OPPORTUNITIES TO REDUCE CARBON FOOT PRINT IN HIGH CARBON FERRO CHROME PRODUCTION PROCESS IN A SUB MERGED ARC FURNACE

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ABSTRACT

High carbon ferrochrome is produced by smelting of chrome ore in a sub merged electrical arc furnace. Chrome ore is reduced to form Fe-Cr thru reduction reaction process using coke . In the reduction reaction a considerable amount of CO-gas is generated. In case of open and semi closed furnace this gas is burnt. In case of closed furnace this gas is sucked out and cleaned by scrubber and can be used as a fuel. It has been observed that the off gas is flared in the atmosphere and thus huge energy goes as waste. There is an opportunity to utilise this CO gas and considerable amount of electrical energy can be saved either by preheating the burden or by utilising this gas to generate electrical energy or both. This paper deals with calculations for the off gas, carbon balancing, and oxygen balancing for one ton of Ferro chrome production and also has attempted to calculate the sensible heat calorific value and its potential to generate power.

Ferro Alloys and Mineral division, Tata Steel, India produces high carbon Ferro chrome. It has both open furnace and closed furnace to produce Ferro chrome. The paper is mainly concentrating on its closed type 30 MVA submerged arc furnace at Bamnipal. It has taken initiatives to reduce its carbon foot print. It has been seen that there is a potential to generate around 1.7 MW power in the current situation, where part of the CO gas is utilised for sintering of pellet and for ladle heating . Further, the sensible heat calculations give clear idea about its potential to generate power. The overall aim of this paper is utilisation of the off gas and sensible heat to help the industry to reduce its carbon foot print and cost.

KEYWORDS: *Ferro chrome, closed furnace, carbon balancing, oxygen balancing, off gas, calorific values, off gas and sensible heat calculations, flaring, power generation& its utilisation, carbon foot print.*

INTRODUCTION

Tata Steel is a leading manufacturer of High Carbon Ferro Chrome in India. Tata Steel's Ferro Alloys Plants are located in Bamnipal and in Cuttack in India and in Richards Bay in South Africa. The Ferro Alloy Plant at Bamnipal is one of the Units of Ferro Alloys and Minerals Division of TATA STEEL. The Unit was originally set up by M/S ORISSA MINING CORPORATION LTD. (A GOVT. OF ORISSA UNDERTAKING) in 1986, under technical collaboration with Consortium Voist Alpine AG (Linz, Austria) and Outokumpu OY, ESPOO Finland. The plant adopts the OUTOKUMPU process of manufacturing sintered chrome ore pellets in shaft furnace. Sintering in shaft furnace is an old and inefficient technology. Now, sintering is done in steel belt conveyor, which is an efficient and latest technology. As a part of waste gas utilization Tata Steel Bamnipal has replaced the furnace oil which was being used as fuel for sintering furnace by off gas.

The furnace here is 30 MVA closed top self baked (Soderberg type) submerged electric arc furnace. It had a production capacity of 50000 MT of charge chrome but due to change in market demand, this plant has switched over to Ferro chrome production from Charge chrome production and the production capacity remained same.

Ferro chrome manufacturing is a power intensive process. It consumes 3400 -3700 Kwh/Mt of Ferro chrome which contributes 30-35 % of total cost. Power is the key for carbon foot print and hence reduction in specific power consumption would greatly help to reduce its carbon foot print and cost of production. Tata Steel in its endeavor to reduce its carbon foot prints has taken various steps. It has mapped its carbon foot print for production of 1 MT of Ferro chrome. Life Cycle Inventory has also been done with the help of ICDA .

In ferrochrome production processes, carbon monoxide is generated by releasing energy when oxygen reacts with carbon during reduction reactions of chromite. This CO gas can be further oxidized to CO_2 if mixed with oxygen before leaving the furnace. By this oxidation process, it releases about 3 times the energy released by oxidation of carbon to CO. The potential use of this energy and the corresponding increase in productivity is the economic driving force behind post combustion (PC) technologies.

