Natural Gas as an Alternative to Fuel Oil Usage in the Steel Industry

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Abstract— **Steel industry is a major energy consumption sector requiring large quantities of fuel in order to operate its various units. There are two main types of fuel used in the steel industry, fuel oil and natural gas. Natural gas burns better than fuel oil and produces less combustion products that are harmful to the environment. The Libyan Iron and Steel Company uses fuel oil as a main source of energy in its operations. Calculations are carried out to determine equivalent amounts of natural gas to fuel oil being used in the company as well as quantities of CO_2, SO_2 produced from combustion of both fuels. The results showed the possibility of reducing the amounts CO_2 by about 25.7% and eliminating SO_2 by switching to natural gas usage in the company.**

Index Terms: **Natural gas, fuel oil, emission factor, combustion, carbon dioxide, nitrogen oxides.**

I. INTRODUCTION

Fossil fuels are the driving force for everything that we know and use and there is no alternatives to them in the foreseen future[1]. There are many types of these fuels ranging from very simple gases to very complex and heavy hydrocarbons [2]. There are vast industrial fields dealing with fuels starting from discovery and extraction and ending with delivery and usage. Looking into the industry with its various areas, fuel combustion is relied on heavily with large quantities which in turn results in the emissions of different products that are harmful to the environment [3-6]. Different fuels burn differently from each other, a fact that is dependent on a number of factors including complexity of fuel, chemical content, physical and thermal properties, etc. Lighter fuels such as natural gas, burn better than heavy fuels in which the former results in cleaner combustion products. The choice of fuel usage by the industry is usually controlled by economic aspects, fuel availability, and local environmental regulations. In this work, we consider the fuel usage by the Libyan Iron and Steel Company which is mainly heavy fuel oil and determine the equivalent amounts of natural gas that can be used by the company, calculating in the mean time the amounts of CO_2 and SO_2 from the combustion of both fuels. The purpose of this work is to clarify quantitatively the advantages of using natural gas instead of heavy fuel oil in terms of CO_2 and SO_2 production.

II. FUEL EQUIVALENCE CALCULATIONS

A. Exported Fuel

The Libyan iron and steel company uses fuel oil as the main fuel in its sectors calcining plant, billet and section rolling mills, hot rolling mill as well as the power plant. The quantities of fuel oil used by the company for one year is given in Table 1.

Table 1: Quantities of Fuel Oil Delivered to Different Sections of the Libyan Iron and Steel Company (m^3).

Month	Calc. plant	Billet R. Mill	Sec. R. Mill	Hot R. Mill	Power Station	Total
Jan.	489	1672	330	1597	61477	65566
Feb.	468	2204	339	1934	50409	55354
March	482	881	393	2248	62916	66919
April	484	1759	1395	2073	50218	55930
Many	741	1745	397	963	52456	56302
June	452	1727	353	1993	55263	59787
July	468	1678	352	2071	48495	53064
Au.	499	1787	357	2110	31497	36248
Sept.	445	1654	347	3050	36692	42188
Oct.	407	1736	417	1914	57239	61713
Nov.	296	1491	372	1430	44111	47699
Dec.	285	1629	351	1614	47558	51437
Total	5518	19961	5404	22996	598331	652209

The largest quantities of fuel oil is delivered to the Power Plant which accounted for (598331 m^3), which is 91.7% of the total fuel, in the year 2005. The largest fuel consuming mills are the Hot and Billet Rolling mills, as shown in Figure1.

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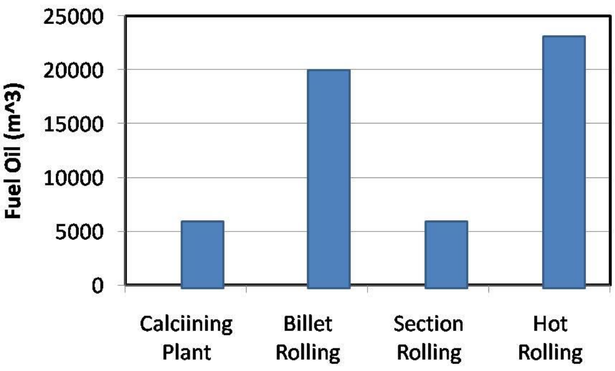

Figure 1. Fuel Oil Eonsumption of the Different Sections of the Libyan Iron and Steel Company for the Year 2005.

