistances of forcing through the densified mixture when the mass of the densified sample gets bigger. The resistances occur as a result of increasing the surface of friction between the densified mixture and the walls of the matrix holes, which raises the values of the densification pressures, and this in turn results in increasing the density of the produced pellets.

The obtained results indicate that both raising the process temperature from 40 to 80°C, and increasing the length of the matrix holes from 37 to 47 mm led to increasing the density of the produced pellets.

The growth of density along with rising temperature (Fig. 2b) was caused by the increased influence of the rising temperature on the densified material and by forming increasingly stable bonds in the produced pellets. The increase in the pellet density along with increasing the matrix length results from a significant increase of the densifying pressures which occurs when the matrix length grows bigger, which is caused by the increased resistance of friction between the densified mixture and the matrix surface.

Adding lemon balm waste to tobacco waste results in an insignificant increase in the maximum densification pressures when compared to the process of densifying tobacco waste exclusively. The maximum densification pressures – 23.37 MPa (occurring at z_m = 30%, t_w = 80°C, l_m = 47 mm and m_p = 0.9 g), obtained during the process of densifying tobacco and lemon balm waste.

The conducted preliminary research into the densification process of the tobacco and lemon balm waste alone (for the same conditions: t_w = 80°C, l_m = 47 mm, and m_p = 0.9 g), shows that the maximum densification pressures are much lower than those occurring when pure lemon balm waste was densified (up to approx. 80 MPa) and they are slightly lower than the pressures occurring when densifying tobacco waste exclusively – 22.79 MPa.

The results show that adding lemon balm waste to tobacco waste results in a significant decrease in the maximum densification pressures when compared to the process of densifying lemon balm waste exclusively.

The conducted research makes it possible to conclude that postproduction waste *eg* tobacco and lemon balm waste can be successfully granulated (pelletized) and might constitute full-value fuel because of its properties (high pellets density (durability), *ie* its elemental composition and energetic properties (Obidziński, 2010; Poskrobko *et al.*, 2010),

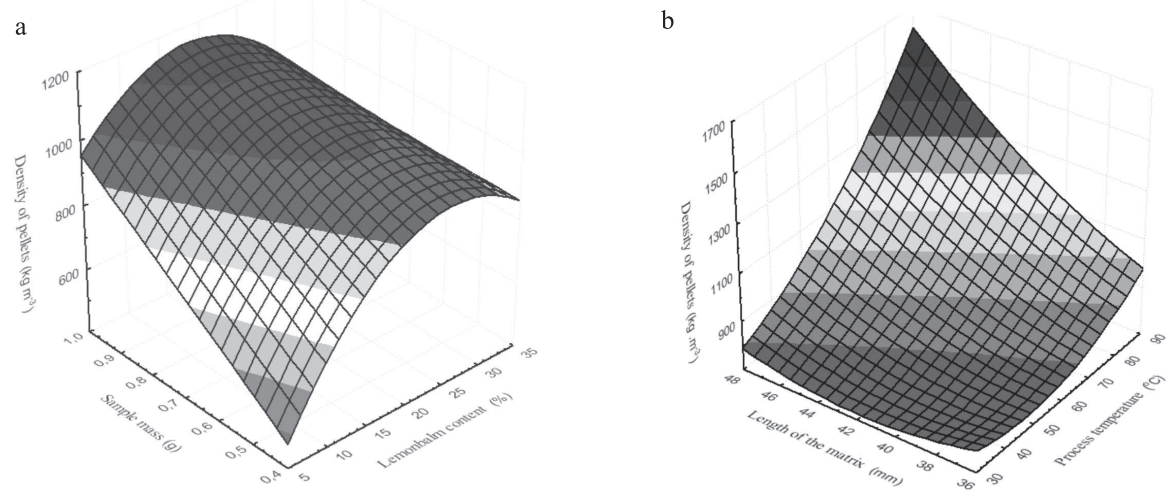

Fig. 2. The influence of material, process, and construction parameters on density of pellets received in the densification process of lemon balm and tobacco waste mixture in the open chamber: a – the influence of lemon balm content and the sample mass of the waste: ■ <1060 $kg\ m^{-3}$, ■<860 $kg\ m^{-3}$, ■<660 $kg\ m^{-3}$, ■<460 $kg\ m^{-3}$, b – the influence of the process temperature and the length of the matrix: ■> 1540 $kg\ m^{-3}$, ■<1140 $kg\ m^{3}$, ■<740 $kg\ m^{-3}$.