FERRO CHROME PRODUCTION PROCESS

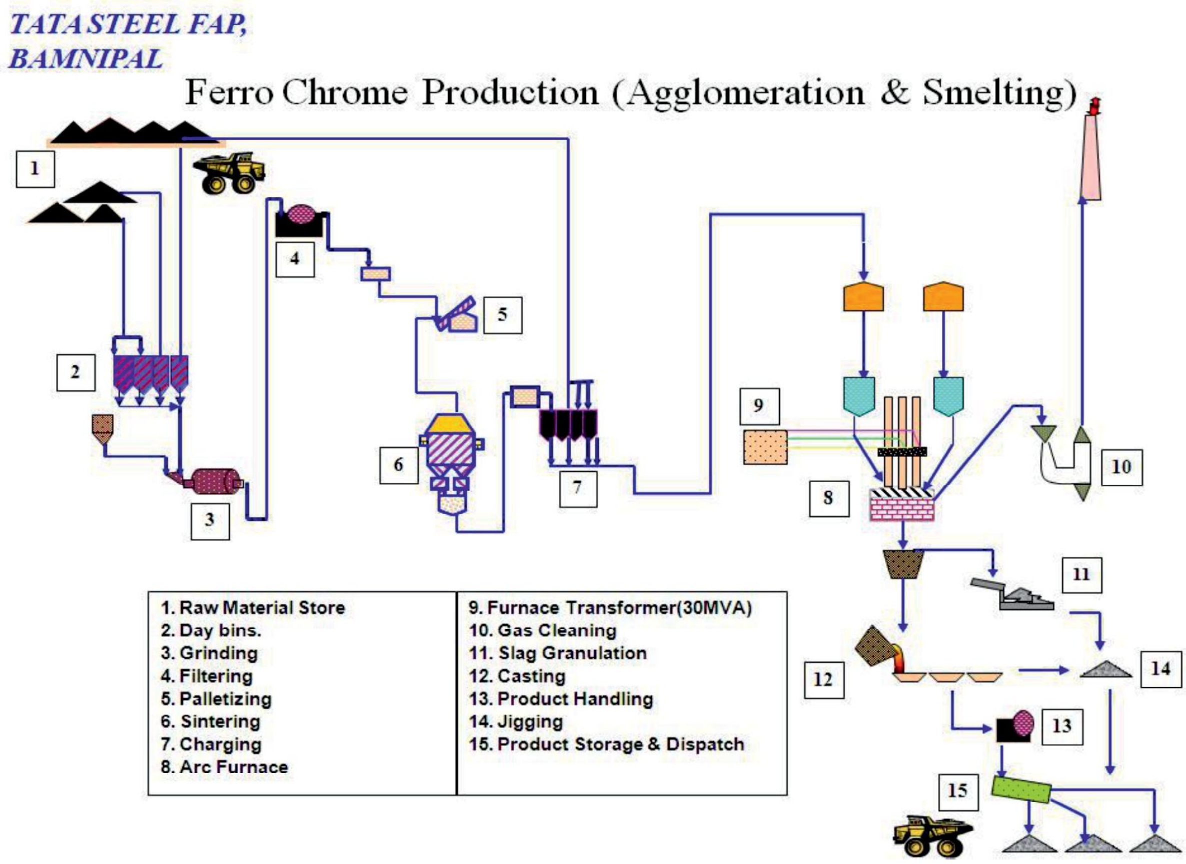

Figure 1: Process Flow diagram

The figure 1 explains the production process flow for Ferro Chrome Production. The chromite ore input is in the form of Friable and Lumpy ore. The friable chrome ore is processed in the GFPS (grinding-3, filtrating-4, palletising-5 & Sintering-6) plant to make pellets. In the GFPS, the chrome ore is ground in the grinding mill after adding water and the slurry is filtered in a drum filter unit then green pellets are formed in the palletising disc, the green pellets are then sintered in the shaft furnace. The input to the furnace-8, are pellets, chrome lumps, coke (reductant) and quartzite (flux).The smelting is done in the submerged arc electrical furnace. The Electrical power to the furnace is fed from 30 MVA furnace transformer - 9. It is a closed type furnace; the photo graph of this furnace is shown in the figure . After smelting, the molten metal and slag are tapped from the furnace. The slug is granulated in the slag granulation pit and the molten metal is casted in the casting bed.