B. Natural Gas Equivalent

Based on fuel and natural gas heating values (*HV*oil) and (HV_{NG}) reported by the supplier for fuel oil and natural gas, shown in Table 2, the equivalent quantities of natural gas can be calculated as follows:

Table 2. Heating Values for Fuel Oil and Natural Gas as Reported by Supplier.

Fuel type	Heating Value (HV)	Specific Gravity, Density
Fuel Oil	43095.2 (kJ/kg)	0.9117 @15.5 °C
Natural Gas	39195 (kJ/Nm^3)	0.7937 (kg/Nm^3)

In these calculations an equivalence conversion factor, *ECF*, to convert from quantities of fuel oil to quantities of natural gas need to be determined as follows:

$$ECF = \frac{HV_{oil}}{HV_{NG}} \quad x \quad SG_{oil} \qquad (1)$$

where SG_{oil} is the specific gravity of fuel oil given in Table 2. The ECF is calculated as (1.00233). Using this conversion factor the equivalent quantities of natural gas in normal cubic meters (Nm^3) can be determined as shown in Table 3.

Table 3: Equivalent Quantities of Natural Gas Delivered to Different Sections of the Libyan Iron and Steel Company (Nm^3 x 10^{-3}).

Month	Calc. plant	Billet R. Mill	Sec. R. Mill	Hot R. Mill	Power Station	Total
Jan.	490	1676	330	1601	61621	65718
Feb.	469	2209	340	1939	50526	55483
March	483	883	394	2253	63062	67075
April	486	1763	1398	2078	50335	56060
Many	743	1749	398	965	52578	56433
June	453	1731	354	1998	55391	59927
July	469	1682	353	2076	48608	53188
Aug.	500	1791	358	2114	31570	36333
Sept.	446	1657	348	3057	36777	42286
Oct.	408	1740	418	1918	57372	61857
Nov.	297	1494	373	1433	44214	47811
Dec.	286	1633	352	1617	47669	51557
Total	5530	20008	5416	23049	599725	653728

C. Fuel Chemical Composition

Chemical composition of fuel can be calculated based on its heating values and heats of combustion of chemical elements in the fuel, Table 4.

Table 4. Thermodynamic Data of Fuels and their Constituents.

Component	Gross Heating Value	*ΔHc (kJ/mol)*	*$ΔH_f$ (kJ/mol)*	*Density*	*Specific Gravity @15.5° C*
Fuel Oil	43092.2 *(kJ/kg)*				0.9265
Natural Gas	39195.7 *(kJ/Nm^3)* 540000kj/kg			0.7937 kg/Nm^3	
C		393.5			
H_2		285.8			
SO_2			296.84		

The simultaneous equations used to calculate the fuel oil chemical composition as follows:

$$X \;+\; Y \;+\; Wt.S \;=\; 1 \quad kg - Fuel\,oil$$
$$\Delta H_{c,C} X \;+ \Delta H_{c,H} Y + \Delta H_{f,S} \;=\; 43092.2 \;\left(\frac{kJ}{kg - Fuel\,oil}\right) \qquad (2)$$

where *X*, *Y* and Wt.S are the weights of carbon, atomic hydrogen and sulfur in fuel oil, respectively. Solving equation (2) and using data from Table (2) gives the values (X = 0.894, Y= 0.96) which gives the weight percentages of carbon and hydrogen in fuel oil as , 89.4 wt.% and 9.6wt.%, respectively. The reported fuel oil composition by the supplier is given in Table 5.

Table 5. Composition Of Fuel Oil Provided by Supplier (Empty Spaces Indicate not Values Determined),

Component	Fuel oil composition (Wt.%)	
	Reported	Calculated
Carbon	87	89.4
Nitrogen	0.28	
Oxygen	0.52	
Sulfur	1.0	
Hydrogen	10.8	9.6
Ash	0.05	

The composition of natural gas is provided by natural gas supplier and is given in Table 6.

