
PRODUCTION OF LIQUID IRON USING COAL

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ON THE POTENTIALITY OF PRODUCTION OF LOW S & P HOT METAL BY VRDR-SAF PROCESS

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ABSTRACT

Blast furnace technology is still the large scale industrial producer for hot metal and is expected to remain in the main stream for number of years. Coking coal reserves are depleting hence, there is a necessity for developing alternative processes using abundantly available non-coking coal. The new iron making processes avoid the dependency of high quality metallurgical coal hence the development has resulted in large number of processes. The important amongst them are COREX, Direct Iron Ore Smelting Process (DIOS), Hi Smelt Process etc. NML has developed a process using non-coking coal as reductant to produce sponge iron in a vertical retort direct reduction furnace developed at NML and the sponge iron so produced is hot charged to sub-merged arc furnace for production of liquid iron containing low sulphur and phosphorus. It has been demonstrated that the liquid iron can be produced with low sulphur (less than 0.02% and phosphorus less than 0.06%) and can be successfully and economically produced by utilising this process. The paper describes the details of the same.

INTRODUCTION

Blast furnace technology has been developed continuously over decades, culminating in its current performance, capabilities and efficiency and many feels that it is at its maturity. The process is still competitive as the large scale, industrial way for obtaining hot metal and is expected to remain a mainstream of iron production through the future. Processes involving scrap melting, smelting reduction or direct reduction have so far not succeeded in displacing the "black giants". But when one considers that it requires quality metallurgical coking coal and iron ores and large investment for replacing coke oven to forestall the imminent coke shortage, it is imperative to funnel resources into the development of new ironmaking processes

that can supplement the blast furnace process.

In India the situation is even of more concern. India has large reserves of good quality iron, fairly dispersed, but adverse $\text{Al}_2\text{O}_3/\text{SiO}_2$ ratio creating problems of high Al_2O_3 slags in blast furnaces. Fast depleting coking coal reserves but abundant reserves of non-coking coal, higher total energy consumption of hot metal production due to high ash of coal/coke, higher refractory consumption, higher capital investment for blast furnace plant, all these factors direct R&D workers to look into alternative processes and resources available elsewhere in the world or to develop one suitable under Indian conditions. Use of all imported raw materials may not present a really viable solution under Indian conditions. Due to high S & P of Indian pig iron the SG/CG foundry plant suffer additional problem. Most of them resort to melting steel scrap in induction furnace then resileconise, recarburise to produce SG/CG castings.

EVOLUTION OF ALTERNATIVE PROCESSES.

One aspect is common in all the development of new ironmaking processes is to avoid the dependency on high quality metallurgical coke as a reductant and fuel source. This is a response by the iron and steel industry to the economics of raw material supply and feed preparation, and in anticipation of increasing environmental processes⁽¹⁾. Thus, using coal, some of the earlier desirable properties such as medium to high volatile content, high swelling index and strength are not relevant to these new processes.

The new process, now being developed in the world can be covered under three basic alternatives as in Fig.1. A shows single stage iron bath coal gasification wherein all the reactants are injected in iron bath. There is no direct utilisation of high value off gas, hence process can be viable only if this gas is used for some useful purpose. B shows first generation processes⁽³⁾. In this smelting reactor is coupled to direct reduction unit. C shows second generation smelting reduction wherein the bath reaction gas is combusted by the injection of air or oxygen into the top space or slag region in the smelting vessel. The heat so

produced can be utilised for preheating of incoming materials and thus making large fuel savings.⁽⁴⁾

THE ALTERNATIVE PROCESSES.

Large number of processes are being developed in the world. These are on pilot plant scale, semi-commercial or commercial scale. The characteristics of some smelting reduction processes are given in Table I and classification of ironmaking processes by pre-reduction degree in Table II.

The three processes that have gained some grounds are COREX, DIOS (Japan) and Hi-Smelt (Australia).

COREX⁽⁵⁾

It is only commercially operating example of a first generation process.

Schematically it is shown in Fig.2. In a shaft type reactor coal is directly injected with oxygen and a gasification reaction takes place producing $\text{CO} + \text{H}_2$. The reducing gases pass through another reactor containing iron bearing materials. The reduction takes place and the reduced material passes to the shaft where it gets smelted and produces iron and slag.

DIOS (Direct Iron Ore Smelting Process)⁽⁶⁾

This is an example of second generation process as given in schematic diagram Fig.3. The off gas from the smelting reactions is post combusted with oxygen supply the process heat. The partially combusted gases are used for preheating and prereducing incoming iron ore fines. Coal, pre-reduced iron and flux are dropped onto the surface of foaming slag. Oxygen is blown in slag layer and thus iron is produced.

