

# On the emission issues during co-combustion of hard coal and biomass under pressurized conditions

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## Abstract

Co-combustion of biomass with coal is reasonable way of energy conversion. Co-combustion helps to obtain many advantages like reduction of fossil fuels exploitation, limitation of gaseous pollutants emission, diversification of energy sources and others. This work presents the results of co-combustion of Ziemowit hard coal with willow (*Salix viminalis*) under pressurized conditions in air and oxy-fuel atmosphere. Impact of pressure and combustion regime on emission of main pollutants (NO, SO<sub>2</sub>) is presented and discussed. Experiments were carried out using pressurized, auto-thermal fluidized bed (bubbling) combustor. It was observed that increasing in pressure enhanced limitation of NO and SO<sub>2</sub> emission.

## Introduction

Co-combustion of fossil fuels with biomass has been realized in industrial-scale boilers. Biomass-coal co-firing means reducing CO<sub>2</sub> and SO<sub>2</sub> emissions and it may also reduce NO<sub>x</sub> emissions [1]. Pressurized combustion can enhance limitation of gaseous pollutants emission. It was confirmed that pressurized combustion generate lower NO<sub>x</sub> emission [2-4]. It is suggested that limitation of NO<sub>x</sub> emission from pressurized boilers is caused by NO+char reaction [4, 5]



Another advantage of pressurized combustion is increase of energy conversion efficiency [6-9]. For example Hagi et al. [8] noticed significantly reduce of energy penalty (e.g. lower fan power consumption) when oxy-fuel combustion was realized under higher pressure. Zebian and Mitsos [10] concluded that pressurized combustion was ideally flexible to variations in thermal load.

Pressurized co-combustion of fossil fuel with biomass has been not widely investigated. Especially, impact of pressure and co-combustion on emission of gaseous pollutants are worth to consider. In this paper emission of main gaseous pollutants (SO<sub>2</sub> and NO<sub>x</sub>) from pressurized fluidized-bed reactor was investigated. Experiments were carried out at air- and oxy-combustion mode.

## Experimental

The experiments were performed using a laboratory-scale, fluidised-bed (bubbling regime) combustor that has been described elsewhere [3, 11]. The reactor was made of a stainless-steel tube, and its main parameters are as follows: a reactor diameter of 0.075 m, a height of 1 m, a bed height of 0.25 m, a fuel tank capacity of 0.01 m<sup>3</sup>, and a fuel feed of 0.17–1.19

kg/h. The silica sand of the bed was laid on a ceramic sieve (mesh of 1 mm). Streams of process gases (CO<sub>2</sub>, O<sub>2</sub>, N<sub>2</sub>, and air; technical purity, cylinders delivered by Linde Gaz, Cracow, Poland) were measured, heated, and fed into the bottom of the reactor. Temperature (inside combustion chamber) was measured using K-type thermocouples (with shells). According to the certificate provided by the thermocouple manufacturer, the uncertainty in the measurements was less than 5 °C. A point of the pressure measurement was 1110 mm above the grid (top zone) and 120 mm below the grid. The pressure drop sensor was connected with the system using the mentioned ports (top and bottom). The flow rate of each gas stream was controlled with valves. The pressure inside the reactor was automatically regulated by a spring controller. The flue gas was continuously analysed for CO<sub>2</sub> (0–100 vol %), CO (0–6000 ppmv and 0–50 vol %), H<sub>2</sub>O (0–30 vol %), NO (0–1000 ppmv), N<sub>2</sub>O (0–200 ppmv), NO<sub>2</sub> (0–200 ppmv), SO<sub>2</sub> (0–6000 ppmv), and SO<sub>3</sub> (0–6000 ppmv) using a Fourier-transform infrared (FTIR) analyser (GASMET DX4000), and O<sub>2</sub> (inlet and outlet) was measured using a paramagnetic analyser (Oxymat 61) and a zirconium sensor analyser (AMS Analysen). The measurement uncertainty of the analysers was less than 1.5% of the total measuring range. “Ziemowit”, coal (diameter of 1.4-1.7 mm) and “willow (*Salix viminalis*, diameter of 1.7-2 mm and 2-3 mm) were introduced continuously into the combustion zone using a screw feeder. Table 1 shows ultimate and proximate analysis of applied fuels.

