PRODUCTION OF GAS EMISSIONS FROM BIOMASS HEAT SOURCE

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The replacement of fossil fuels with renewable sources for heating and drying of cereals nowadays generates a great deal of debate. The greatest representation in renewable fuel sources has biomass, particularly woodchips and straw. This paper presents the results of check measurement on a heat source for heating and warm water preparation. Selected dependences of production of carbon monoxide, carbon dioxide, nitrogen oxides, content of oxygen, of total organic carbon are presented. This knowledge implies requirements to abandon the idea of ecological harmlessness of heat production from biomass. As far as biomass substitutes fossil fuels, the environmental impact is more favourable.

Keywords: *heat source, biomass, emissions, combustion, thermovision*

1. Introduction

The costs of heating of houses and flats and warm water production are an essential part of the housing costs. One method of significant reduction of the fuel costs is to replace fossil fuels with fuels from own sources, mostly with biomass. Currently the chemical energy of biomass is released by burning. The quality of a fuel as a source of energy depends on the quality of the combustible and on the ballast content (i.e. moisture and ash). In comparison with solid fossil fuels, biomass contains considerably higher proportion of the volatile combustible that burns with long luminous flame and influences the structure of the combustion device itself as well as the preparation and transportation of the biomass into the firebox.

Apart from energetic and economic results, in the evaluation and characterisation of fuels used in agriculture we consider the fuels also from the environmental point of view. Current findings from the analyses of combustibles in burning of biomass refer to the need to reconsider the idea of ecologically pure heat production from this fuel.

In this paper we deal with the utilization of biomass from selected heat source designed for heating of flats and for warm water production. The main attention is devoted to the measurement of quantities of produced gaseous emissions, subsequently to the storage of biomass and the costs of heat production in comparison with fossil fuels.

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2. Material and methods

The subject of this investigation is the heat source in CK Lúky in Vráble. The owner of this source is the company Dalkia Vráble a.s., which is a common establishment of supranational corporation Dalkia a.s. and the City of Vráble. Three boilers with natural gas with nominal performance 3.5 MW are installed in the boiler house of the housing estate Lúky. In the year 2010, after complex reconstruction carried out with the financial support from the Norwegian financial mechanism, financial mechanism of the European Economic Area and of the Slovak state budget, the woodchip boiler VESKO-B was put into operation. Irrecoverable contribution from the total cost of the technology reached nearly 785 000 EUR.

The installed boiler for biomass type VESKO-B (Fig. 1) from the producer TTS Třebíč is the basic source of heat production in the boiler house CK Lúky besides natural gas boilers. Power of this boiler is 1.9 MW, interior volume 14300 dm^3, produced in the year 2009. The boiler VESKO-B consists of the firebox and the heat exchanger. The firebox is composed of a welded case which as a bearing construction conveys the burning air and supports the fire grate. The fuel burns on a slant fire grate with a hydraulic control. Primary air is blown in three zones under this fire grate and secondary air is blown through the nozzles. The fire grate chamber has a fettling of heat resistant bricks and is covered with a ceramic vault. The heat exchanger part consists of a whirl separator, a warming chamber and a pipe heat exchanger. The ash is delivered into containers. The combustible is transported into the boiler with a hydraulic press. This hydraulic transporter of the combustible has in this execution great advantage in comparison with the thread transporter in the sense that through the boiler can pass a chunk of wood, a stone or a brick. Before the input of woodchips on the fire grate it is dried in a heated tunnel. The container is filled up by a hydraulic loader from the stock of woodchips. Exhaust gases are blown away by a combustion fan through a whirl separator into the chimney.