Hi-SMELT.⁽⁷⁾

This is also a second generation process. The major difference with other

process is that most of the smelting reactions are performed in an intensely agitated iron/carbon bath. This is shown in diagram in Fig. 4. As shown in Figure the pulverised coal is entrained in a flow of nitrogen and is injected directly into the smelting vessel through basal tuyeres. The hot metal and slag are tapped from the smelt reduction vessel and sent for pig casting.

LIQUID IRON PRODUCTION BY VRDR-SAF PROCESS⁽⁸⁾.

NML has developed a process of production of low S & P iron by using Vertical Direct Reduction and Submerged Arc Furnace Process (VRDR-SAF). VRDR-SAF Process is a combination of Vertical Retort Direct Reduction Process - Submerged Arc Furnace Process as given in Fig.5.

The process comprises the reduction of iron ore with a carbonaceous material and smelting the reduced mass in a sub-merged arc furnace. The resultant high temperature hot metal is relatively low in S & P and is aptly suitable for SG/CG castings. Thus this process has two separate equipments coupled together (1) Vertical Retort Direct Reduction Unit (VRDR Unit) and (2) Submerged Arc Furnace (SAF).

Vertical Retort Direct Reduction (VRDR) Unit for Production of DRI.

The process of production of DRI is based on the reduction of iron oxide by solid carbonaceous materials in a retort reactor. The sized iron ore lump mixed with sized non-coking coal and limestone is pre-determined proportion and fed into the charging hopper through self discharging container. From the charging hopper the mixed material is charged to the **retort reactor** intermittently. The charge material inside the retort passes through stages of preheating, reduction and cooling. This is achieved indirectly by burning liquid or liquid and gaseous fuel in a furnace built around the retort. The slow movement of the charge is controlled depending on time of reduction by controlling the discharge from the retort. The product from the retort is discharged through a screw discharge system and then magnetically separated to remove the non-metallics. The total reduction time in the retort is $3\frac{1}{2}$ to $4\frac{1}{2}$ hours. The process has been developed on a pilot plant scale of single retort producing 1 - 1.3 tonnes/day of DRI. A commercial

size retort will produce about 3 - 3.5 TPD of DRI and a module of 4 retorts can produce about 4200 TPA. If 8 - 10 retorts module is used, 10,000 TPA of DRI can be produced.

Submerged Arc Furnace (SAF).

Normally the sponge iron produced in the VRDR furnace is cooled down from almost the bottom of the retort so that when it is discharged from the unit, it is at a temperature of 70°C. In the case of VRDR-SAF, an intermediate system is used wherein the discharge from VRDR unit is hot screened at a temp. of 900°C thereby most of the fine char is separated and hot sponge iron at 800 - 900°C is discharged directly to the SAF.

It may, however, be mentioned that so far NML has conducted experiments using cold DRI and not hot DRI. The advantage of this hot DRI is obvious, since there will be a distinct saving of power of about 200 KWH/tonne of DRI due to high temperature of the DRI. This hot DRI along with a very small quantity of reductant is reacted in the SAF wherein the smelting takes place and the iron so produced contains nearly 3.2 to 3.8 percent C, 0.6 - 1.8 percent silicon, 0.02 - 0.03 percent S, 0.03 - 0.06 percent P and 0 - 0.025 percent Mn. The temperature of the hot metal ranges from 1350 - 1450°C depending on the quality of the DRI and initial power input. On an average, about 1000 KWH/tonne of the hot metal is the power consumption. This hot metal can be subsequently cast in the form of pigs for subsequent melting and converting to SG iron or can be directly converted to SG/CG iron castings because of appropriate chemical composition and temperature.

Coupling of VRDR unit with SAF.

The schematic diagram is the flowsheet of the VRDR-SAF technology is given in Fig. 5. The coupling of the two units have to match in such a way that the discharge of the VRDR furnace would be able to be smelted

in the SAF. We have conducted experiments at NML in 500 KVA Submerged Arc Furnace which is giving about 9 - 10 tonnes of hot metal of low S & P quality. Thus, by employing a 500 KVA furnace, one can easily produce about 3000 tonnes hot metal per year. One KVA furnace can easily produce about 6000 tonnes/year. The matching VRDR unit can be easily put up based on the designs prepared by MECON. The physical feature as given in the diagram is a unique system wherein hot DRI and char is discharged from the VRDR unit and charged to SAF to 800 - 900°C. This gives an energy saving of about 200 KWH per tonne hot metal. We envisage that this must be included in the commercial unit. We have conducted experiments by using cold DRI produced in VRDR at our pilot plant area and since the SAF is located in the main laboratory, we had no other alternative, but to conduct experiments with cold DRI. It can be logically and technically possible to couple these units and produce hot metal directly.

