

# Numerical Study of Pollutant Gases yield from Combustion of Residual Steel Gases

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*Abstract:* - The combustion and pollutant gases generation in a recovery combustion systems burning residual steel gases has been investigated. These artificial fuels are characterized by reduced lower heating values and high content of nitrogen ( $N_2$ ) and sulphurated hydrogen ( $H_2S$ ). For a steady combustion of these fuels in the furnace there is also used an amount of natural gas. During the combustion of the two artificial fuels results a large amount of nitrogen oxides ( $NO_x$ ) and sulphure dioxide ( $SO_2$ ). To help understand the combustion of this particular type of fuels, in this paper, it has been analyzed numerically the interaction of the turbulent flow processes, the heat transfer and the combustion with the mechanism of NO formation. The simulation results are compared with experimental results.

*Key-Words:* - NO formation, Sulphurated dioxide yield, Coke-oven gas and blast-furnace gas combustion, Low temperature corrosion.

## 1 Introduction

Coal is the main energy sources in the iron and steel industry. Some of the coal energy is converted to coke oven gas during the production of coke and to blast-furnace gas when the iron ore is reduced with coke to metallic iron. These gases may be recovered and used as fuel in various installations. Their burning raises a varies problems such as: high emission of  $NO_x$  due to the high amount of nitrogen the blast-furnace gas contains, high emission of  $SO_2$  due to the high amount of sulphurated hydrogen the coke-oven gas contains. In certain circumstances in the boiler, particularly when the excess air is large,  $SO_2$  converts into  $SO_3$ . The presence of  $SO_3$  in the burning gases leads to the increase of the dew temperature of the gasses and to the risk of reaching this temperature when burning gases cross the terminal surface of heat exchange of the boiler-air preheater, with the initiation of the boiler's low temperature corrosion phenomena.

In Romania, the legislation stipulates for furnace supplied with gas fuel, a maximum emission of  $350 \text{ mg/Nm}^3$  for  $NO_x$  and  $35 \text{ mg/Nm}^3$  for  $SO_2$  for new installations, and a maximum emission of  $500 \text{ mg/Nm}^3$  for  $NO_x$  and  $1700 \text{ mg/Nm}^3$  for  $SO_2$  for old installations. These concentrations are related to a concentration of oxygen in burning gases of 3%.

To respect these limits we must deal with organizing the combustion or treating the burning

gases. The selection of an alternative is determined by cost and the efficiency of the polluting emission reduction.

By all means, among the cheapest solutions to reduce  $NO_x$  emission there is an efficient matching of aerodynamic and combustion parameters and the improvement in designing the burners. These solutions can be capitalized by means of predicting procedures of polluting emissions.

The NO formation is influenced by temperature, the concentration of  $N_2$  and  $O_2$  in flame, the concentration of  $N_2$  in fuel, the burner's construction and the organization of combustion.

This paper presents the results of numerical modeling of the co-combustion of natural gas with blast-furnace gas and coke gas in the furnace of an energetic boiler. The modeling has been done by means of the FLUENT 5.4 programme.

## 2 Analysis and Modeling

The combustion of the two artificial fuels (coke gas and blast-furnace gas) in the furnace of the TGM 89 of 230MW boiler is made simultaneously with the combustion of natural gas.

The two artificial fuels have a reduced heating value and to produce the heat flow in the furnace only with them would require very large flows. For this reason natural gas (or fuel oil) is

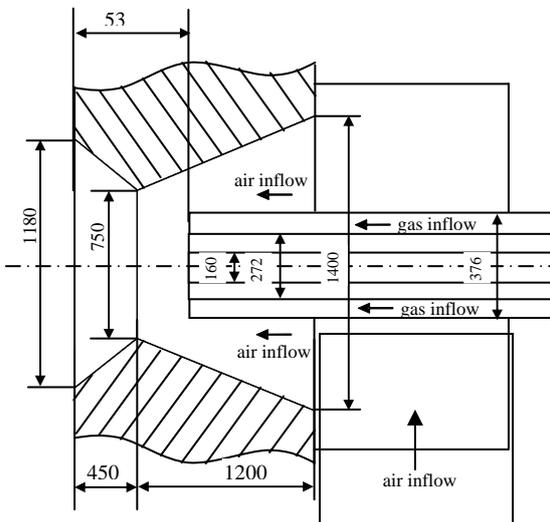
used. The volumetric composition of the fuels can be seen in Table 1.