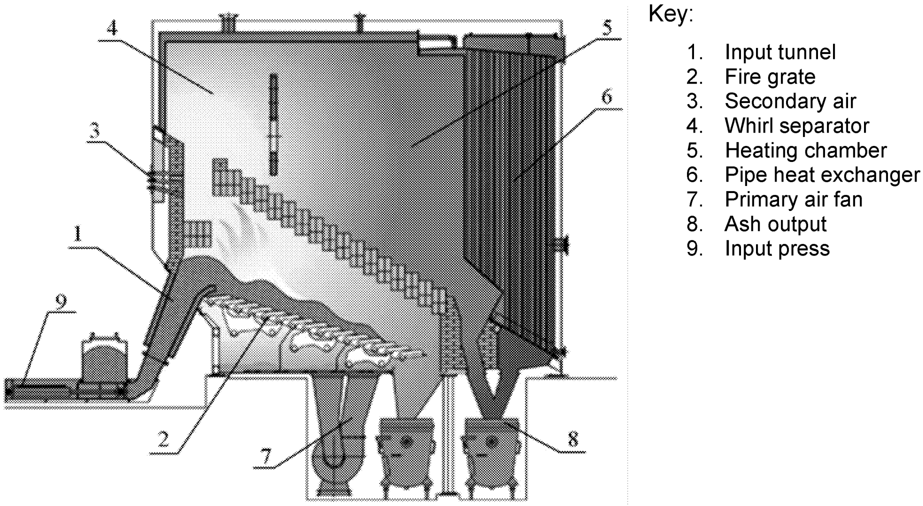

Fig.1: Scheme of the boiler VESKO-B

The measuring apparatus TESTO 330-2 LL (Fig. 2) was used for emissions measurement. It is an analyser of combustion gases, which is able to measure parameters and quantities and to represent them on the display. Available parameters and units are: temperature of combustibles (°C), CO_2 carbon dioxide content (%), q_A chimney loss (%), air surplus (1), O_2 oxygen content (%), CO carbon monoxide content (ppm, %), uCO nondiluted carbon monoxide (ppm), η efficiency of the equipment (%), NO nitrogen monoxide content (ppm, %), NO_x nitrogen oxides content (ppm, %), temperature of ambient air (°C), $O_{2\mathrm{vz}}$ refer. oxygen (%) and other parameters and units.

Measuring of particulate matter (PM) is carried out by a manual taking apparatus. The emissions of PM are caught on the planar filters which are weighed before and after the probing and from their mass is calculated the quantity of the caught particles. The mass flow of particulate matter will be evaluated by the means of a computer from the quantity of gas flow and the quantity of the particles caught on the filter.

Fig.2: Analyser of combustion gases Testo 330-2 LL

For the evaluation of the mass flow of air pollutants it is necessary to find out the gas flow in the flue with a Prandtl tube probe and according to the cross section of the flue to state the gas flow which flows in a time unit. The Prandtl tube is a probe for point measurements of the gas flow rate. It is an L-shaped metal tube which is set up on the measuring point against the flow of the gas and with measured pressure difference will be calculated the gas flow rate. For the calculation of carbon monoxide serves the equation:

$$\mathrm{CO}_{[\mathrm{mg\,m^{-3}}]} = \frac{21\,\% - \mathrm{O}_{2\,\mathrm{ref}}}{21\,\% - \mathrm{O}_2}\, 1.25\, \mathrm{CO}_{[\mathrm{ppm}]} \;. \tag{1}$$

For the calculation of nitrogen oxides content is used the following relation:

$$\mathrm{NO}_{\mathrm{x}\,[\mathrm{mg\,m^{-3}}]} = \frac{21\,\% - \mathrm{O}_{2\,\mathrm{ref}}}{21\,\% - \mathrm{O}_2}\, 2.05\, \mathrm{NO}_{\mathrm{x}\,[\mathrm{ppm}]} \;. \tag{2}$$

where: 21 % is volume concentration of oxygen in the air, O_2 measured volume concentration of oxygen in %, $O_{2\,\mathrm{ref}}$ refer. content of oxygen, in dependence on the combustible, in %.