Trials were conducted in SAF with prereduced materials as given in Table

3. The reductants used in the campaign is given in Table 4. Some of the results are given in Table 5 and Table 6.

The trials concluded as :-

1. Possible to use fine fraction (-15 +1 mm) coal as reductant in VRDR furnace without adversely affecting VRDR operation.
2. Laboratory studies revealed some aspects of mechanism of smelting of pre-reduced iron.
3. Low S & P iron (0.02 - 0.04% and 0.03 - 0.06% respectively) can be produced using DRI in SAF.
4. Desired levels of C, Si, S&P of hot metal possible.
5. 0 - 37% FeO containing pre-reduced material can be successfully smelted to produce low S & P hot metal.
6. Power consumption of 950 - 1400 KWH/tonne of HM can be achieved for different FeO content of raw materials.

7. Petrocoke, nut coke and LTC can be used as reductant in SAF for producing low S & P iron.
8. High temperature ($\sim 1400^{\circ}\text{C}$) HM is suitable for directly converting to SG iron.
9. Use of SAF top cover decreased heat loss and power consumption by about 100 KWH/tonne.
10. Development of thermochemical model for VRDR-SAF process assisted in predicting raw material behaviour.
11. Prototype hot screening and charging of hot DRI to SAF is likely to decrease power consumption.

Status of the technology.

NML has conducted experiments with cold DRI obtained from NML's VRDR furnace, DRI from RDCIS, Ranchi, DRI lump obtained from SIIL, DRI fines from SIIL and DRI from IPITATA. In all the campaigns together, NML has produced about 400 tonnes of hot metal of low S & P quality. As far as NML's VRDR unit is concerned, several campaigns have been conducted with various types of raw materials including the material from SIIL and successfully produced high grade, highly metallised DRI from raw materials. A plant is coming up in Madhya Pradesh with a capacity of 4200 tonnes/annum by a private entrepreneur and trials for Sponge Iron India are being done at their plant. Four parties are seriously contemplating to put up this unit based on our technology in order to produce SG iron for SG castings, CG castings, ingot moulds and rolls from this unit.

These indigenous efforts have led to the conclusion that liquid iron production with indigenously available quality of raw-materials requires a serious consideration. The commercial techno-economics can ofcourse be proved, only if some plants come at the earliest. Serious efforts are on to achieve the same and it is expected that plant may come up soon.

ACKNOWLEDGEMENTS

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Table 1.
Characteristics of some smelting reduction processes ⁽⁹⁾

Process	Raw materials	Furnace	Quality	Present
COREX (Voest Alpine)	Lumpy ores, Pellets, Sinter, Coal Coal rate: 1.05 t/t-p Oxygen rate: 540 Nm ³ /t-p	Shaft (moving bed) for pre-reduction Fine coal injection Oxygen blow	4.3C-0.3Si- 0.04S-0.09P PC: 5%	1981-88 60,000t/y 1989 300,000t/y (South Africa) 1995 600,000t/y (South Korea)
DIOS (Japan)	Fine ores, Coal, Coal rate: 0.81 t/t-p Oxygen rate: 504 Nm ³ /t-p	Fluidized bed for pre-reduction Smelter Gas modifier N ₂ blow, 0.3 MPa	4C-low Si- high S PC: 50%	1993 180,000t/y National project started in 1988
HI-smelt (Australia)	Fine ores & coal, Coal rate: 0.64 t/t-p Air rate: 2,400 Nm ³ /t-p	High-speed CFB for pre-reduction H. smelter (Bottom coal injection)- Hot-blast stove (1200°C)	3.8-C-high S High-FeO slag (ex. 5%) PC: >60%	1993 100,000t/y

Table 2.
Classification of Ironmaking Process by Pre-Reduction Degree ⁽⁹⁾

Process	P-R degree(%)	P-R process	Final Process	η _{CO}		Gas temp.(°C)	
				P-R	Final	P-R	Final
Novolipetsk	0	-	Slag bath Rectangular	-	0.02 -0.93	-	1500
DIOS	30	Fluidized bed	Iron bath	0.7	0.5	800	1700
HI-Smelt	30	Fluidized bed	Iron bath horizontal type	0.7	0.5	800	1690
Plasma-Smelt	50	Fluidized bed	Coke bed + Plasma	0.7	0.4		
Blast Furnace	75	Shaft	Coke bed	0.5	0.01	200	1350
Oxygen BF	75	Shaft	Coke bed	0.5	0.02	400	1400
COREX	90	Shaft	Char bed	0.5	0.1	750	1600
FIOR	93	Fluidized bed	Electric arc		0.2		900
Cupola	100	Scrap	Coke bed	0.5			1500

Table 3 - Composition of DRI lumps and pre-reduced pellets.

