# ALTERNATIVE ROUTES OF IRON MAKING

#### Module- I

# [12 Hours]

Characteristics of raw materials and their preparation. Thermodynamics and Kinetics aspects. Direct Reduction Processes: Reduction of Iron bearing materials in shaft furnace, rotary kiln, retort and fluidized bed with special reference to reductant, energy consumption and operational problems.

# **LECTURE PLAN**

LECTURE NO.	TOPIC COVERED					
01	Introduction					
02	Characteristics of iron ore					
03	Characteristics of coal, natural gas					
04	Raw material preparation, thermodynamics and kinetics aspects					
05	Kinetics of iron ore reduction					
06	Reduction of iron bearing materials in shaft furnace, rotary kiln (with					
	reference to reductant, energy consumption, operational problems)					
07	Reduction of iron bearing materials in rotary kiln (with reference to					
	reductant, energy consumption, operational problems)					
08	Reduction of iron bearing materials in retort and fluidized bed (with					
	reference to reductant, energy consumption, operational problems)					

# Introduction

# Discuss the importance of requirements of different alternative routes of iron making these days.

Four factors that determine importance of alternative routes of iron making are-

- 1. To use iron ore fines that generated around greater than 30% of total iron ore per annum to proceed. Iron ore fines can be utilised in three ways.
- i) Directly : On fluidised bed.
- ii) Indirectly : Converting fines into pellets, briquettes, sinter
- iii) Slinging : By means of slinging process some fines use with lumps.
- 2. To use secondary fuels Coke oven gas, Blast furnace gas, exhaust gases from the kilns.

Coke oven gas produced during production of coke from coal which have a high calorific value.

Blast furnace gas produced during iron production. It has also high calorific value. Exhaust gases from kilns : These gases contain CO, which is used for preheating.

- 3. To use non-coking coal: Non-coking coal is based on presence of carbon percentage. It have 30-42% fixed carbon, contain high amount of ash. This coal is not used in blast furnace as it will form more slag.
- 4. To meet the demand of shortage of scrap materials in steel making. Sponge iron is used as feed material in steel making.

**Sponge iron** means porous iron produced by **direct reduction process** that is a **solid state reaction** process by which removable oxygen is removed from the iron oxide, using coal or reformed natural gas as reductants, below the melting and fusion point of lump ore or agglomerates of iron ore.

# **CLASSIFICATION OF ARIM PROCESSES:**

# Based upon the reductants used-

- 1. Using solid reductant i.e. Coal based Direct Reduction (DR) process
- 2. Using gaseous reductant i.e. Gas based Direct reduction process

Process	Reactor used	Ore used	Reductant used
MIDREX	Shaft	Lump/pellet	Gaseous
HyL	Retort	Lump/pellet	Gaseous
SL/RN, ACCAR, CODIR etc	Rotary Kiln	Lump/pellet	Solid
HIB	Fluidised bed	Fine	Gaseous

# 1.2.1 Coal Based Processes

Non-coking coal is used as reducing agent. In the solid reduction processes, iron oxides toget with solid reductant (non-coking coal) are charged into the reactor. The generation of reducing (mainly CO) also takes place in the reduction reactor and the product has to be separated to excess reductant, ash and/or sulphur absorbing materials (lime, dolomite) after discharge, we makes product handling more complicated<sup>3</sup>. Because of these substances presence in spot iron, hot briquetting and hot feeding is not possible as magnetic separation does not work at temperatures.

Direct reduction (DR) processes like SL/RN (1970), ACCAR (1973), KRUPP (1973), CONT TDR (1975) etc, using rotary kiln as a reactor and coal as a reductant, have been developed wo wide. India, due to its large reserve of non-coking coal, has shown keen interest in pursuing the technologies using such coal as a cheap energy source for highest sponge iron production<sup>4</sup>. The processes are highly sensitive on types of raw materials used.

Out of the coal based technologies SL/RN technology of Lurgi GmbH, West Germany been the most successful one. Little success has been achieved by other coal based technolog namely CODIR technology of Krupp Industriatechnik now Mannesmann Demag, Germany, D technology of Davy Mckee, USA; ACCAR technology of Allis Chalmers now Boliden Allis, US and the TDR, the only indigenously developed technology of Tata Steel, India.

# **Coal Based Processes:**

- 1. Rotary Kiln based processes
  - SL/RN, Codir, Accar, DRC, TDR, SIIL, OSIL, Jindal

Introduction

- 2. Shaft Furnaces based processes
  - Kinglor, Metor, NML, Vertical Retort
- 3. Rotary Hearth Furnace based processes

Inmetco, Fastmet, Comet

Main advantages of coal based processes:

- (i) They does not require high grade coal which is scarcely available,
- (ii) They can used non-coking coal,
- (iii) They can be installed at lower capacity,
- (iv) They can be easily installed at centre where small reserves of coal and iron ore are available.

Main disadvantages of coal based processes:

- (i) Coal based processes have lower economy of scale,
- (ii) High energy consumption (16.0 to 21.0 GJ/t),
- (iii) Low carbon content in the product (< 1.0%),
- (iv) Lower productivity,
- (v) Hot feeding to the steel making furnace is not possible, due to present of residual char and ash.

The basic equipments required for the coal based processes are as follows<sup>5</sup>:

- 1. Raw materials handling and feeding system,
- 2. Rotary kiln with air injection and coal blowing systems,
- 3. Rotary cooler,
- 4. Product separation and handling System,
- 5. Waste gas cleaning system,
- 6. Briquetting system,
- 7. Electrical system,
- 8. Instrumentation and control system.

#### **1.2.2 Gas Based Processes**

Reformed natural gas is used as reducing agent. Iron ore limps or pellets are reduced in the solid state and oxygen from iron oxide is removed by gaseous reducing agent. Natural gas is reformed at 950°C (1223 K), in presence of catalysts (Ni or  $Al_2O_3$ ), to produce reducing gases CO and H<sub>2</sub>, which are take part in reduction of iron oxide. The reducing gas, H<sub>2</sub>, CO or mixtures of H<sub>2</sub> and CO are introduced into the reactor at elevated temperature (up to 1000°C / 1273 K) and pressure (up to 5 bars)<sup>3</sup>. If CH<sub>4</sub> present in the reducing gas results in carburisation of the reduced product.

The processes based on gaseous reduction are confined to their areas where natural gas is available in large quantity at reasonable price. Commercialized processes, which widely used reformed natural gas as reducer, are *Midrex* (1969) and *HyL* (II – 1957, III – 1980). The most successful technologies were the gas based static bed HyL-1 technology of Hojalata Y Lamina of South Africa. (HyL), gas based moving bed technologies of Midrex Corporation of USA and HyL-III process of HyL.

