



Gas emissions from a large scale circulating fluidized bed boilers burning lignite and biomass



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ABSTRACT

Previously established and validated coal combustion model in a circulating fluidized bed (CFB) was employed to predict co-combustion of lignite and biomass processes. The validity of the model was successfully performed on a large-scale 261 MW_e COMPACT CFB boiler. Forest biomass, sunflower husk, willow and lignite coal were applied in co-combustion tests with different shares of biomass and lignite. The energy fraction of biomass in fuel blend was: 7%, 10% and 15%. Emissions of CO₂, CO, SO₂ and NO_x (i.e., NO + NO₂) from the co-combustion tests, measured during experiments and predicted by model were compared. The gaseous pollutant emissions, evaluated using the developed model were in a good agreement with experimental results.

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1. Introduction

Co-combustion of biomass with coal is one of the ways, that helps to achieve greenhouse gas emission reduction targets. Solid biomass is considered as a renewable source of energy and differs from lignite in many characteristics: carbon, sulfur, oxygen, ash and volatile matter content as well as the heating value [1,2]. In addition, there are also some differences in the content of the other components. Biofuels have high content of sodium and potassium, leading to lowering ash softening points. It may cause operational problems during the combustion process due to e.g. defluidization as the effect of the bed sintering, superheater fouling and high temperature corrosion [1–4].

A thorough review on co-combustion is presented in [3]. Author underlined the decrease of SO₂ with the increase of wood fractions in the fuel blend and the peculiar shape of the curve describing NO emissions. Emission of NO during combustion of alone wood was somewhat higher than that from coal combustion. Nitrogen oxides concentrations first increased with the coal fraction in fuel blend and then decreased. As the explanation author underlined the difference between char content in coal and in wood as char has the capability to reduce NO.

As the coal fraction increased in fuel blend CO emissions also increased. The reason was the nature of volatiles combustion, which takes place in the upper part of the combustion chamber, even in the cyclone, leading to the increase of the temperature and enhancing burnout in this part of the furnace.

Carbon oxide and sulfur dioxide emissions were described as a simple linear functions of the fuel mixture.

Co-combustion tests in a CFB boiler of olive cake, straw pellets, meat and bone meal and wood pellets mixed with bituminous Colombian coal in the proportions of 5, 15 and 25% of biomass by weight was presented in [4]. Authors confirmed, that the combustion of biomass material takes place mainly in the riser, where the temperature was higher than that of the dense bed zone. A decrease of CO emissions was also observed when the fraction of biofuel is increased for all types of biomass. As it was explained, this behaviour could be attributed to the increase of secondary air, due to higher volatile matter and improved mixing in the riser as well as to the increase in the riser temperature from the combustion of biofuel volatiles. Co-combustion of all types of biomass caused lower NO_x emissions even though the meat and bone meal had six times more nitrogen than coal. As the explanation authors underlined the role of DeNO_x mechanism where the NH₃ - the main product of thermal decomposition of amino acid structures, released in higher temperature of the riser react with NO_x forming N₂. The DeNO_x mechanism is favored by the presence of H and OH radicals from volatiles. Co-combustion of biomass resulted also in the SO₂ decrease mainly due to lower S content for all types of biomass than it was for coal.

Different ways in which co-combustion can be organized highlighting the advantages of CFB boilers have been shown in [5]. The co-combustion results of sewage sludge with coal and wood in CFB conditions was described in [6]. Investigation were carried out in a laboratory scale plant and a pilot scale 12 MW_{th} CFB boiler. Authors underlined, that char has the dominant role for NO and N₂O reduction.

Similar results are also described in [7], where the strong dependency of the flue gas composition on the sort of combusted fuel is discussed. Author underlined that there are no sufficient data about the behavior of the fuels when they are burned in the mixtures. The change of the operational condition occurs while the fuel type

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Nomenclature

C	Gas concentration, kmol m ⁻³
C _v	Volume fraction of solids, —
C _{v,d}	Volume fraction of solids in the bottom dense zone, —
C _v [*]	Volume fraction of solids in the upper dilute zone, —
d	Particle diameter, m
dH	Height of each element into which the combustion chamber was divided, m
E	Activation energy, J mol ⁻¹
F _s	Specific surface area, m ⁻¹
L _s	Limestone reactivity, —
H _k	Combustion chamber height, m
k	Chemical reaction rate coefficient, s ⁻¹
$\dot{m}_a$	Air (gas mixture) flux, kg s ⁻¹
$\dot{m}_z$	Fuel flux, kg s ⁻¹
$\dot{n}_i$	i-th gas component flux, mol s ⁻¹
R	Universal gas constant, J mol ⁻¹ K ⁻¹
T	Bed temperature, K
u _b	Share of biomass in fuel blend
V _{b, daf}	Volatile content in biomass material, —
z	Distance of cross-section area from the grid, m
z _d	Bottom region upper limit, m
ρ _p	Biomass material density, kg m ⁻³

Subscripts

b	Biomass
calc.	Data obtained by calculations
exp.	Data obtained in experiment
s	Sorbent

changes, so it is difficult to draw out a synonymous dependence. Author gives a review of some research on the fuel interaction in fluidized bed combustors and describe some results of wood and bituminous coal co-combustion tests, performed by Chalmers University of Technology in Sweden at their 12 MW_{th} circulating fluidized bed boiler. Sulfur dioxide was a linear function of the fuel mixture, similar to the results presented in [3]; the SO₂ emissions increased with the bituminous coal share in the blend of fuels. Author underlined that generally all of the SO₂ originates in the coal as the alkaline ash in the wood is known to be able to capture SO₂ released during wood combustion.

