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Investigation of the cigar burner combustion system for baled biomass

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ABSTRACT

Biomass is deemed to be the main source of renewable energy in Serbia. Over the past couple of years, considerable efforts have been made to develop a technology which would enable biomass bales of various sizes and shapes to be used for energy production. A hot water boiler with cigarette type of combustion was constructed and used in the experimental investigation of biomass combustion phenomena. During the experiments performed, numerous parameters were measured: flue gas temperature, water temperature at the boiler inlet and outlet, while O_2, CO_2, CO, SO_2, and NO_x content in the flue gas was measured at the boiler outlet. Experiments were performed with biomass feed rate of 0.12 kg/s, mean boiler output of 1.56 MW and mean excess air coefficient of 2.1. During the steady state boiler operation, exhaust gas temperature was measured to be around 150 −160 °C and obtained CO and NO_x emission rates were found to be quite acceptable. In addition, combustion of biomass bales in cigar burners was modelled by the means of appropriate numerical simulation. A good agreement between experimental and numerical results was obtained.

1. Introduction

In 2011, the average annual energy consumption in the Republic of Serbia was around 15 million tons oil equivalent (Mtoe), out of which 7.4 Mtoe represents the net consumption and 3 Mtoe is electricity consumption. Energy generated by coal combustion accounts for 7.9 Mtoe (52%) of the total annual energy consumption, 4 Mtoe (27%) is provided by liquid fuel combustion, 2.1 Mtoe (14%) by natural gas combustion, while 1 Mtoe (7%) is provided by hydropower utilization [1]. Serbia's potential in renewable energy sources equals approximately 4.3 Mtoe/year (2.7 Mtoe biomass, 0.6 Mtoe small hydropower, 0.2 Mtoe geothermal energy, 0.6 Mtoe solar energy and 0.2 Mtoe wind energy). The specified biomass energy potential mainly represents the potential of agricultural biomass, which accounts for 60% of total biomass potential, while the remaining 40% is the potential of forest biomass [2].

Agricultural biomass is mostly available as biomass bales. There are only few boilers and furnaces burning biomass bales in Serbia, all characterized by very poor performance. The main cause of this situation appears to be the absence of

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properly organized energy market, as well as insufficient number of biomass energy consumers.

Boilers and furnaces combusting biomass bales can be manufactured with a rated output ranging from 0.1 to 10 MW. The use of biomass bales for energy production does not require large investments associated with fuel preparation nor it consumes significant amount of energy per kg of biomass bales used. Use of straw for energy production is associated with different logistic problems (collection, preparation for transport, transport and storage). The problems are less significant and easier to handle if biomass is used in energy generation facilities located in the vicinity of the biomass collection sites.

The use of renewable energy sources is becoming more and more important [3], mainly due to continuously increasing prices of fossil fuels, resource depletion and global attempts to achieve maximum feasible CO_2 emission reduction [4]. The use of biomass fuel has significant environmental benefits since biomass combustion is associated with no net increase in atmospheric CO_2. In this manner, the use of biomass can play a crucial role in the achievement of the Kyoto Protocol goals, accepted by the Republic of Serbia as well. Therefore, great efforts have been made to develop a technology which would enable biomass bales of various sizes and shapes to be used for energy production [5].

2. Biomass-to-energy conversion technologies

Technologies enabling biomass use for energy generation are mainly dependant on biomass characteristics. Different biomass conversion technologies available on the market include [6,7]: fixed-bed combustion, combustion on the grate, combustion in dust burners, fluidized bed combustion and gasification. Literature review [8] provides detail description of all combustion technologies mentioned, including the associated pros and cons.

Basic advantages of available biomass-to-energy conversion technologies include the long history of utilization for the combustion of different fossil fuels, extensive range of equipment suppliers etc. Main disadvantages include the fact that biomass combustion technologies have been shortly in use, as well as inflexibility of combustion technologies with respect to the biomass varieties combusted and lack of well-proven technologies for agricultural biomass combustion [4]. Although the use of forest biomass for energy production is deemed quite simple, utilization of agricultural biomass faces a lot of challenges. One of the main disadvantages is a tendency of agricultural biomass ash to melt.

For the combustion of biomass bales two technologies are currently used. The first is based on whole-bale combustion in the combustion chamber, while the second considers combustion of biomass bales in cigar burners. The first technology is associated with poor combustion control, while the other one can provide better process control. The “cigar” firing technology provides better quality of the combustion process, resulting in lower pollutant emissions and increased plant efficiency. Cigar burner combustion system is also recommended by expert committees of the European Union as the most suitable technology for the combustion of baled agricultural residues [6,9].

Cigar firing technology developed in Denmark [10,11] has been designed exclusively for the combustion of straw bales and is deemed suitable for the combustion of whole-crop bales. A cigar-burner combustion facilities also have been constructed in Schkoelen, Germany (3.15 MWth) and Duernkurt, Austria (2.18 MWth). A cigar firing combustion system is expected to exhibit the following advantageous features: a) combustion of whole bales and whole energy crops; b) compact combustor design; c) short start up period, good load-following performance; d) profitable operation of smaller facilities (down to 1 MWth); e) division of combustion from the heat recovery system, usable not only for the provision of steam (for heat generation or CHP), but also as a hot gas generator in industrial drying applications.

Cigar burner combustion system promises a more competitive use of renewable for “green” heat and power generation as well as their use in various industrial applications. Possible disadvantages of cigar burner combustion system include: a) a need for a “smart” and sophisticated process control system; b) thermal attacks on the metal in combustion chamber.

3. Materials and methods

Grain production provides large quantities of straw residues, which, in some cases, may exceed by up to three times the amount of grain produced [2]. There are two basic types of agricultural bales produced: small bales (usually 40 × 50 × 80 cm square bales) and large bales (usually ø180 × 120 cm cylindrical bales or 80–120 × 70 × 150–250 cm square bales). Each form and size of biomass bales is associated with certain advantages and disadvantages with respect to the baling rates, prices of baling presses, transportation and storage providing means, stowed position for transport or storage, etc. The research investigation described herein was focused on developing a cigar burner combustion system suitable for the bales combustion of various sizes and shapes and their utilization for energy production.

3.1. *Experimental facility*

The initial set of analyses carried out in the research investigation conducted focused on the combustion of small bales in cigar burners. For that purpose, an experimental, 75 kWth hot water boiler was designed and constructed [12]. The furnace was built entirely out of an insulating material providing favourable biomass combustion conditions. In order to properly determine required design parameters and provided a good basis for development industrial scale straw-fired facilities appropriate tests were conducted.

Combustion of rolled ø1.8 × 1.2 m bales in cigar burners was analyzed in the next investigation phase. In order to assess the combustion quality and obtain data needed for proper design of the hot water boiler, a 1 MWth demonstration furnace was constructed and tested [5].

A pilot plant capable of burning large 0.7 × 1.2 × 2 m bales was designed and built as a result of the specified investigation