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Wojciech Nowak
Czestochowa University of Technology, wnowak@is.pcz.czest.pl

Waldemar Muskala
Czestochowa University of Technology

Jaroslaw Krzywanski
Czestochowa University of Technology

Tomasz Czakiert
Czestochowa University of Technology

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THE RESEARCH OF CFB BOILER OPERATION FOR OXYGEN-ENHANCED DRIED LIGNITE COMBUSTION

Waldemar Muskala, Jaroslaw Krzywanski, Tomasz Czakiert, Wojciech Nowak
Czestochowa University of Technology, Faculty of Environmental Protection and Engineering
Dabrowskiego 73, 42-200 Czestochowa, Poland, tel./fax: +48 343250933

ABSTRACT

The paper presents the research of CFB boiler operation for oxygen-enhanced dried lignite combustion. The combustion in oxygen-enhanced conditions generally leads to reducing the emissions of CO and NO_x and N_2O due to reduced volume of flue gas. The maximum oxygen content for oxygen-enhanced combustion in O_2/N_2 conditions should not exceed 60%, however, the maximum drying extent of fuel should not be higher than 50% of the initial moisture content in an examined lignite.

INTRODUCTION

The technology of coal combustion in circulating fluidized bed (CFB) boilers and its chemical and process engineering may be ranked among the technologies referred to as clean combustion technologies including reduced emission of pollutants. Such technologies are crucial as the most favorable conditions for the combustion of solid fuels in oxygen-enhanced conditions appears to be the circulating fluidized bed. This technology brings about a number of advantages such as reducing the pollutants emission, increasing the effectiveness of CO_2 separation from the flue gas owing to higher CO_2 content, decreasing the flue gas volume. The technical knowledge of an operation of circulating fluidized bed boilers is still insufficient within the modeling and simulation of the processes of combustion in such boilers. However, as this new technology has been developing rapidly one may expect a lot of additional data from experiments to appear concerning the operation of CFB boilers under such conditions. The theoretical computations which have been carried out provide the results that satisfactorily simulate the boiler operation parameters and some of those parameters were possible to be determined during the operation of a real facility.

ASSUMPTIONS FOR THE MATHEMATICAL MODEL OF FUEL COMBUSTION IN OXYGEN-ENHANCED CONDITIONS

The model consists of several sub-models which enables the description of crucial processes associated with combustion of solid fuels under circulating fluidized bed conditions. The model considers hydrodynamics of bed material, fuel devolatilization stage, volatiles and char combustion, flue gas desulfurization as well as heat and mass transfer. The core of the model was based on the fluidized bed coal combustion model (1, 2). The structure was developed by adding additional data from experiments on the combustion in oxygen-enhanced conditions (3-5). This paper presents some computations and validations performed for an existing 670 t/h CFB boiler operated at nominal load. The computing data refer to the boiler operation taking into account the initial drying extent of fuel before it was fed to the combustion chamber. The combustion is assumed to occur in oxygen enhanced conditions within the range of 21-100% under O_2/N_2 and O_2/CO_2 conditions. The simulation computations were carried out assuming the constant heat flux within fuel fed to the boiler containing initially 43% of the moisture content and in the dried fuel the moisture content being 30%, 20% and 10% respectively. Table 1. presents the properties and fluxes of fuel in the CFB boiler depending on the drying extent of fuel.

Table 1. The properties of fuel depending on the drying extent of fuel

Moisture [%]	Carbon (c) [%]	LHV [kJ/kg]	The flux of coal [kg/s]
43.5	28	10991.2	63.0
30	34.7	14214.7	48.7
20	39.6	16602.5	41.7
10	44.6	18990.3	36.5