Fig. 3. View of pellets from the mixture of tobacco and lemon balm waste received for parameters of point 8 of the experiment plan (z_m = 30 %, t_w = 80°C, l_m = 47 mm and m_p = 0.9 g).

as it is the case with pelletized wood waste, straw, waste generated in the grain and grain-milling industries (Stolarski, 2006), or waste produced during processing oil plants: rapeseed pomace, sunflower husk or peanut shells (Wandrasz, 2007), utilized as components for producing pellets.

Figure 3 presents a view of pellets from the mixture of tobacco and lemon balm waste received for parameters of point 8 of the experiment plan.

CONCLUSIONS

1. A mixture of tobacco and lemon balm waste is easily susceptible to the pelletization process.

2. The matrix length and the temperature of the process are the parameters which most significantly influence the values of densifying pressures and density of the pellets produced from the tested mixture of tobacco and lemon balm waste.

3.The raising of the process temperature from 40 to 80°C and the lengths of the matrix holes from 37 to 47 mm, result in increased maximum densification pressures.

4. The increasing the mass of the sample of the densified mixture from 0.3 g to 0.9 g, and increasing the content of lemon balm waste in the densified mixture from 10 to 30% result in increased maximum densification pressures.

5. The raising of the process temperature from 40 to 80°C and the lengths of the matrix holes from 37 to 47 mm, result in increased density of the pellets.

6. The increase in the mass of the sample of the densified mixture from 0.3 g to 0.9 g, as well as the increase in the content of lemon balm waste in the densified mixture from 10 to 30%, resulted in the increase in the density of the pellets.

7. The mixture of tobacco and lemon balm waste can be successfully pelletized and might constitute full-value fuel because of its high mechanical properties – high density of the pellets (durability).

REFERENCES

Chou C.S., Lin S.H., Peng C.C., and Lu W.C., 2009a. The optimum conditions for preparing solid fuel briquette of rice straw by a piston-mold process using the Taguchi method. Fuel Proc. Technol., 90, 1041-1046.

Chou C.S., Sheau-Horng Lin S.H., and Wen-Chung Lu W.C., 2009b. Preparation and characterization of solid biomass fuel made from rice straw and rice bran. Fuel Proc. Technol., 90, 980-987.

Ghazanfari A., Opoku L., and Tabil L.G., 2007. A study on densification of timothy hay at different moisture content. Asian J. Plants Sci., 6(4), 704-707.

Gilbert P., Ryu C., Sharifi V., and Swithenbank J., 2009. Effect of process parameters on pelletisation of herbaceous crops. Fuel, 88, 1491-1497.

Hańczakowska E., 2007. Herbs and herb preparations in pig feeding (in Polish). Wiadomości Zootechniczne, 45(3), 19-23.

Kaliyan N. and Morey R.V., 2009. Factors affecting strength and durability of densified biomass products. Biomass Bioenergy, 33, 337-359.

Larsson S.H., Thyrel M., Geladi P., and Lestander T.A., 2008. High quality biofuel pellet production from pre-compacted low density raw materials. Bioresour. Technol., 99, 7176-7182.

Laskowski J. and Skonecki S., 2006. Impact of chamber diameter and sample weight on densification of extracted rape meal (in Polish). Inżynieria Rolnicza, 6, 15-23.

Mani S., Lope G., Tabil L.G., and Sokhansanj S., 2006a. Effects of compressive force, particle size and moisture content on mechanical properties of biomass pellets from grasses. Biomass Bioenergy, 30, 648-654.

Mani S., Tabil L.G., and Sokhansanj S., 2006b. Specific energy requirement for compacting corn stover. Bioresour. Technol., 97, 1420-1426.