Table 1 Characteristics of gas fuels

Gas fuel type -> Analysis, vol. %	Blast-furnace gas	Coke-oven gas	Natural gas
Carbon dioxide, CO <sub>2</sub>	17.98	3.03	
Oxygen, O <sub>2</sub>	0.21	0.689	-
Carbon monoxide, CO	21.21	8.498	-
Hydrogen, H <sub>2</sub>	6.9	51.158	-
Methane, CH <sub>4</sub>	0.3	21.068	99.3
Ethane, C <sub>2</sub> H <sub>6</sub>	-	1.683	-
Sulphurated hydrogen, H <sub>2</sub> S	0.3	6.174	-
Nitrogen, N <sub>2</sub>	53.1	7.7	0.7
Lower heating value, kJ/Nm <sup>3</sup>	3431	17166	35523

Due to the fact that the furnace of the boiler is made of two identical chambers the investigation has been made on one of these chambers. The burners are displayed on the walls of the furnace in the following way: on the frontal wall, at the upper

levels 1 and 2 are placed the natural gas burners, and at the lower level, coke-oven gas burner, on the lateral wall are arranged vertically the two blast-furnace gas burners.

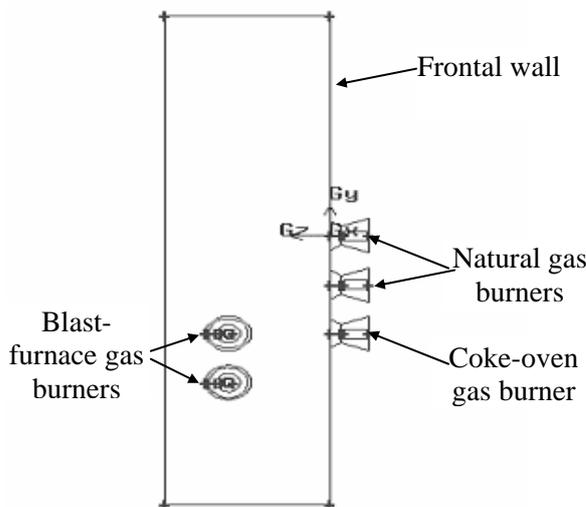


Natural gas operating conditions:

Natural gas feed rate, Nm <sup>3</sup> /s	658
Air flow rate, Nm <sup>3</sup> /s	6645.8
Air temperature, °C	260
Excess air, %	10

Coke-oven & blast-furnace operating conditions:

Coke-oven gas feed rate, Nm <sup>3</sup> /s	10000
Blast-furnace gas feed rate, Nm <sup>3</sup> /s	3500
Air flow rate, Nm <sup>3</sup> /s	7283/16404
Air temperature, °C	260
Excess air, %	10



Furnace operating conditions:

Number of natural gas burners	2
Number of coke-oven burners	1
Number of blast-furnace gas burners	2
Static pressure, atm	1
Temperature of walls, °C	380

Fig.1. Configuration of the burners and their display on the walls of the furnace.

In Fig. 1 can be seen the configuration of the burners and the way they are displayed on the

walls of the furnace. Each burner has two different jets, the air jet is swirled (it goes tangentially into

the air box). The burners are designed to operate combined with natural gas/oil and coke-oven gas or blast-furnace gas. In the case that has been analyzed each burner works with a single fuel. The modeling of flow, combustion and pollutant formation has been done beginning with the exit of the two jets from the burner (air+fuel), from their interaction area.

This investigation has been made to visualize the flame of each burner and the flames interaction for the whole furnace to emphasize the correlation between the parameters of thermodynamics and the pollutant formation.

### 3 RESULTS AND DISCUSSIONS

#### 3.1. Combustion/aerodynamics

Predictions of combustion and thermo aerodynamics include flow-velocity distribution, gas temperature and concentrations of major species (O<sub>2</sub>, CO, CO<sub>2</sub>, H<sub>2</sub>O). The velocity vectors, the temperature distribution and the concentrations distribution of O<sub>2</sub>, CO and SO<sub>2</sub> are shown in the vertical sections which go through the axes of the burners. In Fig. 2 we can see, at the place where the jets of the coke –oven gas burner and the blast-furnace gas burner meet, an internal eddy and in the

areas above and under the burners, the presence of an intense recirculation. As a result of the interaction of the burners' jets we can notice a deviation of the jets towards the walls of the furnace. These turbulences influence the combustion process, the heat exchange and NO formation.