Two different simulations of the boiler operation as well as the assumptions for the mathematical model of fuel combustion in oxygen-enhanced conditions were thoroughly analyzed in the passage referring to modeling of solid fuels combustion under oxygen-enhanced conditions in circulating fluidized bed boiler (5). The sorbent was also fed to the boiler. The sorbent volume is m_s = 2.02 kg/s. The simulation computations for two different boiler operations are presented taking into account variations in the oxygen contents in the mixtures during coal combustion in oxygen-enhanced conditions. The overall results are calculated using Runge-Kutta-IV type Equation. After entering input data, determining the initial conditions and convergence conditions, the computations of bed hydrodynamics and chemical reactions are carried out. Distribution and concentrations of solids and gaseous components concentrations in the whole volume of combustion chamber are established on the basis of solids and gas balances. The physicochemical properties of fuel are the average properties of lignite from the Turow Coal Mine, combusted in fluidized- bed boilers in the Turow Power Plant in Poland. The fluidizing reacting gases were O_2/CO_2 and O_2/N_2 mixtures with increased oxygen content (z_{o2}) The primary gas to the secondary gas ratio was 60/40 and the secondary gas was supplied onto two levels: 0.75 and 1.25 m above the grid. In order to retain the regime of the circulating fluidized bed with the variable oxygen content in a supplied gas mixture, the modification of the overall dimensions of combustion chamber is necessary. In a presented model, only one of the three characteristic chamber dimensions , i.e. the chamber depth, was subjected to changes that ranged from 9.9 m for z_{o2}= 21% to 2.1 m for z_{o2} = 100%, which corresponded to the reduction of the chamber volume to 33,6% of its initial volume. It allows maintaining a constant gas velocity in the whole volume of combustion chamber at a level of w=5.4 m/s.

COMPUTATION RESULTS AND THEIR ANALYSIS

The computational model served for the simulation and assessment of the concentration in dry flue gas (Fig. 1 - 2) and (Fig. 3 - 4) their volume flux of CO, CO_2 NO and N_2O as a function of oxygen content in the inlet gas at the exit of the combustion chamber during combustion. The obtained results presented in (Fig. 1) show that the increase of the oxygen content leads to an increasing carbon dioxide content from 15 % with 21 % of oxygen content in O_2/N_2 mixture to about 98 % during the oxy-combustion, whereas the CO content decreases (within 3 to 0,8 ppm) thus reaching almost zero value. Similar results were reported by other researchers

(6) Decline in the moisture content (W_r) of combusted fuel from 43% to 10 % causes a slight increase of about 2-5 % of CO_2 and CO contents in dry flue gas.

