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INJECTION OF LIGHT PETROLEUM NAPHTHA INTO IRON SMELTING FURNACE [1]

by

A.B. Chatterjea and B.R. Nijhawan
India

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INJECTION OF LIGHT PETROLEUM NAPHTHA INTO IRON SMELTING FURNACE

by

*A.B. Chatterjea and **B.R.Nijhawan

ABSTRACT

Replacement of high ash Indian coke for iron smelting in the blast furnace by the injection of auxiliary fuels is important from economic and metallurgical stand points.

Naphtha, a by-product from petroleum refineries has been surplus in India. An installation and the technique for the direct injection of highly volatile, low flash point liquid naphtha into the hearth of an iron smelting furnace were set up in the Low Shaft Furnace Pilot Plant of the National Metallurgical Laboratory with the objectives of examining the technical merits and operational economics of naphtha injection vis-a-vis coke rate and replacement ratio. The comparative merits of fuel oil and naphtha injections were investigated under different testing conditions. Due to plant limitations in raising the hot blast temperature, optimum increase in oxygen enrichment of the air blast was effected along with progressively increasing rates of liquid hydrocarbon injection in the furnace including fuel oil and light petroleum naphtha; the latter gave a higher replacement ratio in comparison with the former whilst the furnace operations were uniformly stabilised thereby.

At the present price structure of coke, fuel oil and naphtha, the utilization of naphtha as blast additive for iron smelting is economically attractive.

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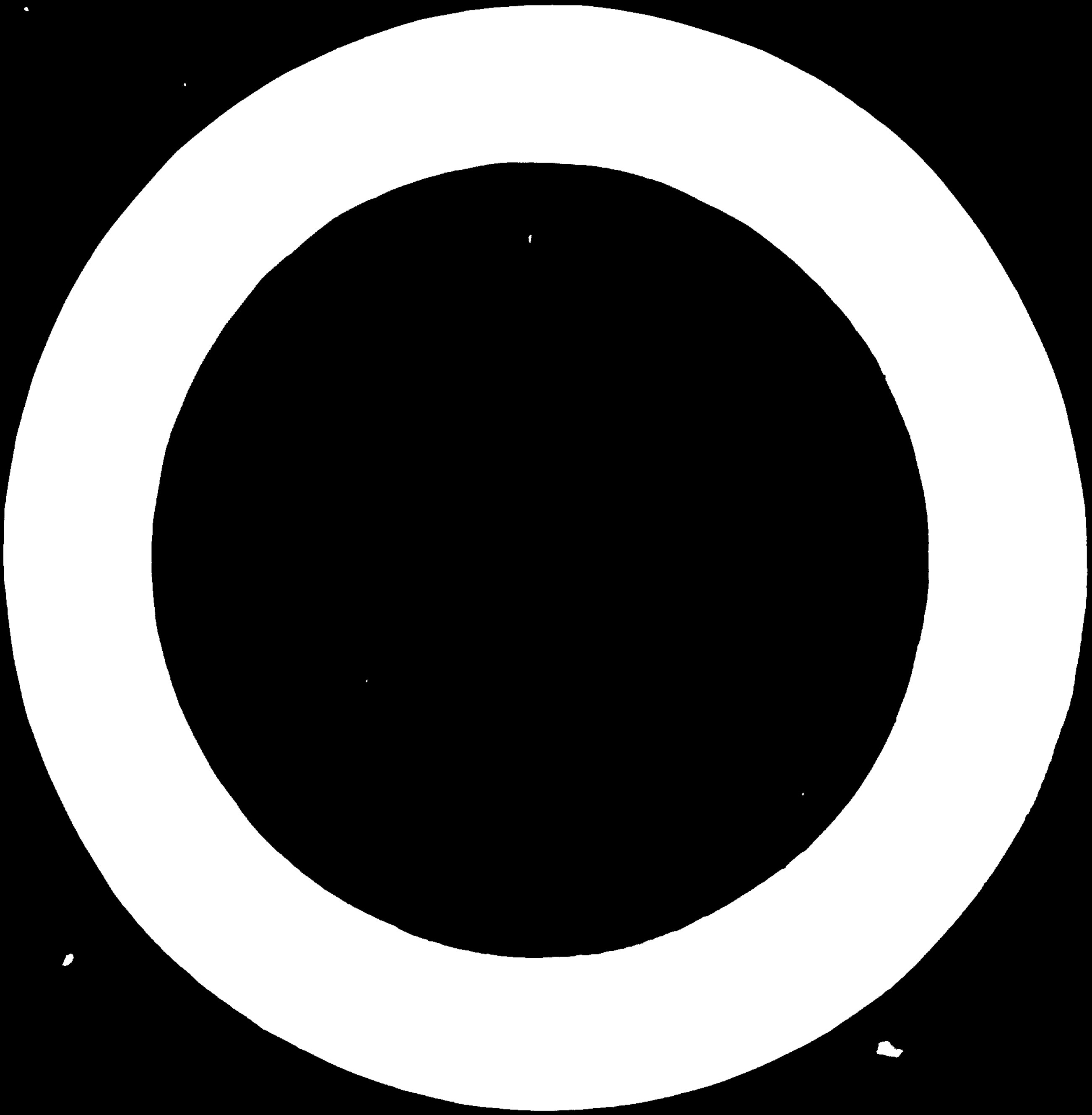


