Nitrogen and Sulfur Oxides Emissions from Fuel Oil Combustion in Industrial Steel Reheat Furnace

Hussein Abuluwefa
Misurata University /Department of Materials Science and Engineering, Misurata, Libya
habuluwefa@yahoo.com

Adel Alnaas
The Libyan Academy/Misurata Branch /Department of Engineering Project Management, Misurata, Libya
adelannaas@yahoo.com

Abstract— **Many industrial heating operations still use fuel oil for combustion instead of the cleaner gaseous fuels. In the steel industry, large furnaces referred to as reheat furnaces are used to heat steel stocks to rolling temperatures using normally fuel oil for combustion. The combustion products of flue gases consist of mainly carbon dioxide, water vapor and traced of other oxides such as nitrogen and sulfur oxides. These oxides are of a concern to the environment and should be minimized as much as possible. Experiments were carried out on a steel billet reheat furnace in which air/fuel ratios are varied while the nitrogen oxide content is being monitored using furnace instruments. These variations in air/fuel ratios for combustion are found to affect the concentration of nitrogen oxides in the flue gas where higher air/fuel ratios promoted the formation of higher nitrogen oxides during combustion. The sulfur dioxide content in the flue gas was calculated based on actual measurements of air and fuel rates to the furnace and found to be minimal in the flue gas.**

Index Terms: **fuel oil combustion, steel reheating, flue gas emissions, nitrogen oxides emissions.**

I. INTRODUCTION

In the steel industry one of the major operations consuming fuel is the reheating of steel prior to hot working.[1]. Fuel oil and/or fuel gas is used for combustion to heat up steel stocks of billets, slabs or other shapes to rolling temperatures using large furnaces consisting of many zones. The combustion process in these large furnaces results in flue gases consisting of various gaseous oxides, depending on the fuel composition. In particular, nitrogen oxides form under certain conditions and are emitted with the flue gaseous, causing concerns with the environment.[2-6]. The formation of nitrogen oxides is enhanced by high flame temperature and the presence of free oxygen in and around the flame. There is a number of method of controlling the formation of nitrogen oxides during fuel combustion.[7-13] One of these methods is controlling the air/fuel ratio for combustion. In combustion, and to ensure complete burning of the fuel, an excess oxygen (of that required by reaction stoichiometry) is used.

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If the air/fuel ratio is not controlled properly, conditions promoting the formation of nitrogen oxides may occur. In terms of sulfur in fuel, it will react with oxygen forming sulfur dioxide which is also a concern with the environment. In this study, the industrial billet steel reheat furnace at the Libyan Iron and Steel Company will be operated with different air/fuel ratios to see if that will affect the formation of nitrogen oxides. Also, the sulfur dioxide content in the flue gas will be calculated based on actually measured flow rates of fuel and air being fed to the combustion system of the furnace.

II. EXPERIMENTAL

Experiments were carried out on the full-scale industrial steel reheat furnace at the Libyan Iron and Steel Company. These experiments involved on-line measurement of combustion air and fuel flow rate as well as measurement of nitrogen oxides in the flue gas.

A.Furnace Description

The industrial furnace under investigation is a pusher type billet reheat furnace with the specifications shown in Table 1.

Table 1. Pusher Type Industrial Reheatt Furnce Properties And Billet Reheating Practice

Manufacturer	KOPE STEEL
Furnace type	Pusher
Production capacity	Tons/hr
Capacity	138 billet
Steel exit temperature	1100 to 1250 ^{o}C
Billet dimensions	12 m x 12 cm x 12 cm
Loading mechanism	Peel par (Charger)
Extraction mechanism	Pusher out nit
Internal movement mechanism	Cross pusher
Furnace external dimensions	18.53 m x 13.53 m
Furnace internal dimensions	17 m x 12.8 m
Fuel type	Heavy fuel oil

The furnace is a pusher type used to reheat steel billets using a pushing and extraction mechanisms to charge and discharge the steel load, as shown in Figure 1.

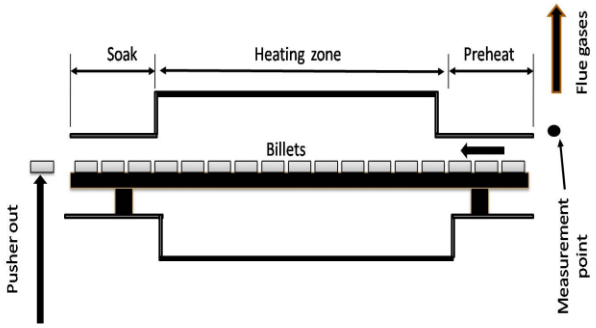

Figure 1. Schematic of the Reheat Furnace Showing the Measurement Point of Nitrogen Oxides.