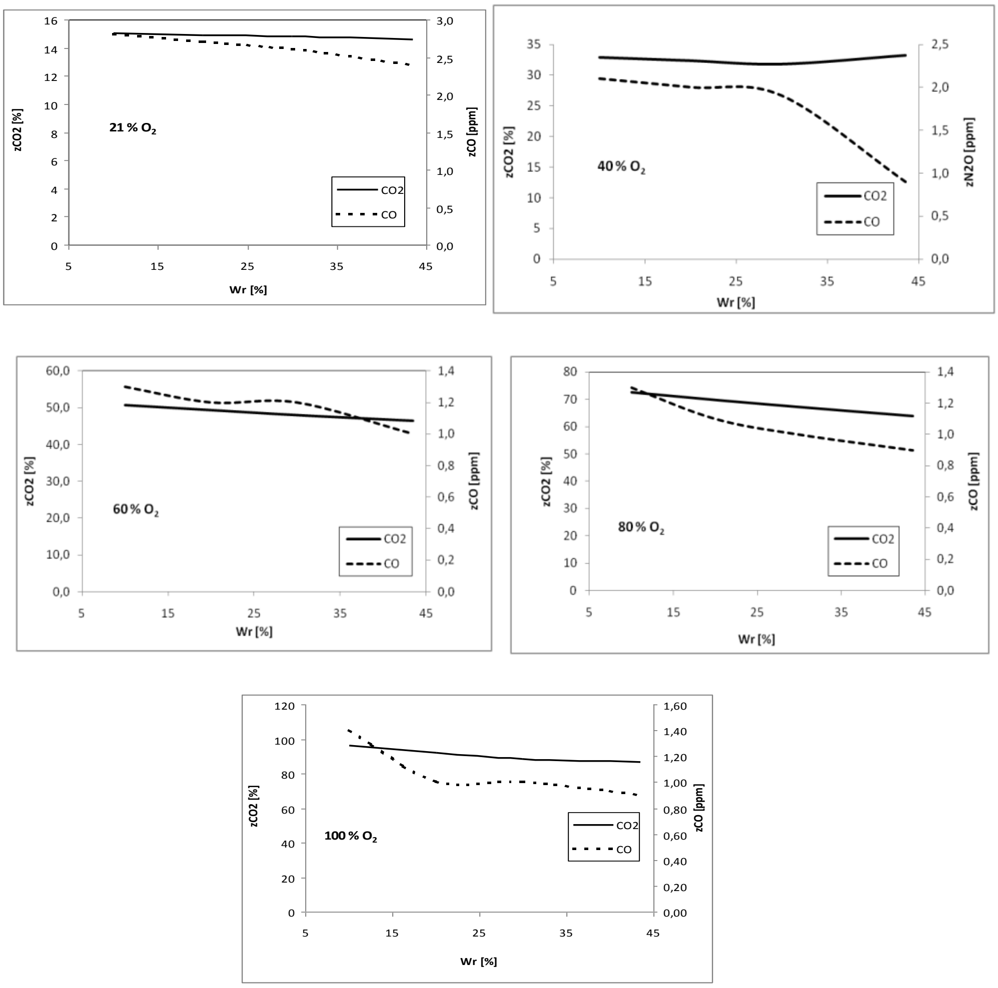

Fig.1. CO and CO_2 concentration in dry flue gas as a function of moisture content in fuel for different oxygen content in the inlet gas of O_2/N_2

Reduction of NO_x and N_2O concentration (Fig. 2) occurs as the moisture content in the inlet gas decreases. For NO_x the reduction is about 30%, from the value of about 110-140 ppm to 90-100 ppm regardless of the oxygen content in the mixtures of O_2/N_2. Reduction of N_2O concentration of about twice (that is from about 8 - 10 ppm to 4 - 5 ppm) is noticed. Decline in moisture content in flue gas results in slight increase of CO concentration in combustion chamber, which promote NO_X reduction.

Fig. 3 and Fig.4. show the comparison of CO_2, CO, NO and NO_2 flux in dry flue gas as a function of oxygen content in the inlet gas for oxygen-enhanced combustion in O_2/N_2 conditions. The CO_2 and CO flux little depends on the drying extent of solid fuel and its values are as follows: for CO_2 from 1,3 to about 1,8 kmol/s and for CO within the range of 2,5 10^{-5} - 1,5 10^{-6} kmol/s. However, CO_2 flux increases whereas CO flux declines as a result of oxygen content increase in O_2/N_2 mixtures.

