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Environmental impact of sawdust briquettes use - experimental approach

Teodora Deac[a], Lucian Fechete-Tutunaru[a], Ferenc Gaspar[a]*

[a]*Technical University of Cluj-Napoca, Faculty of Mechanical Engineering*

Abstract

In the last decade, with increasing global energy demand, pollutant emissions' level, resulting from the process of energy conversion has been increased significantly. With the intensifying activities of wood exploitation has also increased the wood-waste amount resulted from this process. The situation being given, in the present paper is shown the pollutant emissions impact upon environment, as a result of the conversion process from sawdust briquettes in thermal energy, taking an experimental approach. Meanwhile are presented also the results obtained by analyzing the impact of physical and chemical properties, for the available raw material, upon pollutant emissions quantity generated after combustion process.

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Keywords: Thermal energy; solid biomass; environmental emission; pollutant emission; sawdust briquettes

1. Introduction

Increasing population number and raising the living standard has determined the continual increase on energy demand from conventional sources and implicitly to the diminishing of fossil fuels reserves. The statistics [1] show that there is a correlation of raw energy total consumption trend with population evolution, in 1860 – 2010 interval. Thus the global population increased from 0.98 billion inhabitants in the year 1800 at 6.79 billion inhabitants in the year 2010, and primary energy consumption from 20 EJ in 1800 at 536 EJ in 2010.

The long-term estimates [1] show a forward increase in the world population up to 9,46 billion inhabitants in the year 2100 which leads to a significant increase in primary energy consumption. The continued growth of primary

* Corresponding author.
E-mail address: teodora.deac@auto.utcluj.ro

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energy consumption, rediscovers an acute problem, namely that being the depletion of fossil fuel reserves, more over because worldwide, at the present moment, over 50% of primary energy comes from conventional energy sources.

Another serious problem facing mankind is the impact of fossil fuel use on the environment. Due to the discharge of harmful substances into the environment, carbon cycle in nature is strongly affected. This is supported by statistics indicating an increase in CO_2 emissions of 200 million tons emitted annually into the atmosphere in 1850 to 29 billion tons emitted annually into the atmosphere in 2004 [2].

Given the above, the problem of using renewable energy sources is an issue of global importance. Under these conditions the biomass, characterized by a high availability across the planet, with an overall potential of approximately 2900 EJ / year [1], by its renewable and last but not least by reduced quantities of pollutant emissions resulted after its conversion.

Sawdust is one of the major waste resulting from wood exploitation and processing, which stored in un-controlled conditions may be an important factor of environmental pollution. But at the same time is one of the main sources of biomass for the production of solid fuels for generating heat in both centralized system, in co-generation installations and in a decentralized system for residential use, in classic boilers for thermal energy generation.

Converting biomass in general, and the sawdust in particular has beneficial effects on the environment. However as with any source of energy will result pollutant emissions with negative impact on the environment and on biological systems. The resulting pollutants from sawdust briquettes conversion in heat energy are ash and air pollutants emanated through the combustion gases: carbon monoxide (CO), volatile organic compounds (VOCs), nitrogen oxides (NOx), sulfur oxides (SOx) and particular emissions (PE). Among these in the literature [3, 4] are indicated NOx and SOx as dominant components in emissions configuration.

The most adverse impact upon human health is due to the emissions of NOx because it damages the human respiratory system. The existing data [4, 5] show that NO> 3ppm leads to a quantifiable measures of damage to the lungs health, while a value of 0,1ppm cause lung irritation and decreased pulmonary operation causing the development of asthma. The NO_2 high concentrations affects the production of hemoglobin, restricting the oxygen in human tissues. On the other hand NOx emissions have a negative impact also on the ozone layer: it produces ground-level ozone (photochemical smog) and destroys naturally occurring ozone high in the atmosphere [3, 5]. The SOx emissions, by reacting with atmospheric oxygen, lead to the formation of acid rains and snowfalls. Due to the lower amount of sulfur in the chemical composition of solid biomass it produces a small amount of sulfur oxide emissions (SOx) resulted from the conversion into thermal energy. The CO_2 produced in the process of wood burning is considered part of the carbon cycle in nature, not being regarded as air pollutant. For more than 80% of the particulate matter are in the form of ash driven by the combustion gases (fly ash) of which 40% have a diameter <10μm. Of these, the technical literature [4] indicates that 20% is laying on the ground and all the rest is released into the atmosphere where can cause health problems.