The heat that is released through the burners is emphasized by the distribution of temperatures which can be seen in Fig. 3. The maximum of temperature (2000°C) is situated in the area where the jets of the coke-oven gas and blast-furnace gas burners interact. Near each burner's air inlets, temperature is lower (about 850°C) due to the fact that combustion is poor in fuel. This non-uniformity of the thermal field disappears at the exit of the burning gas from the furnace. In this area, predicted temperature (1330°C) is in a good agreement with measurements.

The predicted concentrations of CO are high in the areas where the flame is reach in fuel, and the jets of the blast-furnace gas and the coke-oven gas burners (Fig. 4). The maximum concentration of CO is  $1.47 \cdot 10^{-1}\%$  (mass.) and it gradually decreases towards zero as CO mixes and reacts with O<sub>2</sub> in the upper area of the furnace. The high concentrations of CO influence both the temperature of the mixture and the concentrations of O<sub>2</sub> and CO<sub>2</sub>.

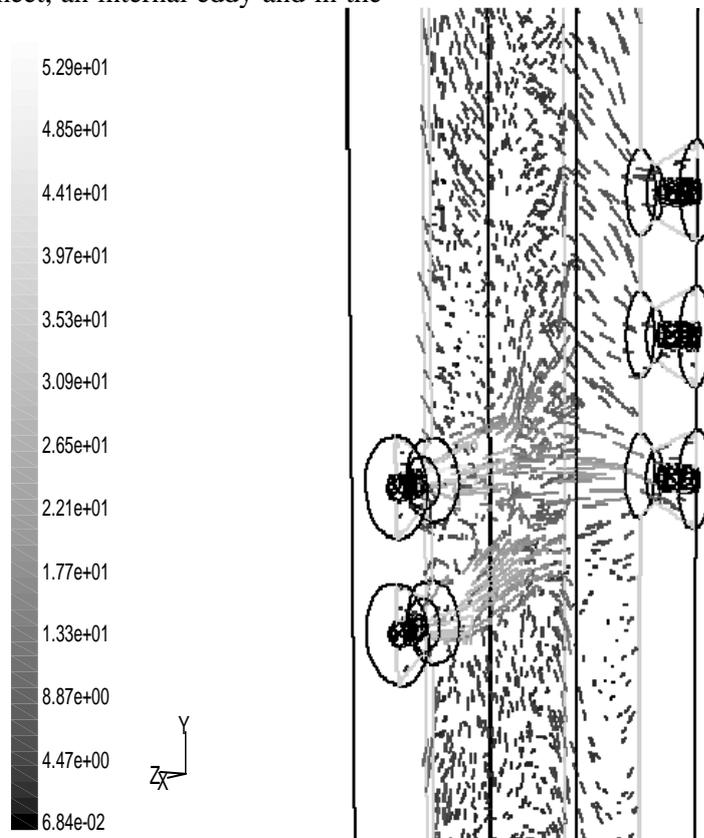