The figure 2 is the simple process flow block diagram is self explanatory to depict the Ferro chrome production process

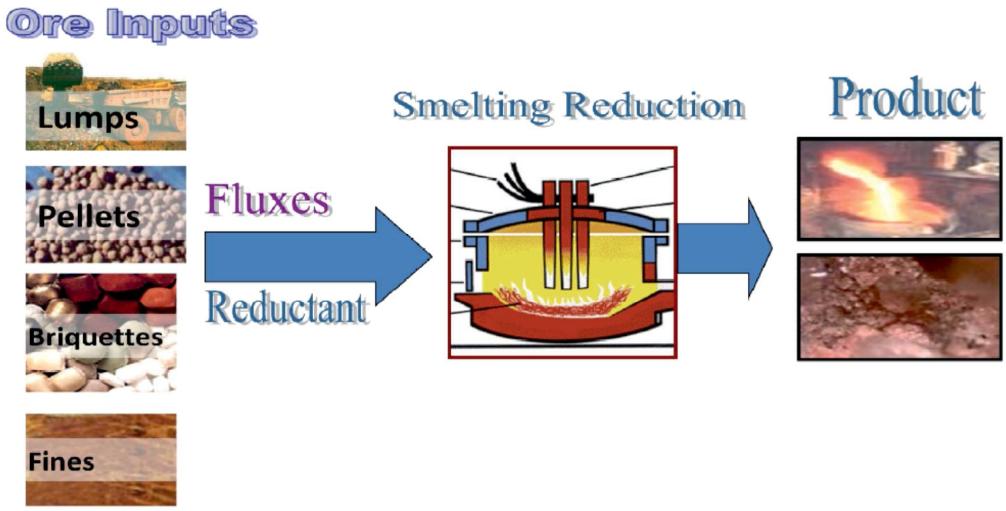

Figure 2: Production process block diagram

RAW MATERIALS

Different raw materials required for the production of ferrochrome are:

- Friable chrome ore.
- Friable lumpy ore.
- Hard lumpy ore.
- Quartzite.
- Pyroxinite.
- Low ash metallurgical Coke (LAM Coke).
- Coke fines.
- Electrode Paste.
- Bentonite.
- Lime.
- Molasses.

The major raw materials of these are chrome ore and Low ash metallurgical Coke (LAM Coke). Chrome ore is obtained in all the three forms for Tata Steel's own captive mines at Sukinda. LAM coke of very low phosphorous is being procured from China. Electrode paste is being procured from ELKEM. Other raw materials like Quartzite, Lime, Coke dust, Bentonite, Molasses etc are procured from local sources. The specifications of various raw materials are shown below

