CHEMICAL ENGINEERING TRANSACTIONS

VOL. 42, 2014

A publication of AIDIC
The Italian Association of Chemical Engineering
www.aidic.it/cet

Guest Editors: Petar Sabev Varbanov, Neven Duić

ISBN 978-88-95608-33-4; **ISSN** 2283-9216

DOI:10.3303/CET1442012

Briquettes from Mixtures of Herbaceous Biomass and Wood: Biofuel Investigation and Combustion Tests

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The background idea of the current research lies directly in the evaluation of combustion performance and its association to the analysis of the quality of different types of herbaceous-based briquettes mixed with wood. In total, 25 briquette samples were prepared using different proportions of herbaceous and woody biomass. Draff, buckwheat hulls, straw, rapeseed by-product from biofuel production, oats, and common reed were used. Briquettes fully produced from wood were used as a benchmark.
A laboratory analysis was completed to determine the following parameters of the samples: moisture and ash content, calorific value, ash melting temperature, content of carbon, hydrogen, nitrogen, and sulphur. The combustion tests were executed using a heating stove for all samples. The results show that some types of non-wood biomass have a positive effect on briquette production and the combustion processes.

1. Introduction

In fact, Latvia has an important agricultural sector connected to different final end uses of the agricultural biomass produced. Biomass residues from industrial processes are not frequently used within the perspective of energy production for different reasons. Some of these weaknesses could represent an opportunity for the usage of biomass residues for briquettes production, in order to provide a higher energy value per unit of mass and to overpass the drawbacks connected to transportation, handling, treatment, and storage (Zhang J. et al., 2014). This evidence is also reflected within the increase of the trend of the production of briquettes from agricultural and forestry leftover during recent years (Heinimo et al., 2009). The production costs of different briquette types can strongly vary (Stolarskia et al., 2013).
Nowadays, different methods to produce briquettes exist with an important role within its final physical and mechanical properties (Chou et al., 2009). It is also noticeable that the quality of the briquettes produced from agricultural biomass can be improved by adding another biomass product (Yaman et al., 2001). Chemical and physical parameters of briquettes have an important influence on the behaviour of the combustion process (Roy and Corscadden, 2012). The ash content in different agricultural fuels can strongly vary, and have a strong effect on the combustion process. Driving attention to the economic aspects, one of the non-wood briquette advantages is the price of raw materials and production costs.
Some agricultural briquettes can be successfully used for private home heating with results similar to briquettes produced from wood (Sellin et al., 2013). The content of nitrogen in the fuel has a strong correlation with NOx emissions in flue gas (Koyuncu et al., 2007). If the briquettes is too dry, the combustion process can happen very quickly, reducing the retention time for the chemical reactions and heat exchange (Yuntenwi et al., 2008). The fuel combustion time decreases when an increase of draught and air flow occurs (Yang et al., 2004). To get more complete combustion, and a lower amount of CO emissions, a pre-treatment of the biomass can be completed (Barmina et al., 2012).
Hence, the goal of this study is to investigate the effects of a partial or full substitution of woody biomass with herbaceous biomass for briquette preparation. In connection to the proposed goal, the scientific novelty lies in the significant and important extension within the understanding of risks and potential gains in use of non-woody biomass in the multidisciplinary local Latvian context.

Please cite this article as: Žandeckis A., Romagnoli F., Beloborodko A., Kirsanovs V., Blumberga D., Menind A., Hovi M., 2014, Briquettes from mixtures of herbaceous biomass and wood: biofuel investigation and combustion tests, Chemical Engineering Transactions, 42, 67-72 DOI:10.3303/CET1442012

2. Materials and methods

A total number of 6 herbaceous types of biomass were used for the experiments. Pure woody biomass was used to make mixtures with other types of biomass, and as a benchmarking threshold in the analysis of the results. Briquette samples were prepared using varying proportions of herbaceous and woody biomass (100:0, 75:25, 50:50 and 25:75). The original sources of the biomass and designation used to describe the biomass mixtures are given in Table 1. In this article, the numbers after the designations (e.g. DR75) describe the mass percentage of non-woody biomass in the mixture. The ultimate and proximate analysis of the biomass samples is performed in the Environmental Monitoring Laboratory of Riga Technical University.

