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Thermochemical energy conversion and environmental aspects of straw biomass regeneration

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Abstract. Biomass is the renewable energy source which has and will have significant influence on the future. In secondary production of agricultural plants for energy purposes various cereals are used: straw, chaff, grasses, ligneous planst and specially grown energy plants, forest and wood processing waste. The biomass is appropriate to use not only ecologically but also economically, because straw is a by-product of grain crops. Biomass is characterized as one of alternative energy sources because it is variable value and can be converted to energy by conversion processes in many ways. One of them is a thermochemical process, which is environmentally friendly and its research and application in practice becomes increasingly important. Straw preparation for technological process and conversion into solid bio-fuels is an important factor to obtain high quality material and energy fuels.

The article analyzes the schematic circuit of straw conversion process and the dependence of straw briquette combustion emissions on straw chaff parameters and straw humidity. It is discussed which environmental aspects to obtain in straw usage as a renewable energy source in adaptation technologies. The research demonstrated that fine chaff and dryer straw briquettes during combustion process produced 22% higher energy value compared to bulk chaff straw briquettes the humidity of which was higher than 10%. Combustion temperature of fine chaff and dryer straw briquettes was higher, but on the other hand, higher emission values of carbon dioxide and nitrogen oxide were determinated, too.

Key words: Biomass, conversion process, combustion, environmental protection.

INTRODUCTION

Agriculture is one of the most important sectors related to renewable energy sources and their consumption (Vares et al., 2007). In an overview of renewable energy sources it is noticed that renewable energy does not depend on our traditional fuel sources and during assimilation process carbon dioxide emissions CO_2 are reduced in the atmosphere. It is noticed that biomass combustion and conversion process into heat energy when it is used as a fuel for engines do not emit more carbon dioxide (CO_2) into atmosphere than plants do during photosynthese process (Schindewolf et al., 2010). Biomass is a natural and rich energy rich source which does not cost much and which keeps ecological balance. Productive usage of agricultural waste reduces emissions into atmosphere, because carbon dioxide (CO_2) is neutral and can make influence into additional benefits (Lucian et al., 2006). Using residue of agricultural plants there is no direct influence on food aviability in general. The highest potential for biofuel production in current agricultural systems and situation is to use and operate agricultural and organic plant residues (Johansson et al., 2010). But even then it should be evaluated, that in plant biomass production together with main production it is absorbed additional energy amount used for soil cultivation and seeding, crop care, harvesting, straw chaff reduces, pressing into bales, transportation, and loading for storage (Jasinskas et al., 2008). In combustion of fossil fuels big amount of carbon dioxide emits into atmosphere where it does accumulate for a long time; on the other hand, in plant biomass combustion process carbon dioxide is assimilated by plants, therefore plant biomass conservation and usage is neutral and do not have influence on greenhouse effect (Rana & Roberto, 2008).

Shredded and free hump straw chaff density is 35–60 $kg(m^3)^{-1}$, baled 60–160 $kg(m^3)^{-1}$, straw briquettes and pellets 300–600 $kg(m^3)^{-1}$. Straw humidity suitable for fuel usage should be no more then 18–25% (Efficient use of renewable energy resources: realized projects, 2008). Straw chaff reduce is not even necessary, but it is beneficial. During harvesting straw chaff is reduced till 5–20mm lenght which has greater influence for storage or bale production; it reduces storage cost under increased conversion and straw combustion efficiency. However, 10–5mm lenght straw chaff affects the combustion process adversely (Kargbo et al., 2009).

During the research of power requirements to reduce straw chaff length (straw humidity 8.5%) it was found out that power requirements increase with the increase of drum speed and with the decrease of screen size and number blades on each flange (Tavakoli et al., 2009). Under straw milling and pressing force research it was noticed that straw chaff lengh had influence on producing straw briquettes. Straw chaff fraction lower then > 15mm has showed the biggest influence on variation. In recent research it was demonstrated that the best briquette quality and maximum density was obtained with straw which contained less then 12.5 mass–% of humidity. Straw with 11% of humidity content was also well pressed. The pressed briquettes from straw which contained 17...19.4 mass–% of humidity gave poorer results (Pupinis et al., 2006).

The advantages of straw briquettes are combustion speed, smooth combustion process, emission reduction, better conditions for storage and higher economy level (Maciejewska et al., 2006). In research of briquetting process (Olt et al., 2009) of different biomass materials, calorific value and their combustion process parameters were analyzed. It was demonstrated that mechanical properties and straw briquette quality is affected by briquette production equipment, material (straw, hay, tree leaves, etc.), biomass parameters (humidity, chaff parameters), cooling process (Olt et al., 2009).