**Gas Based Processes:** 

- 1. Retort Processes
  - HyL-I, Hoganas

- **Shaft Furnace Processes** 2.
  - Midrex, HyL-III, Plasmared, Armco, Purofer, NSC, Ghaem, Arex
- Fluidized Bed processes 3.
- Fior, Finmet, Circored

The above processes have their own merits and demerits; gas based processes have advantages as follows:

- (i) Higher productivity,
- (ii) Lower energy consumption (10.5 to 14.5 GJ/t) and
- (iii) Higher carbon content in the product (> 1.0%).

Gas based processes account for more than 70% of the world sponge iron production Tak 1.2), out of that Midrex alone contribute more than 55% production. This dominance of gas base processes is not without reason. The gas based processes offer distinct advantages over the co based processes as follows<sup>3</sup>:

- 1. Less capital cost: the capital cost per tonne of installed capacity, in case of coal based plant are 1.8 to 2 times as high as in the gas based plants.
- 2. High productivity: the throughput rates for gas based sponge iron plants are much higher than in coal based plants. The productivity for gas based plants can be as high as 11 tonne m<sup>3</sup>/day as against merely 0.5 to 0.9 in case of coal based plants.
- 3. Better quality: the quality of the sponge iron produced in terms of metallization and carbon content is also higher in case of gas based plants.
- 4. Energy efficiency: the gas based processes have over the years improved considerably and are highly energy efficient.
- 5. Better plant availability: the gas based processes are by now highly standardized. Gas is a clean source of fuel and there are no problems of ash content, as in case of coal which lead to ring formation and other attendant problems. The gas based plants do not suffer from the maintenance problems often encountered in case of rotary kilns and therefore the plan availability is better.
- 6. Environmental pollution: since gas is a clean source of fuel, it is advantageous from the environmental pollution point of view.

Process	20	06		-			(indyear)			
	Tetal		2007		2008		2009		2010	
N.C. J	Iotal	%	Total	%	Total	0/2	Total			0%
Marex	35.81	59.9	39.72	50 1	20.05	/0	Iotal	%	lotal	70
HyL	11.06	18.5	11 20	33.1	39.85	58.6	38.62	59.9	42.01	59.7
Other gas based	132	20	11.50	16.8	9.92	14.6	7.99	124	9.92	14.1
Coal based	11.52	2.2	1.05	1.6	1.08	16	0.50	0.0	5.52	0.5
Total	11.60	19.4	15.15	22.5	17 10	25.0	0.50	0.8	0.35	0.0
IUIAI	59.79	100	67.22	100	17.10	23.2	17.33	26.9	18.09	25.7
* MIDREX: 2010 W	orld Direc	t Dad		100	68.03	100	64.44	100	70 27	100

lable	1.2:	World	DRI	Production		A CONTRACTOR OF	
and a start of the				rouuction	by	Process	/ BAthrow

duction Statistics, 2nd Quarter, June 2011.

It must be mentioned that the gas based processes use, comparatively a high cost resource like natural gas, on the other hand coal based processes are gaining grounds where abundant coal is available. Coal based process is the only answer in places where natural gas is not available. The basic equipments required for the gas based plants are as follows<sup>5</sup>:

1. Natural gas reformer,

#### Introduction

- 2. Reduction reactor/shaft,
- 3. Reducing gas heater,
- 4. CO<sub>2</sub> removal unit,
- 5. Reducing and cooling gas compressors,
- 6. Cooling water circuits for equipment and for process gas,
- 7. Boiler feed water system,
- 8. Inert gas generation system,
- 9. Raw materials and product handling systems,
- 10. Instrumentation and control system.

Technological developments by Midrex in the gas reforming system has enabled them to eliminate certain equipments like steam generation system, auxiliary boilers, boiler feed water treatment system, reformed gas quenching system,  $CO_2$  removal system and reducing gas heaters.

Smelting reduction:

This is the process of liquid hot metal production.

a) COREX Process : Fines are used here.

JSL use this process.

b) FINEX Process : Solid as well as liquid used here.

#### **RAW MATERIALS USED IN ARIM PROCESSES:**

DR processes are very sensitive to chemical and physical characteristics of raw materials used in this process. For the successful operations the process of DR technology has specified the characteristics of the raw materials to be used in the process. The principal raw materials used in sponge iron processes are iron ore (Lump, pellets, fines), non-coking coal or natural gas, limestone or dolomite.

#### 1. IRON ORE

#### CHARACTERISTICS OF IRON ORE-

Lumps / pellets with high iron content, low gangue content, good mechanical strength, readily reducible and of non decrepitating variety. The characteristics of the iron ore, feed to the reactors, which are as following:

- Chemical composition
- Reduction properties

• Physical characteristics

#### CHEMICAL COMPOSITION:

The key input material required for sponge iron production is the iron ore. Since sponge iron is a solid reduction process, the gangue in the ore is retained in the product. Due to oxygen removal there is a reduction in weight by about 30%, percentage of gangue material goes up by 1.4 times. Hence it very important to choose a higher grade of iron input.

U.D. Ocological burvey, milleral comments

In all sponge iron processes, the only noteworthy chemical change which takes place is the removal of oxygen from the iron oxide in iron ore charged. Since no melting or refining occurs, all impurities in the ore feed get concentrated in the reduced product. As a result, in any iron ore chosen for DR process, the total iron content should be as high as possible and the gangue content should not only be a minimum, but the gangue should have a composition which is acceptable to the user of the final product<sup>4</sup>. In general, an ore with iron content higher than 65% is preferred. The gangue content of sponge iron, i.e. its silica plus alumina level should be as low as possible. Unfortunately, very low silica contents in the ore often result in excessive swelling and decripitation together with an increased tendency towards sticking within the reduction reactor, which directly affects the furnace space availability. Further, if the silica content of the sponge iron made is inadequate, it could be more prone to degradation during handling. The alumina content is not so critical from the point of view of reduction within the furnace but being an impurity which is acidic in nature, it would require extra fluxes during steel making. Thus, normally the total amount of silica plus alumina in the ore feed should not be allowed to exceed 4%; in some cases it may be too high. Experience with many selected hard lump hematite ores (containing over 67% Fe) has shown that such ores are often not easily reducible and have poor decripitation characteristics, whereas medium hard ores of relatively poorer quality (containing over 64 to 66% Fe) are more likely to be suitable for sponge iron production. Thus, a compromise may have to be made between the gangue content of the ore and its reducibility or decripitation characteristics while choosing the ore feed for sponge iron process.