The main goal of the paper is to determine the environmental impact of using wood chips briquettes for the generation of thermal energy for residential buildings. For this purpose, by means of an experimental approach, have been determined the main physical and chemical characteristics of the briquettes used in order to analyze the quality of fuels used and to determine the amount of ash in fuels' composition. Also, has been carried out a variation analysis, to determine the concentration of NOx throughout the combustion cycle. Considering that in the technical literature [4, 5] it is noted that NOx emissions resulting from the combustion process are formed by 95% of NO, there has been made also the analysis of changes in emissions of NO during one complete cycle of operation correlated with the temperature of resulting gases from the chimney, and also the physical characteristics of the briquettes (i.e. the length).

2. Method and Material

For carrying the experimental research, a laboratory bench has been made, to simulate the conditions for sawdust briquettes burning to generate thermal energy for residential buildings with area less than 100m2 (Fig. 1). The boiler used to burn the sawdust briquettes has a nominal capacity of 23,7 kW, the combustion chamber has a thermal power of 35,4kW. The combustion chamber has been designed to supply large pieces of wood and is equipped with classical grate. Loading it shall be processed manually by the top door, on the grate. Combustion control was achieved by varying the amount of the combustion air (i.e. excess air - λ) via a thermostat and a chain which ensures closing of the ash pan door. During the combustion process, the excess air (λ) varied between: 0.9 – 2.1. Excess air monitoring was performed using a mobile combustion gases analyzer.

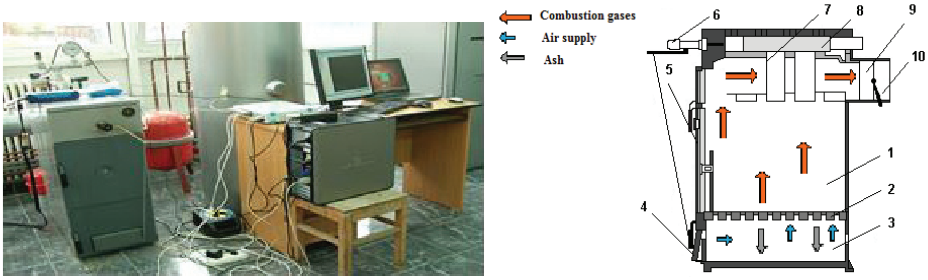

Fig. 1. (a) The bench of heat energy generator supplied with solid biomass; (b) The diagram of boiler: 1 – combustion chamber; 2 – grate; 3 – ash box; 4 - ash box door ; 5 – top door; 6 – thermostat with chain; 7 – heat exchanger; 8 – safety system; 9 – combustion gases evacuation; 10 – flap adjustment.

In order to monitor and collect the conversion process' parameters values, there has been used some data acquisition system consisting of Pt100 temperature sensors; thermocouples temperature sensors type K; eight-channel data acquisition module with amplification; supplementary modules compliant with the measuring device; the software setup, visualization and carrying out EASY CATMAN reports; PC unit for gathering, storing and analyzing experimental data. The temperature sensors for measuring temperature of the combustion gases are thermocouples of K-type. The material that the thermo-electrodes are made of is Ni-Cr/Ni-Al, which enables high-precision for measuring at high temperatures.