Straw briquetting increases the cost, but on the other hand it is possible to better exploit the transportation facilities. Straw briquette energy value is high enough and from 12.0 $MJkg^{-1}$ till 14.3 $MJkg^{-1}$, compared to wood energy value 15.5 $MJkg^{-1}$ (Jasinskas, 2007).

Goyal et al., while investigating thermochemical process of biofuel production, notes that biomass is directly combustion by changed oxygen amount, reaching to convert chemical energy which is accumulated on biomass into heat, mechanical or electrical (Goyal et al., 2006). It should be noticed that fuel combustion and this process strategy objectives are to reduce CO_2, SO_2, NO_x noxios elements (mercury, nickel, canmium) quantity, because NO_x and SO_2 form acid rain, carcinogenic substances are in soot and tar droplets, CO_2 increasing greenhouse effect (Šlančiauskas, 2006). Under air pre-heating and fuel humidity influence for combustion characteristics research results, it is determined that under heated oxygen (O_2) combustion process is shorter and emisions (CO) and (CO_2) concentrations intense. On increasing fuel humidity, combustion speed and nitrogen monoxide (NO) concentration were achieved lower (Zhao et al., 2008).

In order to combust completely 1kg straw in theoretical way it is needed $4.5\,m^3$ oxygen value. The highest straw combustion temperature is reached at 2,000°C, then oxygen access ratio is $\alpha = 1$. On increasing oxygen amount the combustion temperature reduces. When highest straw combustion temperature is around 1,000°C , oxygen access ratio $\alpha = 1.4 - 1.5$. Reducing oxygen access, fuel combustion is not completed, there is higher quantity of carbon monoxide in smoke. Increasing oxygen ratio combustion temperature and equipment efficiency reduces (Pedišius et al., 2005).

The research tasks are to substantiate the straw preparation for conversion of the following aspects:

- Considering of straw preparation procedures,
- Evaluation of briquette quality and combustion by thermochemical and environment process parameters,
- Analyzing straw briquette combustion emission variation on straw chaff parameters and straw humidity should be varied.

MATERIALS AND METHODS

In the independent agricultural plant straw are delivered in bales the diameter of which is 1,400–1,500mm, density 150–250 kgm^{-3} with humidity in straw till 17%. Straw bales are delivered from the fields into the storage place where there is active ventilation and straw humidity is reduced in instant dryer unit. From the storage place bales are transported and loaded into crusher unit, from this place they are partly delivered to straw briquette production element. Produced straw briguettes are supplied into the storage, from where they are delivered in measured parts to combustion element.

However, in order that this independent agricultural plant would be installed and would work efficiency, it is necessary to carry out a detailed analysis of straw briquette combustion parameters and their influence on emissions.

In solid biofuel fired in boilers combustion and emission levels depend on fuel source, quality, and shape. These elements are very important in design and production of new fuel suppliers and combustion equipment.

Agricultural plant principle scheme of technological elements is represented in Fig. 1.