INTRODUCTION

The injection of auxiliary liquid and gaseous fuels through the tuyeres into the blast furnace for iron smelting, has led to high productivity and lower coke rates and thereby gained almost universal acceptance during the last decade. Japan appears to lead with 91% of the blast furnaces operating with oil injection, whereas in the USA and the continent about 50% of the furnaces are operated with auxiliary fuel injection. In the USSR, 75% of the annual production of pig iron was obtained from blast furnaces operating on natural gas injection systems. Natural gas 1-5, coke oven gas, 6-8 furnace oil 9-18, heavy oil 19-20 oil-coal slurry 21, 22, coal-tar 23, 24, and pulverised coal 25-30 have been employed simultaneously in some systems, the air blast has been enriched with oxygen 31-35. No attempt is made to append an exhaustive bibliography.

India is known to possess classical reserves of high grade iron ore, regionally dispersed but the estimated reserves of high grade metallurgical coking coals amount to 1500 million tonnes. As such, coke economy accruing through the injection of auxiliary fuels is of significance. In view of high ash contents of Indian coke, its partial substitution by injected fuels is metallurgically important. In India light naphtha, a by-product of the petroleum industry is currently surplus. Therefore, the possibilities of injection of naphtha through the tuyeres of the blast furnace are attractive. Reference to technical literature shows that liquid petroleum naphtha has not so far been reportedly used for direct injection into the hearth of an iron blast furnace. The National Metallurgical Laboratory undertook a pioneering research programme on the injection of highly volatile liquid petroleum product in its Low-shaft Furnace for iron smelting. It is, however, emphasized that the utilization of naphtha as an injectant for iron smelting will obviously depend upon its surplus availability in India, preference being given to the use of naphtha in Indian petrochemical and fertilizer industries and none the least to its price structure vis-a-vis coke prices in the country. For comparison of oil and naphtha injection merits, the installation system was designed to enable injection of both furnace oil and naphtha in consecutive operations under identical operational conditions.