Table 1: Description of the biomass used (moisture content and price are related to the source site)

Biomass	Designation	Source	Moisture, %	Price, EUR t^{-1}
Draff	DR	Residue after fermentation, beer production	86.7	n/k
Common reed	CR	Pure material, wetlands	15.2	32 - 38
Middlings	OWM	By-product from sieving of oats and wheat	12.1	n/k
Straw	ST	By-product from grain cultivation	16.3	28 - 35
Buckwheat hulls	BH	By-product from production of buckwheat	14.4	n/k
Rapeseeds	RB	By-product from biofuel production	8.46	200 - 270
Wood	WO	Saw dust from sawmilling process	43.3	20 - 40

Draff is typically given or sold to farm enterprises, is sometimes land filled. High moisture content in unprocessed draff. Middlings are typically given or sold to farm enterprises, sometimes used in biogas production or directly combusted. High quality buckwheat hulls are expensive and used as filling material for pillows, mattresses, and toys. Only low quality hulls are useful for energy production. Rapeseed cake has a high nutritional value and is commonly used for animal feed. Because of its high price, it could be used in low amounts as a compressing additive. The briquetting operations, and the energy consumption measurements for processing, were performed in the Biofuel Laboratory at the Estonian University of Life Sciences using the briquetting press Weima C-150. The applied compressive force to the sample in a 50 mm press chamber was approximately 20 t. Combustion tests were performed using the stove Skladova Tehnika Torino K according to the standard methodology (LVS EN 13240, 2002). For every test, 2 kg of biomass fuel was used. All biomass samples were burned using the same strategy for air supply. Thermal performance of the stove was determined according to the standard methodology (LVS EN 13240, 2002).

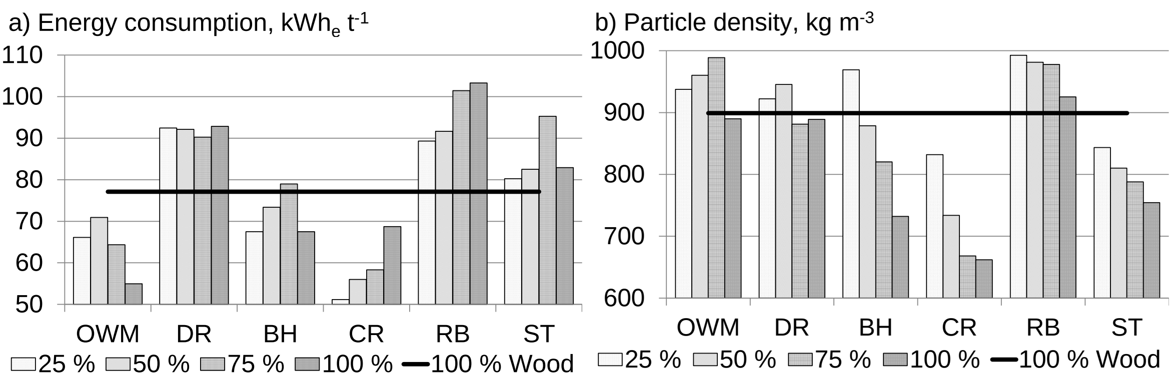

Figure 1. Indicators in the briquetting process: a – energy consumption, b – particle density

3. Results

The measured energy consumption of the briquetting process for the studied cases varied in the range of 51.1 - 101.1 kWh t-1 (see Figure 1.a.). Similar results are reported in a study by (Menind et al., 2012 a). The particle density of the produced briquettes is described in Figure 1.b. All the samples of pure grainy materials do not suit the production of high quality briquettes. For mixtures with a sawdust ratio of 50 % or higher, it was possible to press all the materials into solid and well-shaped briquettes. In order to guarantee the quality and mechanical durability of briquettes, it is recommended to use additional binding materials (LVS EN 14961-1, 2010). In this specific case, straw, hay or some other material rich in lignin may be used instead of sawdust (Menind et al., 2012 b).

