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Oxy-combustion of agro and wood biomass in a fluidized bed

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Abstract. Present trends in the global energy sector effectively drive the development of technologies using renewable energy sources and the improvement of combustion technology towards increasing its efficiency and removing environmentally harmful flue gases. One solution is to replace fossil energy sources with renewable sources, including biomass. The degree of biomass utilization depends on the size of resources and processing technology. There are more and more different types of biomass on the market. There are many technologies for its energetic use. In recent years, fluidized combustion technology has been considered as one of the main directions of development of professional energy in the world. Many units in the world in fluidized combustion technology use as primary or supplementary fuel: sludge, wood waste and biomass, as well as municipal waste, etc. Fluidized bed boilers also allow the implementation of the dynamically developing oxy-combustion technology, which perfectly fits the prevailing trends due to the key advantages of increased energy conversion, as well as the possibility of direct sequestration of carbon dioxide. During experimental research, the mass loss of biomass pellets of various origins was analyzed in an oxidizing and inert atmosphere in a two-phase flow with the use of inert material. The obtained results allow to state that the large variety of biomass offered by suppliers requires a thorough knowledge of its properties and determination of its impact on the process and installations when used in the power industry.

1 Introduction

Growing concerns on the greenhouse gas emissions and their potential impact on climate change demand not only the application of CO_2 capture and storage (CCS) technologies to large point anthropogenic CO_2 emission sources such as coal and natural gas fired power plants but also the implementation of CO_2 negative combustion technologies such as Bio-energy with Carbon Capture and Storage (BECCS) with in the next decades. [1,2]. Biomass is considered as a renewable fuel, a carbon-neutral energy source [3], and hence its combustion integrated with CCS can lead to negative CO_2 emissions. Biomass has already captured worldwide attention in the context of greenhouse gas control even though fossil fuels are expected to retain their dominant role in the world energy supply in the coming decades [4]. Oxy-combustion is one of the most developed CCS technologies and considered as technically feasible and economically competitive for future commercial applications [5, 6, 7]. Oxy-combustion refers to fuel being burned in a mixture of oxygen and recycled flue gas (RFG). Unlike conventional air combustion plants that use air as the oxidant, an oxy-fired plant employs an Air Separation Unit (ASU) to produce an almost pure oxygen stream. The oxygen stream is then combined with RFG to produce an oxygen enriched gas as the oxidant. The flue gas recycle is necessary to moderate the otherwise excessively high flame temperature that would result from fuel combustion in pure oxygen. After the removal of water and other impurities from the flue gas exhaust stream, high-purity CO2 (up to 95%) is produced and almost ready for sequestration [1].

Among all the available combustion technologies, fluidized bed combustion (FBC) is often considered as the best choice for the combustion and/or co-combustion of biomass, waste and other low-quality solid fuels due to its fuel flexibility, long residence times, and uniform combustion temperatures. The characteristics of FBC also offers several advantages for its application in oxy-fuel systems [8]. Firstly, the difficulty of flue gas recirculation for temperature control in pulverized fuel (PF) applications could be reduced in circulating fluidized bed (CFB) by means of the bed material recirculation, since the specific heat of the solids is much higher than that of the recycled flue gas. Secondly, lower NOx emissions and better sulphur removal are possible. Finally, it is easier to retrofit a fluidized bed boiler from air to oxy-fuel combustion as there will be no need for a new burner. The effects of oxy-fuel atmosphere and O_2 concentration in fluidized bed systems firing different kinds of coal have been thoroughly investigated during the past years by a number of researchers [8-18] in which the advantages of oxy-combustion have been confirmed, namely: increased energy conversion and the possibility of carbon dioxide sequestration. In general, the experimental results showed that NOx emissions in oxy-fuel combustion with low O2 concentrations are lower than those obtained under air-firing atmosphere Furthermore, NOx emissions were found to increase with the increasing O_2 concentrations in the oxy-fuel oxidant, which is as a result of a) the increase of the temperature in the furnace which elevates the concentrations of O and OH radicals and enhances NO formation and b) the lower gas velocity in the riser and longer residence time of fuel particles in the combustor, which may promote the fuel-N conversion into NOx precursors [13-16]. In some studies, an opposite trend was found, i.e. a decrease of NOx with the increasing O_2 concentration in the oxy-fuel oxidant, as in the work of de las Obras-Loscertales et al. [17], The authors explained this trend by means of the different operational procedure used, comparing with other investigations: in their work [15], an increase in the oxygen concentration was compensated with an increase of the coal flow rate fed to the reactor, keeping constant the total gas flow rate and excess oxygen coefficient in all tests. As a result, more unconverted char was present in the bed, favouring the NO reduction on the char surface.

