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Energy Efficiency Methods In Ferrous Melting Foundries -Green House Gas Emissions- A Review

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Abstract:

Iron and steel Industry is the most power consuming industry in India and the world, consuming 25 % of the total industrial power consumption. With consumption of 449.27 Mtoe (million tons of oil equivalent), for total requirement of power generation in India during 2009. The Indian Iron and Steel sector emitted 117.32 Mt CO_2 as GHG during 2007.

With the ever increasing power consumption and Green House Gases emission, the industrial atmosphere is changing the climate of the earth and Globe resulting directly or indirectly the human activity. The irreversible climate changes are alarmingly changing the global mean temperature which are leading to rise in mean sea levels and change in rain fall patterns. Further, the rise in temperature is warming the Globe and yielding negative impacts on climate, human life, health, food security, economic activity, water resource and physical infrastructure. Farming is under serious effect leading to fall in crop production. Atmosphere change is also leading to tropical deceases and large scale migration .The poorer countries are being worst effected necessitating the world to adopt energy efficient measures to lessen the emission of GHG and to save the Earth.

The efficient method applied in the industrial sector not only reduces GHG but also the cost of energy and production of the product. Also have the potential of generating additional revenue through sale of Carbon Credits by making road for Clean Development Mechanism.

In this paper, the theoretical quantity of GHG emission is measured from the chemical reactions and Stoichiometry readings for the amount of CO_2 generated by combustion of the fuel that is used during the chemical reactions. The emission factors of GHG are calculated basing on the fuel.

Key Words: Green Houses gases(GHG), Million tons of oil Equivalent (Mtoe), Global Mean temperature, Stoichiometry, Clean Development Mechanism (CDM), Carbon Credits, Emission Factor.

Introduction:

India is the fourth largest Iron and steel manufacturing industry in the world after China, Japan and USA, with consumption of power equivalent to 449.27 Mtoe (million tons of oil equivalent), of generated during 2009 [1], the residential and industrial sectors consumed 38% and 30% respectively. The Iron and Steel sector consumed 33.69Mtoe or 25% of the total industrial energy consumed.

In 2007, GHG emissions from various sectors [1] in India were 1904.73 $MtCO_2$, amongst which 38% (719.31 $MtCO_2$) was from power and 22% (412.55 $MtCO_2$) was from industry sector. The Indian Iron & Steel sector contributed to about 117.32 $MtCO_2$ (28.4% of the industrial sector) of carbon emission.

In 2010 [1], the Government of India announced its policy to reduce the carbon intensity by 25 % of 2005 levels before 2020. This could possibly be accomplished by improved processes, adoption of energy efficient technologies and measures, and renewable energy options.

The Government Agencies are promoting sustainable development and energy efficiency through increased use of Clean Technologies through National Action Plan on Climate Change (NAPCC), National Mission on Enhanced Energy Efficiency (NMEEE), Perform, Achieve and Trade (PAT).The Bureau of Energy Efficiency (BEE) is issuing energy efficiency norms to energy intensive manufacturing units.

An International organization called Inter Governmental Panel on Climate Changes (IPCC) [2],[3],[4] was formed in 1988 to over see the climate changes by (WMO) World Metrological Organization and the UNEP, United Nation Environment Program. An International treaty called the UN Framework Convention on Climate Change UNFCCC was signed by 150 countries in 1992 who have historically contributed for the change in climate. These countries are contributing financially to the developing countries to tackle climate changes. The protocol was called KYOTO PROTOCOL and came to existence in 2005 and since then in operation and trading of Carbon Credit like normal public shares in the market globally [4].

1.0 Origin of GHG Emissions:

The production of iron and steel leads to Green House Gases emissions [5] which consists of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).The emission starts from raw materials to finished products and several other interrelated processes of Foundry Industry. Most of CO_2 emitted by iron and steel industry is associated with the production of iron, more specifically the use of carbon to convert iron ore to iron. Carbon is supplied in the furnace mainly in the form of coke produced from metallurgical grade coking coal as a reduction agent .

The major processes of foundry where GHG is emitted are: 1) coke production, 2) sintering process, 3) iron production, 4) raw steel production, 5) ladle metallurgy, 6) continuous casting, 7) hot and cold rolling, 8) finished product preparation and 9) secondary steelmaking.