Constituents in %	Lump I	Lump II	Lump III	Lump IV	Lump V	Pellet I	Pellet II
Fe(T)	88.48	86.8	88.78	91.80	90.78	77.84	82.90
Fe(M)	61.04	62.7	64.96	70.50	79.09	56.56	64.90
FeO	35.29	30.98	28.60	27.26	15.00	26.98	24.43
C	0.30	0.20	0.38	0.30	0.233	1.37	0.48
S	0.02	0.019	0.02	0.026	0.016	0.044	0.066
P	0.02	0.03	0.03	0.02	0.02	0.07	0.07
SiO ₂	3.32	2.35	1.64	1.90	2.92	5.48	7.89
CaO	0.33	0.36	0.15	0.30	-	0.77	0.97
MgO	0.30	0.80	0.43	0.83	1.10	0.15	1.90
Al ₂ O ₃	-	0.66	1.32	0.52	2.56	5.16	0.97
Metallisation	69.00	72.00	73.00	77.00	87.00	73.00	78.00

Table 4 - Composition of reductants.

Constituents in %	Uncalcined Petro coke	Calcined Petro coke	Nut coke	L.T.C.
F.C.	90.81	97.20	73.68	61.58
V.M.	8.21	2.50	1.20	13.06
Ash	0.20	0.24	24.80	21.76
Moisture	0.28	0.06	0.32	3.60
S	0.50	0.66	0.11	0.23
P	Trace	Trace	0.26	0.35

Table 5 - Smelting of DRI lumps of 72% metallisation.

Charge

DRI Lumps	100 kg
Uncalcined petro coke	12 kg
Limestone	14 kg
Quartzite	4 kg
No. of charges	10
Metal temperature	1398°C
speciic power consumption	1300 KWH/THM

Hot metal composition, in %

C	3.53
Si	1.54
S	0.02
P	0.03
Mn	0.026

Slag composition, in %

SiO ₂	28.60
CaO	31.10
MgO	2.15
Al ₂ O ₃	10.65
FeO	3.62
P	0.020

Table 6 - Smelting of DRI lumps of 87% metallisation.

Charge.

DRI lumps	100 kg
Calcined petro coke	10 kg
Limestone	12 kg
Quartzite	4 kg
No. of charges	13
Metal temperature	1395°C
Speciic power consumption	1200 KWH/THM