Figure 1

Sectional elevation and cross section through the hearth at Tuyere level

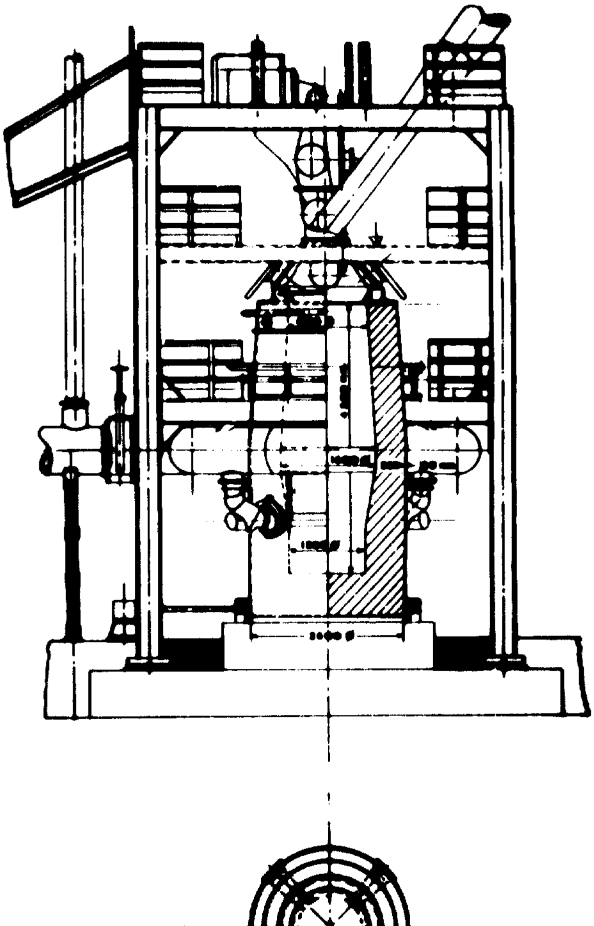


Figure 2

Layout of fuel oil/naphtha injection system

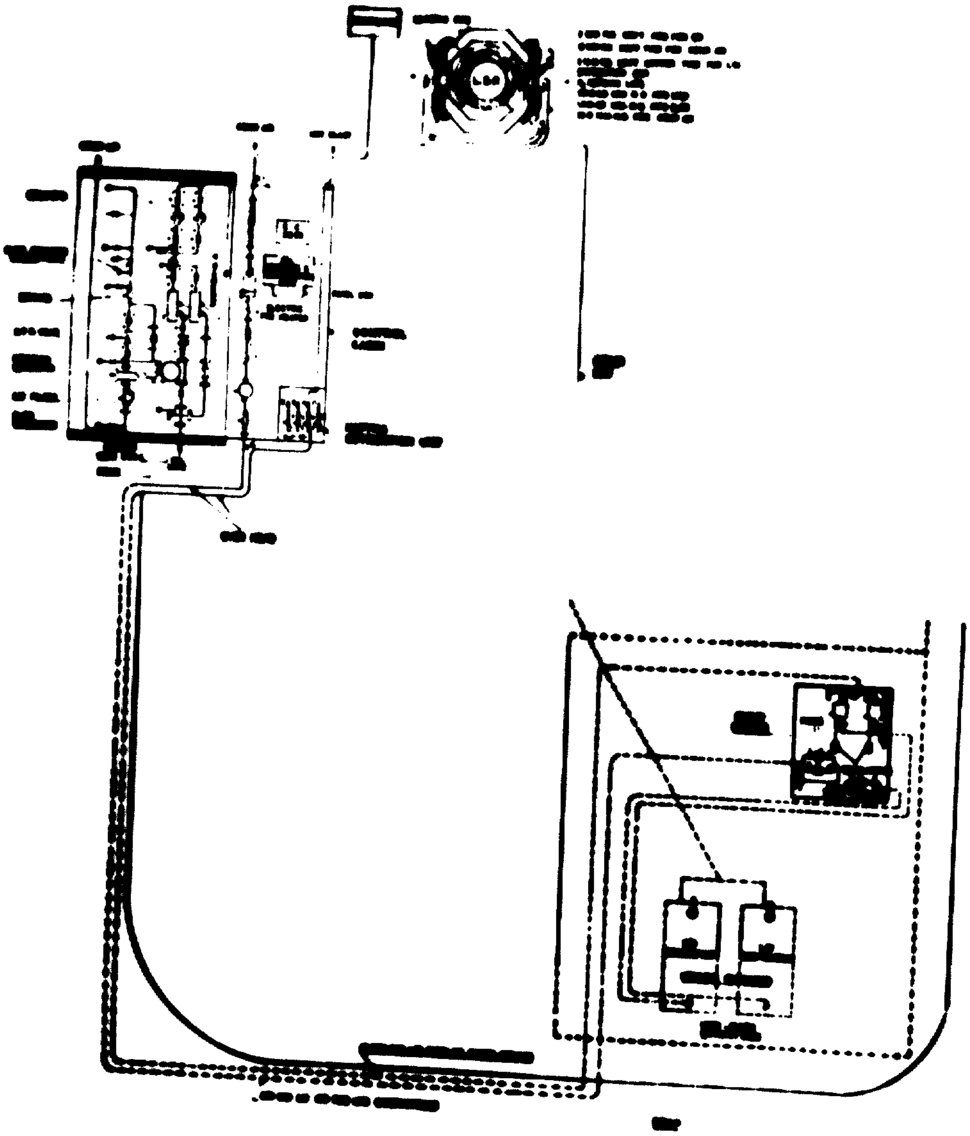
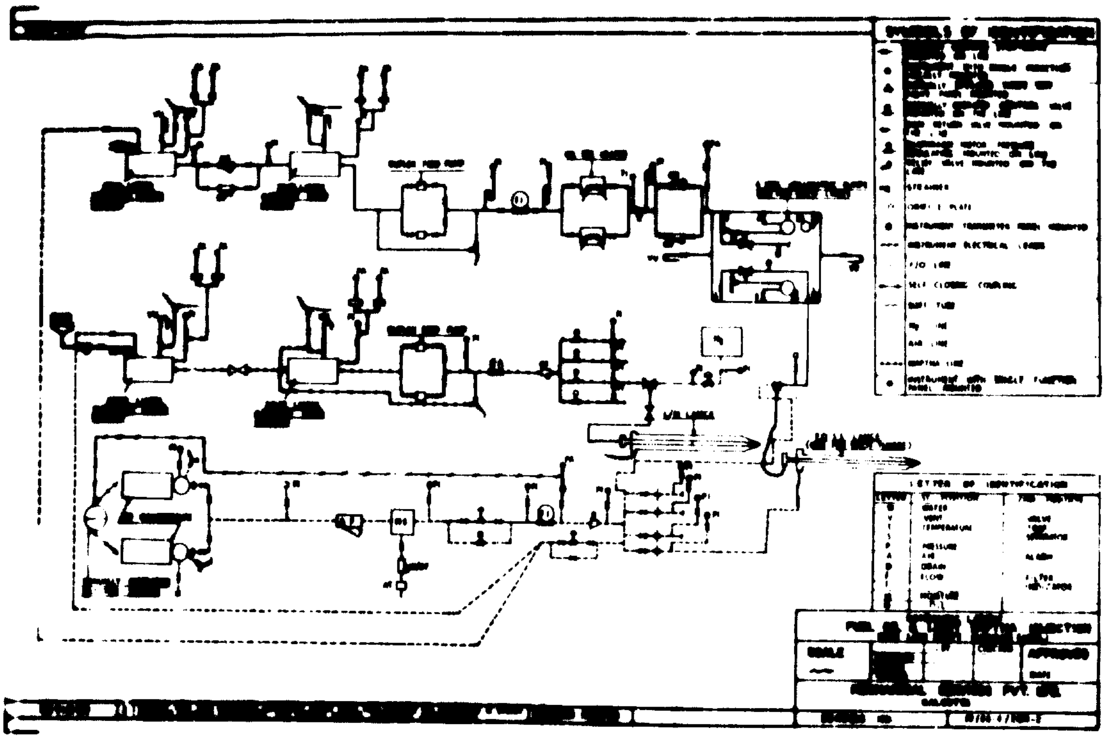