The phosphorus content of the ore is extremely important and should be as low as possible (preferably below 0.03%) because there is no removal of phosphorus during the reduction process. Some ores, e.g. many Indian ores, generally content between 0.04 and 0.08% phosphorus, and if

they are used, the phosphorus content of sponge iron would be at least 0.055% and even 0.10% which is substantially higher than phosphorus in scrap normally used in steel make phosphorus, the sulphur content of the ore has to be low (below 0.02%) since during reduction could be some pick-up of sulphur. The sulphur content of many iron ores available in the generally quite low (0.01 to 0.02%) and consequent low sulphur in sponge iron is a positive particularly if the phosphorus levels are high.

te

h

H fo

SL

cł

cc

hi of

be

2.

fix

Th

ha

The specific requirements of lime (CaO) and magnesia (MgO) in the ore feed if char pellets, are generally determined by the slag characteristics required for steel making; up to CaO and 1.0% MgO are usually acceptable. Higher percentages of these constituents (use binder in some pellets) may have an adverse effect on the reducibility of the pellets. Sim though titania (TiO,) is a slag forming constituent, in excess amounts, it may have a delet effect on reducibility thereby imposing limits on the maximum degree of metallization which e achieved in a given reactor. In general, the titania content should not exceed 0.15% in the one Steelmaking grade sponge iron requires iron ore having a minimum of 65% total Fe, maxim 5% gangue (SiO, and Al,O,), and low sulphur and phosphorous content (less than 0.05% each

#### 2.1.1.2 Reduction Properties

The iron ore should have adequate reducibility and favourable decripitation characteristic any sponge iron process has to be techno-economically feasible. The retention time require reduce iron oxide to sponge iron of a specific quality depends, to a large extent, on the reduci of the ore. There exists a direct correlation between reducibility and retention time, and hence, productivity of any given reactor. The higher the reducibility, the lower is the retention time required and consequently, the higher is the productivity.

The actual break-up of the ore is the combined effect of thermal fragmentation as well reduction degradation. It has been observed that most lump ores are susceptible to some amount thermal (the result of a stress release phenomenon) which takes place when the ore is heated in room temperature to a temperature of around 400°C (673 K). With a high thermal decriptu index, the extent of generation of fines even with gradual heating can be as high as 8 to 10% leaf to a low overall yield of sponge iron and limited reactor's space availability4. Reduction degradated is a chemical phenomenon which takes place during the initial stages of reduction when her is converted to magnetite and expansion occurs. Depending on the type of the ore, fines general owing to reduction decripitation may be as low as 3 to 4% or as high as 10 to 15%.

Another important characteristic of the ore feed, if it is in the form of pellets, is its swell index, since it can influence the descent of the bed and the bed permeability. This index is a men of the magnitude of expansion that takes place during the process of reduction and is express the percentage change in the original pellet volume. For smooth furnace operation, it is desired that the swelling index of pellets should be reasonably low and definitely below 18%

#### 2.1.1.3 Physical Characteristics

The important physical features of the ore feed are its size range, abrasion index and comprestrength (particularly in the case of pellets). The optimum size of the iron ore is determined esset by its reducibility characteristics; with higher reducibilities, the top size can be increased. In the of highly decrepitating type ores, a larger size may be necessary so that even after degradation generation of fines (below  $3 \times 10^{-3}$  m) is minimal. In the case of lump ores, a size range of 8  $\times$  10<sup>-3</sup> m is normally preferred with a mean size of around 12  $\times$  10<sup>-3</sup> m whereas, in case of p the same is 6 to  $22 \times 10^{-3}$  m with a majority of 9 to  $16 \times 10^{-3}$  m sized pellets. Fines in any for undesirable. In rotary kilns they promote ring formation inside the kiln, thereby affecting the of kiln availability and lead to an increased tendency of the ore particles to segregate from the segregate

of the bed. Careful screening is essential in order to guarantee removal of the adherent fines which is particularly difficult in the case of clay bearing lump ores. Abrasive of the ore can also contribute to generation of fines because of physical disintegration arising out of the tumbling action. In order high as possible. The fine concentrates can not be processed in sponge iron reactors such as Midrex, HyL, Rotary hearth and Rotary kiln. Utilization of these fines for extracting metal is of vital concern for resource conservation and pollution control.

Pellets having a more regular shape and superior reduction characteristics are definitely superior to lump ores as the iron oxide feed stock.; especially because of a more uniform size, better chemical consistency as well as the guaranteed higher furnace availability. Extra cost of pellets is compensated by smoother operation, higher furnace availability, higher degree of metallization and higher net yield of sponge iron because of lower generation of fines, depends on the relative costs of ore and pellets and would therefore, very from case to case.

#### 2. COAL

#### CRITERIA OF COAL FOR ARIM

- 1. Fixed carbon
- 2. Volatile matter
- 3. Ash, sulphur and moisture content
- 4. Ash fusion point
- 5. Reactivity
- 6. Caking and swelling indices
- Analysis of coal sample is required to access of coal
- 1. Proximate analysis: It is the process of determination of moisture, volatile matter, ash and fixed carbon content.
- 2. Ultimate analysis: It is the process of determination of composition of various components of coal which includes the determination of % of C, H, S,N,O and ash content. It is necessary for utilization of coal for industrial purpose.

#### **Proximate analysis:**

- Moisture content: 1gm of finely powdered coal, taken in a crucible is heated in an electric oven at 105-107°C for 1hr. %moisture content can be calculated from loss of weight.
- Volatile matter content: 1gm of finely powdered free coal taken in a covered crucible, is heated in a muffle furnace at 950°C for 7min. % volatile content can be calculated from loss of weight.
- Ash content: It is the residue obtained after burning of the coal in a muffle furnace under current of air at 700-750°C till a constant weight is obtained.

Fixed carbon content: It can indirectly obtained by deducting the sum of total moisture, volatile matter and ash content from 100.

- Moisture content should be in 2-3%
- Fuel ratio= (Fixed carbon/Volatile matter)
- Fuel ration maintained at 1.5 (preferrable) or 1.8 (maximum)
- 45% fixed carbon in coal is used.
- Desirable ash content should be less than 15%.