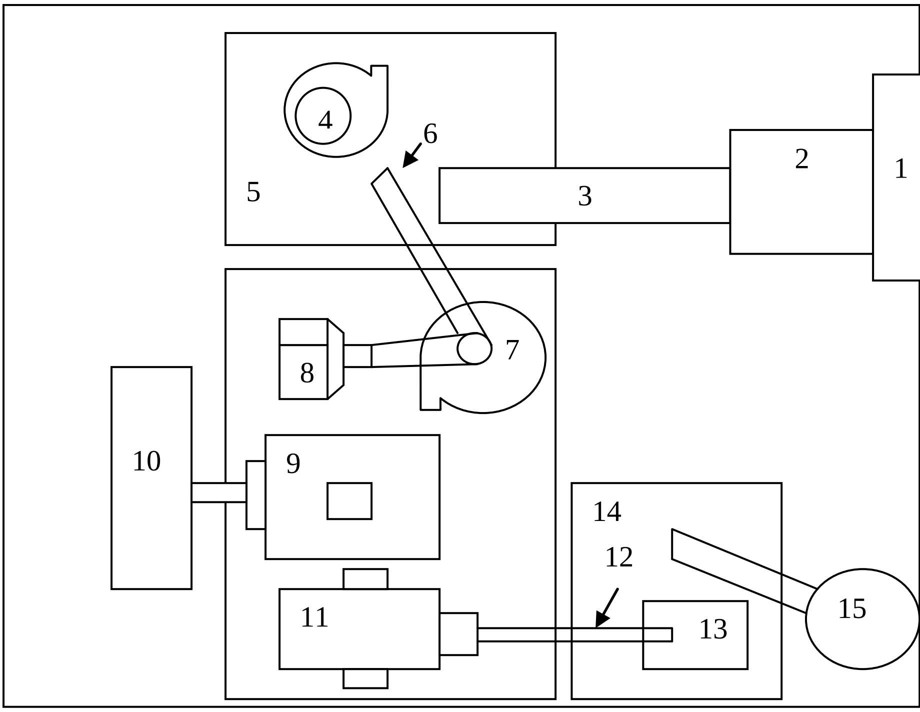


Figure 1. The independent agricultural plant technological mechanism positions schematic circuit: 1 – Boiler/gasification column; 2 – Press; 3 – Transporter; 4 – Cyclone; 5 – Intermediat dry bulk capacity; 6 – Transporter from dryer unit; 7 – Cyclone; 8 – Fan; 9 – Heat exchanger; 10 – Ignition device with capacity; 11 – Aerodynamic column; 12 – Loading transporter; 13 – Separator; 14 – Intermediate capacity; 15 – Bale shredder.

Straw briquette quality is determinated by density which affects start-up briquette preparation, combustion speed, stability of briquettes. Briquettes density ρ is described by mathematical equation:

$$\rho_{\mathrm{N}} = \frac{m_N}{V_N} \tag{1}$$

where: V_N - briquette capacity dm^3;

m_N - briquette weight kg (Križan et al., 2009).

Investigated straw briquette density of expression on pressure force for biomass, which humidity was 9–11%. The measurement results showed that highest pressing force of the reseach energy plants have coriander, rape straw, lowest – barley straw.

According to the results it is determinated briquettes density q matchematical expression according to pressure.

For barley straw:

$$q_m = 11.143 p_D + 338.88 \tag{2}$$

Coefficient of determination: $R^2 = 0.9097$

For rape straw:

$$q_r = 14.971 p_D + 279.4 \tag{3}$$

Coefficient of determination: $R^2 = 0.9424$

there: p_D - pressure force MPa.

Matchematical expression of briquettes resistence force depending on the pressure.

For barley straw:

$$F = 1{,}0641 p_D - 23.727 \tag{4}$$

Coefficient of determination: $R^2 = 0.9184$

For rape straw:

$$F = 4{,}5774 p_D - 140.77 \tag{5}$$

Coefficient of determination: $R^2 = 0.4$

there: p_D - pressure force MPa (Plítstil et al., 2005).

In order to clarify the different quality briquettes, produced by different straw chaff, the influence of combustion process and emissions, it is targeted to carry out the research of:

1) straw briquettes, of fine chaff length (0.1 – 1.0mm);

2) straw briquettes, of bulky chaff length (5 – 20mm).

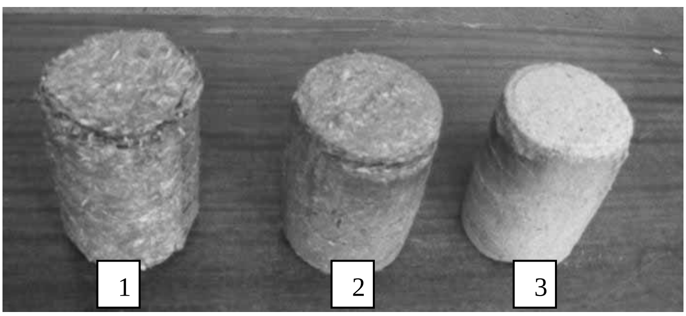


Figure 2. Straw briquettes examples: 1. Bulky chaff straw briquettes; 2. Average chaff straw briquettes; 3. Fine chaff straw briquettes.

The research was done in Lithuanian Agricultural University, laboratory of Agri Engineering institute, straw briquette combustion process was operated in small (10kW) power biofuel boiler, which was adapted for solid biofuel, such as chips, wood reduces, sawdust pellets, and briquette combustion. The heater fuel was combusted on sieves, oxygen needed for combustion process was supplied by the fan. The research was performed under standard (LST EN 303-5:2000 (EN 303-5:1999)) and by the other indicated standartization methods (LST EN 13284-1-2006). Composed pollution during the combustion process was measured by combustion product gas analyser 'UniGas 4000', produced by Italian company 'Eurotron'. It indicated and measured CO; CO_2; SO_2; NO_x emissions, the quantity of which was specified under normative document (LAND 43-2001). Gas flow was measured in flow channels by pressure in speed probe, gas humidity by capacity psychrometer. For each trial two replays were done no less then in 30 minute term with registration of all process parameters.