Table 6. Composition of Natural Gas as Provided by Gas Supplier,

Component	Formula	Molecular Weight (g/mol)	Composition (Vol.%)
Methane	CH_4	16.04	91.9
Ethane	C_2H_6	30.07	5.0
Propane	C_3H_8	44.09	2.0
Butane	C_4H_{10}	58.12	1.0
Atomic Hydrogen	H	1.08	0.1

D.Reactions of Fuel Oil

Fuel oil will burn with 5% excess combustion air where all reactions are assumed to go to completion. Combustion will take place according to the following overall reactions:

$$C + O_2 = CO_2 \quad (3)$$

$$4H + O_2 = 2H_2O \quad (4)$$

$$S + O_2 = SO_2 \quad (5)$$

These equation will be used to calculate volumes of CO_2, H_2O, SO_2 and actual volume of combustion air.

Volume of CO_2

Considering the total fuel oil used in the hot rolling mill for one year (22996 m^3), as shown in Table 1, and using reaction (1), the weight of fuel can be calculated as:

$$W_{fuel\ oil} = V_{fuel\ oil}\ x\ \rho_{fuel\ oil} \quad (6)$$

Where V and ρ are volume and density, respectively. The weight of fuel is calculated as (20965.5 ton). The weight and number of moles of carbon, W_c and MOL_c can be found as follows:

$$W_c = Wt.\%C_{fuel\ oil}\ x\ W_{fuel\ oil} \quad (7)$$

Which gives (18743.1 ton) of carbon. Moles of carbon can be calculated as:

$$MOL_c = \frac{W_c}{MW_c} \quad (8)$$

Where MW_c is the molecular weight of carbon. Molar quantity of carbon is then 1549.9 ton-mol). From the stoichiometry of reaction (3) we can see that moles of CO_2 and C are one-to-one, and hence, molar weight of carbon dioxide is 1549.02 (ton-mol). The volume of CO_2 can be calculated from knowledge of molar volume of gas at STP (Standard Temperature and Pressure) which is one mole of gas occupies 22.4 liters. From this we can calculate the volume of CO_2 at STP as:

$$V_{CO_2} = MOL_{CO_2}\ x\ 22.4\frac{l}{mol}\ x\ \frac{Nm^3}{1000\,l} \quad (9)$$

The volume is then (34698048 Nm^3).

Volume of Combustion Air

Combustion air is considered as normal air of 21 vol.% O_2 and 79 vol.% N_2 at ambient temperature. From the stoichiometry of reaction (3), the number of moles of oxygen are equal to the number of moles of carbon and can be calculated as:

$$MOL_{O_2} = MOL_c\, x\, \frac{1\ mol - O_2}{1\ mol - C} \quad (10)$$

Moles of oxygen are then (1549017 kmol-O_2). Moles of nitrogen can be calculated from the molar composition of air as:

$$MOL_{N_2} = MOL_{O_2}\ x\ \frac{79\ mol - N_2}{21 mol - O_2} \quad (11)$$

That is (5827254 kmol-N_2). The molar weight of air is the sum of molar weights of oxygen and nitrogen (7376271 kmol).

$$V_{Air} = MOL_{Air}\ x\ 22.4\frac{l}{mol}\ x\ \frac{Nm^3}{1000\,l}\ x\ \%Excss \quad (12)$$

i.e., the molar weight of air is (165228470 Nm^3).The same procedure is used to calculate molar weights of H_2O, SO_2 and combustion air. These values are shown in Table (7) for all fuel oil consuming section in the Libyan Iron and steel Company as well as for the power plant.

Table 7. Volumes of Fuel Oil Combustion Products for all Fuel Consuming Sections in the Libyan Iron and Steel Company for One Year.

Section	***CO_2***	***H_2O***	***SO_2***	**Combustion Air**
	Nm^3/year			Nm^3/year
Calcining plant	8325241	5408613	35212	39644005
Billet Rolling Mill	30119163	19567349	127391	187395162
Section Rolling Mill	8153516	5297049	34486	50729482
Hot Rolling Mill	34697369	22541646	146755	165225567
Power Station	902804315	586519850	3818488	5617060460
Total	984099605	639334509	4162334	6060054677

E. Reactions of Natural Gas

We shall assume that natural gas will burn with 5% excess combustion air and that all reactions go to completion. Combustion will take place according to the following overall reactions

$$CH_4 + 2O_2 = CO_2 + 2H_2O \quad (13)$$

$$C_2H_6 + \frac{7}{2}O_2 = 2CO_2 + 3H_2O \quad (14)$$

$$C_3H_8 + 5O_2 = 3CO_2 + 4H_2O \quad (15)$$

$$C_4H_{10} + \frac{13}{2}O_2 = 4CO_2 + 5H_2O \quad (16)$$

$$4H + O_2 = 2H_2O \quad (17)$$

These reaction will be used to calculate volumes of CO_2 , H_2O and actual volume of combustion air. As a sample calculation, reaction (13) will be used for the calculation of combustion products and actual volume of combustion air.