Proximate analysis of coal using TGA:



marces. Reactivity The reactevery of the reductant is a measure of it's ability to react with carbon dioxide to carbon monoraide according to Boudonard Reaction. C+ CO2 = 200 out priviles prival The reactivity has a significance influence on the to In r reduction process, particularly the reader operating lemp. of reactor. The ax's of one reduction as well as coal gasification taxes place simultaneously within a rotary Kem. Coals with high reactivity values are preferred This type of coal makes it possible keln at higher temp.

strength 4 Measure of strength of coal is based on the different index, those are shatter Endex and ingles metter, theganal at tumbler inder. is shatter index is gradually degredation of charge materials due to "onpact only. Around 10 kg of 9000 Ore of size -40 to + 10mm dropped from a height of 2m on the cast ison n of demension 0.5 × 0.5 × 0.03m. Approximately 4 camples are tested, then the iron ore screened Shatter Ender expressed as with of mass from Pasesing by 5mm. Tumbler Endere: Tumbles Endere: is 15 kg of test materials tumbled in a circulard Rotating at 25 mpm for 200 revolutions. Then are is screened and t6.3mm, -0.5mm mass fractions Obtained i.e. Known as tumbles ender & abrasion Ender. This process done for q-5 times & average value is contected obtained.

iterials should be 25+35% that is desirable Fuel sates = <u>fixed carbon</u> < 1 Volatele matter < 1 Coking & Swelling indices : Ev) These values should be as low as passible to avoid problems of formation of large masses with pow density within the reactor. they 0.10 pho coul gene part Free Swelling Ender of Coals used in DR should not enceed 1.0, coals with corring index 5.0 (max<sup>m</sup>) & Preferrably below 3.0 is used. pelle CaO binde VY thou Ach fusion temp, ingos pue knowling tud effe achie Steeh Ash fusion temp. give an indication of softening 2.1.1 & melting behaviour of coal ash when coal is exposed to high temp. and mare hardbar and any s educe f the Coal having ash softening temp. above 1300c rodu 4 id co T is prefored. High ash & low ash softening lump. luct rma for Indian non-coking coal have restricted it's mt X, 1 low usage en many sponge fron processes. by Operating temp. of fic should be 200°C less than it 27 ash fusion temp. Loursolab Listing of Tal 5. How shatter index effect reducibility ?? Shatter Ender is the vertical damage or breakinge due to vertical impact. It effects reducibility when coke converto 201 coxe statilized and Que to more fine formation surface area is nore. > More fine : (-3mm) & rate of reaction Kinetics is faster. 60% more fines produced. Hence pare diffusion 12 60% more . phenomenon hindered. millow. separate Aso of bitalie of

# Ash Fusion Temperature of coal

- Ash fusion temp. gives an indication of the softening and melting behaviour of coal ash when coal is exposed to high temp.
- Four temperatures are-
- 1. Initial deformation temp(IT): The temp. at which the point of cone begins to get rounded.
- 2. Softening temp (ST): The temp. at which base of cone is equal to it's height.
- 3.Hemispherical temp (HT): The temp. at which base of cone is twice it's height.
- 4. Fluid temp (FT): The temp at which cone has spread to a fused mass.
- IT of coal should be at least 100°C higher than the furnace operating temp.
- Operating temp. for furnace should be at least 200°C less than ash fusion temp.

# NATURAL GAS

- Natural gas consists of carbon and hydrogen compounds in form hydrocarbons.
- Natural gas cannot be employed in its virgin form for sponge iron process.it has to be converted into a mixture of H2 and CO to increase calorific value and to increase the proportion of reducing gas in relation to oxidising gases (like CO2)

# 2.4 OTHER RAW MATERIALS

Limestone or dolomite is used in rotary kilns as the desulphurising agent. Since most iron excontain very low sulphur (0.01 to 0.02%), the sulphur pick-up in sponge iron is almost fully for the coal charged; even the best non-coking coals generally contain 0.5 to 0.6% sulphur. It has ber reported that dolomite is a better fluxing agent compared with either limestone alone or a mixtur of dolomite and limestone of the same size. However, both dolomite and limestone are acceptable provided the size is in the range of  $1 \times 10^{-3}$  to  $4 \times 10^{-3}$  m. For minimizing accretion formation insit the kiln without sacrificing efficient desulphurization, it is essential that most of the desulphurise (at least 60%) is  $1 \times 10^{-3}$  to  $2 \times 10^{-3}$  m in size with very little of  $-1 \times 10^{-3}$  m particles<sup>4</sup>. Limeston should contain minimum 46% CaO and maximum 6% SiO<sub>2</sub>, and dolomite should contain minimum 28% CaO, 20% MgO and maximum 6% SiO<sub>2</sub>. Dolomite is mainly used as a desulphurising agent prevent the pick up of sulphur by the sponge iron from the sulphur released by the burning of colinside the furnace.

# ADVANTAGES OF COMPOSITE PELLET:

- Very fast reduction due to intimate contact of iron ore fines and coal/coke/char fines
- Higher rate of production
- Reduction in energy consumption

- Utilization of fines, which are cheap and are being generated in large quantities, awaiting suitable disposal and utilization
- Promising prospect of small scale iron making with higher production rate

# FLOWSHEET FOR COMPOSITE PELLET PRODUCTION:



#### THERMODYNAMICS OF IRON ORE REDUCTION

22 - Contract - 12 - 12

#### TABLE-1

#### **Iron Oxide Reduction Reactions**

			Equation for reaction					
		Heat of ∆H° k C o	reaction, J/mole r H <sub>2</sub>	Free en reaction, ∆ C e	ergy of F° kJ/mole or H <sub>2</sub>	CO/CO <sub>2</sub> or H <sub>2</sub> /H <sub>2</sub> O ratio		
SI No.		1000 K	1400 K	1000 K	1400 K	1000 K	1400 K	
1.	$C + O_2 = CO_2$	-394.63	-395.43	-395.85				
2.	$C+CO_2 = 2CO$	+170.62	+166.31	-5.31	-75.02	2.610	-	
3.	$C + 1/2 O_2 = CO$	-112.01	-114.56	-200.58	-235.60		_	
4.	$C + H_2O = CO + H_2$	+135.73	+135.59	-7.99	-65.56	-	-	
5.	$3Fe_{1}O_{3} + CO = 2Fe_{1}O_{4} + CO_{3}$	-47.07	-48.66	-95.27	-113.72	$1.05 \times 10^{-5}$	5.71 × 10-5	
6.	$Fe_1O_4 + CO = 3FeO + CO_7$	+15.69	+17.87	-1.76	-9.54	0.809	0.440	
7.	$FeO + CO = Fe + CO_2$	-19.87	-17.70	+3.68	+12.64	1.557	2.961	
8.	$Fe_2O_3 + 3CO = 2Fe + 3CO_2$	-14.99	-13.22		-	_	-	
9.	FeO + C = Fe + CO	+150.75	+148.62	-1.63	-62.38		-	
10.	$3Fe_2O_3 + H_2 = 2Fe_3O_4 + H_2O$	-12.18	-17.74	-92.59	-123.18	$1.46 \times 10^{-5}$	$2.53 \times 10^{-5}$	
11.	$Fe_1O_4 + H_2 = 3FeO + H_2O$	+50.58	+48.79	+0.92	+19.00	1.117	0.195	
12.	$FeO + H_2 = Fe + H_2O$	+15.02	+13.22	+6.36	+3.18	2.149	1.314	
13.	Fe.O. + 3H. = Fe + 3H.O	+19.92	+17.69	_				



These services of the strength of the strength store

The above are the no. of chemical reactions occur during iron ore reduction.