In the experimental research have been used sawdust briquettes from two wood species: fir and beech respectively. Thus the three types of solid biofuel sawdust briquettes were tested: Fuel 1 - fir; Fuel 2 - beech; and Fuel 3 - a mixture in equal proportion of 50%, pine (fir) and beech. The material was dried-up in ambient conditions and briquetted using the same parameters in the technological process (briquetting). Following this process were obtained sawdust briquettes with constant diameter (55 mm) and three different lengths, 70 mm, 50 mm and 30 mm respectively, using a briquetting press of commercial use. Determination of the energetic and physico-chemical properties of the sawdust fuels used was carried out in accordance with the prevailing international standards: CEN/TC 335 -15103 [142], CEN/TS 14780:2005: E [104] şi CEN/TS 14775:2004 [109], CEN/TS 15148:2005:E [107], CEN/TS 14780:2005:E [104], CEN/TS 14774-1:2004 [105], CEN/TS 14918:2005:E [110].

The characteristics values of biofuels from sawdust briquettes produced and used in the experimental research are presented in Table 1.

Table 1. Physico-chemical characteristics of the solid biofuels from sawdust briquettes

Material	Moisture content	The technical analysis			The elemental chemical composition			Higher calorific value	Lower calorific value
	W [%]	Vmc [%]	Aa [%]	Cfa [%]	C [%]	H [%]	O [%]	Hs [MJ/kg]	Hi [MJ/kg]
Fuel 1 (fir)	7,042	70,4685	2,065	20,4240	45,0730	5,4311	39,7518	17,268	15,988
Fuel 2 (beech)	7,06	67,4081	4,1136	21,4182	44,3141	5,2931	38,5974	19,377	18,125
Fuel 3 (blend)	6,784	70,3498	2,8238	20,04232	44,7761	5,4039	39,5794	19,174	17,905
	Fuel 1			Fuel 2			Fuel 3		
Length of the briquettes [mm]	30	50	70	30	50	70	30	50	70
The specific density [kg/m3/ briquette]	833,8	784,1	810,8	744,0	715,9	627,7	921,8	735,6	772,1

Values of physical characteristics of the generated briquettes show that they have a smooth outer surface and a compact and homogeneous structure. A specific density value briquette has had readings within the range of 627-922 [kg/m3]. The amount of energy required to attain pyrolysis temperature in the briquettes burning process is directly influenced by the fuel (sawdust) humidity, which directly influences its calorific power, and hence the quality of the combustion process that directly influences the formation of higher amounts of the pollutant emissions (i.e. CO and NOx). The value obtained after the experimental determinations shows a low humidity percentage of the sawdust briquettes, ranging between 6 to 8% (Table 1). That is a fact which provides durability, high storability, a higher calorific value and thus reduced energy losses in the combustion process [9].

The biomass in general contains a high quantity of 60-90% volatile materials and a small percentage of ash, values ranging between 1 to 4% [6, 9]. The sawdust is considered to be a highly reactive fuel, with higher combustion rate during the phase of emanating of the volatile materials, which implies efficient combustion, respectively the formation of small amounts of smoke and gaseous pollutant emissions.

Furthermore considering that the ash is an impurity which does not burn, high percent of the ash contained in a fuel usually involves the formation of emissions of solid particles in large quantities, which either are deposited on the heat exchanger lowering its effectiveness or they are emitted in the surrounding environment by combustion gases [5, 6]. After the experimental determinations the values of volatile materials were obtained in the range of 67 to 71%, respectively the ash values were obtained in an interval from 2 to 4.1%. The data reveal a correlation between the two parameters, low volatile matter content increases the ash content (of fuel 2).