Figure 3

Schematic diagram of fuel oil/naphtha injection system



FACILITIES FOR IRON SMELTING

The low-shaft furnace is of circular cross-section having a hearth diameter of 1300 mm, bosh diameter of 1600 mm, diameter of the top of 1300 mm and an effective height of 3,5 m as shown in Fig.1. The full details of the plant facilities have been reported 36,37.

The significant technical difference between the conventional blast furnace and the low-shaft furnace lies in their effective heights, apart from the dimensional limitation of the cross-section restricting the productivity. The reduction of the shaft widens the choice of raw-materials employed and the restricted cross-section enables the air blast to penetrate to the hearth centre at a much lower pressure. Both these constructional features allow the utilization of iron ore and fuel which are unsuitable for smelting in the conventional blast furnace. The burden may, therefore, consist of friable ores, ore fines and fuels like small size coke, low temperature carbonized coke made from wholly non-coking coals and carbonized lignite briquettes of inferior physical strength and heating value. In the smelting trials with naphtha either nut coke or low temperature carbonized coke was employed as the fuel. Furthermore, the full benefit of auxiliary fuel injection in the conventional blast furnace occurs from the prior preparation of the burden. The replacement ratio of the coke to the injected fuel is known to improve with the prepared burden such as the self-fluxing sinter, pelletized iron ore, sizing and grading of the burden. These factors are to be kept in view in assessing the results of fuel oil or naphtha injection in the experimental low-shaft furnace which was operated with unprepared burden. It has been reported that the injection of light fuel oil in a low-shaft furnace[38] improved the indirect reduction, increased the production and reduced the coke rate.

