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AN OVERVIEW OF BIOMASS COMBUSTION TECHNOLOGIES WITH AN EMPHASIS ON THOSE FOR AGRICULTURAL BIOMASS

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Abstract. *Nowadays increasing energy needs are experienced, while facing environmental issues as air pollution, global warming and acid rains. Due to many disadvantages of fossil fuels biomass is considered as a possible replacement. For energy purpose biomass could be used in direct combustion or in biogas and biodiesel production. This paper provides a review of different direct biomass combustion technologies, with emphasis on agricultural residual biomass as an energy source. Properties of biomass being used directly affect design of combustion furnace and operating parameter. Many agricultural raw materials which might be considered as a potential waste in fact have a great energy potential and when used for combustion this waste management problem can be reduced or even solved. With biomass usage potential issues are present as storage, high moisture contents, lower heating values and possible high emission of NOx during the combustion. New promising technologies and conventional combustion systems have been considered, among which are furnaces with combustion on grade, pulverized combustion, combustion in the fluidized bed and combustion in pushing furnace. Different agricultural biomass types are contemplated, alongside with applied technologies. Systematic comparison of described technologies is given in accordance with several different criteria, including overview of advantages and disadvantages. To achieve sustainable energy development, new technologies are necessary as well as advancement of the existing ones. In order for that to be achieved, it is important to systematize and categorize biomass combustion technologies.*

Key words: *combustion technologies, agriculture (residual) biomass, cigarette (cigar) combustion*

1.INTRODUCTION

Nowadays increasing energy needs are experienced, while facing environmental issues as air pollution, global warming, and acid rains. Due to the many disadvantages of fossil fuels, biomass is considered as a possible replacement. For energy purposes, in Serbia, biomass is mostly used in direct combustion. It is estimated that 63% of the biomass in Serbia comes from agricultural production 1.. Many residues of agricultural goods, which might be considered as a potential waste have a great energy potential. When used for combustion, this waste management problem can be reduced or even solved. This paper provides a review of different direct biomass combustion technologies, with emphasis on the agricultural residual biomass as an energy source. Lately, there is more focus on the research of the type of biomass that is burned. Thus, in scientific papers, in addition to straw, sunflower husk, oats, root crops, and sewage sludge, the spent coffee grounds, tea leaves, spent mushroom substrate and olive cake are also mentioned 2.– 5.. For biomass usage, potential issues are storage, high moisture contents, lower heating values, and high emission of NOx. Other challenges that must be taken into consideration for biomass combustion technologies are shown in Fig. 1.

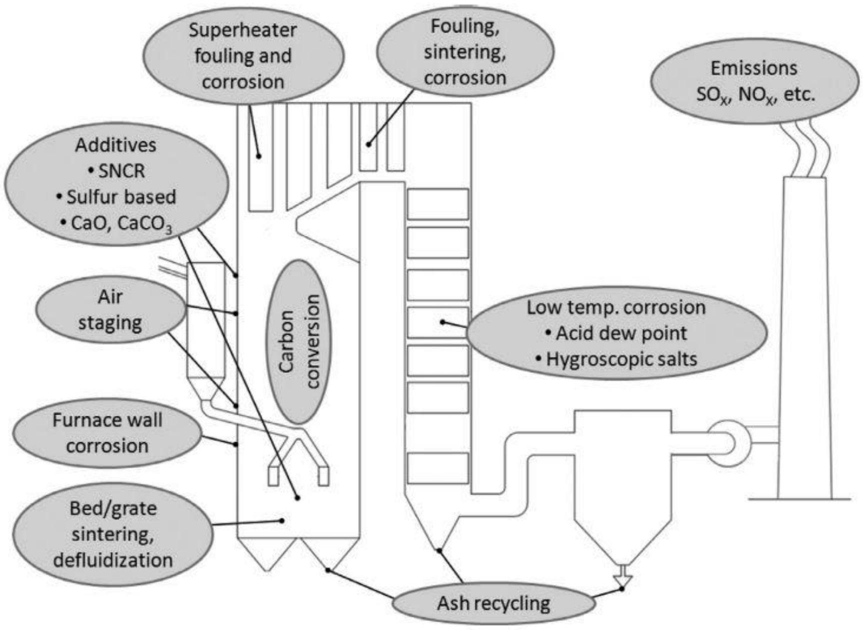

Fig. 1 Biomass combustion technologies: chemistry-related challenges 6.