In the case of hard and dense iron oxides, oxygen is removed from the iron-wustite interface only according to reactions 7 to 13, given in Table 1. The other oxides are reduced to the next lower oxide by diffusion according to the following reactions:

 $Fe_3O_4 + Fe^{2+} + 2e^- = 4FeO$ 

 $4Fe_2O_3 + Fe^{2+} + 2e^- = 3Fe_3O_4$ 

This mechanism requires that the reducing gas, carbon monoxide, and/or hydrogen, should readily diffuse inward through the iron layer to the iron-wustite interface, and the product gas, carbon dioxide, or water vapor should diffuse outward equally easily so that there is no accumulation of any of the species involved.

A totally different mechanism is applicable in the case of porous oxides, through which the reducing gases can penetrate faster than they can react at any one interface. In this case, the reduction takes place according to reactions 5, 6, and 7 of Table 1. Both mechanisms require that the reducing and product gases diffuse freely through the iron layer, in opposite directions. In addition, the concentration of the reducing gas must exceed that of the product gas to the extent that their ratio is greater than the equilibrium ratio shown in Table 1. For this to occur, the flow rate of the gases passing through a bed of solid particles, whether fixed or moving, must be large enough to ensure that a stagnant layer of gas does not build up around the particles. Fluidized bed reactors, where each individual particle of fairly small size is supported by an upward thrust of gas, approach these ideal conditions; a somewhat similar situation also exists in shaft furnaces with a larger size of oxides. Such a situation, however, cannot prevail in a rotary kiln, and thus rotary kilns are at a disadvantage in reaction kinetics.

Inermodynamics & Kinetics aspects of iron ore (oxide one) reductions (Inderect)

Os Calculate the equilibrium constant of equilibrium reaction for wustite reduction by co at operating temp. of 1050°C.

Given  $temp = 1050°_{\text{C}} = 1323K$  $Fe_2O_3 \xrightarrow{I} Fe_3O_1 \xrightarrow{II} FeO \xrightarrow{III} Fe (metallic ison)$ 

Since in coal based processes ison oxide reduction occursed by <u>co</u> this is the indirect reduction.  $3Fe_2D_2 + CO \rightarrow 2Fe_9D_1 + CO_21; \Delta H = \frac{12636}{12659} cal - (2)$ (Exothermic 3.x?)  $Fe_3O_4 + CO \rightarrow 3Fe_0 + CO_21; \Delta H = 48669 cal - (3)$ (Endothermic  $\pi$ ?)  $Fe_0 + CO \rightarrow Fe + CO_21; \Delta H = -9136 cal - (4)$ (Exothermic  $\pi$ ?) As wurfite is metastable below 5to'c magnetiteobtained in first stage of reduction reduces tometallic iron below this temp. by passing wurfite<math>3tage of reduction.

By Omitting wustite reduction as temp. is low, we have the reaction

44 Fe301 + co -> 3/4 Fe + co21; AH - - 936 cal So Calculate the CEXOThermic six7) 5 AHR 1323K = AHR 292K + J ACPAT of wouste te FeO + 1 Greven that ACP = Heat capacity of product - Heat capacity of reactant From thermodynamic relation sg= aH-Tes · KG find out sq. (standard free energy) AGº - - RTINK > lnK = \_ dg° We Kno  $\Rightarrow \log K = -\frac{4}{2\cdot 303} \frac{KG^{\circ}}{RT}$ 7 K = exp (-1 Ang) (Ang) S: For wristete reduction why temp. mentioned at 1050°C only ?? Case I A: For vousfête reduction temp. mentioned at 1050°C because geven Above this tamp. entected reaction occur (1100°c) Juis C will be and melts, which stick to the walk of the kin. are pre This well attract other particles towards et. K = The bulk stecked amount will decrease the productive ty. If oth Below 1050°C; if taken 570°C wustite is not stable. JURIS reduction 95 an indirect reduction & 1050C is the ideal one.

So Calculate the free energy change for the reduction of whethere to metallic From at 1050°C. Case I six") (5)  $FeO + CO \rightarrow Fe + CO_2$ Gener that  $-\Delta G_{T}^{\circ}$ , FeD =  $\pm 42271$  cal - $\Delta G_{T}^{\circ}$ , Co =  $\pm 52483$  cal - $\Delta G_{T}^{\circ}$ , Co =  $\pm 94464$  cal apacity ant LS :  $AG = [(-AG_{T, Fe}) + (-AG_{T, CO})] - (-AG_{T, CO})$ - 96754 - 94464 = 2290 cal We Know that dg = - RTInk  $\Rightarrow \ln K = -\frac{4G}{RT}$   $\Rightarrow \ln K = -\frac{2290}{1.987} \frac{601}{\times 1323} \times \frac{1323}{\times mol}$ K.mol > lnK = 0.8711 Eoned 7 K = 2.389 When partial press. of reactant & product. geven en data. This concept can be considered when the reaction will be in equilibrium and when no other gases 100%) are present. FeO + co -> Fe + co2 kiln. K = Pcoz Pco Pro If other gares are not present, then Pco2 + Pco = 1 04 => Pco2 = 1- Pco (OR) Pco = 1- Pco2 soc

Pcoz Pco Pco Pco \* K Pco - 1/ Pco + K+ 1 Pco = 4/CK+1) Thermodynamics fores Edea about for of the reaction or the product is stab Macoy + co = rem + y cos If the = -ve; product is stable de = +ve; product is unstable To calculate eq use thermodynamic rel AG = AH -丁 (部) = KH as = at Standard State



Fig.4.6. Iron-Carbon-Oxygen Equilibrium Diagram.

From the fig.4.6. it can be inferred that: *i*. Reduction of magnetite  $\rightarrow$  metallic iron can be achieved with composition at which both carbon monoxide and carbon dioxider in equilibrium with each other just above a temperature of 800°C *ii*. To the left of CO-CO<sub>2</sub>equilibrium line at low temperatures, tends to decompose to CO<sub>2</sub> depositing carbon in the form of so *iii*. At higher temperatures, carbon dioxide reacts with carbon produce carbon monoxide.

iv. At about 1000°C the reaction is essentially complete and the phase contains 100%CO and no CO<sub>2</sub>.