So far, few researchers have analyzed oxy-fuel combustion in fluidized bed reactors fueled with 100% biomass fuels, so further research is needed.

Biomass properties differ from those of coal in many important ways which results in different combustion behaviours [19]. For example, biomass generally has less carbon, more oxygen, higher hydrogen content and lower heating value. There are huge differences in volatile matter contents between biomass and coal: biomass can lose up to 90% of their masses (as volatiles) in its first stage of combustion [20].

Duan et al. [21] conducted a series of experiments firing three kinds of Chinese biomass fuels, i.e. rice husk, wood chips and dry wood flour, under air and oxy-fuel atmosphere in a 10 kWth CFB combustor. The main objective of their study was to investigate the pollutant emissions of the co-firing of biomass with coal under oxy-fuel combustion conditions although experiments firing only the biomass fuels were also carried out for comparison purposes. They observed lower NO emissions in the oxy-fuel atmosphere compared with those with air combustion. This behaviour was explained as the result of the reduced yield of NOx precursors like NH_3 during the devolatilization process and the enhanced NO reductions via char/NO/CO reactions under the oxy-fuel combustion conditions. The objective of the work [1] was oxy-fuel combustion of biomass fuels firing three kind of biomass fuels, two non-woody (miscanthus and straw) and one woody (wood), in a 20 kWth bubbling fluidized bed (BFB) combustor, studying the effects of the combustion atmosphere (air and oxy-fuel) and the oxygen concentration in the oxy-fuel oxidant on the gas emissions and temperature profiles. In contrast, work [21], unlike the abovementioned, was devoted to the analysis of the combustion of a single biomass particle in a fluidized bed in different oxidizing atmospheres. In this research, spherical 8-mm particles of wooden biomass (willow, Salix viminalis) were used. Biomass was combusted in a fluidized bed at 850 ° C and various atmospheres: air atmosphere: 21% O_2 + 79% N_2 and oxidizing atmospheres: 21% O_2 + 79% CO_2, 30% O_2 + 70% CO_2 and 40% O_2 + 60% CO_2. The results of the experiment indicate that the composition of the oxidizing atmosphere strongly affects the combustion process of biomass fuels. The replacement of N_2 in the combustion environment by CO_2 resulted in a slight ignition delay and lower maximum mass loss during the combustion of raw biomass. Increasing the amount of oxidant resulted in shorter burning time. Unlike studies [21], the experiment described in this work was conducted using applications on the market of processed biomass fuels specifically dedicated to combustion in the energy sector.

2 Motivations

The aim of the experimental research was:

1) analysis of the oxy-combustion process of selected biomass fuels dedicated for combustion in technology with CFB,
2) comparison of the agro and wood biomass combusting process,
3) comparison of the combustion mechanism of selected pellets without inert material and in the conditions of the circulating fluidized bed,

3 Experiment

During the experimental research, the impact of inert material and oxidizing atmosphere on the mass loss of pellets of two types of biomass was analyzed: wood biomass - oak sawdust pellets and pellets from a mixture of sawdust 30% beech / 70% oak) and agro-pellets from sunflower husk and pellets from straw. The temperature of 850 ° was corresponds to the combustion temperature of fuels in professional fluidized bed boilers. The research was performed in air atmosphere and gas compound: 21% O_2 and 79% CO_2, 25% O_2 and 75% CO_2, and 30% O_2 and 70% CO_2. The research was carried out in a stream of inert material Gs=0 kg/m^{2}s, 2,5kg/m^{2}s and 5kg/m^{2}s. The values of the stream of inert material are characteristic for the upper and middle area of the real zone of the fluidized bed boilers.