The NO emissions was roughly the same for the pure fuel, i.e. coal and wood, in spite of the fact that the nitrogen content in the wood was about 10 times smaller than one for the coal. It was explained using the NO profiles along the combustion chamber achieved during combustion of pure fuels separately. For coal NO is very rapid formed to very high local NO concentrations (about 380–500 ppm) in the lower part of the combustion chamber and then effectively reduced in the upper part by the high amount of char contained in the bed. For wood combustion concentration of NO formed in the lower part of the fluidized bed remains roughly the same along the rest of the combustion chamber as the bed contained of an order of magnitude less char than it is during coal combustion [7].

A review of combustion and co-combustion of biomass technologies are also given in [8]. Author underlined the decrease of SO_x and NO_x during the biomass and coal co-firing in fluidized beds due to lower sulfur and nitrogen content in biomass than in coal. In addition, the high volatile content in biomass fuels favors the NO_x reduction.

Sami et al. [9] also emphasized the above mentioned DeNO_x mechanism. No increase of the gaseous pollutant emission was observed in [10]. Author described the results of several co-combustion studies

performed under the EU-project “Combined Combustion of Biomass/ Sewage Sludge and Coals of High and Low Rank in Different Systems of Semi-industrial and Industrial Scale”. Some of them were conducted in CFB facilities: 0.3 MW_{th} INETI, 1 MW_{th} CIEMAT, 1 MW_{th} RWE Energie and 80 MW_{th} CFB at Grenaa, ELSAM/Midtkraft.

All partners involved in the project confirmed that biomass co-combustion leads to SO₂ reduction. Some of them underlined that low NO_x emissions of about 200 mg/m³ was roughly the same with biomass addition. Other found decreasing NO_x concentrations in flue gas due to lower fuel-N content in biomass (e.g. wood) [10].

Interesting results obtained during co-combustion of pine bark with lignite and bituminous coal in the CIEMAT 0.3 MW_{th} CFB boiler was shown in [11]. Authors presented the temperature distribution along the furnace chamber and gaseous pollutant emissions. With the increase of pine bark in the fuel blend the temperature in the top of the combustion chamber increased. The emissions of CO and SO₂ decreased with the biomass fraction in the fuel blend. As the explanation, authors underlined that higher volatile content and thus higher reactivity of biomass fuels results in a rapid burn-out and lower CO concentrations. Lower sulfur content in the biomass gives lower SO₂ emissions. Authors also observed the decrease of NO_x emissions with the share of pine bark in the fuel mixture with bituminous coal due to fast release of volatile matter from biomass causing the high levels of hydrocarbon radicals. No clear influence was observed during pine bark and lignite co-combustion as these two fuels have similar reactivity [11].

Armesto et al. investigated the influence of the temperature and fluidization velocity on the combustion efficiency and CO emissions during rice husk combustion in a bubbling fluidized bed [12]. The research was performed using a 30 kW_{th} atmospheric bubbling fluidized bed pilot plant of CIEMAT. Combustion efficiency was higher than 97% and it was shown that CO emissions strongly depend on the temperature profile in the furnace.

The CIEMAT bubbling fluidized bed pilot plant was also used for co-firing of coal and a biomass waste from the olive oil industry-foot cake [13]. Lignite and anthracite were used during the tests. The fuel-N conversion to NO_x increased with the rank of coal. A slight decrease of the NO_x emissions was noticed during co-combustion due to higher volatile matter content in biomass.

An interesting chemical kinetic model for the oxidation of ammonia was presented in [14]. Authors underlined that the model is recommended for modelling of NO reduction by primary measures during combustion of biomass.

The technical and economic aspects of coal co-combustion with biomass and plastic wastes in CFB boilers was examined in [15]. The obtained results show that the fluidized bed technology is a very suitable method for co-firing such fuels. Authors noted, that generally co-firing have an almost negligible effect on system efficiency.

Knobig et al. used wood, peat and coal to investigate the scale-up problem during combustion in a lab scale facility and 12 MW_{th} boiler, with respect to emissions of flue gas species [16]. Authors presented axial concentration profiles of oxygen, carbon monoxide, nitric oxide, nitrous oxide and ammonia along the riser height, which were similar both in a small-scale and a large-scale CFB boiler [16]. Nitrous and carbon oxides were rapid formed in the bottom part of the combustion

Table 1
Properties of lignite, as received.

No of test	LHV	Moisture	Ash	VM	C	H	S	N	O _{by diff.}
	[MJ/kg]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]
0	11.2	40.0	15.5	20.1	28.6	6.30	0.65	0.34	8.61
1	9.6	38.2	22.0	19.1	27.2	6.85	0.77	0.41	4.57
2	10.5	39.7	18.2	20.4	29.3	6.37	0.79	0.37	5.27
3	9.6	37.3	23.0	18.9	27.0	6.42	0.80	0.32	5.16
4	9.5	36.0	24.1	20.1	27.0	6.20	1.06	0.34	5.31

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