However, the reduction reaction still continues as it is a combination of the following reactions:

 $4.3Fe_2O_3 + CO \rightarrow 2Fe_3O_4 + CO_2$ 

b.  $CO_2 + C \rightarrow 2CO$ 

The areas between the curves indicate the stabilities of the three solid phases such as magnetite, wustite and metallic iron. In a flowing solid partition is composition is constant at 20%CO  $^{gas}$   $^$  $Fe_2O_3 + CO \rightarrow 2Fe_3O_4 + CO_2$  will proceed in the forward direction while  $Fe_3O_4 + CO \rightarrow 3FeO + CO_2$  and  $FeO + CO \rightarrow Fe + CO_2$ reactions will proceed in the reverse direction to oxidize both iron and wustite to magnetite. Likewise for a reactor gas of composition 40%CO + 60%CO<sub>2</sub>, wustite will be the stable phase at 800°C. This means that hematite and magnetite will be reduced and metallic iron will be oxidized to wustite. If the temperature is raised to 1000°C for a reactor gas of (  $80\%CO + 20\%CO_2$  ) composition, where the magnetite-wustite equilibrium curve is intersected, wustite becomes the more stable and magnetite gets reduced preferentially. As the reaction b is endothermic, its equilibrium shifts in such a way that it absorbs heat and performs reduction of magnetite. On the other hand, an increase in temperature will cause iron to be oxidized to wustite. Hence, the rate of reduction is directly proportional to the operational temperature. Higher the operational temperature higher is the rate of reduction and productivity. Though a higher temperature inside the bed should be maintained for facilitating faster reduction the selection of operational temperature is governed by the ash fusion temperature of the coal used both as reductant and fuel. The gas exiting from the ore bed is a mixture of completely and partially oxidized fuel and its further <sup>combustion</sup> in presence of air generates heat. The generated heat gets radiated to the ore bed and maintains its temperature. Thus, by varying the amount of the ports of the the amount of air and/or fuel and its distribution through the ports of the reactor d reactor, the ore bed temperature profile in the reactor can be controlled.

## **KINETICS OF IRON ORE REDUCTION**

Kinetics Aspects of Iron one (Iron onide) Reduction Assumptions : Ison ore particles are spherical in nature. Reduction takes place in Stages. Reduction reactions takes place at the Enterfaces. contracting Spherical model Spherical size of Eron oxide one gradually decrean during the tourse of reduction. Phase baundary control Reduction reaction takes place at the Enterface who too different phases comes in contact & different phases of product are produced. (0) 38 Pore Diffusion Contriel Here for the diffusion entering path of reducing gases and coming out path for the product gas are the pares developed during the course of reduction of ison oxides where oxygen present in iron oxide are gradually taken out by reducing gases leaving a posous structure produce Since this is a stagenise reduction of ison oxide. Phenomenon, the sequence is Jopochemical Pattonn Fesos => Fesos => Feo (Metallic izon.) righer (Fearing Oxide) (Fearons (Fearoso Fearing Oxide) (Fearoso fearing oxide) Stifferent sequenteal kinetic stages involved in Oxide Izon Oze Reduction: Fe-co Interface Fe (porous Fe (Porous Jayer) (Thin wustele layer) Fea og (Thin magnetete layer) ( ( cm)) IIII (Requestant) formation of Outer Fe metallic layer 1. Jransport of reducing gas co/H2 from the bulk of gas phase to the Fe202-co/H2 Enterface 2. Adsorption of co/H2 gas at the Fe202-co/H2 interface 1- Before Adecaption of CO/H2: gas at the trace Corriging Chenical reaction between Fe203 & Co/H2- reducing gas at Fe203- CO/H2 Enterface. Desorption of Product gas CO2(H2O from the Enterface & migrate to bulk of outer gas phase. Iransport of product gas cO2/H2O from Fe203-Co/H2 Iransport of product gas cO2/H2O from Fe203-Co/H2

After formation of metallic layer Gransport of CO/H2 gas from bulk gas phases Fe- colt2 Enterface. Adsorption of colliz gas at the Fe-colitz Enterface. Jaansport of CO/H2 gas from Fe-CO/H2 interf to Festa- Fe Enterface. · Chemical reaction between Fezos & COLH2 at Fezoz - Fe enterface ? (abino 5. Description of product gas CO2/H2D from Fe203-Fe interface. 6. Jransport of CO2/HDO gas from Fe2O3-Fe enter to Fe- CO/ H2 enterface. conclusion: 4 The steps Envolved are either diffusional & Chemical. Slowest steps among them is the re controlling. 4 Generally chemical reaction is the slowers at them

Mathematical Interpretation of Contraction Sphere model. Let us assume Bon Oxide (FerO3) particles or

Let us assume bun Durae (Fizes) presented spherical in nature. These particles are dipped in to sea of reducing gas/gases. Surface area A = 4178<sup>2</sup> Valume V = 4/3 TT2<sup>3</sup> Where & = radius of sphere at time=t

det us assume critical radius of the spherical

Oxide one i.e. at t=0;  $\tau=\tau_0$ ,

In case of phase boundary contact reaction rate Es geven by -1 Dw = - Dr == K.A -Where I = density of the ison one. -A A = Surface area of the spherical (soon mite ore) particle V = Volume of the solid sphere t = Time taken for reduction K = Isothermal rate constant Eqn (1) can be revoritten as  $-\frac{\partial V}{\partial t} = K \cdot 4\pi s^{2} - Co$  $-\frac{\partial V}{\partial t} = -\frac{\partial}{\partial t} (43\pi s^{3}) = -4\pi s^{2} \cdot \frac{\partial s}{\partial t} - C$ Also, This implies that  $-\frac{\partial s}{\partial t} = k \cdot t \cdot \frac{\partial s}{\partial t} = k \cdot \frac{\partial s}{\partial t}$ Onide one decreases at a constant rate if in gaseous reduction of iron fraction reduction that is degree of reduction (F) can be represented Vo-Vt Vo as, F =<u>1/3</u>П×03 - 1/3П23 1/3П703  $= \frac{35^3 - 3t^3}{35^3}$  $= 1 - \left(\frac{3t}{30}\right)^3$  $\frac{\sigma_{\rm E}}{\sigma_0} = (1 - F)^{\frac{1}{2}}$ 

Integrating eq (4) with proper limits of 1000 1 - (1-F) 13 = (K/30) + = K'+ aran Cull 1 - (1-F) 1/2 = K'E Degree of Reduction The amount of oxygen removed from the ore is expressed as a percentage of the Profilal amount of oxygen in the ron are. ". R = 02 Removed x 100 O2 mittal - 4118: 51 - dela Blue Emplese that and ET as cuticates that case of the unreactant chide one decaders of a constant aste? gaussium accountion of zoon faction aschuck on atrait to degree of accountion (F) can be actual

# **REDUCTION OF IRON BEARING MATERIALS IN SHAFT FURNACE (WITH REFERENCE TO REDUCTANT, ENERGY CONSUMPTION, OPERATIONAL PROBLEMS)**

Table Classification of Processes					
Direct Reduction Processes—Reducing Gas Generated Externally from the Reduction Furnace (Section 11.3)	Direct Reduction Processes-Reducing Gas Generated from Hydrocarbons in the Reduction Furnace (Section 11.4) Coal-based Processes				
Gas-based Processes					
Shaft Processes Midrex HYL Process Purofer Fluidized Bed Processes Fior/FINMET Iron Carbide Circored	Rotary Kiln Processes Krupp-CODIR SL/RN DRC ACCAR/OSIL Shaft and Hearth Processes Kinglor-Metor Fastmet INMETCO				
Reduction Smelting Processes (Section 11.5)	Inactive Processes of Historical and Developmental Interest (Section 11.6)				
COREX Direct Iron Ore Smelting (DIOS) AISI Direct Steelmaking HIsmelt Romelt Cyclone Converter Furnace (CCF)	Höganäs Process <sup>(a)</sup> Wiberg-Soderfors Process Sumitomo Dust Reduction Process (SDR) Sumitomo Pre-reduction Method Process (SPM) Kawasaki Process Armco Process Nippon Steel Process High Iron Briquette Process (HIB)				

# **SHAFT FURNACE:**

**PARTS :** (1) charging device,(2) gas outlet,(3) tuyere, (4) outside crucible,(5) slag notch, (6)Matte hole, (7) inside crucible. Figure given below.