3.1 Quality parameters of the briquettes

The results of proximate and ultimate biofuel analysis are presented in Table 2. Numbers represent the average value from a repetitive analysis of samples taken before the combustion tests.

Table 2: The characteristics of the tested samples of briquettes

	A_d, w-%,d	M_{ar}*, w-%	$Q_{gr.V.d}$, MJ/kg	$Q_{net.P\cdot ar}$, MJ/kg	C, w-%,d	H, w-%,d	N, w-%,d	S, w-%,d	T_a, °C
DR25	1.66	7.09	20.8	17.7	48.30	7.13	1.08	0.02	1,510
DR50	2.65	7.50	20.7	17.5	48.52	7.37	2.40	0.03	>1,520
DR75	4.01	7.49	20.8	17.6	46.69	7.39	3.12	0.04	>1,530
DR100	4.91	7.82	21.0	17.7	46.29	7.26	4.05	0.05	>1,530
CR25	1.61	6.70	20.2	17.4	47.59	6.10	0.18	0.01	1,370
CR50	2.93	6.84	19.6	16.9	46.47	6.21	0.29	0.03	>1,530
CR75	3.93	6.61	19.1	16.4	44.92	5.95	0.37	0.03	>1,520
CR100	4.89	6.65	18.8	16.2	44.53	5.84	0.38	0.04	>1,530
OWM25	1.30	7.50	20.2	16.9	47.38	7.90	0.61	0.06	1,200
OWM50	1.97	7.95	19.7	16.4	45.97	7.91	1.31	0.08	1,300
OWM75	2.87	8.42	19.4	16.0	45.21	7.96	1.68	0.09	1,360
OWM100	3.61	8.66	19.0	15.6	43.58	7.52	1.84	0.09	1,400
ST25	1.51	6.95	20.2	17.2	46.60	7.03	0.21	0.05	1,090
ST50	2.54	7.06	19.8	16.8	46.85	6.76	0.39	0.08	1,130
ST75	3.69	7.33	19.2	16.2	45.33	6.92	0.42	0.09	1,180
ST7100	4.72	6.97	18.9	16.2	45.08	5.77	0.42	0.10	1,200
BH25	1.23	7.10	20.3	17.3	48.09	7.16	0.28	0.03	1,200
BH50	1.50	7.75	20.0	16.9	46.84	6.81	0.42	0.04	1,490
BH75	1.92	8.01	20.0	16.9	47.74	6.33	0.61	0.03	1,480
BH100	2.19	12.37	19.8	15.9	47.20	6.15	0.65	0.08	1,480
RB25	3.95	6.93	21.0	17.9	48.29	7.35	1.06	0.03	1,220
RB50	6.57	7.10	21.0	17.9	48.24	7.28	1.73	0.04	1,260
RB75	8.71	7.30	21.1	17.9	48.64	7.44	2.46	0.05	1,220
RB100	11.3	7.52	21.3	17.9	48.02	8.00	3.05	0.06	1,230
WO100	0.82	6.39	20.7	17.8	50.19	6.98	0.14	0.01	1,310

In the case of a non-standard deviation, additional analyses were applied. Variations between the results of the final analysis are seen due to the low mass of the sample (10 mg), an inhomogeneity of the sample (owing to the mixture of materials with different physical properties). Such variations are not typical for non-mixture samples. For samples where one material has significantly higher ash melting temperature, the overall melting temperature strongly depends on the proportions of each biomass. A rapid change of form is seen after reaching the critical temperature for both of the materials. The results are rounded to the nearest 10 °C according to the standard methodology (LVS CEN/TS 15370-1, 2007).