3.1 Experimental stand

The research was carried out on a specially constructed test stand. The experimental stand made it possible to model the conditions of the circulating fluidized bed.
the experimental stand is presented in Fig. 1. [11].

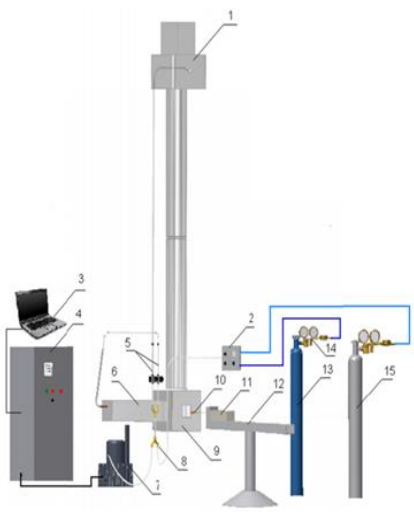

Fig. 1. The scheme of test apparatus. (1) vessel of inert material, (2) gas mixer, (3) PC-computer, (4) control panel, (5) rotametres, (6) gas heater, (7) ventilator, (8) T-connector, (9) combustion chamber, (10) coal particle, (11) tensometric branch scale, (12) support, (13,15) technical gases, (14)-reducer [1].

3.2 Research material

Four types of biomass pellets, each in the shape of a cylinder, were used for the study. Oak sawdust pellets, a mixture of beech and oak sawdust and straw had a diameter of 6mm, while the diameter of pellets from sunflower husk was 8mm. The mass of the samples was 0.73 ± 0.03g. Table 1 contains the results of the technical analysis of the tested fuels.

Table 1. Results of technical analysis of biomass fuels.

Pellets	Volatile [%]	Moisture [%]	Ash [%]	Fixed coal [%]	Combustion heat [MJ/kg]
Oak sawdust	79.6	8.7	1.2	10.5	18.2
30%beech and 70%oak sawdust	77.7	8.8	1.3	10.7	17.9
Sunflower husk	73.8	8.4	5.5	12.3	19.8
Straw	71.8	8.7	12.2	7.3	16.2

4 Results of the experiment

Fig. 2. presents a comparison of pellets combustion time combusted at different conditions in a circulating fluidized bed. Fig. 3. presents percentage comparison of pellets combustion time during reduction of the combustion chamber temperature compared to the reference reference atmosphere (21% oxygen). In all cases, according to the theory, a change in the combustion atmosphere consisting of an increase in the concentration of the oxidizer results in the reduction of the total loss of mass of the biomass pellets combusted. Supplying more oxidizer to the combustion area causes acceleration of the combustion process, therefore the loss of mass is accelerated due to the increased concentration of oxidizer and temperature, which is caused by the occurring chemical reactions. During combusting pellets without inert material, the wood biomass pellets were combusted the longest, and straw pellets the shortest. In the case of pellets combusting in the stream of inert material Gs = 2.5 kg/m^{2}s, wood biomass pellets were the shortest combusted, the longest combusted pellets from sunflower husk. At this temperature the phenomenon of ash softening is manifested by the sticking of sunflower husk pellets through quartz sand. The sand forms a durable surface surrounding the incinerated pellet, consequently preventing the oxidizer from entering the combusted pellet. The residue after combusting sunflower husk pellet at 850°C, tests were carried out in a stream of inert material at Gs = 2.5 kg/m^{2}s was shown in Fig. 4. A similar effect was observed when combusting straw pellets at 850°C. The straw pellets combusted at 850 °C were sintered. The residue after combusting straw pellet at 850 °C, tests were carried out in a stream of inert material at Gs = 2,5 kg/m^{2}s was shown in Fig. 5. With an increased value of the inert material stream to Gs = 5 kg/m^{2}s, similar to Gs = 2.5 kg/m^{2}s of inert, the longest combusted pellets from sunflower husk, and the shortest pellets from forest biomass. In the case of agro biomass combustion, as in the case of combustion in Gs = 2.5 kg/m^{2}s, during the combusting of pellets from sunflower husk, the formation of a coating was observed, which was partially broken down as a result of the mechanical impact of inert material - Fig. 6. On the other hand, the sinter was formed during combustion of straw was completely broken down.

