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# Environmental Impact and Forecast of pollutants from coke oven gas and natural gas combustion

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***Abstract***—Basic air pollutants found in an industrial belt are CO, $NO_x$, $SO_x$, HC and PM. These pollutants are dispersed throughout the atmosphere in concentrations depending on the point of origin. In a steel plant the combustion of Natural gas and coke oven gas (residual gases from steel plant blast furnace ) results in pollutants. The residual gases of blast furnace and coke oven are characterized by reduced lower heating values(LHV) and high content of carbon monoxide (CO), Carbon dioxide ($CO_2$), Nitrogen($N_2$) and Hydrogen sulphide ($H_2S$). Combustion of these fuels leads to increased emission of pollutants. Formation of these pollutants are influenced by excess $O_2$ of combustion, the case with less excess air (10%) was numerically simulated on a steam generator furnace. The study was done in a 230MW, water-tube boiler having vertically aligned burners. It defines the temperature, NO, CO and $SO_2$ distribution in the combustion chamber. The simulation results were compared with the actual boiler furnace measurements (corresponding to 25% excess air).

***Keywords*** - NO formation, $SO_2$ yield Coke-oven gas and blast furnace gas combustion, Low temperature corrosion.

## I. INTRODUCTION

Most of the iron and steel industry uses coal as the main source of energy. Some of the coal is converted to coke oven gas during the production of coke and in blast-furnace gas where iron ore is reduced with coke to metallic iron. These gases may be recovered and used as fuel in various installations. This combustion is a direct way to increase the overall efficiency of process, but raises a variety of problems such as high emission of $NO_x$ due to the high amount of nitrogen in the blast-furnace gas, high emission of $SO_2$ due to the high amount of Hydrogen sulphide ($H_2S$) in the coke-oven gas and relatively high $CO_2$ emission, if compared with other hydrocarbon fuels like natural gas.

In cases when excess air is more, $SO_2$ gets converts into $SO_3$. The presence of $SO_3$ in the burning gases leads to the increase of dew point of the gases. The risk of reaching this temperature is that, when burning gases cross the surface of the air preheater, leads to low temperature corrosion. Besides the demand for Green House Gases reduction due to Global warming, industries have to abide by the National and International regulations.

The legislation stipulates a maximum emission for furnace supplied with gas fuel, 350 $mg/Nm^3$ for NOx and 35$mg/Nm^3$ for $SO_2$ for new installations, and a maximum emission of 1700 $mg/Nm^3$ for $NO_x$ and 350 $mg/Nm^3$ for $SO_2$ for old installations. These concentrations are related to excess 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.

$NO_x$ formation during the combustion process in gas fired boiler occurs mainly through the oxidation of $N_2$ from the combustion air and from the fuel. The formation of NO is an extremely complicated problem due to many parameters that influence its formation. The main parameters are the flame temperature, the concentration of $N_2$ and $O_2$ in flame (determined by the excess air), the concentration of $N_2$ in fuel, the burner's construction (combustion air swirl angle) and the organization of combustion (staged combustion). Carbon monoxide is formed during combustion because of either [1] inadequate supply of oxygen, or insufficient values of the three *T'*s, which are the Temperature, Time or Turbulence.
Turbulence is characterized by,
(i) poor mixing of fuel and air;
(ii) insufficient residence time to complete combustion;
(iii) quenching of combustion gases.
During combustion of fuels which is having sulphur, or hydrogen sulphide, $SO_2$ is produced (typically 1–3%). Under certain conditions $SO_2$ is being transformed into $SO_3$, which at lower temperatures, reacts with water vapour forming sulphuric acid [10]:
$SO_3 + H_2O \leftrightarrow H_2SO_4$

If the temperature of flue gases, containing $H_2SO_4$ and $H_2O$ vapours decreases below the dew point, it results in condensation and the sulphuric acid solution formed is highly corrosive on the heat exchanger metal surfaces, in which the low-temperature corrosion appears. The numerical calculation of NO & CO is a three dimensional problem that involves combustion, turbulence and the heat transfer. By all means, among the cheapest solutions to reduce $NO_x$ emission is an efficient way of combustion ratios and improvement in the burner design. As the excess air in the furnace influences NO, CO and $SO_3$ formation this paper presents the results of the co-combustion of natural gas with blast furnace gas with reduced excess air than the actual one (10% instead of 25%).

## II. BOILER SPECIFICATIONS

The combustion of the two artificial fuels (coke gas and blast-furnace gas) in the furnace of 230 MW boiler is made simultaneously with the combustion of natural gas. The two artificial fuels have a reduced heating value compared to that of natural gas. The volumetric composition of the fuels can be seen in Table 1. The furnace of the boiler is made of two identical chambers consisting of four coaxial jets. Starting from the axis of symmetry, it is composed of a natural gas central jet, surrounded by an air flow, followed by a coke gas or blast-furnace gas flow and air at the periphery.

The burners are displayed on the walls of the furnace in the following way: on the upper level the burner fuelled with natural gas burners, and at the lower level, the burner fuelled with coke-oven gas and natural gas, on the lateral wall are arranged vertically the two burners fuelled with blast-furnace gas and natural gas.