For the calculation of the efficiency of combustion in the boiler it is necessary to identify the moisture content of woodchips and thereafter we calculate the heat value of the fuel in dependence on the moisture content (tab. 1). Moisture content of these combustibles is measured by the moisture meter HG 63 from the company METTLER TOLEDO (Fig. 3).

Moisture content Heat value	15 %	20 %	25 %	30 %	35 %	40 %	45 %	50 %	55 %
$GJ\,t^{-1}$	15,5	14,1	12,9	11,7	10,5	9,4	8,3	7,2	6,2
$kWh\,kg^{-1}$	4,306	3,917	3,583	3,25	2,917	2,611	2,306	2,00	1,722
$kWh\,t^{-1}$	4305,6	3916,7	3583,3	3250	2916,7	2611,1	2305,6	2000	1722,2

Tab.1: Dependence of the heat value of woodchips on the moisture content

Fig.3: Moisture meter HG 63

For the definition of the moisture content of woodchips we use measured values from a fixed time period. From this we calculated the weighted mean value.

Combustion efficiency we calculate with the relation:

$$\eta_{\%} = \frac{Q_V}{Q_P} 100 \, . \tag{3}$$

Heat in the fuel we calculate:

$$Q_P = m \, PCI \tag{4}$$

where: $\eta_{\%}$ – efficiency of the source, %; Q_V – heat produced in the source (measured with a calorimeter), kWh; Q_P – heat in the fuel, kWh; PCI – heat value of the fuel, $kWh\,t^{-1}$; m – quantity of the fuel, t.

The quantity of air pollutants we calculate from the mass flow, which is identified by the experimental measurement with available equipment. For the calculation of quantity of air pollutants was used this relation:

$$E = q \, t \, 10^{-3} \tag{5}$$

where: E – quantity of air pollutants, t; q – mass flow of air pollutants, $kg\,h^{-1}$; t – operating time of the boiler, h.

The fee was calculated in accordance with the supplement No. 2 from the Slovak law No. 401/1998 Z.z. by the means of this universal relation:

$$P_{ZLi} = Z_{Pi} \, K_K \, K_{EL} \sum M_{xi} \tag{6}$$

where: $P_{\mathrm{ZL}i}$ – fee for air pollutant (i) released from the source of air pollution, $Z_{\mathrm{P}i}$ – basic fee for air pollutant (i), K_{K} – compensating coefficient, K_{EL} – coefficient of the emission limit in the case of keeping the emission limit, M_{xi} – amount of air pollutant (i) from the place of output (x) emitted in the case of keeping the emissions limit.

3. Experiments and results

Consumption of woodchips in the observed boiler house in the year 2011 was 3794.7 tons. Total working time of the boiler in the year 2011 was 6 144 hours. The boilers VESKO-B are designed for heating plants for central supply of heat and for industrial boiler rooms. This conception enables to produce a boiler with optimal efficiency in accordance with specific requirements of low pressure hot water (LPHW) networks with the following range of parameters:

- Heat performance 1.0–8.0 MW,
- Operational overpressure 0.35–1.0 MPa,
- Operational temperature 90–110 °C.

The construction of the firebox as well as fuel transport with a hydraulic feed block with great transit performance enables to combust wood waste from woodworking industry, wood cutting, forest work etc. It is a mixture of sawdust, wood cuttings, tree barks, woodchips, wood shavings etc. The boiler is constructed for burning of fuels with moisture content up to 50 %, but it is able to combust the fuel with moisture content of 70 %. In winter season it operates at full performance and the required heat is supplied by one boiler of the three natural gas boilers if necessary. In summer and in transition period is used only this biomass boiler for the production of heat. Its automatic control makes its performance reliably safe in the range from 30 to 100 %.