The main components of such a furnace are as follows: a top, through which the charge is loaded and the gaseous combustion products are discharged; a shaft equipped with tuyeres, through which either a blast for fuel combustion or hot gases are supplied; and an inside crucible with a refractory lining, where the molten products collect. The smelts are tapped through an outside crucible or directly from the inside crucible to a forehea rth for the stripping of the slags. The forehearth is often equipped for electric heating.

Shaft furnaces were constructed from metal jackets, through which water for cooling circulated. Later, evaporative cooling came to be used instead of water cooling. The shaft is constructed of thick-walled tubing welded into units.

- It's height is 5-15m. The shaft height can be reduced without impairing the thermal efficiency if the heating and smelting zones are compressed by accelerating heat and chemical reactions.
- The immediate suggestion to this is oxygen enriched blast usage which increase heat to do chemical reactions.

# SHAFT FURNACE OPERATION AND REDUCTION REACTIONS:

- The blast preheated at 780-800°C and operated on a bedded charge of small lump of iron ores, limestone, low temp. carbonized lignite coke briquettes as raw materials. It can also be charged as batch process individually.
- The reactions taking place in the shaft furnace are given below.

Reduction by CO

- $Fe_2O_3 + 3CO = 2Fe + 3CO_2$  (Overall reaction)
- $3Fe_2O_3 + CO = 2Fe_3O_4 + CO_2$  (Exothermic reaction)
- $Fe_3O_4 + CO = 3FeO + CO_2$  (Endothermic reaction)
- $FeO + CO = Fe + CO_2$  (Exothermic reaction)

Reduction by H<sub>2</sub>

- $Fe_2O_3 + 3H_2 = 2 Fe + 3H_2O$  (Overall reaction)
- $3Fe_2O_3 + H_2 = 2Fe_3O_4 + H_2O$  (Exothermic reaction)
- $Fe3O4 + H_2 = 3FeO + H_2O$  (Endothermic reaction)
- FeO + H<sub>2</sub> = Fe + H<sub>2</sub>O (Endothermic reaction) Carburizing reactions
- $3Fe + CH_4 = Fe_3C + 2H_2$  (Endothermic reaction)
- $3Fe + 2CO = Fe_3C + CO_2$  (Exothermic reaction)

•  $3Fe + CO + H2 = Fe_3C + H_2O$  (Exothermic reaction)

#### ADVANTAGES:

The advantages of low shaft furnace can be summarised as  $f_{0}$ .

lows. 1. It can take fine, friable, low grade and such inferior type of ores in the charge.

2. Fuels of inferior grade like lignite can be successfully used. It can therefore be adopted for making iron where metallurgical coal is not available but non-metallurgical coal is abundant.

3. The furnace top gas, a by-product, is a rich fuel which can be economically used elsewhere in the plant or partly for preheating the blast.

4. The blast pressure necessary to run the low shaft furnace is of the order of 2 kg/cm<sup>2</sup> which is much lower than that for normal blast furnace and hence costly high capacity turbo-bloweres are not nccessary.

5. Preheating of the blast can be readily accomplished in a recuperator and hence costly stoves are not necessary.

6. Prior carbonisation of fuel and agglomeration of ore is unccessary if briquettes are used. It therefore eliminates the coking and agglomeration plants and thereby reduces the capital investment

7. The furnace can be readily started and stopped without any expensive and prolonged procedure involved.

8. Control of smelting operation is easy and is exercised by control of blast temperature, pressure and volume.

9. Silicon content of the pig iron would be low in the case of basil irons.

10. Production rate is around 2.5 t/m<sup>3</sup> of useful volume of the furnace, which is much more than that of blast furnace.

#### **DISADVANTAGES:**

- Briquetting of charge mix may be necessary for efficient production and which adds to cost of raw material preparation.
- Physical and chemical preparation of charge is desirable.
- Daily production of individual unit is low i.e. 100-200tpd.

# REDUCTION OF IRON BEARING MATERIALS IN ROTARY KILN (WITH REFERENCE TO REDUCTANT, ENERGY CONSUMPTION, OPERATIONAL PROBLEMS)



# FLOW SHEET OF A ROTARY KILN PROCESS

# CONSTRUCTION AND OPERATION

- Size is 4-6m diameter, length is 60-125m long.
- Length to diameter ratio is 15-20.
- Inclination is 1-4% of length.
- Rotation is 0.5 to 4.0rpm.
- Coal not only used as reducing agent but also act as fuel to supply heat to maintain temp. profile inside rotary kiln.
- A finer fraction of coal is introduced from discharge end of kiln along with air to complete the reduction, since by the time the charge travels to around 70% of length of kiln.
- Feed of raw materials are done from one end, which is at higher level. It travels under gravity aided by rotating motion.
- Flux is added with coal to control sulphur level in sponge iron.

#### **REDUCTION REACTIONS:**

Rate of Reduction	
Within the charge	two reactions take place simultaneously:
1. Gasification of	coal and
2. Reduction of in	ron ore.
Gasification reac	tion is controlled overall reaction.
Gasification read	tion:
And the for the might of the	$C + CO_2 = 2 CO$
Therefore, where	$r_{c} = k_{c} (C_{CO_{2}}^{\circ} - C_{CO_{2}}^{eq,C})$ $r_{c} = \text{rate at which carbon is going to convert into CO gas k_{c} = \text{rate constant,}$ $C_{CO_{2}}^{\circ} = \text{concentration of CO}_{2} \text{ gas in gas mixture,}$ $C_{CO_{2}}^{eq,C} = \text{concentration of CO}_{2} \text{ gas in equilibrium with carbon}$
Reduction react	tion: $r_{+} O + CO = r Fe + CO.$
Therefore, where	$Fe_x^{o} = k_0 (C^{eq,Fe}_{CO_2} - C^{o}_{CO_2})$ $r_0 = \text{rate at which oxygen from ore is converted to gas,}$ $C^{eq,Fe}_{CO_2} = \text{concentration of CO}_2 \text{ gas in equilibrium with iron.}$ $r_1 = r_0$

**Case I:**  $k_c \ll k_0$ , then  $(k_c/k_0)$  is a very very small value which trend to zero. Hence,  $r_0 \approx 0$ , therefore no reduction will be occurred. **Case II:**  $k_c \gg k_0$ , then  $(k_c/k_0) \ge 1$ . Therefore,  $r_0 = k_0 (C^{eq.Fe}_{CO_2} - C^{eq.C}_{CO_2}) = r_0 (\text{maximum})$  *i.e.* to get high productivity in the kiln. Since  $k_c \gg k_0$  *i.e.* the reactivity of coal should be higher than reducibility of ore.