Volume of CO_2

Considering the equivalent total volume of natural gas for use in the hot rolling mill for one year (23049x10^3 Nm^3), as shown in Table 2, and using reaction (13), the volume of CH_4 can be calculated as:

$$V_{CH_4} = V_{Natural\ Gas}\ x\, Vol.\%CH_4 \qquad (18)$$

where $Vol.\%CH_4$ is volume percentage of methane in natural gas as given in Table (6), i.e., volume of CH4 is (21182031 Nm^3). Moles of CH_4 can be calculated as:

$$MOL_{CH_4} = \frac{V_{CH_4}}{22.4\frac{l}{mol}}\, x\, \frac{1000l}{Nm^3}\, x10^{-6} \qquad (19)$$

Molar quantity of CH_4 is then (945.63 ton-mol). From stoichiometry of reaction (13) we can see that moles of CO_2 and CH_4 are one-to-one, and hence, molar weight of carbon dioxide is 945.63 (ton-mol). The volume of CO_2 can be calculated from knowledge of molar volume of gas at STP (Standard Temperature and Pressure) which is one mole of gas occupies 22.4 liters. From this we can calculate the volume of CO_2 at STP as:

$$V_{CO_2} = MOL_{CO_2}\ x\ 22.4\frac{l}{mol}\ x\ \frac{Nm^3}{1000\,l} \qquad (20)$$

The volume is then (21182031 Nm^3). It is important to note here that since the molar quantities of CH_4 to CO_2 are one-to-one, their volumes are equal, as shown in the above calculations.

Volume of H_2O

Since the molar quantities of CH_4 to H_2O in reaction (13) is one-to-two, and as discussed above, the volume of H_2O is twice the volume of CH_4, i.e., the volume of H_2O is (42364062 Nm^3).

Volume of Combustion Air

As discussed above, the volume of O_2 is twice the volume of CH_4, i.e., volume of O_2 is (42364062 Nm^3). The molar weight of air can be calculated as:

$$V_{Air} = V_{O_2}\ x\ \frac{100\,Vol.\%\ \ Air}{21\,Vol.\%\,O_2}\ x\ \ \%Excss \qquad (21)$$

i.e., volume of combustion air is (201733629 Nm^3). The same procedure is used for reactions (13) to (17) to calculate volumes of CO_2, H_2O and combustion air. These values are shown in Table (8) for all consuming section in the Libyan Iron and steel Company as well as for the power plant.

Table 8. Quantities of Natural gas Combustion Products for all Fuel Consuming Sections in the Libyan Iron and Steel Company for One Year.

Section	CO_2 Nm^3/year	H_2O Nm^3/year	Combustion Air Nm^3/year
Calc. plant	6188502	11716122	62493360
B. olling	22388840	42386736	226089270
Sec. Rolling	6060852	11474454	61204311
Hot Rolling	25792013	48829651	260455539
Power Station	671091951	1270516799	6776889226
Total	731522157	1384923763	7387131706

III. DISCUSSION OF RESULTS

The quantities of fuel oil delivered to the different sections of the Libyan Iron and steel Company (calcining plant, billet rolling, section rolling, hot rolling and power plant) for the year 2005 show that the power plant consumes the major part of the fuel accounting for about (91.7%), followed by the consumption by the hot rolling process (3.5%). Tonnages of produced carbon dioxide (CO_2) from the combustion of fuel oil and natural gas, as calculated above, are shown in Figure 2. This figure shows lesser tonnage of carbon dioxide are produced by burning natural gas compared to fuel oil. The percentage in reduction is about (25.7%).

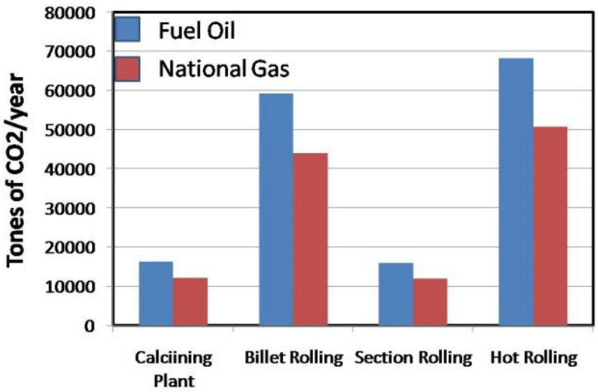

Figure 2. Comparison of CO_2 Emissions.