The moisture content for all the samples varied from 6.39 w-% to 12.4 w-%. The non-woody biomass used for the experiments has a much higher ash content in comparison to the wood sawdust. The gross calorific value is fully dependent on the amount of combustible elements in the solid fuel. Typically, wood presents a higher gross calorific value than herbaceous biomass. Briquettes from draff, rapeseeds and oat, and wheat middling show a higher nitrogen content than other samples. Some of the analysed biomass has a high ash melting temperature. In fact, a low melting temperature of ash can cause significant problems in terms of both the reduction of efficiency, and damages to the technical aspects of the combustion unit.

3.2 Combustion experiments

The main results related to the thermal performances of the studied combustion tests are presented in Figure 2. The combustion of wood briquettes has a very fast ignition, and an intense combustion in the first stage of the test. However, adding herbaceous biomass allows for the stabilisation and extension of the combustion process. The concentration of free oxygen in flue gas shows a strong correlation with the duration of the combustion tests. An intense combustion results in a lack of free oxygen within the combustion chamber and a higher flue gas temperature

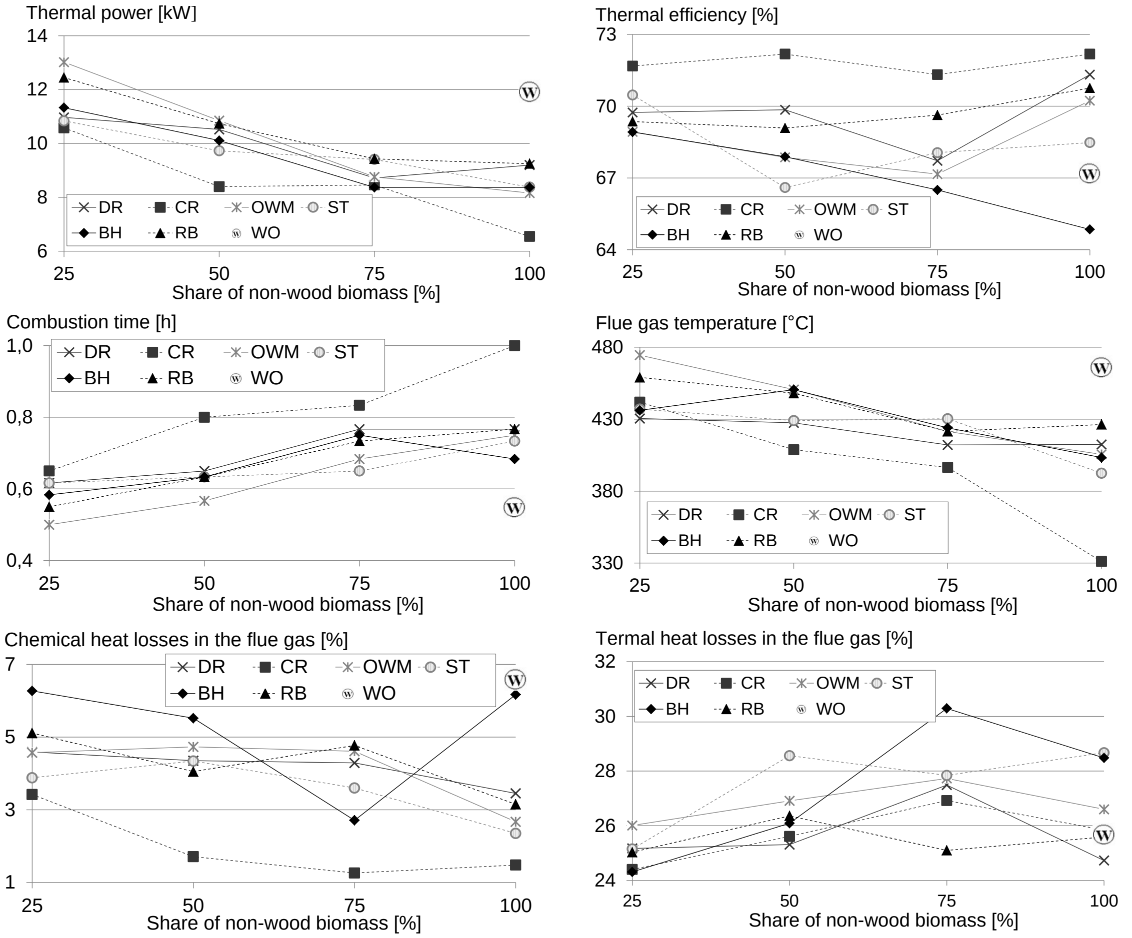

Figure 2: Thermal performance of the stove. Pure wood briquettes as a reference test

An increase in the share of herbaceous biomass in general caused lower emissions of CO (see Figure 3). The reason for that is that the less intense combustion process with a higher retention time for chemical reactions and a higher concentration of free oxygen in the combustion chamber. A lower trend for CO emissions can be observed in the case of full non-woody biomass (except rapeseed briquettes). The concentration of free oxygen in the flue gas shows a strong correlation with the duration of the combustion tests. Roy and Corscadden investigated a similar trend – grassy briquettes showed lower emissions of CO, and higher excess oxygen in comparison to wood briquettes.