#### **ENERGY CONSUMPTION:**

- Most of reduction reactions are endothermic; so heat should be provided in to kiln. It can be done in two ways.
- i) Burning of gas, oil or coal powder in a burner through the discharge end.
- ii) Exits gas from kiln is rich in CO and volatile matter of coal. In present of oxygen, partial combustion of them takes place and generates a lot of heat to produce electricity.
- The heat of the process is provided by burning volatile matter of coal and excess carbon monoxide emerging from charge. This is done by introducing controlled

quantity of air in kiln. Part of coal introduced from discharge end to supply energy at discharge end maintaining reducing temp.

#### DISADVANTAGES OF ROTARY KILN PROCESS :

#### **Problems of Rotary Kiln Process:**

- 1 Low productivity
- 2 Building up of accretions or ring formation
- **3** Erratic operation
- 4 Heat loss through exit gas
- 5 Sponge iron contains low carbon.

1. Low productivity: Rotary kiln has low productivity (0.5 to 0.7 t/m<sup>3</sup>/day) than me BF (2.0 to 2.5 t/m<sup>3</sup>/day). Since (i) furnace is only partially filled (40%) i.e. a lot of space is unutil ii) low rate of reduction, (iii) lack of mixing of ore and reductant, here movement of the be gentle, so the mixing is not proper.

Productivity can be improved by:

- High reactivity coal can be used
- Pick up of ore with high reducibility
- Gasification rate depends on temperature, so higher the temperature of kiln it will be improved. By proper controlling the combustion, maximum possible temperature can be keep within the kiln as long a length as possible.
- Try to induce some gaseous reductant (H<sub>2</sub>), especially towards the later stages of reduction At later stage by introduce some H<sub>2</sub> in the kiln; it will be effective to reduce the inner part of ore. Since rate of reduction with  $H_2$  is higher (5 to 6 times) than with CO.
- Only solution of drastic increase in productivity by using composite pellets. Since resident time in the reduction zone is 40 to 60 minutes for composite pellet than 4 to 5 hours in

ba

(su

pel

use to th

167

in bur

Fastme

reducti the pell

the resid

to 95%

2. Building up of accretions or ring formation: Accretion or ring formation means the process of growing together (i.e. separate particles) into one, i.e. deposit on refractory surface. The present of fines accelerates the formation of these deposits. These are occurred due to some kind of fuse mass, some of coal ash has low fusion temperature. It is not that entire ash fuses. Due to fusion ash and some other reaction, this build up occurs. If accretion occurs, than the kiln must be stopp This problem has overcome by adopting proper selection of coal so that ash should not fust low temperature. Coal having ash softening temperature above 1300°C (1573 K) are preferred operation temperature is more, then accretion will be more that is why very high temperature in b are o can not be adopted to improve the gasification reaction. pelle carbo

3. Erratic operation: Erratic means irregular operation having no certain course. This is do lack of proper mixing.

4. Heat loss through exit gas: Exit gas has very high temperature (heat content is 6.28 GJ/t), it can be used to preheat the materials.

5. Low carbon content of sponge iron: Carbon content is less than 1% for rotary kiln pro This can be improved by injection of hydro-carbon under the solid bed. Carbon in sponge iron go up to 1%, generally carbon in sponge iron is 0.3 to 0.5% without injection.

EXAMPLES OF ROTARY KILN PROCESSES : SL/RN, ACCAR, KRUPP, CODIR, TDR etc.

# **REDUCTION OF IRON BEARING MATERIALS IN RETORT AND FLUIDIZED BED (WITH REFERENCE TO REDUCTANT, ENERGY CONSUMPTION, OPERATIONAL PROBLEMS)**

## CONSTRUCTION AND OPERATION:

- It uses a train of four fluid bed reactors in which the gas and solids moving in counter current directions come in contact with through out the entire reaction train.
- The feed concentrate charged to top most reactor which is maintained at 500-570°C. this is the preheated zone. Here reducing gas comes from 3<sup>rd</sup> reactor.
- Preheating, dehydration and reduction of haematite to magnetite and then FeO take place in stages as the feed is transferred downwards to the subsequent reactors.
- The gas required for reduction is a mixture of recycled top gas and fresh reformer make up gas provided by a standard steam reformer.

The product is hot briquetted. But product is being low metallized.

# FLUIDISED BED PROCESS:



[FLOW SHEET]

#### **REDUCTION REACTIONS:**

- Pre-heat and Pre –reduction
- $3Fe_2O_3 + H_2 = 2Fe_3O_4 + H_2O$
- $3Fe_2O_3 + CO = 2Fe_3O_4 + CO_2$
- $Fe_3O_4 + H2 = 3FeO + H_2O$
- $Fe_3O_4 + CO = 3FeO + CO_2$
- Metallisation Reaction
- $FeO + H_2 = Fe + H_2O$
- $FeO + CO = Fe + CO_2$

# ADVANTAGE:

1. Ore fines recycled plant wastes have not been able to come up in competition with other DR processes.

#### **DISADVANTAGES:**

- 1. Fluidised processes requires relatively more energy for their operation.
- 2. It faced problems with regard to operation of fluidised beds.

FIOR plant is not operating anywhere in this world.

#### **RETORTS IN ARIM:**

Retorts are of different types.

- Continuous retorts are used in Midrex, Purofer, Armco processes. Sized lump ores, pellets used in Midrex and Purofer process. But in Armco process only pellets are used.
- It can be a gaseous reduction process.
- It can be batch wise process where pre-reduction and reduction will occur.
- Another example is Echevarria where pellets are used.
- Reduction plant comprises of raw material stockyard, ore crushing and screening equipment, reduction retort, gas reformer, magnetic separator etc.

# Advantages:

- Simple process.
- Minimum investment.
- Continuous operation on industry scale.

There are many disadvantages to this are-

- Local deposits of ores ad fuels.
- Availability of unskilled labour.
- Scrap collection is low.