Fig. 2. Flow patterns

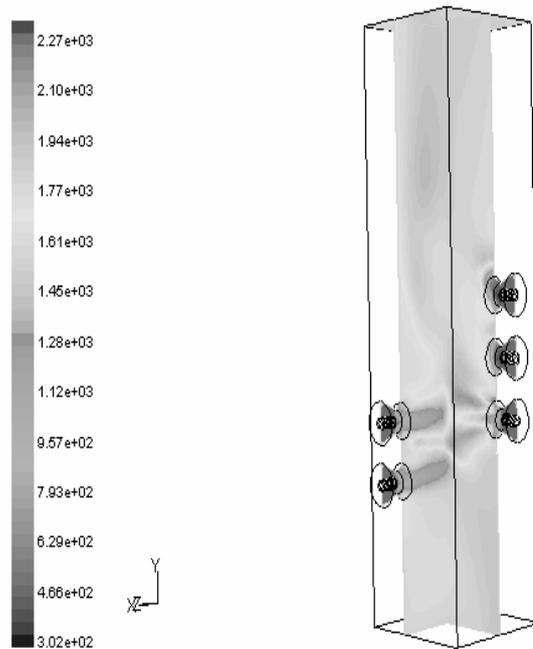


Fig. 3. Gas temperature

The predicted concentrations of  $O_2$  can be seen in Fig. 5. From a value of 23 % (mass.) at the outlet of each burner, the  $O_2$  concentration reaches a value of 2.35% after combustion is completed. At the exit of the furnace, the  $O_2$  concentration is 0.015% (mass.), which means that there is an adequate amount of air in excess in the furnace. The air in excess in the furnace influences a lot the NO formation.

The presence of oxygen in the post-combustion area is undesirable because it leads to the increase of the conversion rate of  $SO_2$  into  $SO_3$  and eventually to the occurrence of the boiler's low temperature corrosion phenomenon

We can see in Fig. 6 that only the coke-oven gas burner have an average content of  $SO_2$  of 2300  $mg/Nm^3$ , which means that its value is higher than the one stipulated by law.

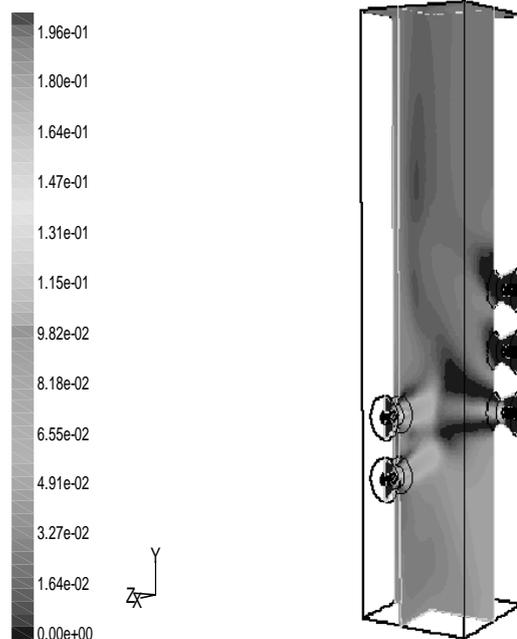


Fig. 4. Carbon monoxide concentration

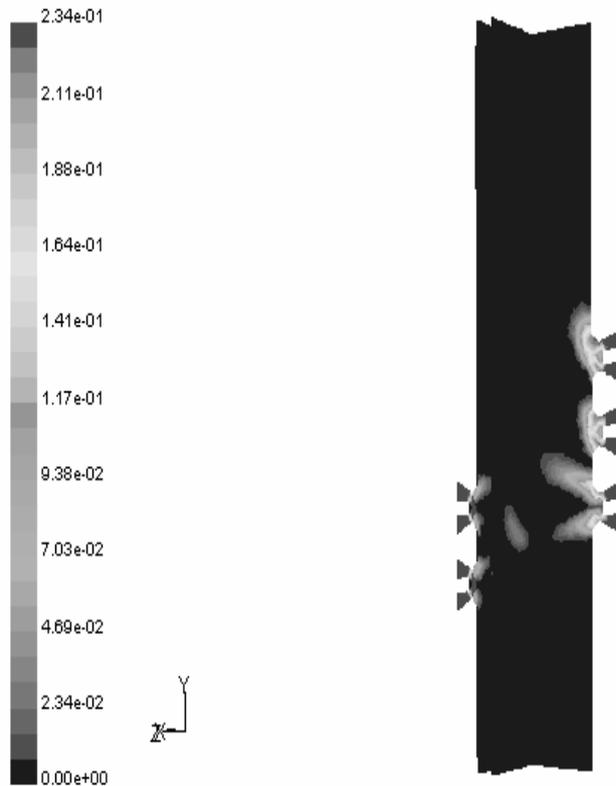


Fig. 5. Oxygen concentration.