DESCRIPTION OF FUEL OIL/NAPHTHA INJECTION SYSTEM

The installation of the fuel oil and naphtha injection system is schematically shown in Fig.2. The fuel oil or naphtha circulation, distribution, metering system and safety devices are diagrammatically illustrated in Fig.3. These auxiliary fuels are stored separately in underground tanks, each of

12,500 litres capacity provided with vent for the escape of vaporised oil/naphtha and indicators for indicating the amount of oil/naphtha available in the storage tank (Fig.2). The fuel oil tank is subjected to the requisite pressure of air for the transfer of the oil to the service tank provided with pressure gauges and switches for the automatic transfer of the fluid.

Fuel-Oil Injection

Fuel oil is continuously supplied from the service tank to one of the two transfer pumps which feeds the fuel oil through filters, automatic temperature controlled oil heaters to the volumetric pump unit[11] consisting of four pumps of multi-piston type and positive displacement characteristics one for each tuyere. The amount of oil for injection can be varied by changing the speed through a set of infinitely variable speed pulleys, but different rates in individual tuyere cannot be possible. A prior calibration of the r.p.m. of the pulley with the amount of oil collected is employed for ascertaining the injection rate. In order to maintain the fluidity of oil, the four oil pipes 12,5 mm diameter, from the volumetric pump to the controlling arrangement at the furnace floor are placed around 50 mm diameter pipe connected to hot blast main of the low-shaft furnace and thoroughly lagged.

Naphtha Injection

The naphtha injection system consists of identical underground storage tank and transfer facilities. In the underground storage tank naphtha is subjected to a pressure of 1 kg/sq.cm for its transfer to a 225 litres capacity service tank installed above the ground in the naphtha pump room. The service tank is provided with relief valve so that pressure in excess of 1 kg/sq.cm can be automatically released. It is equipped with pressure gauge and pressure switches. From the service tank, naphtha flows into two duplex gear feed pumps coupled individually to flame-proof motors which are designed to supply 100 litres of naphtha per hour at a pressure of 27 kg/sq.cm. The total amount of naphtha passing through the 18 mm dia, pipe line is determined by the flow meter and recorder. In order to ensure correct measurement of the naphtha injected into the furnace, the volume meter was previously calibrated. The entire naphtha pipe line is of welded construction, properly lagged and is laid underground upto the control cubical in the control room, where it is divided into four 6 mm dia. pipes each having a control valve and a pressure indicator to control the rate of flow of naphtha through individual lances placed in the four tuyeres of the low-shaft furnace. A three way air purging cock has been provided to facilitate stoppage of naphtha and its purging with compressed air or nitrogen.

Technique of Injection.

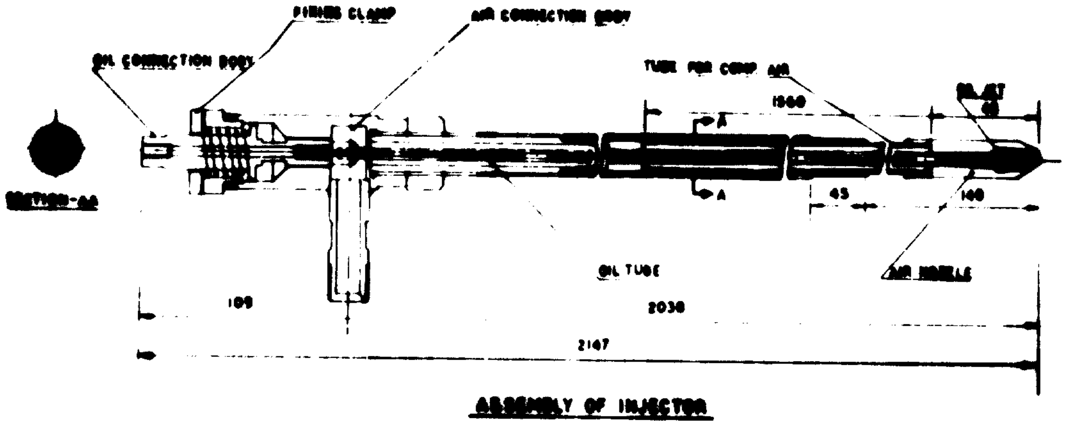
After a study of various technical features of different types of injection lances, such as axial injection lance, blow pipe injection lance and tuyere injection nozzles, it was decided to employ axial lance, as the complete combustion of the injected fuel was of primary importance, particularly in view of short stack height of the experimental furnace. Besides, it did not require elaborate alteration in the tuyere assembly.

