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Influence of biomass furnace volume change on flue gases burn out process

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ABSTRACT

In this paper has been shown improvement of the existing furnace for biomass combustion in the way of improving energy efficiency and meeting environmental protection criteria. One of the main problems during baled biomass combustion process is high CO emission due to incomplete combustion of flue gases. By proper furnace dimensioning that problem can be avoided and also high investment costs can be reduced, since the cost of the furnace is 30–40% of total biomass plant costs. Two-dimensional turbulent flow model with homogeneous chemical reactions has been developed. Turbulent flow is considered using time averaging *Navier–Stokes* equations that are closed by $k-\varepsilon$ turbulence model. Calculations based on the proposed models were conducted using commercial CFD package *FLUENT*. Accuracy of the model has been previously confirmed with experimental data obtained on the existing furnace. Comparative analysis of the results of modeling existing and proposed (improved) furnace has shown lower CO emission (more than 50% less CO emission) at the proposed furnace outlet.

1. Introduction

In regard to sustainable energy development not only in Serbia, but also in the whole world, there is a growing need for using renewable energy sources. A need for the utilization of this kind of energy sources is imposed by both the market demands and environmental protection criteria. Since in Serbia available reserves of fossil fuels, especially those of high quality, are relatively limited, the use of renewable energy further gains in importance. Besides, it is necessary to harmonize the energy production legislation and practice in Serbia with the relevant European Union directives, in terms of intensifying the utilization of renewable energy sources and in this way reducing detrimental pollution and greenhouse effect.

Technically usable energy potential of the renewable energy sources in the Republic of Serbia is very significant and estimated at over 4.3 million tons of oil equivalent per annum [1] - of which 2.7 million *toe* per annum lies in the production of biomass, 0.6 million *toe* per annum in the unused potential of hydro-energy, 0.2 million *toe* per annum in already existing geothermal sources, 0.2 million *toe* in wind power and 0.6 million *toe* per annum in solar energy.

Currently, only a small portion of waste biomass is being used in heat and electricity production (without taking into account burning in small ovens in the individual households), for several reasons: low electricity price and unresolved problems in biomass gathering. Also, there is neither regulated biomass market nor technologies developed for its utilization as a fuel. Besides, low purchasing power of potential buyers and costly commercial credits as well as total absence of state subsidies for biomass facilities is worth mentioning.

The biomass boiler described in the present paper has been operating properly for a long period of time, burning soybean straw. However, in order to review deficiencies and improve further work it is necessary to perform many experimental studies on the boiler. In addition to experimental research it would be very useful to develop a mathematical model of the process occurring in the furnace, which would contribute to the better understanding of biomass burning mechanism and discovering the possible flaws in its design, as well as creating opportunity for the improvement of performance from the standpoint of energy efficiency and environmental protection.

Researches in this area are very complex and for obtaining reliable data it is necessary to carry out theoretical and experimental research of the process.

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2. Furnace for biomass combustion

Over the past couple of years, in the Laboratory for Thermal Engineering and Energy, considerable efforts have been made to develop a technology which would enable biomass bales of various sizes and shapes to be used for heat production. For this purpose, a 1.5 MW industrial-scale hot water boiler was constructed and installed in the Agricultural Corporation Belgrade [2]. The boiler is based on waste baled soybean straw combustion, and it is used for heating 1 ha of greenhouses. Combustion in the boiler is based on so-called "cigarette" principle, where 0.7 × 1.2 × 2.0 m straw bales are used as fuel.

Baled biomass is fed (Fig. 1, item number 1) into the combustion chamber (12) through a water-cooled inlet (2) using a piston feeder (3), which is powered by a suitable hydraulic system (5). The primary air for combustion, which is divided into two parts, is provided through primary air fan (4). One part of the primary air is injected below and above the bale whereas the second one passes through the storage of ash (7), where unburnt particles and ash falls through water-cooled grate (11) and burn out in the fluidized bed of their own ash. For maintaining the desired height of fluidized bed the ash is removed from the furnace by a conveyer (6). Secondary air is injected through a water-cooled secondary air inlet (8) directly into the combustion zone of coke residue. This cross-like element is able to move translatory and rotationally. By translatory movement of this cross-like element the furnace power is regulated allowing for the smaller or larger amounts of biomass to be involved in the combustion process whereas by rotational movement the ash and partially burnt biomass from the top of the bale is removed. Secondary air is provided by a fan (9), while translational and rotational movements of the cross-like element are ensured by the transmission mechanism (10). Upon leaving the combustion chamber (12), flue gas passes through a heat pipe (13) and enters the first and second section of the gas-to-water heat exchanger (14 and 15). After leaving the heat exchanger, cooled flue gases enter the cyclone filter (16), and then forced by fan (18) into the chimney (17).