Raw Material Specifications

SL. №	Material	Size	Chemical Analysis	
1	Chrome ore			
	a) Hard lumpy	10 – 40 mm (+/- 5 %)	Cr_2O_3	38 – 42 %
			Cr/Fe	3.0 – 3.2 %
	b) Friable Lump	25 – 75 mm (+/- 5 %)	Cr_2O_3	48 – 52 %
			SiO_2	05% (max.)
			Cr/Fe	2.2 – 2.6
	c) Friable fines	0 – 25 mm	Cr_2O_3	48 – 52 %
			SiO_2	04 % (max)
			Cr/Fe	2.4 – 2.8
2	Pyroxinite	10 – 50 mm (+/- 5 %)	SiO_2	50 – 52 %
3	Quartzite	20 – 50 mm (+/- 10 %)	SiO_2	97% (min.)
4	Lam Coke	10 – 30 mm (+/- 10 %)	Fixed Carbon	85% (min)
			Ash	12 – 14 %
			Volatile Matter	2 % (max)
			P	0.05% (max)
			S	0.05% (max)
5	Coke Dust	0 – 10 mm (+/- 10 %)	Fixed Carbon	70 % (min)
6	Bentonite	- 200 # 85 % (min.)	SiO_2	50 % (min.)
			Na_2O	5 % (max)
			Swelling Index	25 ml / 24 Hrs
			pH	8.5 - 10
7	Molasses	Sp. Gravity = 1.4 (min)	Reduced Sugar	60% (min)
8	Electrode Paste	Cylinders	Fixed Carbon	80% (min)

Furnace Details - the details of closed type furnace being used at Tata Steel Bamnipal is shown in figure 3.

RAW MATERIALS

The following are some of the raw materials that are used for producing Ferrochrome, slag and off gas at Tata Steel Bamnipal

1. Sintered pellets
2. Total Hard lumps
3. Total Friable lumps
4. Coke and
5. Quartz

The objective of this document is to describe carbon balance and oxygen balance with fixed composition for ferrochrome alloy and slag.

Figure 3: The details of closed type furnace

METHODOLOGY AND CALCULATIONS

The methodology in these calculations gives the carbon balance and oxygen balance for the production of ferrochrome from submerged electric arc furnace. Table 1 shows the type of raw materials input needed to produce 1 ton of Ferrochrome.

The typical compositions of all the raw materials are given in the following table 2.

Table 1: Raw materials input into the electric arc furnace for producing 1 ton of Ferrochrome

Type of raw material	Total, kg
Sintered pellet	1370
THL	613.22
TFL	283.11
Coke	523
Quartz	173.82
Total	2963

Table 2: Typical composition of different raw materials

Type of raw material	Values in %					
	Cr_2O_3	Fe	SiO_2	Al_2O_3	MgO	CaO
Sintered pellet	49.81	14.19	5.48	11.92	10	0.72
Hard Lumpy	39.16	8.58	14.37	8.14	18.81	2.54
Friable Lump	41.16	17.78	3.97	11.22	9.68	0.84
Coke		1.08	6.70	3.39	0.26	0.66
Quartz			97	1.5		

ASSUMPTIONS

The following are some of the reasonable assumptions.

1. Iron present in total hard lumps and total fried lumps is in the form of FeO only.
2. Iron present in the sintered pellets is in the form of Fe_2O_3 only.
3. 85% of Cr_2O_3 present in the raw materials reacts by direct carbon reduction, 5 % of Cr_2O_3 reacts by gaseous reduction with CO gas and the rest remain in the slag.
4. 30% of FeO present in the raw material reacts by direct carbon reduction, 60 % FeO reacts by gaseous reduction with CO gas and the rest FeO remains in the slag.
5. Entire Fe_2O_3 reacts by gaseous reduction with CO gas.
6. Carbon input from coke is 404.42 kg.
7. Moisture present in the total raw material undergoes 100 % conversion by water gas shift reaction.

The following are the reactions that occur in the submerged electric furnace.

$$\mathrm{Cr_6O_7 + 3C = 2Cr + 3CO} \quad (1)$$

$$\mathrm{FeO + C = Fe + CO} \quad (2)$$

$$\mathrm{SiO_6 + 2C = Si + 2CO} \quad (3)$$

$$\mathrm{FeO + CO = Fe + CO_6} \quad (4)$$

$$\mathrm{Fe_6O_7 + 3CO = 2Fe + 3CO_6} \quad (5)$$

$$\mathrm{C + CO_6 \rightarrow 2CO} \quad (6)$$

$$\mathrm{Cr_6O_7 + 3CO = 2Cr + 3CO_6} \quad (7)$$

$$\mathrm{H_6O + CO \rightarrow H_6 + CO_6} \quad (8)$$

The above reactions (1), (2) and (3) are the direct reduction reactions Cr_2O_3, FeO and SiO_2 with carbon in the coke.