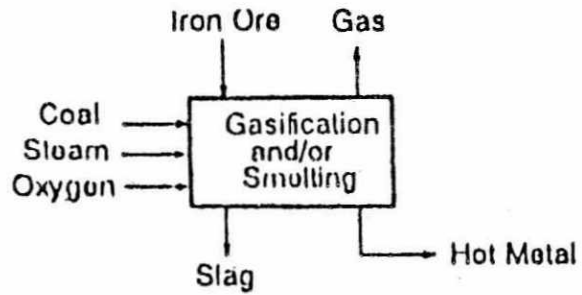
Hot metal composition in %

C	4.10
Si	1.40
S	Trace
P	0.025
Mn	0.001

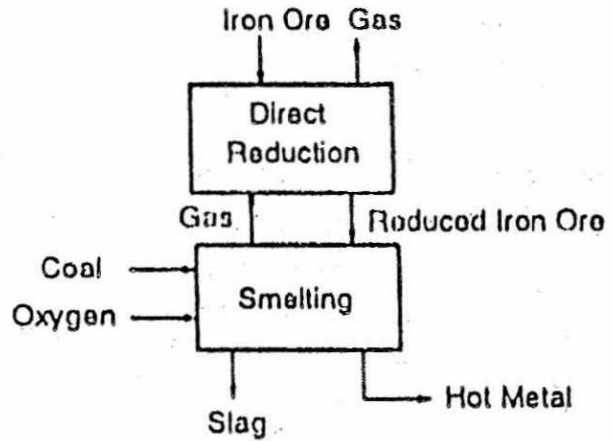
Slag composition in %

SiO ₂	23.10
CaO	30.45
MgO	5.65
Al ₂ O ₃	26.14
FeO	15.50
P	0.014

A Single stage iron bath coal gasification



B 1st Generation Smelting Reduction



C 2nd Generation Smelting Reduction

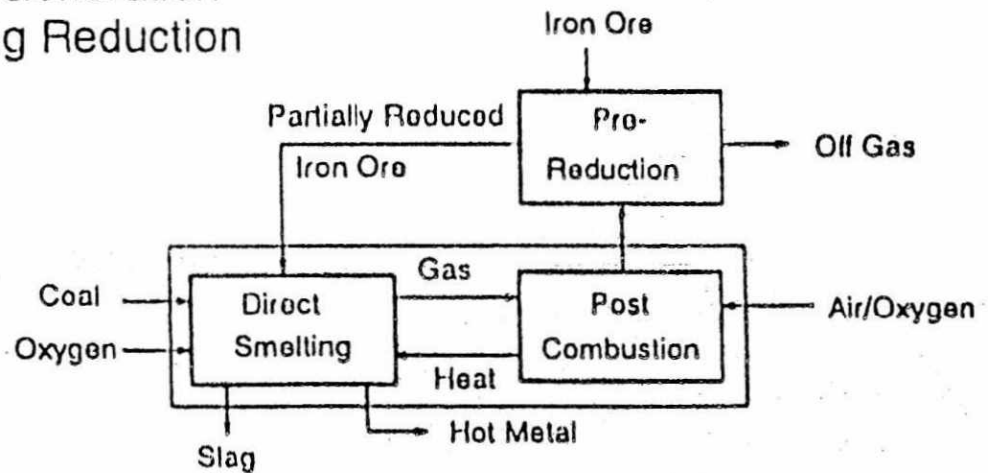


Fig.1 : Evolution of Direct Smelting Processes (2)

