Air Pollution reduction in metal industry using residual gas and natural gas combustion.

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Abstract:
Air pollution is the effect of atmosphere getting filled with toxic chemicals, particulate matter, or biological materials that cause harm or discomfort to humans or other living organisms, or damaging the environment. 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.
The aim of this paper is to study the effect of gases generated from coal used 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).

Key-Words - NO formation, SO_2 yield, Coke-oven gas, Low temperature corrosion, LHV.

Introduction

The air we breathe is polluted majorly by burning fossil fuels like oil, coal, natural gas and also during the manufacture of chemicals. Millions of people live in areas where urban smog, tiny particles and toxic pollutants pose serious health concerns. Rapid industrialization is a major factor contributing towards growing air pollution problem. Air pollutants [1,2,3,4,5,6] threatens not only the health of human beings and other living things but also our planet. Invisible pollutants in air create smog and acid rain causes cancer or other serious health effects, diminish the protective ozone layer in the upper atmosphere, greenhouse effect and contribute to the greatest potential for world climate change besides causing property damage.
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 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. This paper studies the ways to combat pollution by burning 2 different fuels separately and as a mixture.

Materials And Methods

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].

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 35mg/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]:

$$SO_3 + H_2O \leftrightarrow H_2SO_4$$
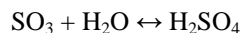
If the temperature of flue gases, containing H_2SO_4 and H_2O vapours decreases below the dew point, it results in condensation and the sulphuric acid solution formed is highly corrosive on the heat exchanger metal surfaces, in which the low-temperature corrosion appears. The numerical calculation of 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%).

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).

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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