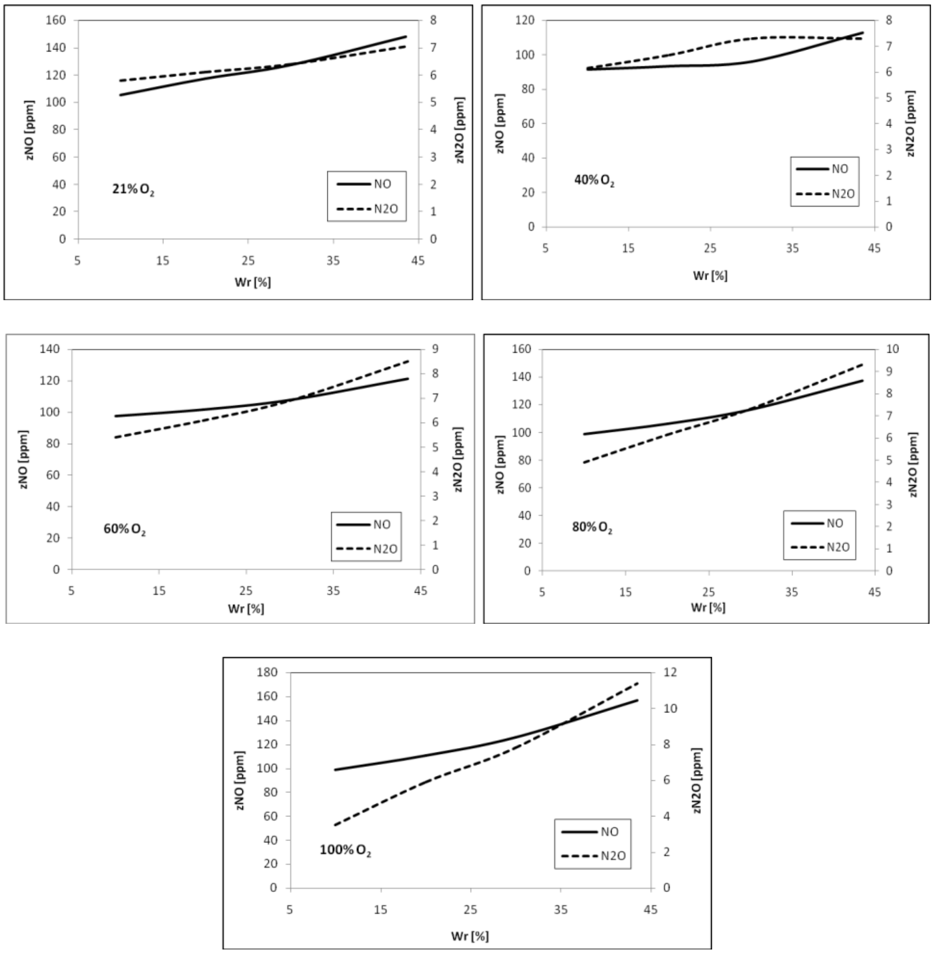

Fig.2. NO and N_2O concentration in dry flue gas as a function of moisture content in fuel for different oxygen content in the inlet gas of O_2/N_2

Decline of NO_x and N_2O flux (Fig.4) of about 40 % was found as a result of decreasing moisture content in fuel from 43 to 10 %. Decline of N_2O and NO_x flux with O_2 content in an inlet gas occurs as oxygen concentration in O_2/N_2 mixtures increases. The general conclusion could be drawn that the combustion in oxygen-enhanced conditions leads to reducing the pollutants emission of NO_x and N_2O which makes it possible to obtain the required reduced emission of pollutants and no additional technologies need to be implemented. As it is in the case of oxygen enhanced combustion in O_2/N_2 conditions, the CO_2 and CO concentrations are regardless of the drying extent of fuel. The concentration of CO_2 is estimated at about 95-98%. The CO concentration increases as the moisture content in combusted fuel decreases and they range within 1-3 ppm. Decline on average of about 30 % of NO and N_2O with O_2 content in an inlet gas was also found, which could be explained by the effect of increasing CO concentration in dry flue gas.