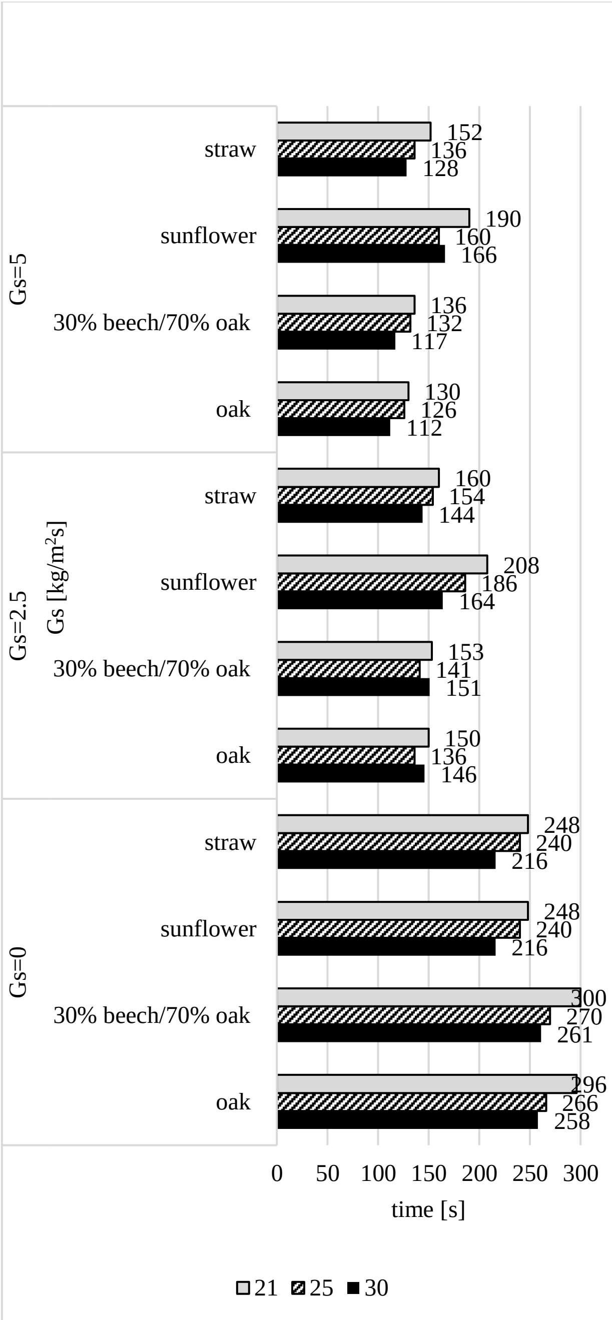

Fig. 2. Comparison of pellets combustion time combusted at different conditions in a circulating fluidized bed.