**Table 1: Characteristics of gas fuels.**

| Analysis vol. % | Blastfurnace | Cokeoven | Natural gas |
|---|---|---|---|
| Carbon dioxide, $CO_2$ | 17.98 | 3.03 | - |
| Oxygen, $O_2$ | 0.21 | 0.689 | - |
| Carbon monoxide, CO | 21.21 | 8.498 | - |
| Hydrogen, $H_2$ | 6.9 | 51.158 | - |
| Methane, $CH_4$ | 0.3 | 21.068 | 99.3 |
| Ethane, $C_2H_6$ | - | 1.683 | - |
| Hydrogen sulphide, $H_2S$ | 0.3 | 6.174 | - |
| Nitrogen, $N_2$ | 53.1 | 7.7 | 0.7 |
| Lower heating value, kJ/Nm$^3$ | 3431 | 17166 | 35523 |

The air jet is swirled i.e., 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. The flow, combustion and pollutant formation has been done with the exit of the jets from the burner (air and fuels), from their interaction area. The Table 2 lists the operation conditions of the investigated furnace boiler. 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 thermogas dynamics and the pollutant formation.

**Table 2. Natural gas operating conditions**

| | |
|---|---|
| Natural gas flow rate, Nm$^3$/h | 658 |
| Air flow rate, Nm$^3$/h | 6645.8 |
| Air temperature, °C | 260 |
| Excess air, % | 10 |

**Coke-oven & blast-furnace operating conditions**

| | |
|---|---|
| Coke-oven gas flow rate, Nm$^3$/h | 10000 |
| Blast-furnace gas flow rate, Nm$^3$/h | 3500 |
| Air flow rate, Nm$^3$/h | 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 |

The experiment has been done to analyze the pollution characteristics of flows inside the boiler furnace. The operating parameters include the excess air, combustion air, temperature and air jet swirl angle as refered in Table3.

***Table3:***

| Parameter | Natural Gas | Mixture Gas(Coke oven +Blast furnace gas) | Natural Gas + Mixture gas |
|---|---|---|---|
| Sox ppm | 12 | 50 | 20 |
| NOx ppm | 5 | 38 | 7 |
| CO ppm | 50 | 120 | 75 |
| PM nJ/m3 | 100 | 180 | 110 |
| Excess Air % | 15 | 15 | 15 |

It is clear from the results that in the increasing demand of Natural gas as a main source of fuel which is scarce in supply, a combination of Natural gas and Mixture gas(coke oven and blast furnace gas) can be used to combat all the emissions and particularly the NOx emissions to the tune of 90%. The burners are fed with this combination gas instead of depending solely on natural gas and also the steel industry produces coke oven and blast furnace gases.

$NO_x$ are formed or destroyed during the combustion process by two separate reaction processes, which are classified as thermal NO and prompt NO. Thermal NO is formed by oxidation of atmospheric and fuel molecular nitrogen at relatively high temperatures in fuel lean environments, and has a strong temperature dependence. The prompt NO is formed by combination of molecular nitrogen in the air and fuel with fuel in fuel-rich conditions. Many investigations have shown that the prompt NO contribution to total NO from stationary combustors is small[3]. The thermal NO process is described by the Zeldovich mechanism [5]:

## III. RESULTS AND DISCUSSIONS

The operational mode with reduced excess air (10% instead of actual 15%) was investigated. The results are given for the furnace exit. The temperature distribution and the concentrations distribution of $O_2$, CO and $SO_2$ are shown in

the vertical sections which go through the axes of the burners. The heat that is released by gases combustion is emphasized by the distribution of temperatures.

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 furnace exit. The predicted temperature at furnace exit (1330°C) is a little higher than that measured temperature for 15% excess air (1295°C). The predicted concentrations of CO are high in the areas where the flame is rich in fuel, and the jets of the blast furnace gas and the coke- oven gas burners. The maximum concentration of CO is 1.96 to 10.1% (mass) and it gradually decreases towards 01.64·10-1% (mass) as CO mixes and reacts with $O_2$ in the upper area of the furnace. The high concentrations of CO influence both the temperature of the mixture and the concentrations of $O_2$ and $CO_2$. It was expected an increase in CO concentration is due to the reduced excess air. Even with less excess air the CO concentration is low, almost equal to that corresponding to 15% excess air. 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 excess air in the furnace.

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. With less excess air in furnace it is expected a lower conversion rate. The coke-oven gas burner have an average content of $SO_2$ of 2300mg/Nm$^3$, which means that its value is higher than the one stipulated by environmental norms.

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 mg/Nm$^3$) at the furnace exit, corresponding to an $O_2$ concentration of 1.5 % (vol.). If we recalculate the NO emission for a concentration of $O_2$ of 3%, we obtain a value of 608 mg/Nm$^3$. This value of the predicted NO concentration is higher than the value stipulated by emission norms , but is lower than that corresponding to 15% excess air (753 mg/Nm$^3$).

## IV. CONCLUSION

The study provides insight on the correlation the effect of excess air on emissions like CO, $SO_2$ and $NO_x$. The results have shown that the decrease in excess air from 25 to 10% results in an increased exit temperature, almost the same CO and $SO_2$ concentrations and increase in reduction of $NO_x$ concentrations. As the SO to $SO_2$ conversion rate depends on $O_2$ concentration it is expected a decrease of $SO_2$ concentration and therefore an alleviation of low-temperature corrosion of the steam boiler surfaces (air preheater, flue gas channels) is expected. Although the reduction of air excess leads to a reduction of pollutant concentrations, the pollutant emissions are slightly higher which can be reduced further by using techniques like flue gas recirculation, change in aerodynamic conditions in the furnace and burner design.

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