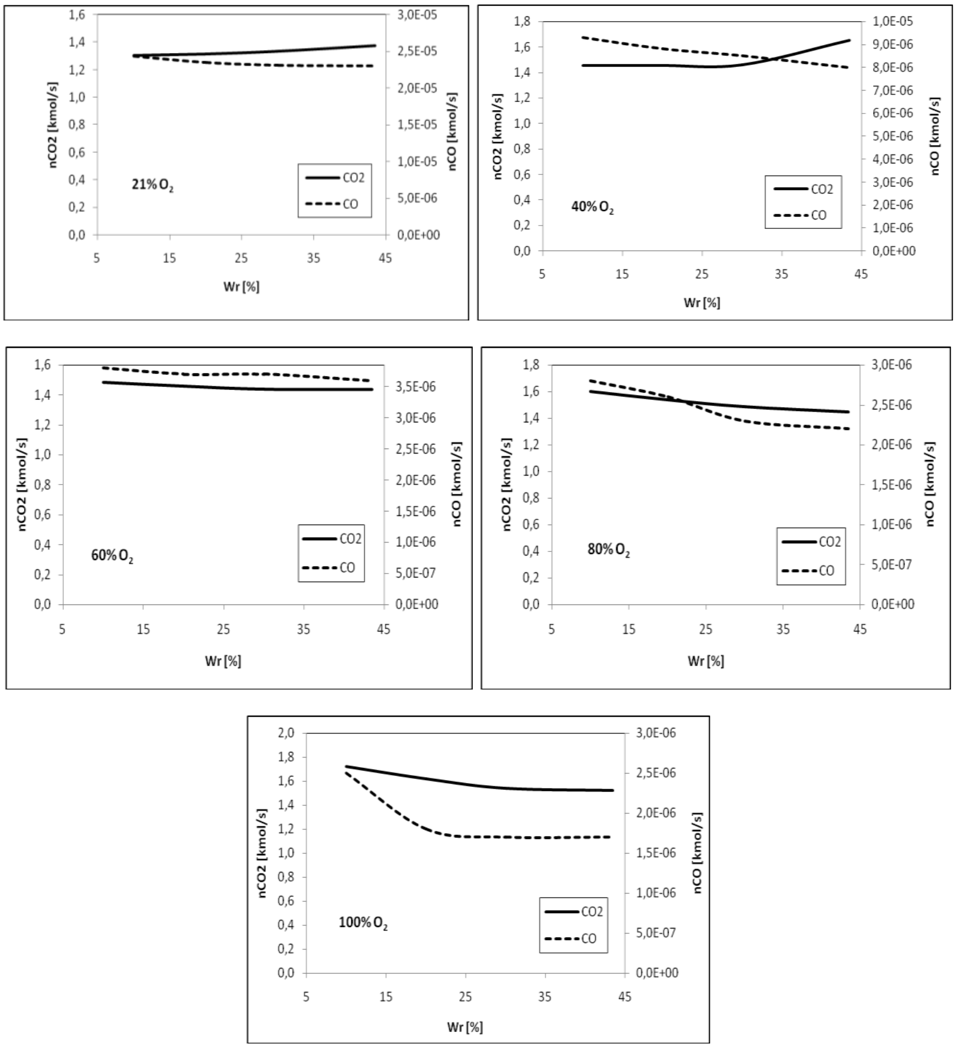

Fig.3. CO_2 and CO flux in dry flue gas as a function of moisture content in fuel for different oxygen content in the inlet gas of O_2/N_2

CO_2 and CO fluxes little depend on the drying extent of fuel and they range within: for CO_{2}:: 9,0 – 1,6 kmol/s, for CO: 2,8 10^{-5} – 1,6 10^{-6} kmol/s, higher concentrations is noticed when there is a decline of oxygen contents in O_2/CO_2 mixtures. Similarly as it is in case of O_2/N_2, there is a decline of NO_x and N_2O concentrations in O_2/CO_2 conditions as well as decline of moisture content of about 40%. Besides increase in oxygen concentration from 21% to 100 % for oxygen-enhanced combustion in O_2/CO_2 conditions results in NO_x and N_2O 4-times reduction. As it was in the case for oxygen-enhanced combustion in O_2/N_2 conditions, it may be supposed that combustion of initially dried fuels in oxygen-enhanced conditions could lead to reducing pollutants emissions of NO_x and N_2O.