The reduction in tonnage of CO_2 in each section is shown in Figure 3. The total reduction in CO_2 production in all steel sections accounts for (8430 tones). In the power plant, the total reduction is (455149 tones) for one year.

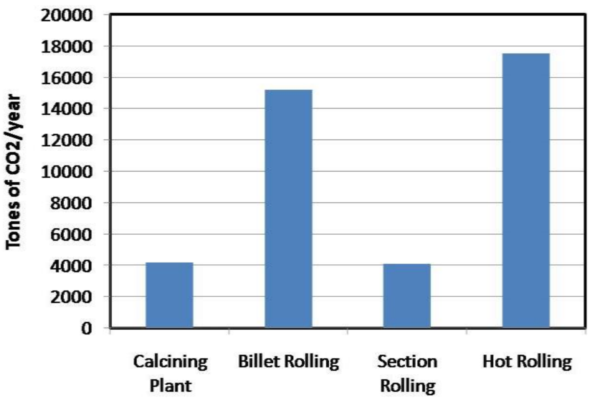

Figure 3. Reduction of CO_2 Emissions per Year by Using Natural Gas Instead of Fuel Oil.

The volume of combustion air for the burning of fuel oil and natural gas are shown in Figure 4. It can be seen from this figure that combustion of natural gas requires required more combustion air than for the burning of fuel oil. The percent increase accounts for about (17.9%).

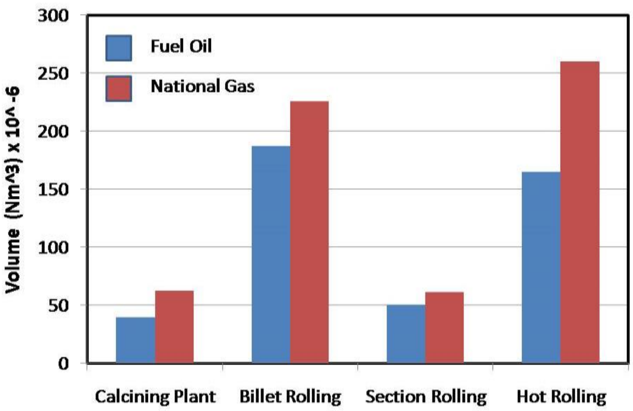

Figure 4. Required Combustion Air for the Burning of Fuel Oil and Natural Gas.

The production of nitrogen oxides estimated from emission factors for the combustion of fuel oil and natural gas are shown in Figure 5. The estimations show that quantities of produced nitrogen oxides are quite similar for both fuel.

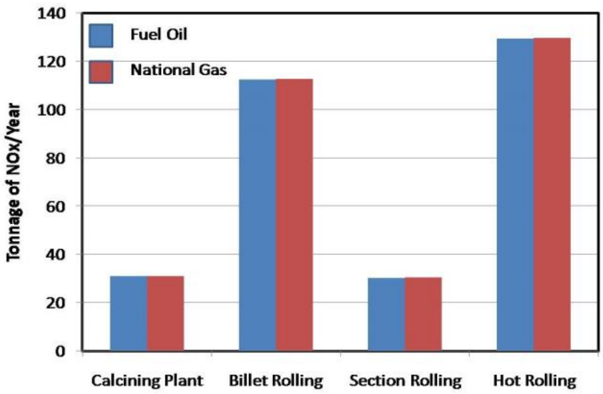

Figure 5. Tonnage of NO_x Produced from Burning of Fuel Oil and Natural Gas.

IV. CONCLUSION

Calculations of the equivalent amounts of natural gas as an alternative to fuel oil being used at the steel company showed it is possible to reduce the amount of emitted carbon dioxide by about (25.7%) by using natural gas instead of fuel oil. Required combustion air is (17.9%) higher for combustion of natural gas as compared to fuel oil. Also, no sulfur content was reported in the chemical composition of natural gas, and hence, sulfur dioxide emission is eliminated by the use of natural gas.

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