The boiler VESKO-B was during the measurement of emission values of air pollutants working in accordance with prescribed operational method with full nominal heat performance. In gas emissions which were produced during the combustion of wood matter are present significant shares of CO, NO_x, TOC (total organic carbon) and PM. These gases from the firebox are cleared up. The boiler is equipped with a whirl separator of powder particles and ash, which is installed on the flue at the boiler output. This separator works on the principle of sucking of the boiler output gases. Powder particles separated from these output gases are caught in a container installed under the separator. Purified output gases are taken away with the combustion gases fan through the flue into the atmosphere.

From the measured values presented in Table 2 it follows that all prescribed emission limits for given air pollutants, as can be found in the Notice of the Ministry of Agriculture and Rural Development of the Slovak Republic No. 358/2010 Z.z., were kept. The excess of the limits was not observed in any measurement. This fact is presented in the graph (Fig. 4).

Emission limits are in accordance with the Notice established for stabile equipment for burning of fuels with total nominal heat performance from 0.3 MW to 2.5 MW, namely for equipment with boilers with working permission released until the 31$^{\mathrm{th}}$ December 2010. In accordance with this Notice, for calculation of emission values were used standard state conditions for dry ideal gas at burning of biomass: concentration of ref. Oxygen ($O_{2\,\mathrm{ref}}$) of 11 % of volume.

The total fee for air pollutants released into the atmosphere during the combustion of biomass in the year 2011 was 1208 EUR, after calculation rounded to integers. We present

Emission	O_2	CO			NO_x			TOC		
Taking time	%obj	ppm	$mg\,m^{-3}$	$g\,h^{-1}$	ppm	$mg\,m^{-3}$	$g\,h^{-1}$	ppm	$mg\,m^{-3}$	$g\,h^{-1}$
15:00	13,2	79,7	127,2	1198,00	94	246,1	2316,60	1,2	2,6	15
15:30	12,7	30,7	46,2	460,8	106,2	262	2618,20	1,2	2,3	14,5
16:00	11,9	46,1	63,6	692,5	107,4	243	2647,90	1,2	2,1	14,4
16:30	11,4	73,8	96,4	1110,00	103	220,6	2540,00	1,2	2,1	14,7
17:00	11,4	65	85	976,6	107,5	230,5	2649,60	1,3	2,1	15,2

Emission	PM		Average mass flows				
Taking time	$mg\,m^{-3}$	$g\,h^{-1}$	Air pollutant	CO	NO_x	TOC	PM
15:15	13.19	134,6	Mass flow, $g\,h^{-1}$	887.6	2554.50	14.8	228.9
15:30	19.21	196,7					
16:00	29.55	355,4					

Tab.2: Measured values of observed parameters

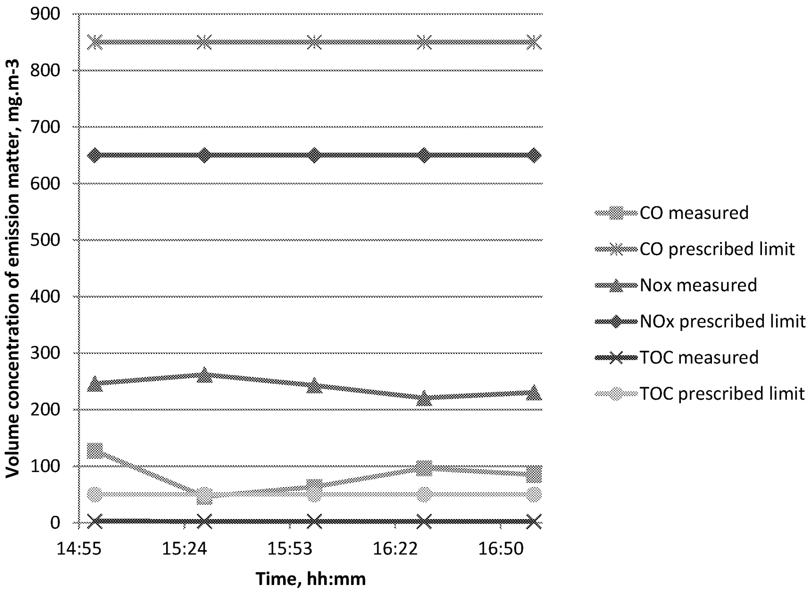

Fig.4: Measured values of volume concentrations of emissions of air pollutants and of emission limits