Experimental results show that the amount of fixed carbon content (Cfa) of the biofuel used has values between 20.4% and 21.4%. This represents the proportion of solid carbon in solid fuel composition that remains after gassing volatile materials. The chemical element composition shows the primary content of the carbon, oxygen, hydrogen, nitrogen, sulfur and chlorine respectively, contained in the examined biofuel. These values provide information for the determination on the one hand of the air volume required for the combustion process (determining the excess of air), as well as for determining the volume and composition of the exhaust gas emitted in the process of combustion [7]. Following the analysis of the experimental biofuels is observed that considered the proportion of oxygen, hydrogen and carbon has a low variation considered by type of fuel in the maximum limit of 2%. Thus some values were determined within the following ranges: 38.5 to 40% oxygen, 5 to 5.5% hydrogen, 44.3 to 45% carbon. The content of nitrogen, sulphur and chlorine respectively are important in the process of forming emissions. However considering the low rate in which they are present in the fuel, we can assert that sawdust briquettes have only a limited effect in this respect on the environment. Regarding the lower calorific value of sawdust briquettes used, its value determined experimentally as having variations between 15 and 18 MJ/kg, comparable values to other types of biomass used to produce solid briquetted biofuels [6, 8].

Composition values of nitrogen oxides (NOx) and smoke temperature were being measured throughout the whole investigation period using a mobile gas analyzer. Particles and hydrocarbons were not measured. Before starting the experiment, constant amount (3kg/charge) of used fuel has been loaded into the combustion chamber, as layer on the grid. Monitoring and collection of the process parameters has started from the fuel ignition phase (combustion gases temperature range: until 140°C), continuing throughout the combustion phase (combustion gases temperature range: more than 140°C) and boiler cooling phase (lower than 140°C).

3. Results and Discussion

The pollutant emissions in the combustion process of solid biofuels in general and sawdust briquettes used to generate thermal energy, in particular are influenced mainly by energetic, physical and chemical characteristics and biofuel combustion process and burning related parameters. One of the main parameters of the combustion process with a direct influence on the amount or the composition of the gaseous emissions emitted into the atmosphere (smoke) is the volume of air required by combustion. According to the utilized technology for the combustion, the amount of air actually required in the combustion process is higher than that which has been theoretically predicted. Therefore combustion process is performed using the excess amounts of air. The scientific literature [10, 11] recommending for the combustion of solid fuels an excess air in the range 1.3-1.4. During the entire process of combustion, the gaseous pollutant emissions (NOx) are of a variable character, largely depending upon the quality of the combustion process. Therefore regarded under the experimental conditions have been taken into consideration emission level monitor during the entire process of burning briquettes from sawdust which were analyzed.

Major pollutant emissions resulted after burning solid biofuels from sawdust are nitrogen oxides (NO_x) [4]. More than 95% of their composition is nitrogen oxide as demonstrated by the values obtained through measurements made with the combustion gases analyzer, which recorded the same values for NO and NO_x. The concentration of nitrogen oxide in the exhaust gases on the one hand has a negative impact on the environment and on the other hand is an indicator of the combustion process intensity. The presence of nitrogen oxides in the combustion gases provides information on the combustion temperature, because they are formed at high temperatures [11]. In such context, it was examined real time variation of the NO amount, on a complete operating cycle of the generator, in correlation with the temperature of the combustion gases. The curves of variation in the concentration of NO with respect to temperature variation of the combustion gases, while, on a complete operating cycle (including fuel ignition phases, combustion phases and cooling period) , the combustion of fuel type i and briquettes of the length j, have been plotted using values resulting from experimental tests performed. The results are shown in Figure 2.

