DEVELOPMENT OF THE BOILER FOR COMBUSTION OF AGRICULTURAL BIOMASS BY PRODUCTS

by

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Republic of Serbia consumes about 15 million tons of equivalent oil per year. At the same time potential of the renewable energy sources is about 3.5 Mtoe per year. Main renewable source is biomass, with its potential of about 2.6 Mtoe per year, and 60% of the total biomass source is of agricultural origin. Mainly, that type of biomass is collected, transported and stored in form of bales. At the same time in one of the largest agricultural companies in Serbia there are over 2000 ha of soya plantations, and also 4000 t per year of baled soya straw available, none of which being used for energy purposes. Therefore, efforts have been made in the Laboratory for Thermal Engineering and Energy of the Vinča Institute to develop a technology for utilizing bales of various sizes and shapes for energy production. Satisfactory test results of the 1 MW experimental facility – low CO levels and stable thermal output – led to the building-up of a 1.5 MW soya straw bales-fired hot water boiler, with cigarette type of combustion, for the purposes of greenhouse and office heating in the PKB. Further more, achieving good results in exploitation of that hot water boiler, the next step is building up the first combined heat and power (electricity) production facility, which will use agricultural biomass as a fuel, in Serbia.

Key words: *biomass, cigarette combustion, low CO emission, combined heat and power facility*

Introduction

There is a growing need for utilization of alternative, renewable energy sources in Serbia, which is caused by rising price of fossil fuels with gradual exhaustion of their reserves, and limited available reserves of fossil fuels, especially those of high quality. On the other hand, it is necessary to harmonize the energy production legislation and practice in Serbia with the directives of the European Union, in the sense of intensifying the utilization of renewable energy sources and thus reduce pollution and greenhouse effect. Nearly two-thirds of renewable energy sources (RES) in the European Union (EU) stem from biomass, including wastes [1].

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Serbia has ample biomass resources, consequently in the total energy balance of the country biomass represents a true energy potential.

Serbia consumes about 15 million tons of equivalent oil (Mtoe) per year. At the same time potential of the renewable energy sources is about 3.5 Mtoe per year. Main renewable source is biomass, with its potential of about 2.6 Mtoe per year, and 60% of the total biomass source is of agricultural origin. Mainly, that type of biomass is collected, transported, and stored in form of bales.

Production of cereals leaves straw residue, which, in some cases, exceeds grain quantity by up to three times. Straw, which is usually baled, is a secondary agricultural product with a considerable energy potential. It is a cheap and available fuel, but its utilization is linked to the problems of its collection, preparations for its transportation (cutting, tying into haystacks, baling), transportation, and storage [2]. These problems are less significant and easier to handle if the biomass is used for energy purposes near places of its collection, in enterprises dealing with agricultural production, where the obtained energy – heat – could be used for heating of greenhouses, stables, poultry raising farms, offices, *etc*. [3].

Therefore, efforts have been made in the Laboratory for Thermal Engineering and Energy of the Vinča Institute to develop a technology for utilizing bales of various sizes and shapes for energy production. The development began with the design and building up of a small-scale hot water boiler, with thermal power of 50 kW, for combustion of small cubic soya straw bales [4]. Although this was a small-scale application, developed for an individual farmer for the purpose of house heating, it represented a good base for the development of industrial scale straw-fired facilities – furnaces and boilers.

Before the actual scaling-up of the baled straw-fired hot water boiler to thermal power of 1-5 MW could have been done, the combustion conditions had to be tuned up, bearing in mind the experience gathered during the development of the small boiler. Hence a real-scale demo energy production facility – furnace – with combustion of large rolled soya straw bales (1.2-1.5 m in diameter), which were available at PKB Corporation (Agricultural Corporation PKB) at the time, and with thermal power of 1 MW, has been developed.

Based on conclusions drawn from combustion tests carried out on the experimental 1 MW furnace, a real-scale hot water boiler for greenhouse and office heating, with thermal power of 1.5 MW and combustion of soya straw bales, has been designed and built, and started with work in February 2008. The boiler house is placed on the fields belonging to the PKB Corporation, in the immediate vicinity of the greenhouse complex.

In Serbia there are few boilers and furnaces burning baled biomass, and their technical level could be considered as low [5].

Description of the facility

At the time when the boiler was being built-up, rectangular soya straw bales were produced on the fields of PKB Corporation, with dimensions 0.7 × 1.2 × 2.0 m. Average lower heating value of this fuel is 13686 kJ/kg, and its density is 130-140 kg/m^3. A scheme of the energy production facility – hot water boiler with combustion of these bales – is given in fig. 1 (vertical cross-section) and fig. 2 (horizontal cross-section).