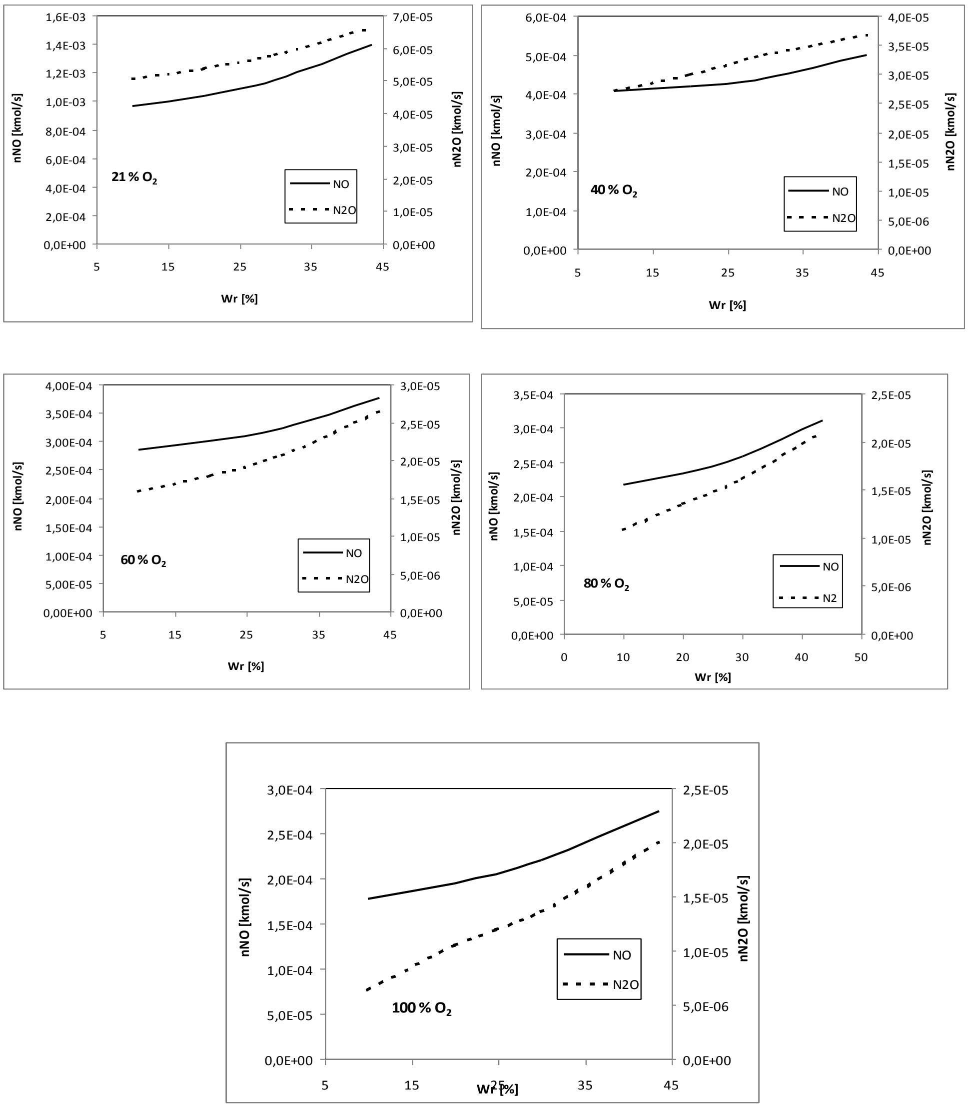

Fig.4. NO and N_2O flux in dry flue gas as a function of moisture content in fuel for different oxygen content in the inlet gas of O_2/N_2

The extent of fuel drying largely influences the overall flue gas flux which is shown in Fig.5 for oxygen-enhanced combustion with various moisture contents in fuel combusted under O_2/N_2 and O_2/CO_2 conditions and various fraction of oxygen. There is a decline of about 15-20% of wet gas concentration as the moisture content declines from 43 to 10 %. The increase of oxygen content both in O_2/N_2 and O_2/CO_2 mixtures results in 4-times reduction of pollutant emissions. On the one hand it may reduce chimney loss due to the reduction of flue gases in a volume, however, it may also result in limiting the heat transfer in combustion chamber, which may make difficult to keep the temperature to 1173 K required in CFB boilers.

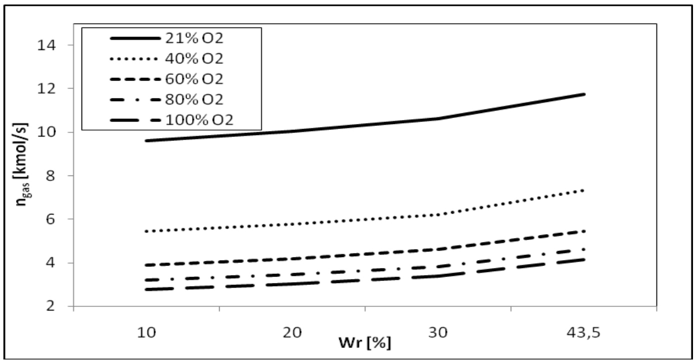

Fig.5. Flux of wet flue gas as a function of moisture content in fuel for different oxygen content in the inlet gas of O_2/N_2