Table 1. Proximate and ultimate analysis of applied fuels (dry-air state)

| Parameter              | Unit  | Ziemowit hard coal | Willow ( <i>Salix viminalis</i> ) |
|------------------------|-------|--------------------|-----------------------------------|
| Moisture (as received) | %     | 12.7               | 8.9                               |
| Moisture               | %     | 3.6                | 6.7                               |
| Ash                    | %     | 24.1               | 2.4                               |
| Volatile matter        | %     | 29.18              | 72.19                             |
| HHV                    | kJ/kg | 22358              | 18477                             |
| LHV                    | kJ/kg | 21449              | 17115                             |
| LHV (as received)      | kJ/kg | 19194              | 16654                             |
| S (total)              | %     | 1.31               | 0.08                              |
| S (in ash)             | %     | 0.27               | 0.02                              |
| S (combustible)        | %     | 1.04               | 0.06                              |
| C                      | %     | 56.2               | 47.4                              |
| H                      | %     | 3.76               | 5.49                              |
| N                      | %     | 0.85               | 0.82                              |
| O (calculated)         | %     | 10.45              | 37.13                             |
| P                      | %     | 0.017              | -                                 |
| Cl                     | %     | 0.431              |                                   |

## Results and discussion

Co-combustion of Ziemowit coal with willow was carried out under overpressure range of 0-5 bar. In all co-combustion cases mass fraction of willow in total mass of introduced fuel was 15%. Fig. 1 shows comparison of SO<sub>2</sub> emission during combustion of Ziemowit coal (only) and co-combustion of the coal with willow. Addition of biomass to combustion chamber caused decrease of SO<sub>2</sub> emission. It was caused partly by decrease of total sulphur content in fuels mixture introduced into combustion chamber. Total amount of sulphur in willow is much more lower comparing to Ziemowit coal (see Table 1). However, effect of SO<sub>2</sub> decreasing was also connected with impact of biomass and coal ash that is converted during combustion process. SO<sub>2</sub> can be captured in reactions with some species of the mineral matter in fuel ash. This process is called sulphur-self retention (SSR). It is assumed that calcium plays a dominant role in the SSR process. The impact of other elements, such as Mg, Al, Fe, K, and Na, are still under discussion [12-16]. It can be noticed from Fig. 1 that SO<sub>2</sub> emission is lower in case of smaller biomass particles. Finer particles have larger surface area. Moreover, devolatilization and combustion of smaller particles is faster thus active compounds of ash for SSR process can be easier activated during combustion process. It is known that SSR occurs during second stage of combustion (char combustion) [17]. Thus, impact of particle size can be also observed for SSR process. Fig. 2 shows the average SO<sub>2</sub> emission during combustion of Ziemowit coal and co-combustion with willow under different pressure at air- and oxy-fuel mode. Increasing in pressure significantly limited SO<sub>2</sub> emission.

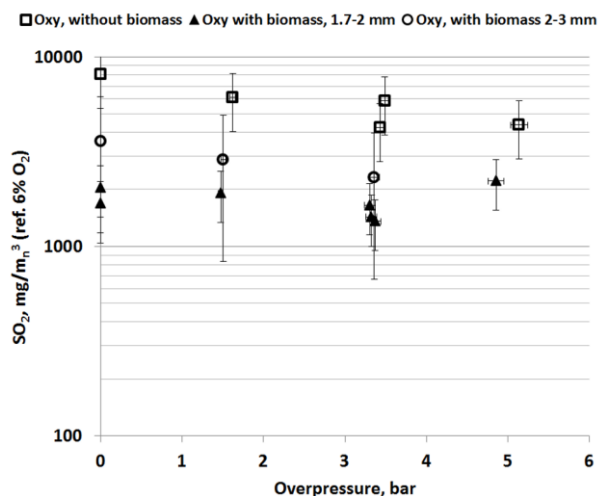


Fig. 1. Impact of pressure on SO<sub>2</sub> emission during combustion of Ziemowit coal and co-combustion of Ziemowit coal with willow. Oxy-fuel O<sub>2</sub>/CO<sub>2</sub> 30/70 %, average temperature inside bed without biomass 900°C±10°C, with biomass 1.7-2 mm 890°C±10°C, with biomass 2-3 mm 900°C±20°C