The highest concentration of NOx was observed during the combustion tests of the draff, rapeseeds and oat and wheat middlings briquettes. A higher share of herbaceous biomass in general caused a higher concentration of NOx in the flue gas. This behaviour is strongly linked to the fuel-NOx formation mechanism. During biomass combustion, nitrogen content in fuel (Zhang et al., 2008) and the amount of free oxygen available for chemical reactions are the main factors affecting the formation of NO_x (Dias et al., 2004). In this case, both these factors are present and negatively affect the amount of NO_x emissions.

Beside the technical aspects and the design of the combustion appliance, the ash content in the fuel, the temperature, and the flow velocity in the combustion chamber and flues are the main parameters affecting the amount of dust emissions. Herbaceous biomass presented a much higher ash content, and higher emissions of dust in comparison with wood. However, there is no obvious trend observed between these two parameters. Similar results are obtained by the Roy and Corscadden (Roy and Corscadden, 2012). Only in the case of rapeseed briquettes is there a higher ash content in fuel caused by the continuous increase of dust emissions. The intensity of the combustion process, represented as combustion time and thermal power (see Figure 3), can be stated as a parameter with a possible high influence on the formation of dust emissions. This could explain the non- significant increase of dust emissions with a higher share of herbaceous biomass in briquettes and a higher amount of ash as a result.