the following expample to provide better understanding of the amounts and costs. By consumption of biomass of nearly 3795 tons and operational time of the biomass boiler of 6144 hours, the total amount of produced heat was nearly 9172 MWh. From these values we calculated the fee for air pollution in the total of 1208 EUR. For the same heat production from natural gas is the consumption nearly 975 000 m^3 of natural gas and the fee for air pollution is 121 EUR.

Fuel storage is one of the most significant problems in the operation of a boiler house or a biomass heating plant. Therefore it is necessary to follow the safety principles and proper methods of biomass storage. From the guiding principles for storage of solid biofuels we choose the following examples: woodchips and sawdust should be stored in free piles without moving up to 60 days; temperature in a recently formed pile of woodchips or sawdust is measured by a thermometer, in the depth of 1.5 m and in the distance up to 10 m one from another, once a day. If the temperature does not exceed 35 °C during the first week, it is possible to extend the measuring interval to three days. After three weeks of storage it is possible to extend this interval to once a week. If the temperature in the pile reaches 50 °C or it increases of more than 3 °C in 24 hours, it is necessary to shovel or rearrange the woodchips or sawdust.

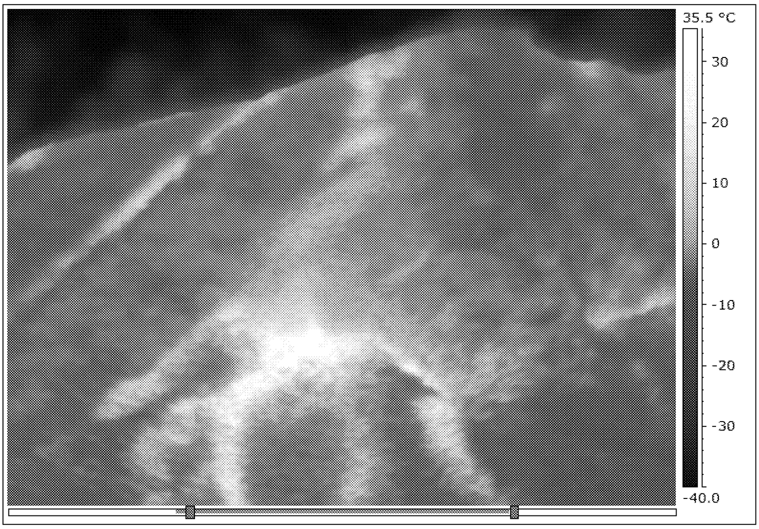

Fig.5: Thermovision screen photography of stored woodchips

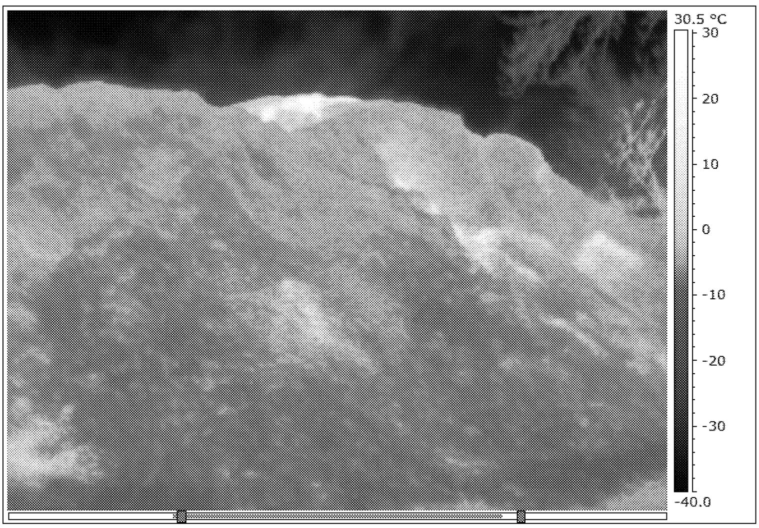

Fig.6: Thermovision screen photography of stored woodchips

For the evaluation of storage space condition we used the infrared camera from the company FLIR, type T 335. From the examination of the stock and from the screenshots we drew the following conclusions. In order to prevent mashing and the risk of self-ignition it is necessary: to form piles of fuel with only one top to eliminate the rain water flow into the pile; to accumulate fuels of the same sort and fraction; to provide fuel supply if possible only with the good quality material with low relative humidity (maximum 40 %); to accumulate fuel with approximately the same moisture content; not to form too high piles if possible; to prevent moistening of the stored fuel; to cover the whole storage space despite the higher costs.

Fig. 5 and 6 show that the maximum surface temperature of various piles ranged from 30 °C to 36 °C. These differences are related to the quality and especially to the humidity of the pile, where woodchips with higher moisture content in damp weather start to mash and the decay process accompanied by rising temperature begins. Recommended time for consumption of fresh produced woodchips is up to 15 days, maximum up to three months, because the decay process proceeds gradually and after the second month is the volume loss of the stored woodchips nearly 5.5 % in a month. The problem of volume loss of the stored dry woodchips due to the bacterial activity was not observed in practice.

4. Discussion