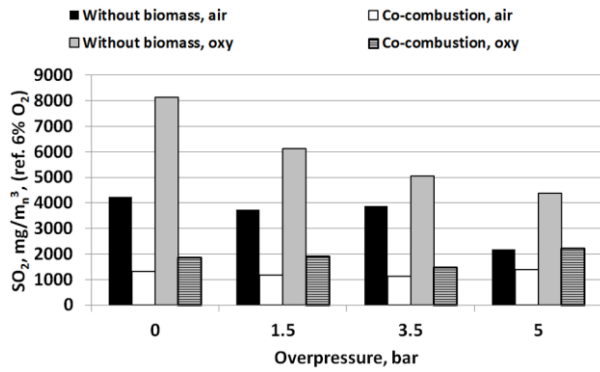


Fig. 2. Average SO<sub>2</sub> emission during combustion of Ziemowit coal and co-combustion with willow (15% by weight, particle average size of 1.7-2 mm) under different pressure at air- and oxy- regime.

Impact of pressure and co-combustion on NO emission is presented in Fig. 3. Decrease of NO emission under higher pressure was observed before [3, 11]. Addition of biomass into the main fuel (Ziemowit coal) caused reduction of NO emission. It is known that this reduction partly came from limitation of fuel-nitrogen due to mixing of coal with biomass containing less amount of nitrogen [18, 19]. However, addition of biomass can create local reducing zones (like during reburning process) and, as a consequence, NO can be reduced. In case of biomass, devolatilization occur at lower temperature and it is faster comparing to the devolatilization of coal [20, 21]. Amount of nitrogen in Ziemowit coal and willow is almost the same (see Table 1), thus limitation of NO emission was mainly caused by creation of local reburning zones. Similar conclusions were presented by Pedersen et al [19] and Armesto et al.[18].

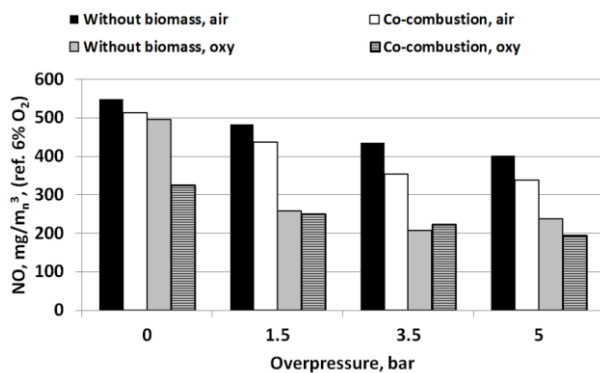


Fig. 3. Average NO emission during combustion of Ziemowit coal and co-combustion with willow (15% by weight, particle average size of 1.7-2 mm) under different pressure at air- and oxy- regime.

## Conclusions

Co-combustion of hard coal and biomass under pressurized conditions was carried out. It was observed that increase of pressure and addition of biomass into main fuel caused beneficial effects of limitation of NO and SO<sub>2</sub> emission. Decrease of SO<sub>2</sub> emission was caused probably by the impact of sulphur retention in fuel ash. Limitation of NO emission was caused by creation of local reburning zones where NO could be reduced. Beneficial impact of pressure

on SO<sub>2</sub> and NO limitation was confirmed. Hence, pressurized combustion can be recognised as environmental-friendly technique for energy conversion.

## ACKNOWLEDGEMENTS

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