In this study noxios material emissions into atmosphere during straw briquette combustion process were determined and compared. Each trial was repeated five times, for this reason two sources of briquette examples were used for the trials. Before each trial chaff humidity and straw briquette density were determined with methodology which was mentioned before.

The research object is fine and bulky chaff straw briquette combustion process and related to this process results (oxygen and temperature variation during the combustion process), oxygen (O_2), carbon dioxide (CO_2), carbon monoxide (CO), nitrogen monoxide (NO), and nitrogen oxide (NO_x) emission amount during combustion of 1kg fine and bulky chaff straw briquettes.

RESULTS AND DISCUSSION

Fine and bulky chaff length straw briquette parameters were specified in three measurements. Humidity of fine chaff straw briquettes was determined 7.04%, bulky chaff straw briquettes 11.7%. Straw briquette parameters are showed in Table 1.

Table 1. Straw briquettes parameters.

Straw briquettes	1st trial	2nd trial	3rd trial	Average values
Fine chaff (humidity 7.04%)	Ø = 74.1mm	Ø = 75.0mm	Ø = 74.7mm	Ø = 74.5 $\pm$ 1,4mm
	h = 95.5mm	h = 120.1mm	h = 97.3mm	h= 104.3 $\pm$ 5.6mm
	m = 31.3g	m = 40.0g	m = 31.6g	m= 34.3 $\pm$ 2g
Bulky chaff (humidity 11.7%)	Ø = 78.2mm	Ø = 77.3mm	Ø = 76.4mm	Ø = 77.3 $\pm$ 1.4mm
	h = 121.5mm	h = 124.2mm	h = 103.9mm	h= 116.5 $\pm$ 5.6mm
	m=40.8g	m= 41.4g	m=41.3g	m= 41.1 $\pm$ 2g

Estimated straw briquette density is showed in Table 2:

Table 2. Researched straw briquette density.

Straw briquettes	Density (kgm^{-3}) 1st trial	Density (kgm^{-3}) 2nd trial	Density (kgm^{-3}) 3rd trial
Fine chaff (humidity 7.04%)	ρ = 76.0	ρ = 75.4	ρ = 74.1
Bulky chaff (humidity 11.7%)	ρ = 69.9	ρ = 71.0	ρ = 66.7

2.5kg fine chaff straw briquettes were combusted 40 min and 2.41kg bulky chaff straw briquettes 48 min. Combustion process results were recalculated for 1kg of straw briquettes combustion capacity per hour. Oxygen (O_2), carbon dioxide (CO_2), carbon monoxide (CO), nitrogen monoxide (NO), and nitrogen oxide (NO_x) variation during combustion process is showed on figures 3–7. During combustion process for bulky chaff straw briquettes it was needed to deliver higher oxygen access ratio comparing to fine chaff straw briquettes from 10% till 13% (Fig. 3). Higher amount of carbon dioxide was determinated in fine chaff straw briquette combustion from 0.2 till 0.4% (Fig. 4).

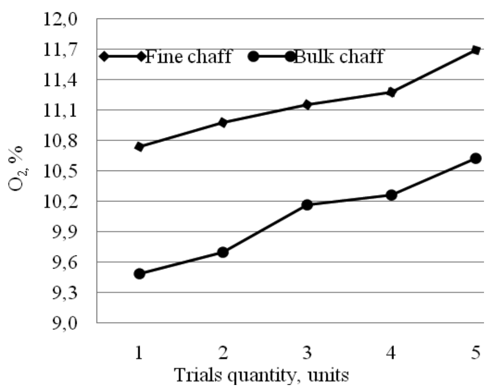


Figure 3. Oxygen variation in fine and bulk chaff straw briquettes combustion process.