2. BIOMASS COMBUSTION TECHNOLOGIES

The most commonly used technologies for agricultural biomass combustion are fixed-bed combustion with grate furnace, pulverized combustion, and fluidized bed combustion. The usage of different types of biomass in the same boiler significantly complicates its operation. However, that can be convenient due to the uneven availability of agricultural biomass throughout the year. Biomass combustion systems that have been considered in this review are shown in Fig. 2. Comparison of these technologies concerning temperature, mixing conditions (turbulence), and needed residence time is shown in Table 1.

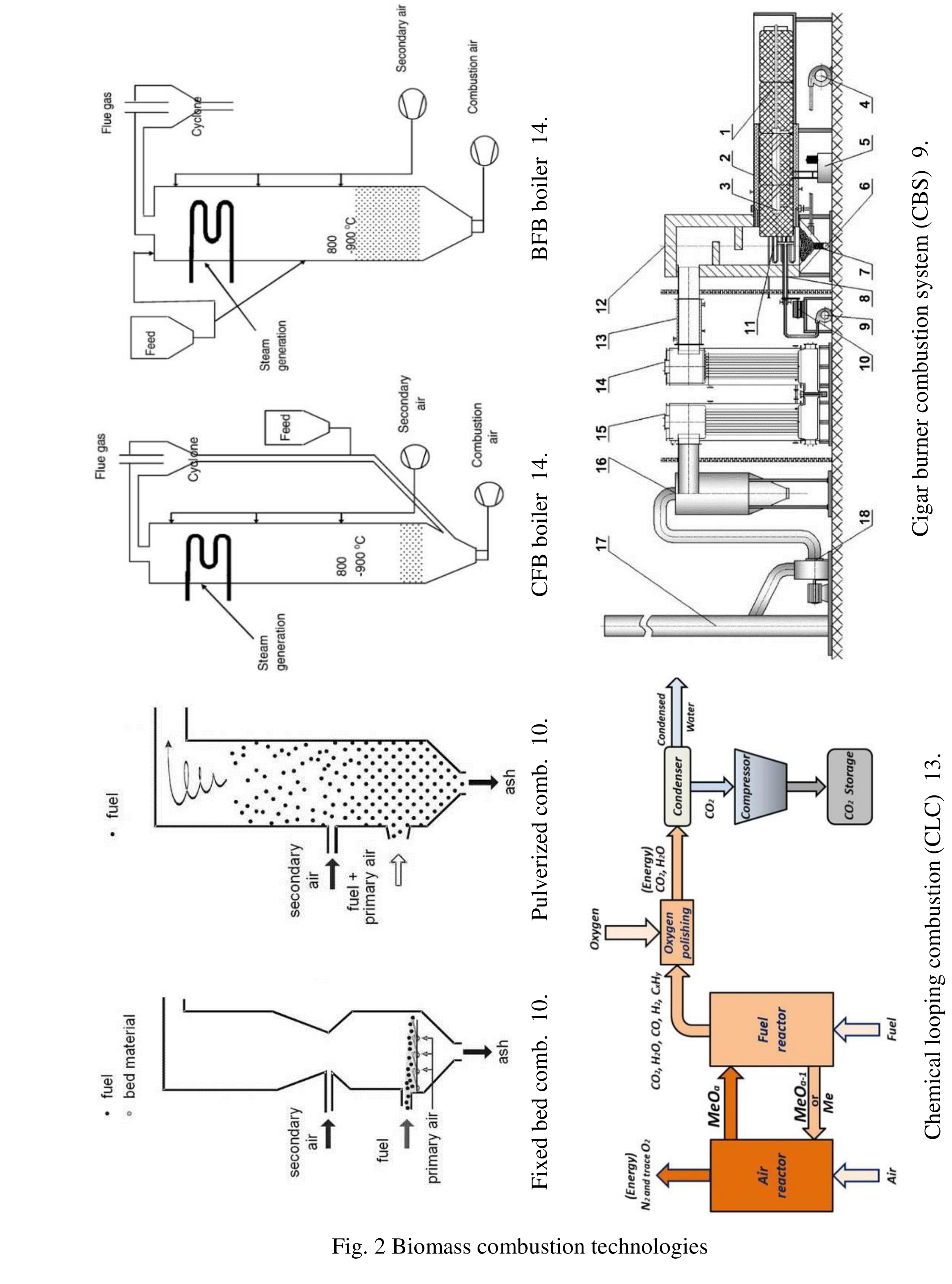

Fig. 2 Biomass combustion technologies

Table 1 Temperature, turbulence and residence time for combustion technologies 7.

Grate furnaces	Pulverized combustion	Fluidized bed combustion
Intermediate temperature	High-temperature	Low-temperature
Low mixing	Good mixing	Good mixing
Very long residence time	Very short residence time	Long residence time

1.1. Fixed bed combustion

Fixed bed combustion technologies can be divided into systems with grate furnaces and underfeed stokers. There are various solutions for **grate furnaces:** fixed grates, moving grates, traveling grates, rotating grates, and vibrating grates. The difference in grate design allows the combustion of different types of fuel. These technologies have a great ability to adapt to various fuel types. The primary air supply must be divided into sections so that adjustment to the required amounts of air for different combustion zones is possible. The effect of air supply and oxygen (O_2) enrichment on the biomass combustion in the grate boiler was investigated by 8.. It was concluded that O_2 enrichment of the primary air flow promotes the fuel burnout, but also increases the maximum temperature. They suggested that it is optimal for the secondary/primary air ratio (SA/PA) to be 57/43 for the 1.5 excess air, which is similar to the air ratio mentioned by 7. (SA/PA tends to be 60/40). Other suggested improvements are flue gas recycling (FGR) and optimized grate assembly. With FGR the excess air, slagging, as well as emissions of NOx and dioxins could be reduced. However, there are various practical difficulties that come with FGR in these systems. For high-moisture fuels, like silage and municipal solid waste, grates can be air-cooled. As a result, grates are kept under relatively high temperatures 7..