The type of fuel used for combustion is heavy fuel oil which is burned with preheated combustion air. The billets moving along the furnace were heated gradually from ambient temperate until about 1150°C. The heated billets are then pulled out the furnace and sent to the rolling units for the production of steel bars.

B.Fuel Properties

The fuel oil produced by the Libyan Emirates Oil Refining Company used for heating practices in the steel company has the properties shown in Table 2.The fuel oil is heated to approximately 93°C before delivery to the burners.

Table 2. Some Properties of Fuel Oil Used for the Steel Reheating Practice

Parameter	Value	Units
Specific Gravity at 15.6 °C	0.9082	
Total sulfur	0.270	Wt.%
Viscosity at 50 °C	123.1	CST
Carbon residue	7.5	Wt.%
Ash content	0.03	Wt.%
Heat of combustion (GROSS)	10641	kcal/kg
Vanadium	< 10	ppm

C.Measurements

Fuel flow rates and combustion air flow rates were measured on-line using furnace measuring instruments. Since the furnace is divided into three heating zones, where each zone is fired independently, flow rates for each of these zones were measured every five minutes. The total measurement time of one hour was divided into twenty minutes periods and for each period the fuel/air ratio was kept constant. The set air/fuel ratios for the three measurement periods are 8, 10 and 12. These values were chosen based on furnace minimum and maximum operation limits. The purpose of this air/fuel ratio variation is to see if this will have any effect on nitrogen oxides formation during combustion. The measurement point of nitrogen oxides was at near the bottom of the flue duct, as indicated in Figure 1.

III. RESULTS AND DISCUSSION OF RESULTS

The fuel flow rates, combustion air flow rates and furnace zone temperatures in the different furnace zones are measured every five minutes from furnace instruments as shown in Table 3. In these measurements the air/fuel ratio was changed every twenty minutes as 9, 10 and 12. From this table it can be seen that the top and bottom soaking zones are quite similar in temperatures which is approximately 1130 ±5° and kept unchanged during the measurement time period. This observation applies for the top and bottom heating zones but with lower temperatures of approximately 920±5°C.

TABLE 3. ON-LINE MEASURMENTS OF FURNACE AIR AND FUEL FLOW RATES AND GAS TEMPERATURES IN DIFFERENT ZONES.

(Time)	**Temperature** (°C)				**Air Flow Rate** (m^3/ hr)				**Fuel Flow Rate** (l/hr)			
(Min.)	**Soak**		**Heating**		**Soak**		**Heating**	**Preheat**	**Soak**		**Heating**	
	West	**East**	**Top**	**Bottom**	**West**	**East**	**Top**	**Bottom**	**West**	**East**	**Top**	**Bottom**
0	1133	1126	928	926	1095	1029	3286	2500	140	128	410	313
5	1132	1225	922	930	1093	1076	3242	2487	138	134	422	310
10	1130	1225	926	923	1070	1139	3372	2320	135	142	424	286
15	1030	1025	927	919	1063	1206	3425	2400	132	150	430	308
20	1128	1126	924	926	1060	1260	3528	2534	134	159	450	312
25	1122	1128	925	917	1479	1654	4575	3410	146	166	462	341
30	1125	1129	926	925	1567	1684	4717	3525	156	169	479	357
35	1129	1132	926	927	1634	1701	4835	3360	160	171	486	358
40	1131	1131	925	927	1640	1649	4869	3540	164	169	491	348
45	1130	1130	926	922	1638	1654	4930	3460	161	163	494	345
50	1124	1125	926	921	2487	2435	7785	4600	191	186	603	350
55	1127	1130	926	920	2574	2494	7844	4650	196	192	606	360
60	1128	1131	927	921	2587	2507	7880	4937	198	193	600	376

The fuel flow rates into the different combustion zones were seen to increase slightly as the air/fuel ratio is increased, as shown in Figure. 2. It can also be seen that fuel flow rates are much larger in the heating zone compared to the soaking zone and that in the soak zone the flow rate is almost steady as the temperature is supposed to be kept constant in this zone.