1.1 The major process units at Iron and Steel facilities emit GHG which include the following:

1. Sinter plant emissions and combustion sources
2. Non-recovery coke oven battery combustion stack
3. Coke pushing ,raw material and combustion
4. Blast furnace and flue gases
5. Basic oxygen furnace (BOF) exhaust and EAF exhaust.
6. Indirect emissions from consumptions of electricity

1.2 The primary combustion sources of GHGs are of the following:

1. Coke oven battery combustion stack
2. Blast furnace burners
3. Boiler
4. Process heater
5. Reheat furnace
6. Flame-suppression system
7. Annealing furnace
8. Ladle re heater
9. Other miscellaneous combustion sources.

1.3 Indian Scenario of GHG Emissions.

India's total energy consumption/generation was [1] 449.27 Mtoe in 2009. Out of this, the residential and industrial sectors consuming 38% and 30% respectively. Iron and steel sector consumed about 33.69Mtoe or 25% of the total industrial energy consumption. The sector contributes to about 6.2% of the national Green House Gas (GHG) emissions.

In 2007, GHG emissions from various sectors in India was 1904.73 MtCO2, amongst which 38% (719.31 MtCO2) and 22% (412.55 MtCO2) were from power and industry sector respectively. The Indian Iron & Steel sector contributed to about 117.32 MtCO2 (28.4% of the industrial sector). In this context, India announced a voluntary 20-25 per cent carbon emission intensity reduction by 2020 on the 2005 levels, ahead of the UNFCCC's COP15 summit held in Copenhagen. This could possibly be accomplished by improved processes, adoption of energy efficient technologies and measures, and alternate and renewable energy options.

2.0 Theoretical Calculations of GHG Emissions [6]:

The theoretical quantities of CO_2 emissions associated with the energies required to produce steel are summarized below which present CO_2 emissions from various steelmaking processes for a number of conditions. These conditions are based on [6],[7] analysis of theoretical energy consumption for steel production. Emission factors were calculated by considering the heats of reaction for the following reactions:

$C + ½ O_2 \rightarrow CO_2$ H = 395.3 kJ/mol (1)

$H_2 + ½ O_2 \rightarrow H_2O$ H = 247.3 kJ/mol (2)

$C + 2H_2 \rightarrow CH_4$ H = 91.0 kJ/mol (3)

$CH_4 + 2O_2 \rightarrow CO_2 + H_2O$ H = 798.9 kJ/mol (4)

These reactions represent the basic reactions that occur when fuel (carbon or methane) is combusted. By using these heats of reaction and the energy requirements for each process , the necessary amount of moles of fuel are calculated. Once the amount of fuel is known, Stoichiometry dictates the amount of CO_2 generated by the combustion of that fuel. The emission factor for electricity of U.S. grid, accepted by the American Iron and Steel Institute (AISI) was used in this analysis (AISI 1996) [5] for this paper.

The emission factors used in this analysis are shown in Table-1 and compared them to the AISI emission factors for each fuel source considered. The assumptions made for the study are :

1. 100 % Carbon the fuel is burnt for melting of steel and 100% CO_2.is formed
2. Natural gas is assumed to be 100% methane and converted entirely to CO_2 and H_2O when consumed.
3. Electricity emissions include efficiency and transmission losses.
4. Emissions for BOF steelmaking are a result of 50 kg C/ton LM that remains in the liquid pig iron and is used as fuel during oxygen steelmaking. This carbon is not combusted to CO_2 during the iron making and thus is not included in the emissions for iron making. Since oxygen steelmaking generates rather than consumes energy, this process has no additional combustion emissions beyond the 50 kg C/ton LM remaining in the liquid pig iron.

2.1 Emission Factor of GHG for Various Steel Making Processes [6]: The ratio between consumption of fuel to the power consumed is known as the Emission Factor. The emission factor for different processes are Tabulated in the Table -1.The assumptions are 1) Coke is assumed to be 100% carbon combusted fully CO_2, 2) Natural gas is assumed to be 100% methane and combusted to fully to CO_2 and H_2O. 3) Electricity emission factor accounts for transmission and efficiency losses at the power plant. 4) Hydrogen used as fuel does not result in any CO_2 emissions. 5) Coke oven gas used as fuel is considered as natural gas when considering CO_2 emissions.

Table -1. Emission Factors Used to Convert Theoretical Energy Consumption to CO_2 Emissions.