Reactions (4), (5) and (7) are the gaseous reduction reactions of FeO, Fe_2O_3 and Cr_2O_3 with CO gas. Reaction (6) is termed as Boudouard reaction. Reaction (8) is termed as water gas shift reaction.

The following table 3 gives the carbon balance over the electric arc furnace.

Table 3: Carbon balance over electric arc furnace

Consumption	Total in kg
Carbon goes to Ferrochrome alloy	78
Carbon goes to sludge	5
Carbon requirement for reaction (1)	209.18
Carbon requirement for reaction (2)	6.62
Carbon requirement for reaction (3)	25.71
Carbon for Gasification reaction (6)	79.91
Grand Total	**404.42**

Table 4: Gas balance and analysis

	CO gas		CO_2 gas	
Reaction No	Consumption, kg	Formation, kg	Consumption, kg	Formation, kg
(8)	136.40			214.34
(4)	30.88			48.52
(7)	28.71			45.12
(5)	145.80			229.12
(6)		372.90	292.99	
(1)		488.09		
(2)		15.44		
(3)		60.00		
Total	**341.79**	**936.42**	**292.99**	**537.10**

From the above table 4, following are the conclusions

1. The net CO gas formed and present in the off gas is 936.42 – 341.79 = 594.63 kg.
2. The net CO_2 gas formed and present in the off gas is 537.1 – 292.99 = 244.11 kg.
3. The net H_2 that is formed by reaction (8) is 9.74 kg (assuming 100% conversion of H_2O present in the burden).

Hence the composition of off gas is given in the following table 5 which shows that the major component of off gas is CO gas followed by CO_2 and H_2.

Table 5: Composition of off gas

Component	Kg	Kmol	%
CO	594.63	21.24	67.09
CO_2	244.11	5.55	17.53
H_2	9.74	4.87	15.39
Total	**848.48**	**31.65**	

Heat of reaction for $CO+1/2O_2 \rightarrow CO_2$ 281 kJ/mol

Table 6 shows the oxygen balance over the raw material, slag and off gas which are exactly balanced in the total amount. Oxygen in raw material is equal to the oxygen present in the slag + oxygen present in off gas.

Table 7 shows the carbon balance over input and output materials to electric arc furnace. The Carbon that enters from coke is equal to summation of carbon present in off gas, ferrochrome alloy and sludge which are exactly balanced.

Table 6: Oxygen balance over raw material, slag and off gas

Raw material	Kg	Slag	Kg	Off Gas	Kg
Cr_2O_3	328.12	Cr_2O_3	32.81	CO	339.79
FeO and Fe_2O_3	112.72	FeO	2.94	CO_2	177.53
SiO_2	201.89	SiO_2	167.61	H_2O	0
Al_2O_3	124.97	Al_2O_3	124.97		
MgO	111.62	MgO	111.62		
CaO	8.94	CaO	8.94		
H_2O	77.94				
Total	**966.21**	**Total**	**448.89**	**Total**	**517.32**

Table 7: Carbon balance over input and output materials to electric arc furnace

Carbon input	Kg	Carbon output	Kg
Coke	404.4174	Off gas	321.42
		Ferrochrome alloy	78
		Sludge	5
Total	**404.42**	**Total**	404.42

The following table 8 and table 9 give the composition of ferrochrome alloy and slagcomposition respectively. These compositions are fixed up for the calculations needed for off gas composition, Carbon balance and oxygen balance.