Naphtha or Fuel Oil Injection Lance.

The naphtha or oil injection lances, as shown in Fig.4, are made out of two concentric austenitic stainless steel tubes, the inner tube will carry oil or naphtha at a previously determined appropriate pressure attaining the desired rate of injection. The space between the inner tube and outer tube is for the passage of compressed air at a pressure of 3 kg/sq-cm which besides cooling the oil or naphtha to prevent cracking, will admit the requisite amount of air for the atomisation of oil or naphtha through suitable designed jet system. The diameter of the orifice was decided after lengthy trial and error aimed to obtain a maximum injection rate and complete atomisation. It is known that the injected fuel can be atomised by compressed air, oil pressure or by the pressure of the blast in the tuyere injection. For injection in the low-shaft furnace with its restricted reaction zones, complete atomisation by optimum quantity of compressed air was preferred to assess the implications of hydro-carbon injection. The naphtha is kept at high pressure to prevent its vaporisation either in the lance or in the supply pipe line. The lances have been provided with a self-closing coupling to prevent possible ignition of naphtha in the lance assembly or in the supply pipe line at the time of withdrawal of the naphtha lances. The centralisation of the lance in the tuyere assembly was assured by welding a pipe on the back side of the gooseneck door which also acted as the lance support. The naphtha lance assembly in a tuyere is shown in Fig.5.

Figure 4

Fuel oil/naphtha injection lance



ASSEMBLY OF INJECTOR

The compressed air for atomisation and lance cooling is supplied by a compressor.

Necessary alarms have been provided in the system to indicate failures due to the stoppage of circulation of naphtha in the lances, burning of the lances, choking of the lances, and failure of the compressed air lines.

The control of the air compressors, transfer of the liquid fuel from the underground storage tank to the service tanks, its circulation, metering and injection are remote controlled from the control desk. To prevent interruption during plant operation on the failure of remote control mechanism, local controls at various points have also been provided. The control at the furnace floor was of simple design and indicates the pressure of oil/naphtha, compressed air for atomisation and oil/naphtha temperature. The valves have three positions including purging. Flexible connections join the pipes at the furnace floor to the lance assembly placed axially in the tuyere. For naphtha injection, at the beginning, the air from the injector lance was removed by passing nitrogen and then nitrogen was replaced by naphtha.