Changes in the combustion air flow rates are more noticeable than the fuel flow rates. As can be seen from Figure. 3, as the air/fuel ratio is increased the flow rate of the combustion air in the different furnace zones responded to these increases especially in the top heating zone where the air flow rate is the highest. In each measuring time period of twenty minutes the flow rates are kept constant indicating good control of the combustion process in the furnace. The combustion air flow rates show considerable increase as the air/fuel ratio is increased. This indicates that the furnace combustion system ensures enough excess air for combustion when the fuel is being increased. Although fuel and combustion air are both increased the higher air/fuel ratio is actually burned with lower air that the lower air/fuel ratio.

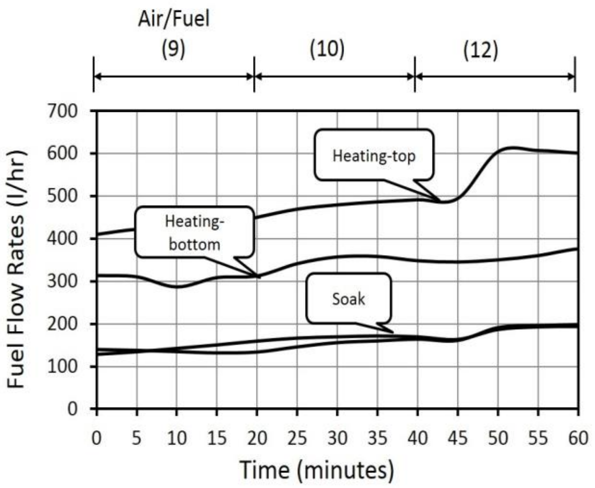

Figure 2. Measurements of Fuel Flow Fates for combustion with different fuel/air ratios during billet the reheating process.

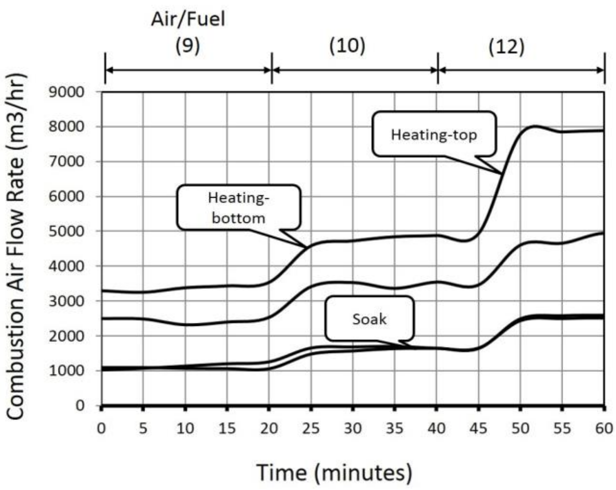

Figure 3. Measurements of Combustion Air Flow Rates for Combustion with Different Fuel/Air Ratios During Billet the Reheating Process.

The reheat furnace is equipped with a nitrogen oxides detection system where the sulfur dioxide content is measured on line. The location of this detector is located in the fume hood prior to any ambient air entrainment in the flue gas. Although this detector has not been recently calibrated, and hence, absolute values being measured may not be exact, these measured values are being looked at as relative. This means that the behavior of these measurements of sulfur dioxide content is considered in terms of increases or decreases with time as the air/fuel ratio being changed. Figure. 4 shows the concentration of nitrogen dioxides content in the flue gas during the three periods of the measurements. It can be clearly seen from this figure that the concentration of nitrogen oxides increases with increasing air/fuel ratio. Since the formation of nitrogen oxides is enhanced by the presence of plenty of free oxygen and high temperatures, this behavior is actually expected. The increase in free oxygen is obvious from the increase in air/fuel ration and must be coupled with an increase in flame temperature. The increase in flame temperature may not be detected from the measured in-furnace temperatures since these temperatures are measured by thermocouples installed in the furnace wall, which are far from the actual flame temperature. This behavior shows that the formation of nitrogen oxides can be controlled by altering the air/fuel ratio in industrial processes such as the process of steel reheating.