Cigar burner combustion systems (CBS) are developed for bale combustion (straw and cereal). Hot water CBS boiler with thermal power of 1.5 MW is shown in Fig 1. Firstly, bale (1) is delivered to the isolated combustion chamber (12) through a water-cooled feeding channel (2) by a hydraulic feeder (3). Through an air fan (4) primary air (PA) is provided for combustion. PA is divided into two streams, the first is distributed around the bale and the second air is entered through the ash hopper, at the bottom of the furnace (7). The screw extractor (6) is used for the ash (7) removal and maintenance of the fluidized bed, of own ash, height. During combustion, ash falls through a water-cooled gate (11). The secondary air is delivered with an air fan (9) into the combustion zone through a water-cooled inlet (8), which can partially translate to regulate power and rotate to remove ash with a partially burnout segment from the front part of the bale. These movements are provided by the transmission mechanism (10). Flue gas exit combustion chamber (13), enter the first (14) and the second (15) sections of the heat exchanger (gas-water), flow through multi-stage cyclone (16) and leave the system. Flue gas extraction is achieved with the flue gas fan (18), through the chimney (17) (Fig. 2). Experimental investigation of CBS was performed by 9.. It was concluded that described technology is convenient for agricultural biomass with higher ash melting temperature, such as soybean straw. In cases of lower ash melting temperature, like the one that wheat straw has, the usage of additives is necessary. During the combustion of soybean straw bales, a slightly higher NOx emission was recorded and therefore, denitrification methods have to be applied. In 1., alongside primary measures for deNOx, selective catalytic reduction and selective non-catalytic reduction techniques were suggested.