In the combustion facilities, which are using biomass as fuel, a well designed main combustion chamber is very important, while other elements such as heat exchangers and flue gas dusters can be like those in any other boiler plant for solid fuels combustion [2,8]. Therefore, optimally sized combustion chamber is of great importance. For this purpose, in addition to extensive experimental research, it is very important to develop a detailed mathematical and numerical model in order to describe the reliability of the burning out process of the flue gases, produced during the combustion process. In addition, the possible effects of changes in furnace construction would result in better combustion in terms of both energy efficiency and environmental protection. Of course, the economic factor should not be ignored, because by the properly sized furnace the high investment costs can be also avoided. Considering the fact that for the construction of the existing furnace 40 tons of chamotte were used any reduction in the combustion chamber volume, without compromising the quality of the flue gases, is desirable. Taking into account that the price of 1 kg chamotte is about 1 euro indicate that great savings can be achieved. Also it should be noted that the cost of building biomass furnace is 30–40% of the total biomass plant investment.

3. Mathematical modeling

Since the previous analyses [3] confirmed the efficient operation of the furnace, the question arises whether the same effect could be achieved with some similar furnace of smaller volume. As it was previously mentioned any reduction in combustion chamber volume will lead to reduction in investment cost and accordingly to cheaper energy obtained from this facility.

In the analysis presented in this paper the furnace depth was reduced from 1.5 to 0.7 m, while its other dimensions remained the same (height 3 m, width 1.2 m). The width of the furnace had to remain the same because it was dictated by the size of baled biomass given that the analysis was done for the same type of fuel (soybean straw) and same bale size. The height of the furnace also remained at the existing level, because the idea was to decrease the furnace depth but to leave the flue gases enough time to stay at high temperature, and thus enable the completion of burnout process. Also, three compartments featured within the combustion chamber, compared to only two at the existing furnace, allow for the better mixing of the flue gases due to the extension of their pathway.

The validity of applied mathematical model has been confirmed by good agreement with experimental data shown in Ref. [3]. This model is applicable on all developed turbulent flows, in this case well known $k-\varepsilon$ and eddy-dissipation model [2,3,5,6,13], both

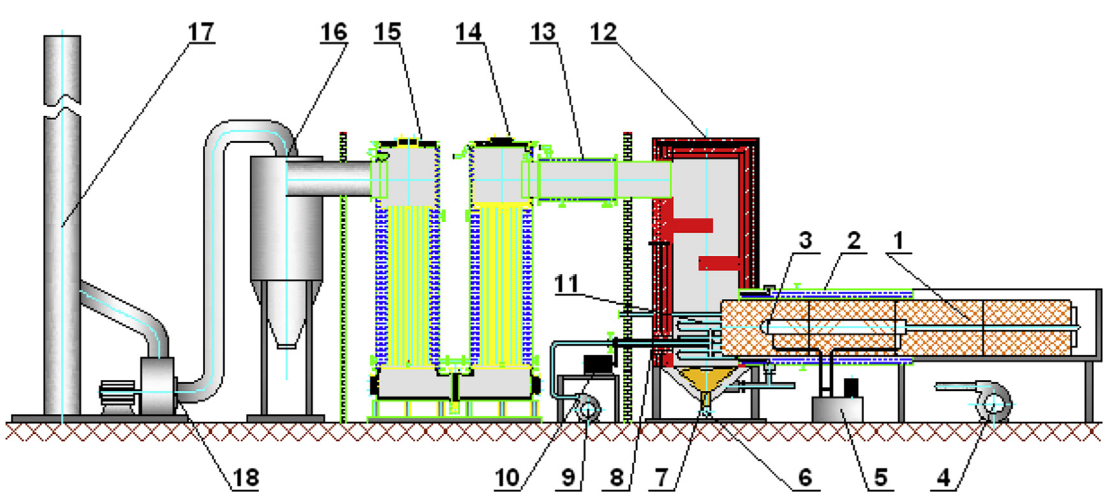

Fig. 1. Scheme of the biomass boiler. 1 – baled biomass, 2 – water-cooled inlet, 3 – hydraulic conveyer, 4 – primary air fan, 5 – motor driven VSD controlled conveyor, 6 – ash conveyor, 7 – ash collector, 8 – secondary air inlet, 9 – secondary air fan, 10 – mechanical actuator, 11 – water cooled grate, 12 – furnace, 13 – heat pipe, 14,15 – heat exchangers, 16 – multicyclone, 17 – stack, 18 – flue gas fan.