The fuel – baled straw – (position 1, fig. 1) is fed to the facility by cylinder-type bale transporters (2, 3). After entering the rectangle-cross-sectioned bale feeding channel (4), bales are carried by a motor-driven, VSD-controlled conveyor (6) towards the furnace (7). The section of the channel (4) nearest to the furnace is made of multiple steel sheets (5), with primary air flowing through space between the sheets, thus cooling the sheets and being pre-heated at the same time. The furnace is made of refractory material – chamotte (8), and is completely insulated (9). Ash is removed from the furnace by a transporter (10). Pre-heated primary air (13) is supplied around the bale, and a portion of it also from under the grate (12), which is water-cooled. Secondary air (11) is supplied through the movable cross onto the bale forehead. The cross also serves as bale support from the forehead, for shaking-off ash from the forehead and for bale positioning inside the furnace. Leaving the furnace chamber, the flue gases pass through a heat pipe to the first section of the gas-to-water heat exchanger (14), and then through a chamber with screen-barrier--type particle separator (15) to the second section of the heat exchanger (16). After final particle removal in the multi-stage cyclone-type separator (18), the flue gases, transported by the flue gas fan (19), leave the furnace through the stack (20). The boiler is operated and controlled by a SCADA-based system, through a PC.

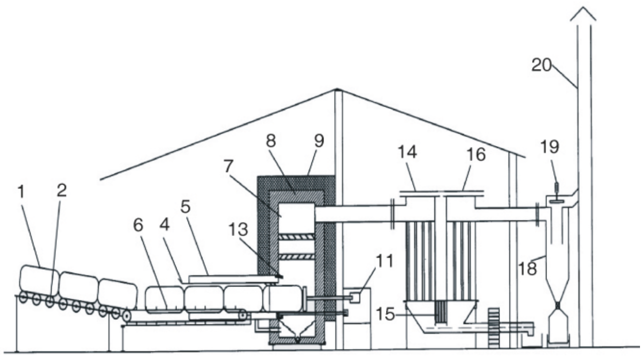

Figure 1. Boiler house – vertical cross-section

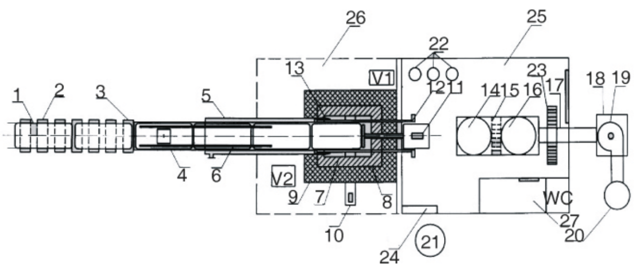

Figure 2. Boiler house – horizontal cross-section

Legend: *(1) straw, (2,3) transporter, (4) feeding channel, (5) channel, (6) conveyor, (7) furnace, (8) chamotte, (9) insulating material, (10) ash transporter, (11) secondary air supply, (12) grate, (13) primary air supply, (14) heat exchanger, (15) particle separator, (16) heat exchanger, (17) flue gas channel, (18) cyclone, (19) flue gas fan, (20) stack, (21) heat accumulator, (22) water preparation, (23) stairs, (24) boiler fittings, (25) boiler house, (26) awning, (27) control room*

Apart from the presence of the movable cross – used for secondary air supply – which can be considered as innovative, another new concept is the existence of a 100 m^3 heat storage vessel – heat accumulator with thermal insulation (21). It was introduced so that the whole facility could respond more appropriately to the heating needs of the greenhouses. Hot water produced in the boiler is stored in the heat storage vessel. At times when the ambient temperature is relatively high and weather conditions are mild (sunny days, without wind), the boiler produces much more heat (hot water) than necessary for greenhouse heating. The greenhouse heating system "takes" only the amount of hot water necessary for heating, and the heat (hot water) surplus is stored inside the heat storage vessel. At times when outside temperature is below zero, on windy and cloudy days, the heat produced by the boiler might not be sufficient, and then is the lacking heat supplied from the heat storage vessel [6].

Figures 3 and 4 show boiler facility and part of the greenhouse with ground heating.