Table 8: Ferrochrome alloy composition

Metal	Kg	%
Cr(85%)	604.29	60.42
Fe	287.88	28.78
Si	30	3.00
C	78	7.80
Total	1000.18	

Table 9: Slag and its composition

Slag	Kg	%
Cr_2O_3	155.86	14.73
FeO	10.29	0.97
SiO_2	314.27	29.69
Al_2O_3	265.55	25.09
MgO	281.15	26.56
CaO	31.29	2.96
Total	1058.41	

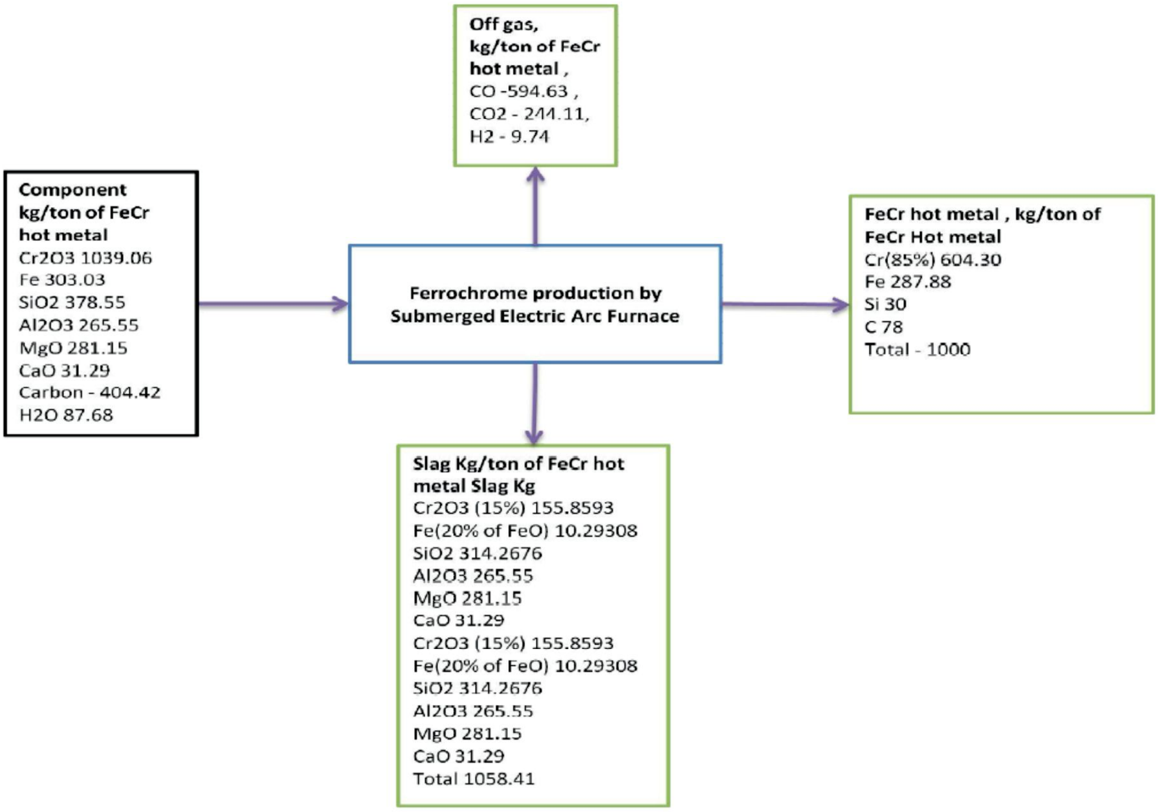

Figure 4: Pictorial presentation of calculations for 1 MT of FeCr production

Sensible heat and calorific value calculations

			Specific heat data, Cp in cal/deg mol				
Elements	**total number of kmoles**	**Mole fraction, xi**	**A**	**B**	**C**	**D**	**Σxi*Cpmix = Σxi*(Ai+B*Tam+C/3*Tc+D*Td)**
CO	20.75	0.72	6.6	0.0012			5.19
CO_2	4.06	0.15	10.34	0.00274		-195500	1.57
H_2	4.06	0.13	6.62	0.00081			0.91
Total	28.87						7.68