Underfeed stokers, so named because they use ram to force a fuel up underneath the burnning fuel bed, are considered safe and inexpensive. The fuel is fed from below with screw conveyors. Afterwards, it is transported upwards to the grate. The grates can be outer or inner, but the first solution is more often implemented due to the easier appliance of the automatic ash removal system. The combustion air is divided into two streams, the primary air is introduced through the grate, while the secondary air is provided at the beginning of the secondary combustion chamber. Underfeed stokers provide good flexibility for load changes and their control. One of the important problems that could arise with this technology is the appearance of ash deposits on the upper surface. 10.

1.2. Pulverized combustion

Pulverized biomass combustion systems can be found in literature as suspension-fired furnaces. The term suspension comes from the fact that biomass has a fibrous structure very difficult to fracture. During pulverized combustion, biomass particles have a larger size and uneven shape compared to coal. For pulverized combustion, a significant amount of energy is required for biomass preparation. Fuel is injected into the furnace with the primary air which is used as a transportation fluid. Pulverized coal combustors were widespread, their adaptation for biomass combustion still presents a challenge. Overcoming such problems for small and intermediate, horizontally fired, industrial scale boilers was investigated by 11.. They suggested including a pre-combustion chamber for performance improvement of the adopted pulverized coal combustor (0.5 MW). Pulverized straw combustion in a low-NOx multifuel burner was researched and compared to coal combustion by 12.. They noticed that straw flame was significantly longer and that the particle size of biomass, as well as their shape and distribution, are the most influential parameters during combustion. Alongside the particle size, biomass quality must be constant. Fuel supplying can be problematic due to possible explosion-like gasification 10.. This technology enables good flexibility in load changes.

1.3. Fluidized bed combustion (FBC)

During fluidized bed combustion, the primary air is supplied from below, through a nozzle distributor plate. This affects the formation of fluidized bed, the mixture of particles and bubbles at high temperatures. The bed consists of solid particles (silica sand, dolomite, etc.) located in the bottom of the furnace, which has been stationary before start-up. **Bubbling fluidized bed (BFB)** is characterized by lower fluidization velocities (1-3 m/s) compared to **Circulating fluidized bed (CFB)** (3-6 m/s). Due to higher velocities in CFB solid particles are continuously taken away from the bed, increasing height above distributor plate. For CFB, the external cyclone is necessary to separate the bed particles and return them into the bed alongside the additional particles and fuel. The fluidized bed has a defined surface for BFB and has to be heated before fuel (1-2 % of the bed material) is fed. The cyclone separator exists in solution with the BFB furnace as well, the difference is that separated particles are usually taken out of the system. The secondary air is supplied at the top of the bed (and higher). FBC is characterized by low excess air needed, good mixing conditions, and intense heat transfer. For FBC usage of high alkali biomass, such as agrarian, is problematic due to ash agglomeration.

1.4. Chemical looping combustion (CLC)

Chemical looping combustion is novel combustion technology with carbon dioxide capture. Oxygen carrier (OC) is used for oxygen transport between two reactors - fuel reactor (FR) and air reactor (AR). OC consists of metal particles, usually metal oxide. After oxidation in AR, oxidized OC is introduced into FR for fuel combustion (oxidization of the fuel, reduction of OC to metal or less oxidized state). Afterwards reduced OC is supplied into AR and through oxidization with air returned to initial state. Then OC is once again brought to the FR in the second loop, hence the name chemical looping combustion. Important for CLC is that the flue gas does not include nitrogen, mostly it is from carbon dioxide and water vapor. The main advantage of CLC is that carbon dioxide capture is possible. Most of the fuel reactors used are based on fluidized bed reactors. For solid fuel usage, the reaction between fuel and OC is slow, so improvement is needed: fuel gasification inside FR with the recirculated flue gas (in situ gasification chemical looping combustion) or usage of specific OC as copper oxide (chemical looping oxygen uncoupling). For OC is important to have a high melting temperature, high oxygen transport capacity, good fluidization characteristics, a great thermodynamic and kinetics capability of convert fuel to H_2O and CO_2 in the CLC operation, without releasing carbon dioxide from the AR, low cost and to be safe 13.. Although tests have been performed with biomass, and especially on mixtures of biomass, as a highly volatile fuel and coal, as a fuel with a highly pronounced char content, this technology has not yet come to practical application on large-scale systems. What is posed to the authors as a crucial issue is the economic viability of such systems that would be applied to real-scale plants, because biomass is already considered as a CO_2 neutral fuel that is therefore not subject to CO_2 taxes.