Figure 3. Boiler facility

Figure 4. Part of the greenhouse with the ground heating for the replantation

Cigarette-type combustion of baled biomass has also been recognized by the EU as the most suitable method to be utilized for burning baled agricultural residue, as shown in tab. 1. Apart from being used as primary fuel, biomass is often used in co-combustion with fossil fuels, even in large-scale utilities [7]. Whereas forest biomass utilization is quite simple, the use of agricultural biomass for energy production faces quite a lot of difficulties [8]. One of the most dis-

Table 1. Biomass for the heating purpose [9]

		Fire-wood	Wood chips	Wood powder	Pellets	Briquettes	Straw
(1)	Open fire-place	0	–	–	–	0	–
(2)	Manual stove	+	–	–	–	+	–
(3)	Automatic burner	– –	+	–	+ +	– –	+
(4)	Batch combustion	0	– –	– –	– –	–	+
(5)	Fixed inclined grate	– –	+	–	+	–	–
(6)	Traveling grate	– –	+ +	–	+ +	–	+
(7)	Vibrating grate	– –	+	–	+	–	+
(8)	Underfed stoker	– –	+	–	+	– –	–
(9)	Dust burner	– –	– –	+	– –	– –	–
(10)	Cigar burner	– –	– –	– –	– –	– –	+ +

Note: Combustion systems (1)-(3) are suitable for small-scale applications, while combustion systems (4)-(10) are appropriate for large-scale facilities

Legend: (– –) not possible; (–) not appropriate; (0) the penalties are compensated to a given extent by the advantages; (+) appropriate; (+ +) very appropriate advantageous is that its ash has an excessive inclination towards melting, and problems with slagging and fouling in biomass-fired facilities are present even in case of co-combustion.

Test demonstration and results

Fuel tested

As it was said earlier baled soy straw has been used as a fuel. In tab. 2 has been shown data about proximate and ultimate analysis of used biomass.

Ash fusion test (AFT) has been shown in tab. 3

Table 2. Proximate and ultimate analysis

Ultimate analysis				Proximate analysis		
C [%]	H [%]	S [%]	O [%]	Moisture [%]	Ash [%]	H_d [kJkg^{-1}]
45	7	0.1	47	11.35	6.49	13981

Table 3. Ash fusion test

Temperature	Oxidation atmosphere
Sintering temperature	1185 °C
Softening temperature	1310 °C
Half sphere temperature	1420 °C
Melting temperature	1450 °C

Test trials

During the test the following measurements were made:
- flue gas temperatures in the combustion zone, T2,
- flue gas temperature at the furnace exit, T3,
- temperatures in the ash collector, T4 and T5,
- flue gas temperatures at inlet and outlet of heat exchangers,
- water temperatures at inlet and outlet of heat exchangers, and
- flue gas concentrations at the boiler exit (CO, CO_2, O_2, SO_2, and NO).

Measurements of the temperature were performed with thermocouples (type K, Chromel-Alumel), and acquisition is done with the SCADA system and computer. Gas concentrations were measured with three gas analyzers, Servomex, 4900 C1, M&C Products Analysetechnik GmbH, and Fuji Electric Sysmes Co. Ltd. Flue gas was sampled using a sampling line, which were consists of a probe, hoses, filters, and conditioners for quick drying and mechanical separation of impurities from flue gases for analysis.

Biomass flow rate is measured and during experiments average value was 0.12 kg/s.

During the test the power of the boiler was varied (1.52-1.59 MW) by changing fuel (biomass) flow rate and air flow rate by a SCADA-based system, through a PC.

Test results

Figure 5 shows movements in the measured temperatures for a period of five hours.

In figs. 6, 7, 8, and 9 has been shown the test results about flue gas concentrations, power, and efficiency of the boiler during experiments. Vertical lines in figures show the moment of the new ball put on the transporter.

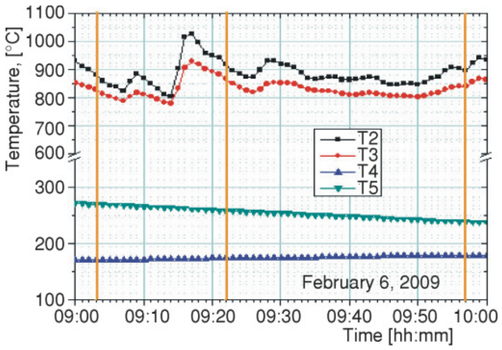

Figure 5. Temperatures in the furnace and in the ash collector

Boiler test results have been shown in chosen working regime during one hour in stationary conditions. Power of the boiler was regulated by adjusting fuel flow rate and primary and secondary flow rate, whereby temperature of the flue gas was kept up constantly. Mean value of the boiler power during the test was 1.56 MW, with mean value of the excess air 2.1. Temperature of the exhaust flue gas in stationary regime was around 150-160 °C. With this combustion conditions, and taking into account that it was fully combustion, from fig. 6 can be seen that mean value of CO concentration was around 120 ppm (150 mg/m^3 calculated for 11% O_2), mean value of the boiler efficiency was 83%. This value is obtained taking into account concentration of the oxygen in exhaust flue gases.