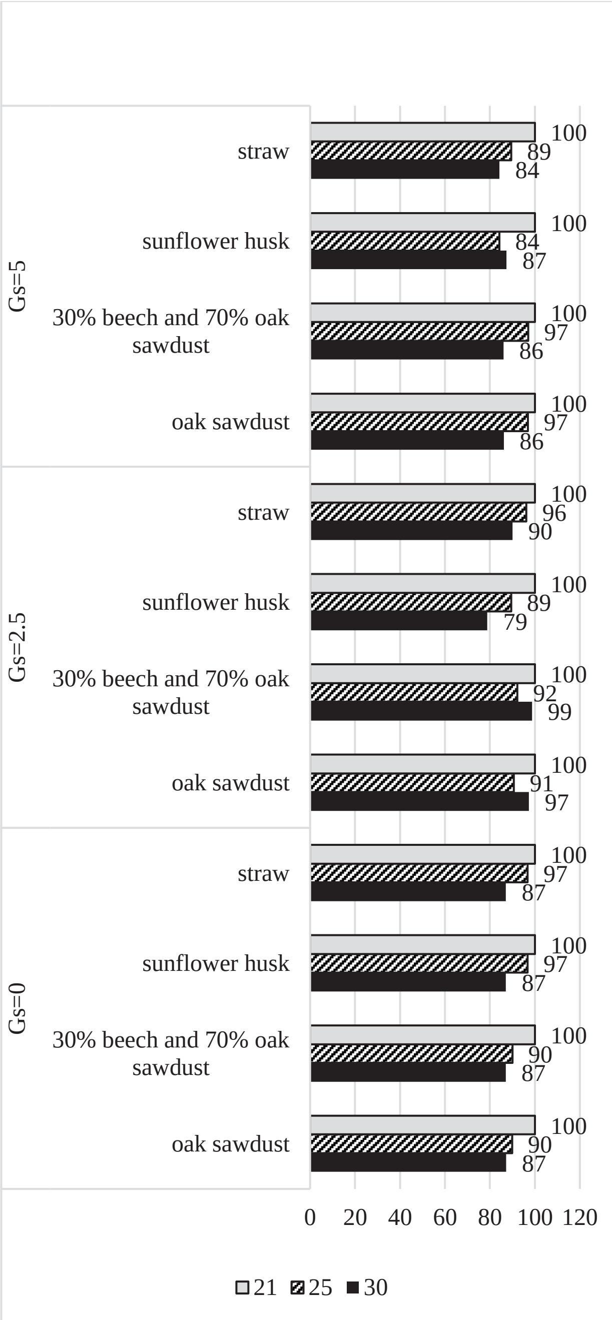

Fig. 3. Combustion times during the change of the oxidizing atmosphere compared to the reference atmosphere (21% oxygen) of all types of pellets.

Fig. 4. The residue after combusting sunflower husk pellet at 850°C, tests were carried out in a stream of inert material at Gs = 2,5kg/m^{2}s.

Fig 5. The residue after combusting straw pellet at 850 ° C, tests were carried out in a stream of inert material at Gs = 2,5 kg/m^{2}s.

Fig 6. Residue after combusting sunflower husk pellets at 850°C and Gs = 5 kg/m^{2}s.

Fig. 7. shows a comparison of pellet combustion times depending on the stream of inert material combusted at different at different atmosphere (Gs = 0 reference level). The presence of inert material to varying degrees accelerates the mass loss of all types of pellets in all atmospheres. In the case of wood biomass, the combustion in the stream of material Gs = 2.5 kg/m^{2}s in each atmosphere is shorter by about 50% compared to incineration without inert material. However, further increase of the inert material stream to Gs = 5 kg/m^{2}s accelerated the combustion process by a further 10%. In the case of combusting sunflower husk pellets compared to incineration without inert material, the combustion time in the stream Gs = 2.5 kg/m^{2}s is reduced by about 20-30%. Increasing the value of inert material stream to Gs = 5 kg/m^{2}s resulted in shortening the combustion time in the case of two oxidizing atmospheres of 21% and 25% oxygen by about 10%, while in the case of 30% oxygen concentration, the combustion time was extended by 1%. In the case of straw pellets compared to incineration without inert material, the combustion time in the stream of inert material Gs = 2.5 kg/m^{2}s is reduced by about 35%. Increasing the value of the stream of inert material caused a reduction of the combustion time by about 10%.