3. CONCLUSION

To achieve sustainable energy development, new technologies are necessary as well as the advancement of the existing ones. For that to be achieved, it is important to systematize biomass combustion technologies. This paper is providing a review of existing technologies and summarizing their most important features. A comparison of described technologies is given in Table 2 with their main advantages and disadvantages. Description of biomass content is given alongside types of biomass that could be used. Serbia has a significant potential for biomass usage, which is not used enough. This is especially present for biomass from agriculture. Switching to biomass combustion instead of coal combustion would result in carbon dioxide reduction, which presents one of the major issues nowadays. However, for agricultural biomass to truly be considered a renewable energy source, it needs to be used in the right way. This includes the control of nitrogen oxides, which are especially present for this type of biomass (due to the high content of bound nitrogen in the fuel), as well as emissions of particulate matter. Solutions for overcoming the limitations of biomass usage could be the development of new and improvement of existing combustion technologies, as well as the modification of existing coal combustion plants.

Table 2 Overview of biomass combustion technologies 5., 9., 10., 13-15.[1]

	Advantages	Disadvantages	Fuel - Biomass
Grate furnaces	Low operating cost Slagging is less problematic	No mixing with wood fuel Combustion conditions not homogeneous deNOx measures are necessary[2]	High moisture content Various fuel particle size High ash content Good fuel flexibility; Mixtures[3] (vibrating grates, rotating grates)
Cigar-firing	Low investment and operating costs Compact combustor design Short start-up period Combustion of whole bales No energy consumption for fuel preparation Good load-following performance	deNOx measures are neccesary[1] Sophisticated process control system Larger storage space	Biomass bales (straw and cereal)
Underfeed stokers	Continuous fuel feeding Low fuel mass in the furnace Good partial-load behavior	Not applicable for fuels with high ash content and low ash-melting point such as agricultural biomass	Fuel particle size <50mm Low ash content Woodchips, sawdust, pellets
Pulverized bed	deNOx with air staging Good load control	Limited fuel particle size Hard fuel preparation with high energy consumption Low fuel flexibility Extra start-up burner is necessary	Fuel particle size <10-20mm Sawdust and fine shavings
CFB furnaces	Without moving parts in the combustion chamber deNOx by air staging Not sensible to the moisture content in fuel High specific heat transfer capacity	High investment and operating costs Bed agglomeration, high dust load in flue gas (higher than BFB) Sensitivity to ash slagging Loss of bed material	Fuel particle size <40mm Various fuel mixtures Not for high alkali biomass fuels
BFB furnaces	Without moving parts in the combustion chamber deNOx by air staging Not sensible to the moisture content in fuel	High investment and operating costs Bed agglomeration, high dust load in flue gas	Fuel particle size <80mm Various fuel mixtures Not for high alkali fuels Low ash-melting temperature
CLC	Efficient char conversion Power generation with integrated carbon capture Flue gases free of nitrogen	Difficult to achieve full volatiles conversation The effect of biomass alkalis is not well known Formation of deposits, corrosion, bed agglomeration Not tested on systems larger than 50 kW	Methane, hydrocarbons (propane, ethane) Co-firing with sulfur-containing fuels, or using sulfur addition

[1] Fuel particles size from [10]

[2] Primary and secondary measures (Combustion control and flue gas treatment)

[3] Hard to achieve, applicable only with mentioned furnaces, hence they provide good mixing conditions

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