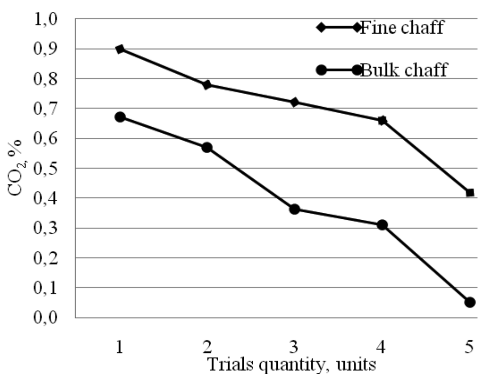
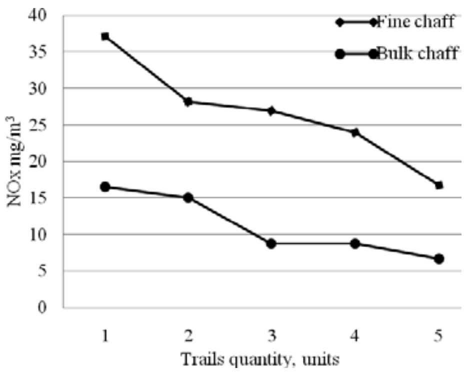


Figure 4. Carbon dioxide variation in fine and bulk chaff straw briquette combustion process.

Carbon monoxide concentration was similar in the first and second trials of fine and bulk chaff straw briquettes during combustion process, but continuing trials carbon monoxide concentration has increased in fine chaff straw briquette combustion (Fig. 5). Highest concentration of nitrogen monoxide was determined during fine chaff straw briquette combustion trials (Fig. 6).



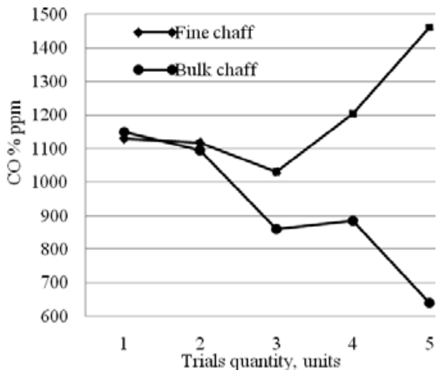
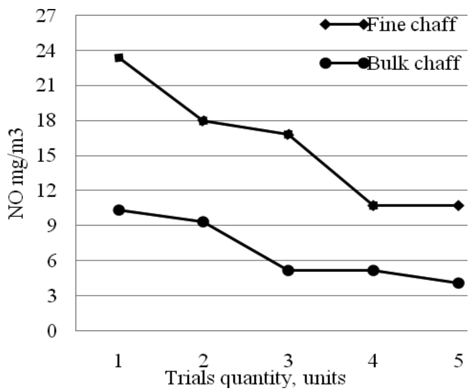


Figure 5. Carbon monoxide variation in fine and bulk chaff straw briquettes combustion process.

Figure 6. Nitrogen oxide variation in fine and bulk chaff straw briquettes combustion process.

Highest concentration of nitrogen oxide amount was determined in combustion process of fine chaff straw briquettes (Fig. 7). Figure 8 shows variation of temperature during fine and bulk chaff straw briquette combustion process. During combustion of fine chaff temperature has been reduced increasing oxygen quantity, but on the third trial results achieved temparature results were different from general tendency.



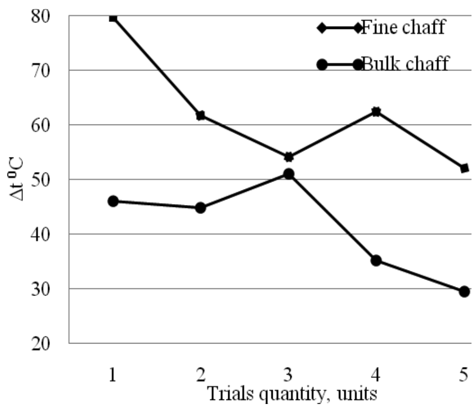


Figure 7. Nitrogen oxide variation in fine and bulk chaff straw briquettes combustion process.

Figure 8. Temperature variation in fine and bulk chaff straw briquettes combustion process.

Research and experimental results confirm that higher calorific value 22% was achieved and generated by drier fine chaff straw briquette combustion compared to bulky chaff straw briquettes, but on the other hand it is important to notice that higher emissions values were determined during fine chaff straw briquette combustion process.

CONCLUSIONS

The results of the analytical and experimental research results demonstrated that:

- straw biomass reduces are one of the renewable energy sources;
- straw biomass usage for energy purpose requires additional preparation for qualified conversion process as usage of bale crasher, straw crushing, drying, briquetting process, injection of micro particles into combustion fire place;
- fine chaff and drier straw briquettes during combustion process produced 22% higher energy value compared to bulk chaff straw briquettes the humidity of which was higher then 10%;
- bulk chaff straw briquettes and higher humidity have influence for oxygen access ratio which was needed to increase from 10% till 13%;
- combustion temperature of fine chaff and drier straw briquettes was higher, but on the other hand higher emission values of carbon dioxide and nitrogen oxide were determined too.

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