The Book of Regulations on emission limitations, issued by Serbian Ministry of Environmental Protection [10] recommends that furnaces and boilers burning wood, briquettes, and waste biomass should satisfy certain CO and NO_x limitations. During these tests, CO emission varied in a

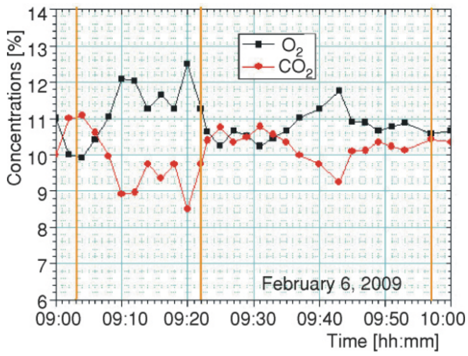

Figure 6. Concentration of O_2 and CO_2

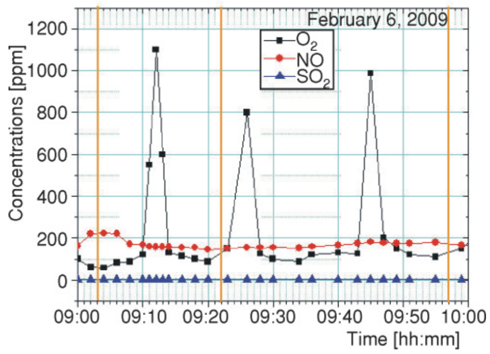

Figure 7. Concentration of CO, NO, and SO_2

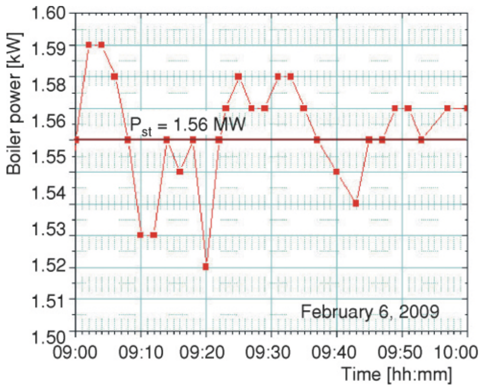

Figure 8. Power of the boiler

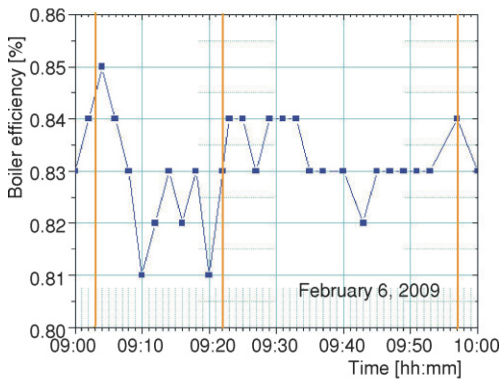

Figure 9. Boiler efficiency

wide range, but at times when stable regimes were established, it was below the emission limit (for furnaces and boilers with power 1-50 MW it is 250 mg/m^3, calculated for 11% O_2). The nitrogen oxides emission was around 160 ppm (215 mg/m^3), which is below the 500 mg/m^3 limit.

The temperature in the combustion zone was mostly between 850-900 °C, which is safely value from ash sintering point of view. According to AFT of the ash, see table 3, sintering temperature is 1185 °C. On the other hand this working temperature is enough high for the quality combustion process [11].

During experiment the sample has been taken from multi-cyclone and by the standard procedure has been determined that content of unburnt in the ash was 3.95%.

Since this is a demonstration facility, which served to proof the used technology for biomass combustion, it has only multi cyclone for particle separation, with efficiency of maximum 95%, which indicates that this multi cyclone can not satisfy environmental protection regulations on particle matter emission. In the case of building commercial facility electrical filters would be installed and environmental protection regulations on particle matter emission would be satisfied.

Conclusions

The development of the technology for efficient and environmentally acceptable utilization of baled straw at the Vinča Institute, through its phases, came to fruition by building-up of the first boiler of this kind in the Agricultural Corporation PKB near Belgrade. The boiler is meant for heating of 2 ha of greenhouses, and additional capacities are planned on site in the near future.

This technology enables by-products from agricultural production to be used, which increases the revenue from agricultural production and at the same time preserves food production balances and decreases pollution. This technology could also be used for the combustion of energy crops, which is of importance for Serbia. Cigarette-type combustion of baled biomass has also been recognized by the EU as the most suitable method to be utilized for burning baled agricultural residue, and has been used recently in a wide range of facilities in the EU, especially in Denmark.

After achieving good results in exploitation of this hot water boiler, the next step is building-up the first combined heat and power (electricity) production facility (CHP), in Serbia, which will use agricultural biomass as a fuel.

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