Biomass has global potential for exploitation in power engineering by replacing fossil fuels with intention to emphasize the support of renewable sources. Emission limits are for NO_x 650, for CO 850 and for TOC 50 mg m^{-3}. If we compare the maximum values of measured parameters, we can state that in all cases are the measured values lower than permitted limits. It may be concluded that the accordance with required values was achieved in all cases. These permitted limits are established in the Notice of the Ministry of Agriculture and Rural Development of the Slovak Republic No. 356/2010 Z.z., § 9, point 4. According to Janíček (2007), exploitation of biomass as a source of energy significantly contributes to economic development of the countryside in developed as well as in developing countries. This transition to the biofuel production results in the increase of profit in agriculture, diversification in agricultural production and reduction of emissions in power engineering. The increase of profit leads to other (indirect) advantages, such as revival of the local economy.

In spite of the fact that significance and support of renewable sources is widely discussed, contemporary law regarding fees for air pollution is not established in favour of these sources. Obviously, the reason can be found in considerably higher amount of emissions of air pollutants than occurs in the combustion of natural gas. For example, it is nearly 19 times more emissions of particulate matter, even in the case that the heat equipment has a whirl separator, the amount of CO is nearly 13 times higher, and NO_x nearly 9 times higher than in the heat production from combustion of natural gas.

5. Conclusion

Apart from the fact that biomass is considered the most significant renewable source of energy and there is no need to further discuss its economic suitability, particularly when it comes from domestic supply, the attention is paid to the environmental aspects. To state that the combustion of biomass releases the same amount of CO_2 that was consumed during its growth is not satisfactory. The obtained results demonstrate that the observed heat source in the company Dalkia Vráble a.s. fulfils all established technical parameters and environmental limits as well. The combustion of woodchips seems economically advantageous; production of emissions does not exceed permitted limits. From the evaluation of the operation of the woodchip stock by the means of the thermal imaging camera we concluded that in order to maintain high quality of the stored fuel and to provide highly efficient combustion it is necessary to manage the logistics of supply in a way which ensures only short-term storage. It is also recommended to cover the whole storage space in order to prevent moistening of woodchips which accelerates its deterioration. The operation of biomass heat source supports regional employment in the process of production and transport of this fuel. Moreover, the operator benefits from the convenient input prices of this fuel and there is also a positive influence on the landscaping.

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