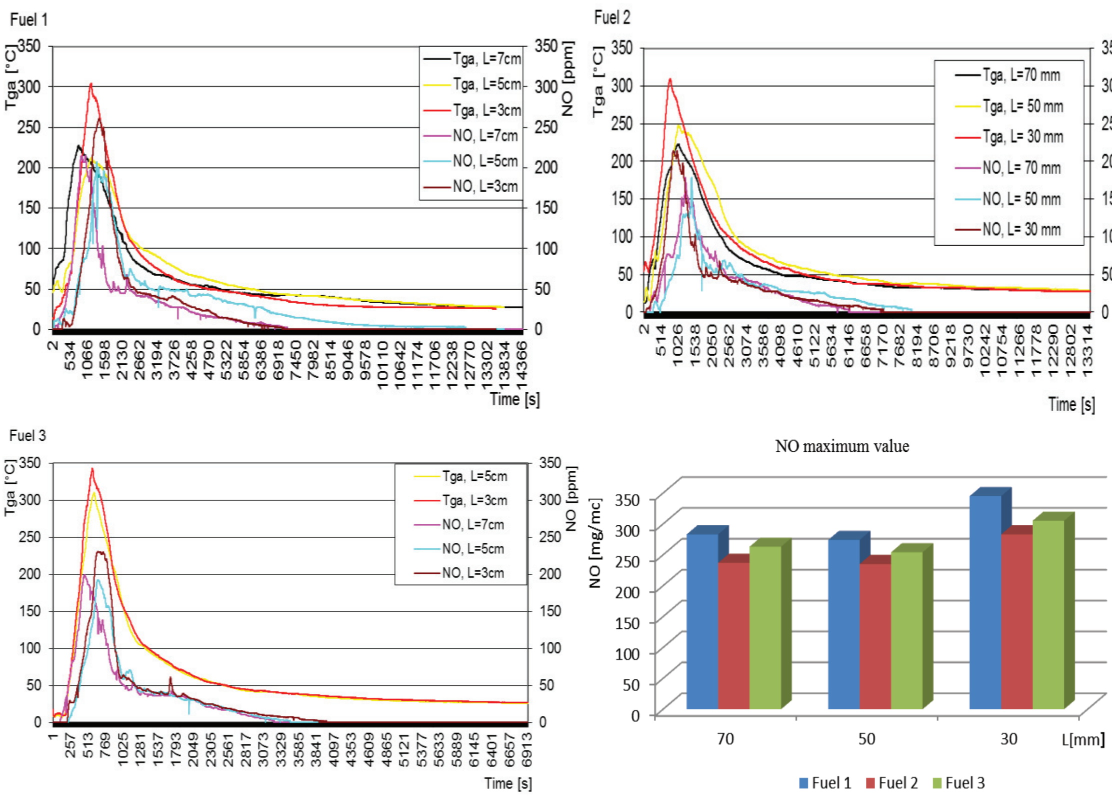

Fig.2. Variation of the concentration for NO in the combustion gases

The analysis of experimental results highlights a correlation between the combustion gases temperature variation and NO emissions. Thus in all analyzed cases maximum emission values of NO (Table 2) were recorded at the maximum temperature of the combustion gases, for fuel with briquettes' length (L = 30 mm). Also, increasing the length of briquettes positively influences the NO emissions.

Comparing the values obtained by experimental determinations carried out, with the data presented from the scientific literature [11, 12] indicates that in terms of environmental impact, using sawdust briquettes for heat generation is more beneficial than burning wood, due to the lower quantity of pollutants, but less advantageous compared to the burning of pellets.

Table 2. The maximum value of the NO concentration in the combustion gases

	Fuel 1			Fuel 2			Fuel 3		
Length [mm]	70	50	30	70	50	30	70	50	30
NO [ppm]	214	207	261	179	178	214	199	192	231
NO [mg/m^3]	283	274	345	237	235	283	263	254	305

4. Conclusions

From the results obtained by fulfilling experimental determinations on the impact of using sawdust briquettes on the environment it may be concluded the following:

The burning process was very unstable. This will cause an incomplete combustion and large quantity of pollutant emissions. The reason is, in this boiler type, that during the burning process of sawdust briquettes it is very difficult to control the burning process. Throughout the burning process it is difficult to control the supply of air into the combustion chamber which is control by the chain thermostat. A solution for the stabilization of the combustion process and thus a decreasing of pollutant emission quantity can be the improvement of the combustion air supply control.

During the entire burning process, gaseous pollutant emissions (especially NOx) maintain a variable trend, depending largely on the quality of the combustion process. In terms of the NO emissions the peak values in all cases were recorded at the maximum temperature of combustion gases, respectively for 30 mm length briquettes (Fuel 1: 261ppm; Fuel 2: 214ppm; Fuel 3: 231 ppm). So, for this boiler type, reducing of NO emission can be achieved by increasing of briquettes length.

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