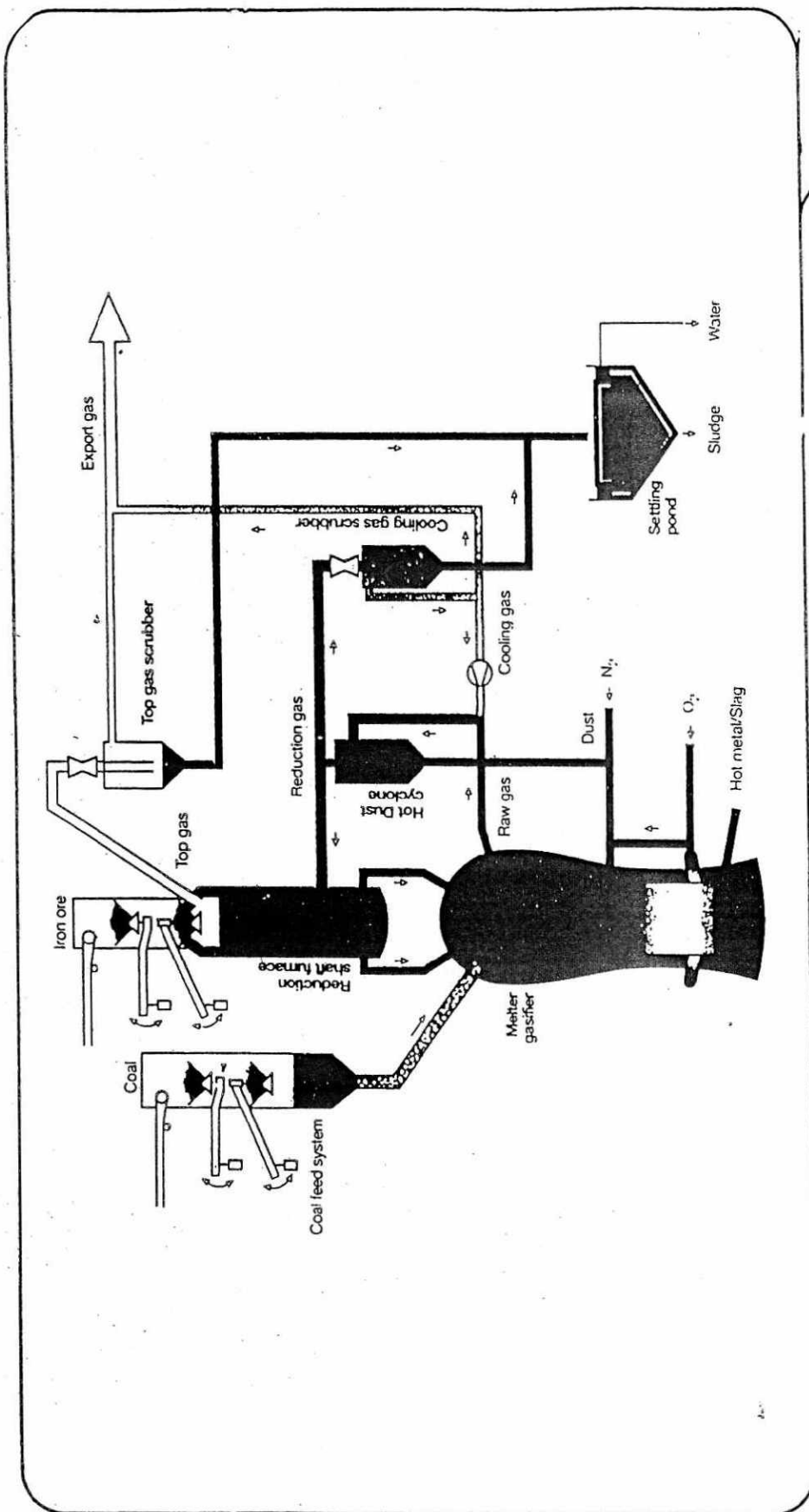


FIGURE. 2 :
THE COREX[™] PROCESS
BASIC FLOW SHEET (2)