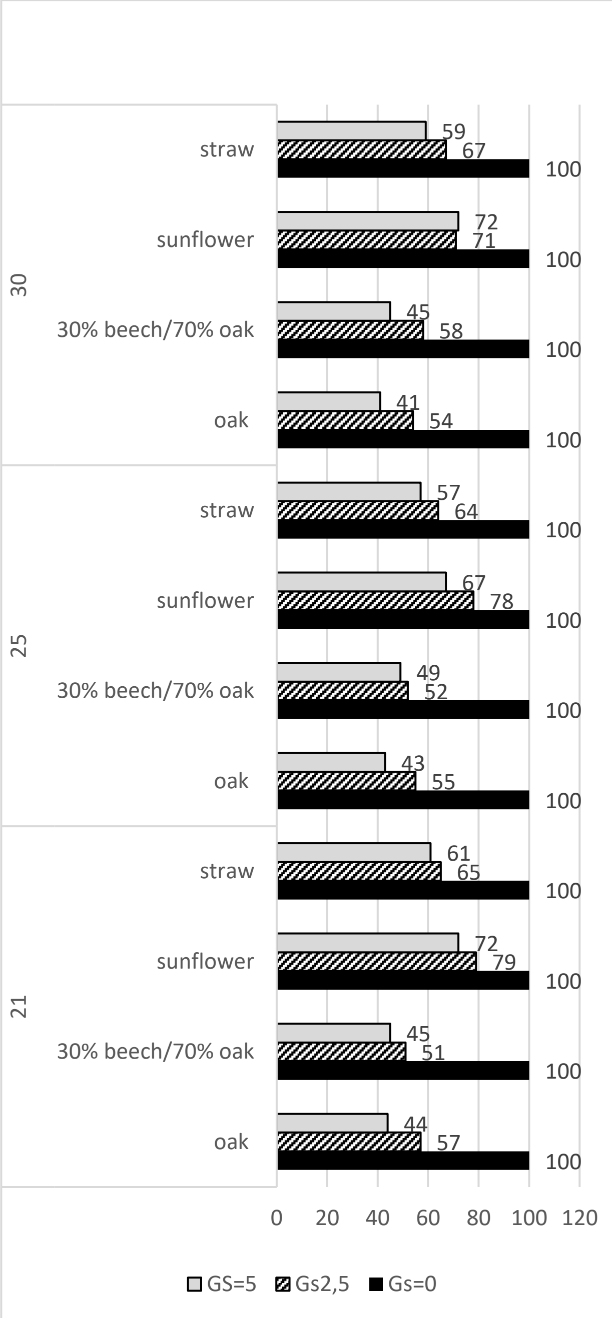

Fig. 7. Comparison of pellet combustion times depending on the value of the Gs material stream combusted at different atmosphere (Gs = 0 reference level).

5 Conclusions

Biomass is a source of energy characterized by dispersion and different fuel properties compared to fossil fuels, among which there should be mention of lower calorific value and high moisture content. Nevertheless, biomass has the highest energy potential as it accumulates a large amount of energy that can be obtained from renewable sources. One of the best methods for direct biomass combustion is that of fluidized bed technology, characterized by high efficiency and stable working conditions as well as the possibility of easily adapting the installation for oxygen combustion of fuels.

The analysis carried out as part of the work facilitates the formulation of the following conclusions:

a) Increasing the concentration of oxidant in the atmosphere of combustion causes the reduction of the time of total mass loss of combusted particles of all tested biomass fuels. According to the theory of providing more oxidizer to the combustion area, it accelerates the combustion process, therefore the mass loss is accelerated.

b) The introduction of inert material into the combustion zone of the particle resulted in the reduction of the total combustion time for all tested fuels in comparison with the combustion time without its participation in each analysed oxidizing atmosphere.

c) In case of combustion of oak sawdust pellets, the inert material at Gs = 2.5 kg / m^{2}s, the total combustion time lasts about 45% shorter than without the inert material in each analysed oxidizing atmosphere. A further increase in the value of the inert material stream results in the reduction of the combustion time by approximately 10%.

d) In the case of the combustion of the sunflower husk pellets in an inert material stream, the ash softening temperature was exceeded and the sample sand was glued through the quartz sand in each analysed oxidizing atmosphere. In the case of combusting sunflower husk pellets in all atmospheres compared to incineration without inert material, the combustion time in the stream Gs = 2.5 kg / m^{2}s is reduced by about 20-30%. Increasing the value of inert material stream to Gs = 5 kg/m^{2}s resulted in shortening the combustion time by another 10%.

e) During the combustion of straw pellets in the flow of inert material, in each analysed oxidizing atmosphere the formation of sinters was observed, which at the lower value of the stream of inert material at the level of Gs = 2.5kg / m^{2}s did not break down. During the intensification of the flow of inert material, the sinters were fragmented due to the interaction of inert material. In the case of straw pellets compared to incineration without an inert material, the combustion time in the stream of inert material Gs = 2.5 kg / m^{2}s is reduced by about 35%. Increasing the value of the stream of inert material caused a reduction of the combustion time by about 10%.

Based on the conducted experimental research, it was found that forest and agricultural biomass can be successfully used during oxy-combustion in boilers with a circulating fluidized bed under several conditions. Due to the chemical composition agricultural biomass (high content of chlorine and elements alkaline) and low temperatures softening and melting ash, it should be combusted under appropriate controlled conditions. Due to significant differences in biomass quality first of all, quality should be monitored fuel supplied to the combustion chamber.

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