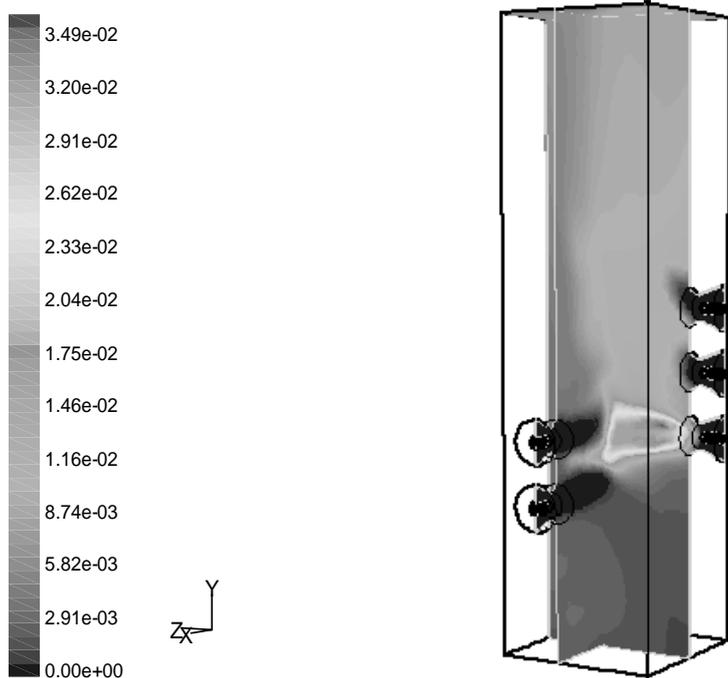


Fig. 6. Sulphurated dioxide concentration.

### 3.2. Predictions of NO

The predicted NO concentrations can be seen in Fig. 7. The NO formation occurs during the burning process and the main mechanism of

formation is the thermal one. That is emphasized by the high concentrations of NO in the zones with high temperatures of the flame (260-330 ppm) and low concentrations of NO in the zones with low

temperature (50-120 ppm). Mixing within the furnace results in an average NO value of 270 ppm ( $554 \text{ mg/Nm}^3$ ) at the furnace exit, corresponding to an  $\text{O}_2$  concentration of 1.5 % (vol.). If we recalculate the NO emission for a concentration of  $\text{O}_2$  of 3%, we obtain a value of  $608 \text{ mg/Nm}^3$ . This value of the predicted NO concentration is higher than the value stipulated by law.

In conclusion, we can say that the polluting emissions are higher than the maximum values that have been accepted. To improve the performances of the furnace, it is interesting to find in a future investigation, if the NO emission is influenced by the interchange of fuels on burners.

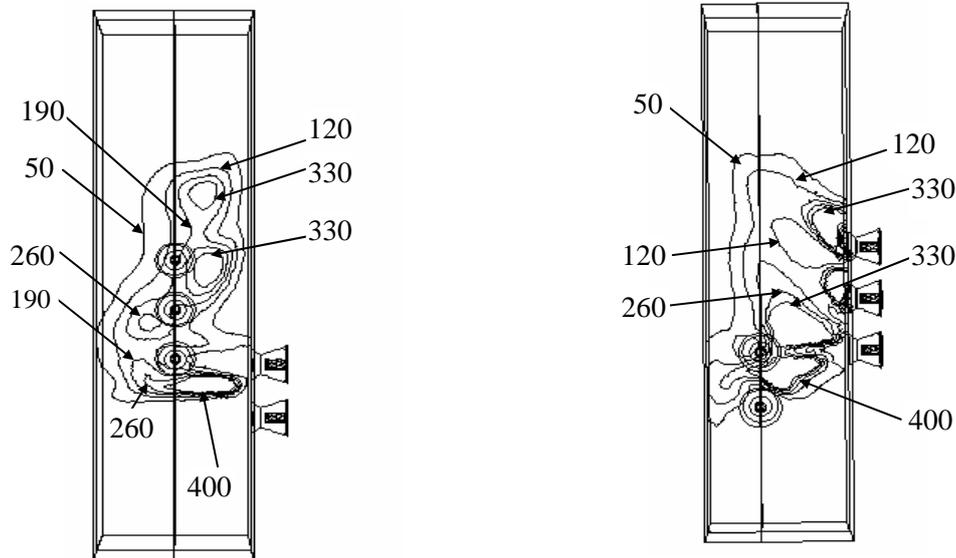


Fig. 7. Concentration of nitric oxide (ppm).

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