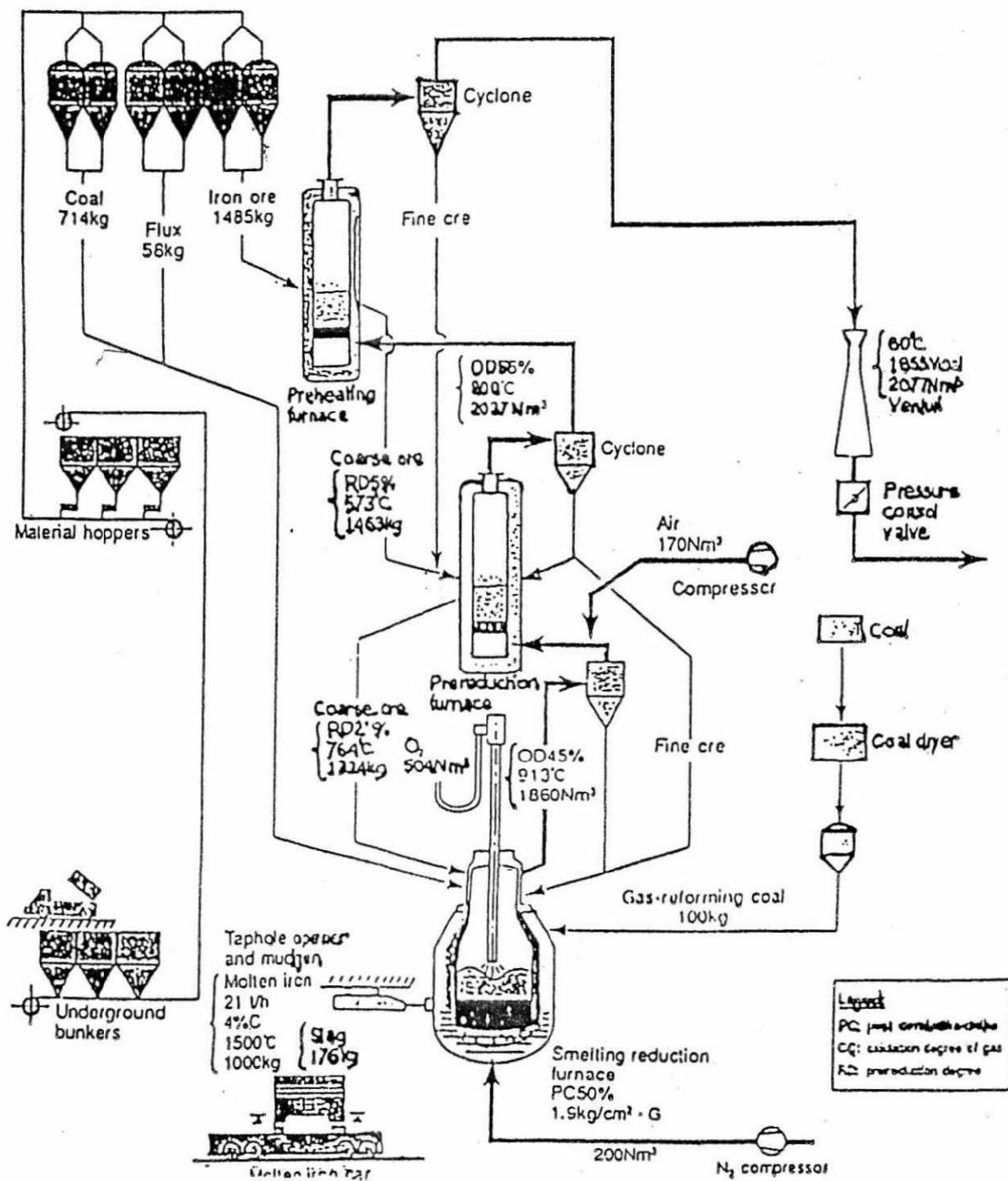


Fig.3 : Schematic flow sheet of DIOS Process (5)

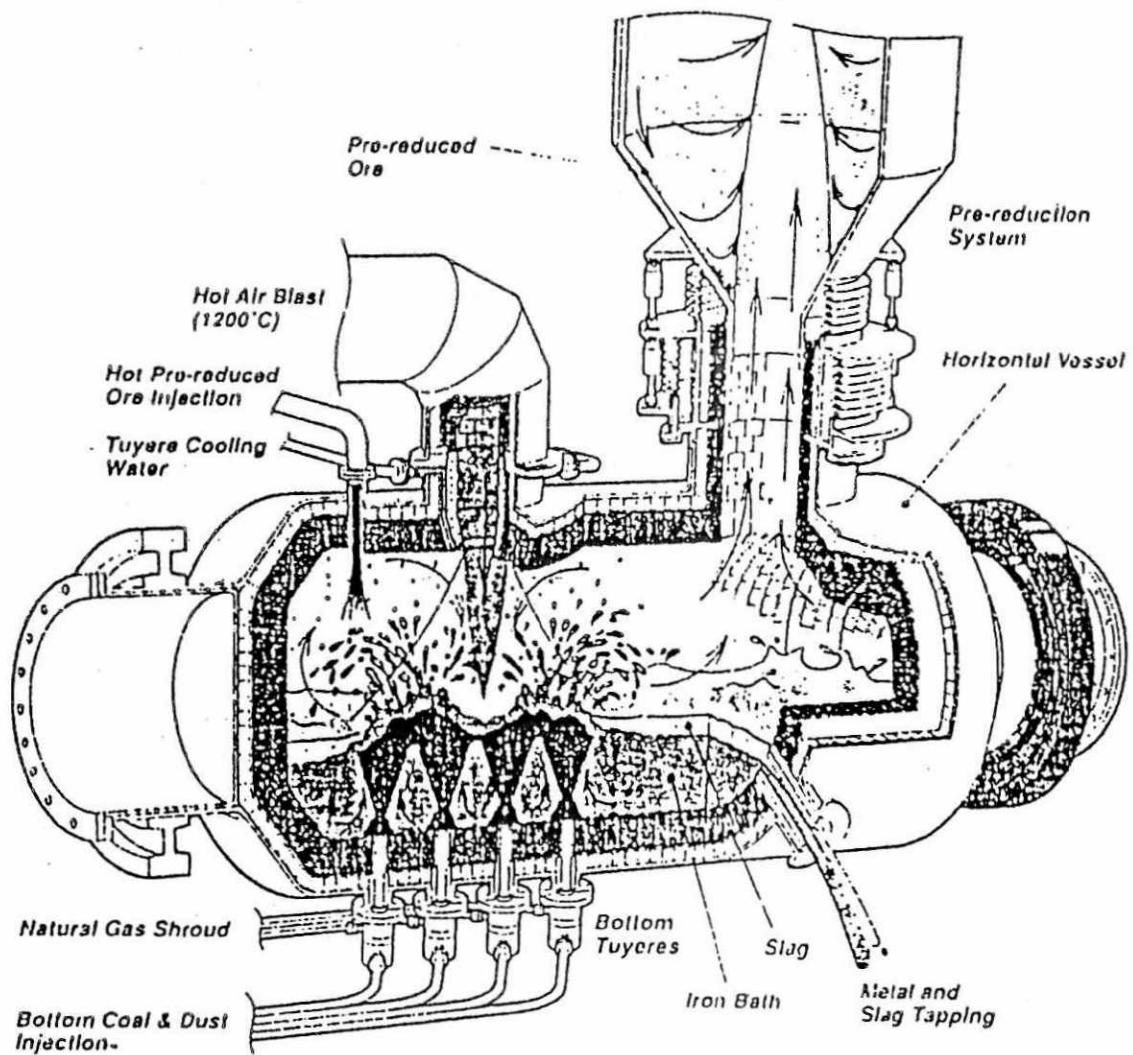


Fig.4 : Hismelt smelt reduction vessel. Vigorous bath agitation leads to the top space being an important reaction area (7)