Combustion in an oxygen-enhanced conditions leads to an increase in the adiabatic temperature. The variations in the heat duty are the result of the changes in the temperature distribution in the combustion chamber. The variable temperature distribution, in turn, results from an increase in the adiabatic temperature, which is mainly caused by the reduction of the flue gas volume with the increase in the oxygen content of the gas supplied to combustion. Slight increase of CO_2 flux and decrease in CO flux during combustion in oxygen-enhanced conditions prove higher efficiency of the process under these conditions. Maximum oxygen content in O_2/N_2 and O_2/CO_2 mixtures should not be higher than 60 %, however, the maximum drying extent of fuel should not exceed 50 % of the initial moisture content, which means the value of 20 - 25 % for the examined brown coal.

SUMMARY AND CONCLUSIONS

The research of CFB boiler operation for oxygen-enhanced dried lignite combustion under O_2/N_2 and O_2/CO_2 conditions allow the following general conclusion to be drawn:

- The CO_2 concentration in dry flue gas little depends on the drying extent of fuel but depends on the oxygen content in mixtures of O_2/N_2 and O_2/CO_2 and its concentration ranges within 15 - 96 % depending on the increasing oxygen content.
- The CO_2 flux little depends on the drying extent of fuel in the mixture of O_2/N_2, however, it declines about six times as oxygen content in the mixture O_2/CO_2 increases.
- Decrease in CO concentration in dry flue gas is close to zero (about 1 - 5 ppm) for oxygen-enhanced combustion in O_2/N_2 and O_2/CO_2 conditions, however, it slightly increases as the decline of the initial moisture content is noticed.
- Slight increase in CO flux (about 10%) for oxygen enhanced combustion in O_2/N_2 and O_2/CO_2 conditions is noticed as the moisture content decreases, however, there is a significant decline of CO flux of about one degree as the oxygen content increases.
- Decrease in NO concentration in dry flue gas of about 30 % for oxygen enhanced combustion in O_2/N_2 and O_2/CO_2 conditions is noticed as the initial moisture content declines.
- Decrease in NO flux of about 40 % for oxygen-enhanced combustion in O_2/N_2 and O_2/CO_2 conditions is noticed as the initial moisture content declines.

- N_2O concentration in dry flue gas decreases about twice for oxygen enhanced combustion in O_2/N_2 and O_2/CO_2 conditions as the initial moisture content declines.
- Decrease of N_2O flux on average of about 40 % for oxygen-enhanced combustion in O_2/N_2 and O_2/CO_2 conditions is noticed as the initial moisture content declines.
- The analysis of operation of a circulating fluidized bed boiler show that combustion in oxygen-enhanced conditions cause an increase in the adiabatic temperature. The variation in the heat duty is the result of the changes in the temperature distribution in the combustion chamber. It mainly refers to membrane walls of the combustion chamber, superheaters SH I and SH II and heat exchangers located in the 2nd pass.
- Coal combustion in oxygen-enhanced conditions causes an increase of heat transfer between fluidized bed, membrane-walls and superheaters. That increase in the heat transfer is the result of the changes in the temperature distribution in the combustion chamber.
- The research show that the maximum oxygen content for oxygen enhanced combustion in O_2/N_2 and O_2/CO_2 conditions should not be higher than 60 %, however, the maximum drying extent of fuel should not exceed 50 % of initial moisture content, which means the 20-25 % for the examined coal.

NOTATION

n_i	–	i-th gas component flux, $kmol \cdot s^{-1}$
n_{gas}	–	wet flue gas flux, $kmol \cdot s^{-1}$
w	–	superficial gas velocity, $m \cdot s^{-1}$,
W_r	–	moisture content, %
z_i	–	concentration of i-th gas component, %, ppm

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