Fuel source	Theoretical emission factor kg CO_2/MJ	AISI emission factor kg CO_2/MJ	Difference percentage
Coke	0.111	0.109	1.8
Natural Gas	0.055	0.050	9.1
Electricity	N/A	0.173	N/A
Coke Oven Gas	0.055	0.046	16.4

3.0 Comparisons of GHG Emissions with Iron Ore and Steel Making Processes:

Absolute theoretical minimum energy consumption [7],[8] is calculated from the enthalpy, entropy and specific energy of the materials. The main three fuel have been used to tabulate theoretical carbon emissions for each process in table -2 against the theoretical energy requirement per ton of liquid metal.

Table-2 Tabulation of Theoretical Energy Requirements [7],[8] with Theoretical CO_2 Emissions for Producing Steel from Pure Iron Ore (Fe_2O_3) and Pure Mild Steel Scrap (Fe) at different tapping temperatures.

Raw Material for Melting	Tapping Temperature in ^{0}C	**Theoretical Energy requirement Kwh/ Ton of Liquid metal**	**Theoretical Carbon Emissions Theoretical (kg CO_2/ton of liquid metal)**		
			Carbon as Fuel	Natural Gas as Fuel	Electricity as fuel
Ore (Fe_2O_3)	1540	2394.5	960	475	1494
	1600	2409.0	966	478	1503
Scrap (Fe)	1540	354.0	142	70	221
	1600	368.6	148	73	230

Its observed from the table that carbon as fuel is emitting 960 kgCO_2 per one ton of liquid metal produced from Ore and 142 kgCO_2 from Steel Scrap. The emissions of CO_2 is midway when natural gas is used as fuel.

Table-3: Tabulation of Theoretical Energy Requirements [7],[8] with Theoretical CO_2 Emissions to Produce Liquid Hot Metal at 1450 C for Selected Charge compositions.

Material Consumption	**Gangue 4% SiO_2, 1% Al_2O_3, 1% MnO.**	Ash	**Theoretical Energy required Kwh/T of liquid metal**	**Theoretical Emission of CO_2 (kg/ Ton LM)**
Fe-5%C	No	No	2724.0	908
Fe-5%C	Yes	No	2838.0	954
Fe - 5% C - 0.5% Si - 0.5% Mn	Yes	No	2852.0	960
Fe - 5% C - 0.5% Si - 0.5% Mn	yes	No	2895.0	977

It can observed from the table that there is not much variation in the emission of GHG from Steel and steel alloys.

Table-4: Tabulation of Theoretical Energy Requirements [7], [8] with Theoretical CO_2 Emissions to Produce Direct Reduced Iron at 900^{0}C Reduction Temperature for Selected Conditions.

Ore	**Product**	**Theoretical Energy required MJ/Tof liquid metal**	**Theoretical Emission of CO_2(kg/ton LM)**
Pure Fe_2O_2	Fe	8360	461
Fe_2O_2- 1.4% SiO_2	Fe - 2% SiO_2	8380	462
Fe_2O_2- 1.4% SiO_2	Fe - 2% SiO2 – 8.0% FeO	7900	435
Fe_2O_2- 1.5% SiO_2	Fe - 2% SiO_2 – 8.0% FeO - 2% C	8427	391
Fe_2O_2- 1.5% SiO_2	Fe - 2% SiO_2 - 7.7% FeO - 6% C	9432	300

It can be observed that when carbon remains in the final product, as seen in the final two rows in the above table, that carbon is subtracted from the overall CO_2 emissions of the process. The subtracted CO_2 is attributed to the process in which the carbon is used as fuel, because of this reason, the emission is less.

Table -5: Tabulation of Theoretical Energy Requirement with Theoretical CO_2 Emissions to Produce Steel from Hot Metal and Scrap for Selected Conditions.

Hot metal	Slag	Tap Temp. (C)	Scrap (kg)	Steel (kg)	**Theoretical Energy required /T of liquid metal**	**Theoretical Emission of CO_2**(kg/ton LM)
Fe - 5%	--	1600	290	1240	7907	148
Fe - 5%	--	1650	244	1194	8212	135
Fe - 5% C - 0.5% Si	B = 3; 20% FeO	1600	401	1328	7853	138
Fe - 5% C - 0.5% Si	B = 3; 20% FeO	1650	353	1278	8154	143
Fe - 5% C - 0.5% Si	B = 3; 20% FeO	1600	389	1320	7894	139
Fe - 5% C - 0.5% Si	B = 3; 20% FeO	1650	341	1270	8205	144

It can be observed that, BOF steelmaking is theoretically an energy-producing process due to the exothermic nature of the reactions taking place in the furnace. Therefore, fuel consumption is theoretically not needed, and carbon emissions do not result from the combustion of fuels and hence the emission values are less compared to other processes. The CO_2 emissions shown are the result of the 5% carbon (50 kg/ton LM) in the hot metal feed that is consumed during steelmaking. The carbon is actually used as a fuel source for melting scrap and is converted to CO_2 in this process.