Mediavilla I., Fernández M.J., and Esteban L.S., 2009. Optimization of pelletisation and combustion in a boiler of 17.5 kWth for vine shoots and industrial cork residue. Fuel Process. Technol., 90, 621-628.

Miranda M.T., Arranz J.I., Rojas S., and Montero I., 2009. Energetic characterization of densified residues from Pyrenean oak forest. Fuel, 88, 2106-2112.

Nasrin A.B., Ma A.N., Mohamad S., Rohaya M.H., Azali A., and Zainal Z., 2008. Oil palm biomass as potential substitution raw materials for commercial biomass briquettes production. Am. J. Appl. Sci., 5, 179-183.

Obidziński S., 2010. Estimate of energy properties of lemon balm (in Polish). Zesz. Probl. Post. Nauk Roln., 546, 253-262.

Obidziński S., 2011. The investigation of the process of densification tobacco wastes (in Polish). Inżynieria - Aparatura Chem., 1, 50(42), 29-30.

Öztürk T. and Bayraklı M., 2005. The possibilities of using tobacco wastes in producing lightweight concrete. Agric. Eng. Int.: the CIGR Ejournal, VII, BC 05 006.

Paschma J., 2004. Effect of using herbs in diets of periparturient sows on the course of parturition and reproductive performance. Ann. Anim. Sci., 1, 293-295.

Piotrowska-Cyplik A., Cyplik P., Białas W.Z., and Czarnecki Z., 2008. Influence of composting technology of tobacco industry solid wastes on selected physico-chemical and enzymatic parameters (in Polish). Acta Agrophysica, 162, 487-498.

Poskrobko S., Łach J., and Król D., 2010. Investigation of the calorific proprieties of chosen industrial wastes and fuels formed from wastes (in Polish). Energetyka Ekologia, www.energetyka.eu.

Prochnow A., Heiermann M., Plöchl M., Linke B., Idler C., Amon T., and Hobbs P., 2009. Bioenergy from permanent grassland. Bioresour. Technol., 100, 4931-4944.

Razuan R., Finney K.N., Chen Q., Sharifi V.N., and Swithenbank J., 2011. Pelletised fuel production from palm kernel cake. Fuel Proc. Technol., 92, 609-615.

Sahoo N.K., Pradhan S., Pradhan R.C., and Naik S.N., 2009. Physical properties of fruit and kernel of *Thevetia peruviana*: a potential biofuel plant. Int. Agrophysics, 23, 199-204.

Serrano C., Monedero E., Lapuerta M., and Portero H., 2011. Effect of moisture content, particle size and pine addition on quality parameters of barley straw pellets. Fuel Proc. Technol., 92, 699-706.

Shaw M., 2008. Feedstock and process variables influencing biomass densification. Ph.D. Thesis, Dept. Agric. Bioresour. Eng., University of Saskatchewan, Saskatoon, Canada.

Skonecki S. and Potręć M., 2010. The influence of moisture content on compression process of plant biomass (in Polish). Zesz. Probl. Post. Nauk Roln., 546, 341-346.

Sotannde O.A., Oluyege A.O., and Abah G.B., 2010. Physical and combustion properties of charcoal briquettes from neem wood residues. Int. Agrophys., 24, 189-194.

Stolarski M., 2006. Utilization of the biomass to the pellet production (in Polish). Czysta Energia, 55, 28.

Stolarski M., Szczukowski S., Tworkowski J., Kwiatkowski J., and Grzelczyk M., 2005. Characteristic of chips and pellets from coppice willow and virginia mallow biomass as a fuel (in Polish). Problemy Inżynierii Rolniczej, 1(47), 13-22.

Szmigielski M., Maniak B., and Piekarski W., 2008. Evaluation of chosen quality parameters of used frying rape oil as fuel biocomponent. Int. Agrophysics, 22, 361-364.

Wandrasz J.W., 2007. Utilization of flammable organic substances in forming chosen fuels (in Polish). Przegląd Komunalny, 192, 69-70.

Wandrasz J.W. and Wandrasz A., 2006. Formed Fuels (in Polish). Seidel-Przywecki Press, Warsaw, Poland.