Change in enthalpy from the temperature of off gas and the reference temperature ($h-h_o$)	83123.17	kcal/t of FC
Sensible heat from Off gas	348.02	MJ/t of FC
	12.0545458	MJ/kmol

Assuming the temperature of off gas to be at 673 K

$$\text{Sensible heat} = \frac{m \times x_i \times \int_{298}^{673} C_{pi} dT}{(673 - 298)}$$

$$C_{pi} = A_i + B_i \times T + C_i \times T^2 + D_i / T^2$$

$$T_{am} = 0.5 \times (673 + 298)$$

$$T_c = 673^2 + 673 \times 298 + 298^2$$

$$T_d = 1/(673 \times 298)$$

Calculations for Power Generation from OFF GAS

	Kg/ton	Kmol/ton	%	Heat released by reaction, kJ/ton
CO	594.63	21.24	67.09	=281*21.24*1000=5967579.019
CO_2	244.11	5.55	17.53	
H_2	9.74	4.87	15.39	
		31.65608		
Total gas flow	709.54	Nm3/ton		Total gas flow=total kmol/ton*22.414
Gas utilized for sintering	177.38	Nm3/ton		

All gas for power case			Only 75% for power case		
Production rate	6.25	ton/hr	**Percentage of use**	0.75	Fraction
Heat flow rate to turbine	37297368.87	kJ/hr	**Heat flow rate to turbine**	27973026.7	kJ/hr
	8908323.51	kcal/hr		6681242.63	kcal/hr
Heat rate of turbine	2312	kcal/kWh	**Heat rate of turbine**	2312	kcal/kWh
Power capacity	3853.08	kW	**Power capacity**	2889.81	kW

From the above we could see that there is a potential to generate 3.85 MW of power with 100 % gas utilization and 2.89 MW with 75 % gas utilization. However, GE's Genbacher gas engines for power generations are available in multiple of 1.7 MW and so plant can generate 3.4 Mw.

CONCLUSION

Ferrochrome production generates large amounts of CO gas ,the composition and volume of which depend on the combination of the raw materials used, feed pre-treatment, furnace type, and operating conditions. These operating conditions include changes in temperature, electrical input, material flow, segregation, and electrode position, as well as the time to tap.

Within open and semi-closed furnace setups the gas generated would be burned off as it leaves the furnace, while a closed furnace setup allows the gas to be extracted by fans, scrubbed, and utilized as fuel. Furthermore, the volume of off-gas generated within a closed furnace setup is much lower than that of any other furnace setup. Off-gas volumes range between 650-850 Nm^3/t FeCr, whereas semi-closed and open furnaces generate off-gas volumes of up to 10000-15000 Nm^3/t FeCr.

The off-gas as per our typical theoretical calculations shown in this paper consists of 67.09 per cent CO,15.3 per cent H_2,17.5 per cent CO_2. However, it can largely vary depending on the raw material, furnace condition, coke used and its reaction.

Off-gas formed within a closed furnace setup is a source of energy that could be utilized as fuel in a variety of different processes on the plant. It could be utilized for pre-heating or pre-reduction processes in order to reduce the plant's overall power consumption. The typical off gas volume is calculated and is observed that volume is quite substantial to produce 3.4 MW of power. In the current plant process the part of the off gas is used for sintering and for ladle heating and rest is flared. The flared gas can be used either for generating power or for pre heating of the ore. If the installation of pre-heater is feasible, it can reduce the specific power consumption almost by 20% and can enhance the production by more than 10 %. Tata Steel, Bamnipal plant has taken steps to utilize the off gas for power generation and for preheating of the burden to reduce specific consumption.

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