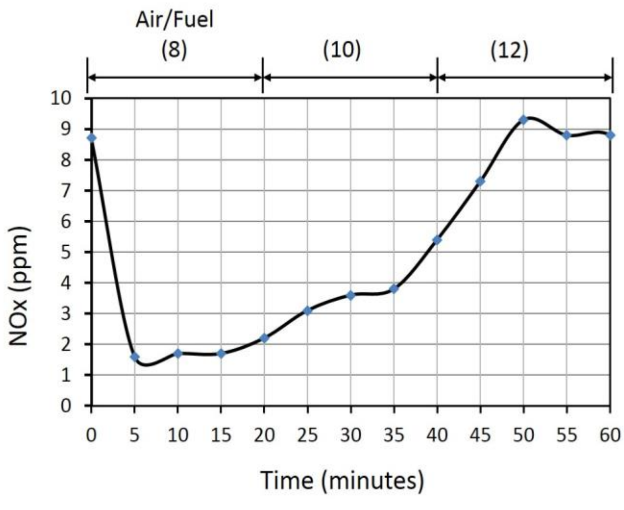

Figure 4. Measurements of Combustion Air Flow Rates for Combustion with Different Fuel/Air Ratios During Reheating.

The traces of sulfur present in the fuel is expected to burn completely to sulfur oxide. From the measured values of input parameters such as actual fuel and combustion air flow rates and fuel chemical composition the composition of flue gas is calculated. A sample calculation of this is shown in Table 4.

The sulfur dioxide content in the flue gas is very small compared to the concentrations of carbon dioxide and was calculated as parts per million, Figure 5, which is due to the small amount of sulfur in the fuel. This decrease in concentration with increasing air/fuel ratio is due to the increased nitrogen content in the flue gas.

Table 4. Sample Calclation of Flue Gas Composition Based on Measured Industrial Steel Reheat Furnace Combstion Parameters

Compound		**Input**				**Output**
		MW (g/mol)	**Volue (m^3)**	**Wt (kg)**	**kmol/hr**	**Vol.%**
C		12.0		1206.8	100.5	
H		2.0		145.1	72.0	
S		32.1		4.1	0.1	
Theo.	**O2**	32.0		1356.0	136.6	
	N2	28.0		5101.1	513.9	
Actual	**O2**	32.0	3708		165.5	3.7
	N2	28.0	13949		622.8	79.0
CO2		44.0				12.8
H2O		18.0				4.6
SO2		64.0				16 (ppm)

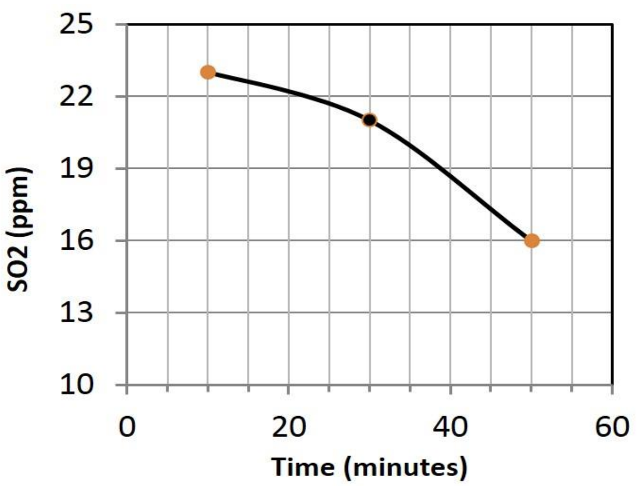

Figure 5. Concentration of Sulfur Dioxide in the Flue Gas Calculated from the Industrial Steel Reheat Furnace Combustion Process.

V. CONCLUSION

From the measurements of nitrogen and sulfur oxides carried out on the industrial billet steel reheat furnace at the Libyan Iron and Steel Company, t was found that nitrogen oxides in the flue gas was dependent on the air/fuel ratio used in the combustion process. As the air/fuel ratio is increased the content of nitrogen oxides, as measured by furnace instruments, increases. Although absolute values of nitrogen oxides in the flue gas were not measured, the trend of these measurements indicated that control of air/fuel ratio is a very important parameter in controlling the formation of nitrogen oxides during combustion. Sulfur in the fuel was present in trace amounts and based on the calculations of the flue gas compositions carried out the concentration of sulfur dioxide in the flue gas was minimal.

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BIOGRAPHY

Hussein Abluwefa was born in Misurata /Libya, on January 5, 1960. He received M.Eng. Degree in Metallurgical Engineering from McGill University, Montreal, Canada, 1992. He got his PhD degree from same university in 1996. He is currently at the department of Materials Science and Engineering, Misurata University as an Associate Professor. His field of interest is modelling of metallurgical processes.

Adel Elnaas was born in Misurata/Libya, on November 24, 1971. He received his Masters degree from The Libyan Academy/Misurata Branch in Engineering Project Management. He is currently working with the Iron and Steel Company.