Table-6: Tabulation of Theoretical Energy Requirement with Theoretical CO_2 Emissions to Produce Steel from Scrap for Selected Conditions at Tapping Temperature 1600 C

Scrap	Slag	**Theoretical Energy required MJ/T of L M**	**Theoretical Emission of CO_2 (kg/ ton LM)**
Fe	--	1327	230
Fe - 0.1%C - 0.2% Si	B=2.5;25% FeO	1289	223
Fe - 0.1%C - 0.2% Si -1% dirt	B=2.5;25% FeO	1352	234
Fe - 0.1%C - 0.2% Si -1% dirt	B=2.5;35% FeO	1325	230
Fe - 0.1%C - 0.2% Si -1% dirt - 100 Nm^3 air	B=2.5;25% FeO	1577	275

It can be observed that, BOF steelmaking is theoretically an energy-producing process due to the exothermic nature of the reactions taking place in the furnace. Therefore, fuel consumption is theoretically not needed, and carbon emissions do not result from the combustion of fuels and hence the emission values are less compared to other processes. The CO_2 emissions shown are the result of the 5% carbon (50 kg/ton LM) in the hot metal feed that is consumed during steelmaking. The carbon is actually used as a fuel source for melting scrap and is converted to CO_2 in this process.

Table -7 :.Tabulation of Theoretical Energy Requirement with Theoretical CO_2Emissions to Produce Liquid Steel at 1600 C from 50% Scrap and 50% Scrap Substitute.

Input	**Theoretical Energy required MJ/Tof liquid metal; Electrical : in put**	**Theoretical Energy required MJ/T of liquid metal: Coke in put**	**Theoretical Emission of CO_2 (kg/ TLM**
100% Scrap Fe	1289	--	234
Fe - 2% SiO_2	1403	4296	480
Fe - 2% SiO_2 - 8% FeO	1559	4233	503
Fe - 2% SiO_2 - 8% FeO - 2%C	1483	4565	548
Fe - 2% SiO_2 - 8% FeO - 6% C	1328	5223	640
Liquid Pig Iron	487	5388	779
Solid Pig Iron	1145	5388	893

Liquid pig iron is charged at 1450 C, all others at 25 C. Charge energy is assumed to be 100% natural gas for DRI and 100% coke for pig iron. In addition to the CO_2 emissions generated from fuel consumption, the carbon contained in the input materials is converted to CO_2 in this process (10.8 kg C/ton, 2%C DRI; 33.2 kg C/ton, 6%C DRI; 25.8 kg C/ton pig iron).

Table-8: Comparison of Theoretical Energy Requirement with[7], [8] Theoretical and Actual minimum CO_2 Emissions for Selected Processes.

Process	Absolute Minimum	Practical Minimum	Actual CO_2(kg/tone

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	CO_2(kg/tone product	CO_2(kg/tone product	product
Liquid Hot Metal	1091	1158	1447-1559
Liquid Steel (BOF	144	144	189- 207
Liquid Steel (EAF	225	277	364- 416
18-8 Stainless Melting	208	260	--

Conclusions: Green House Gas emission is part and parcel of the Iron and Steel Industry. The increase in power consumption also increases the Green House Gas emissions**.** With the increase in Green House Gases emission, the atmosphere and climate of the Globe are changing resulting directly or indirectly the human activity. The irreversible climate changes are alarmingly changing the global mean temperature which are leading to rise in mean sea levels and change in rain fall levels. Further, the rise in temperature is warming the Globe and yielding negative impacts of climate changes on human life, health, food security, economic activity, water resource, physical infrastructure, farming and fall in crop production. Atmosphere change is also leading to tropical deceases and large scale migration. The poorer countries are being worst effected necessitating the world to adopt energy efficient measures to lessen the emission of GHG and to save the Earth.

The inclusion of the energy efficiency methods in foundry process not only change the Global atmosphere but also the cost of the product. Further emission of green House gases also earns Carbon Credits, a form of shares in the market, which can be traded for money in the international market. Hence, its highly recommended to adopt the energy saving methods for reducing GHG and the Global warming.

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