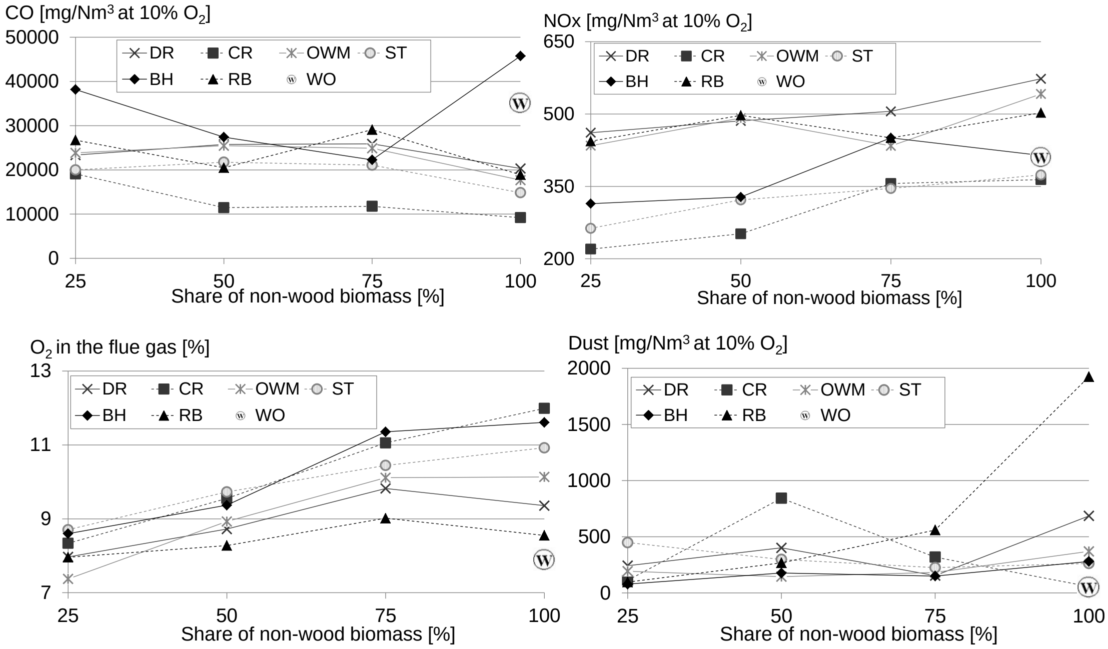

Figure 3: The environmental performance of the stove. Pure wood briquettes as a reference test

4. Discussions and conclusions

The results of the combustion tests prove that several types of herbaceous biomass can stabilize and prolong the combustion process by reducing combustion intensity. This can result in a much longer and safer combustion process with a lower emission of CO. For every appliance, fuel and/or environmental conditions, the optimal amount of combustion air and supply strategy will be different.

A high ash content should not create any significant mechanical problems in the case a herbaceous biomass is used in the appliances designed for wood logs and briquettes. In automated combustion appliances equipped with a fuel supply and an ash removal system, this aspect can cause significant problems in terms of both the reduction of efficiency, and disorders to the technical parts of the combustion unit. However, some of the analysed non-woody biomass has a high ash melting temperature and can be used to prevent the problems of ash sintering.

Due to the diverse properties of herbaceous biomass, it can be effectively used in mixtures to improve the specific parameters of the final product. However, for every type of non-woody biomass, actual drawbacks related to the production process and final use have to be identified and understood. Based on the results of this study, high energy consumption of the production process in some cases can be stated as an example of this.

The foreseeable increase of the use of biomass fuel in medium and large power plants, and combined heat and power plants, will reduce the availability of biomass in the local markets. The use of both herbaceous biomass and leftover biomass from agricultural and industrial processes represent a potential solution to offset this lack. In relation to this aspect, as well as the overall sustainability connected to the use of local biomass energy sources, an important beneficial contribution will be received. However, it is recommended that a more extended and holistic analysis of the overall energy performances (not only taking the production phase into account) must be taken in order to provide the real beneficial effect.

In general, the use of agricultural left-overs, residues and by-products represent a potential to gain several economic and environmental benefits such as industrial symbiosis, use of waste, the partial replacement of wood as a main source of solid biofuels, a more efficient use of energy sources, a lower amount of harmful emissions etc. However, any decision has to be based on real-life testing, and a deep understanding of the advantages and drawbacks of using a particular biomass.

Acknowledgements

This work has been supported by the European Regional Development Fund from the European Commission within the framework of “Central Baltic INTERREG IV Programme 2007-2013” for the implementation of project “ECOHOUSING” and by the European Community’s Seventh Framework Programme’s project “BioWALK4Biofuels”.

Nomenclature

A_d	ash content of the test fuel (on dry basis), w-%,d;
M_{ar}	water content of the fuel (as fired basis), w-%;
C, H, N, S	respectively, carbon, hydrogen, nitrogen and sulfur content of test fuel (on dry basis), w-%,d;
T_a	ash melting temperature, °C;
$Q_{gr. V.d}$	gross calorific value of the fuel (on dry basis), MJ kg^{-1};
$Q_{net.P.ar}$	lower calorific value of the fuel (as fired basis), MJ kg^{-1}.

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