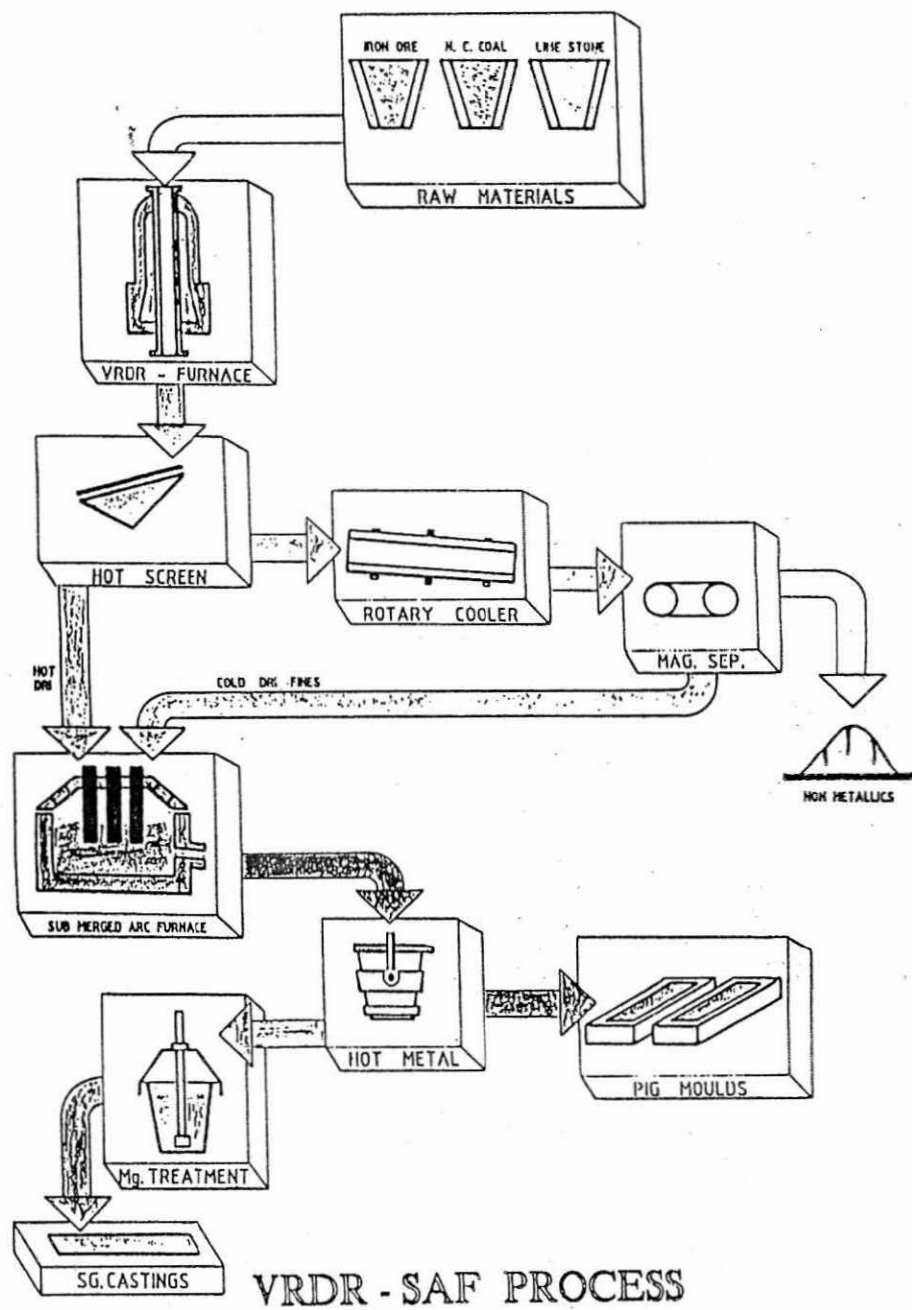


Fig.5 : Schematic VRDR - SAF Process (8)