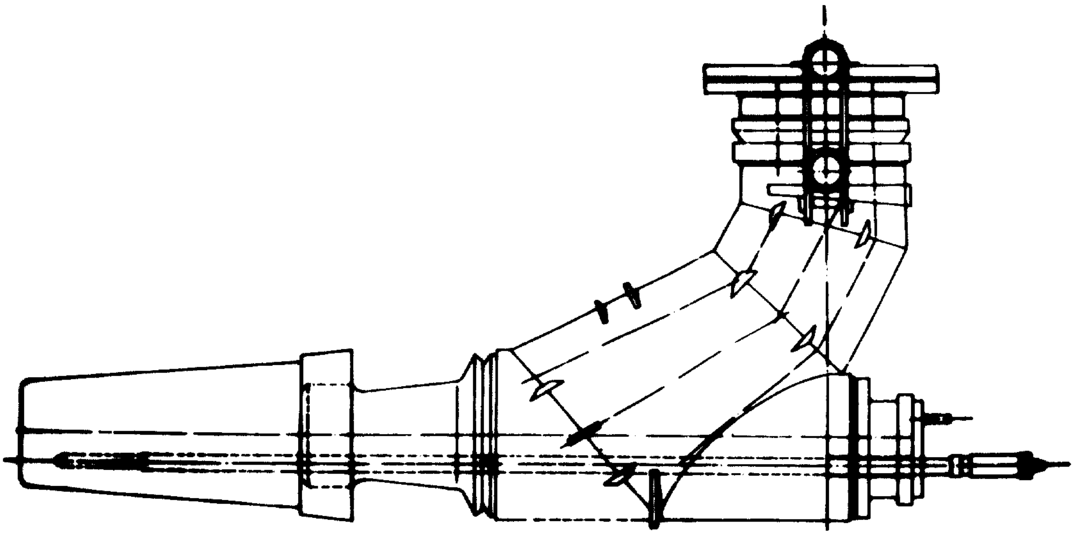
PROPERTIES OF FURNACE OIL AND NAPHTHA

Naphtha is a light petroleum fraction similar to motor gasolene. During the refining of crude oil, naphtha comes from the same petroleum cut from which motor gasolene is also obtained. The petroleum fraction distilling between 90 - 120°C consisting mainly of heptanes and octanes is designated as naphtha. Because of the imbalance in the demand pattern of petroleum fuels like motor gasolene , kerosene, diesel oil and heavy fuel oils, the naphtha is presently surplus in India, due to low demands petrochemical industries.

Physical properties of petroleum naphtha vary widely. Naphtha is a cyclic hydrocarbon (consisting mainly of haptenes and octanes) with carbon to hydrogen ratio of 5.3/1. Natural gas having the lowest carbon to hydrogen ratio amongst the injected fuels has been extensively used and therefore, naphtha with carbon to hydrogen ratio of 5,3 to 5,8/1 can also be used. Under the combustion conditions prevailing in the tuyere region of a blast furnace, it may not be easily dissociated into CO and H_2 as the carbon from naphtha is not easily reformed. It cracks and produces H_2 while the chemical constitution of furnace oil favours its conversion to CO and H_2. Naphtha has a higher hydrogen content

Figure 5

Fuel oil/naphtha lance assembly in Tuyere



than the furnace oil which means that endothermal de-composition of naphtha will release a higher volume of hydrogen in the bosh with respect to carbon monoxide than would be the case of injection of furnace oil. Owing to the lower amount of carbon in either natural gas or naphtha, less radiant heat is imparted to the bosh area. The presence of hydrogen in the ascending gases will catalyse the indirect reduction by CO, but bearing in mind that only about 40-45% of hydrogen present in bosh gas is utilized in the reduction of iron oxide in the shaft of a blast furnace, the top gas will contain higher amount of hydrogen. In an integrated steel plant, the purified top gas is used for heating purposes and therefore, increase in its calorific value due to presence of hydrogen will be advantageous.

Naphtha is a fluid at room temperature and its fluidity is much higher than that of furnace oil. It will consequently not require any prior heating arrangements to impart fluidity and the filtration arrangement can be simple. In view of its high fluidity no choking of pipe lines carrying naphtha can occur. As it is a very light fuel, its atomisation is not a serious problem but as naphtha is much more volatile and inflamable due to its low flash point, the installation of the auxiliary fuel oil system should have ample audio-visual safety devices and controls so that the operation does not become hazardous to the plant operators. Naphtha contains a maximum amount of 0,25 per cent sulphur against of 3,0 percent sulphur in furnace oil. The introduction of naphtha, therefore, will not create any additional difficulty of desulphurisation of iron smelted in the furnace. The properties of naphtha and furnace oil are given in Table I for comparison.

TABLE I - Comparative Properties of Naphtha and Furnace Oil

Data on	Naphtha	Furnace Oil
Carbon/Hydrogen weight ratio	5,3:1	7,5:1
Carbon %, Wt.	84	88
Hydrogen %, Wt.	16	12
Sulphur %, Wt.	0,25 max.	3,0 max.
Distillation-Evaportation basis °C, 90%	175 max.	-
Density at 15°C g/ml.	0,714 max.	0,98 max.
Viscosity Kinematic at 50°C	-	80 max.
Flash Point P.M. °C	51,5 (?)	66 min. (ASTMD 93)
Vapour Pressure Reid, kg/cm^2	0,5	-
Calorific Value Kcal/kg.	11,220 min.	10,000
Heat of formation Kcal/kg.	-470	-320

A typical test data on naphtha employed in the smelting trials are given in Table II.

TABLE II - Typical Test Data on Naphtha

Gravity API, 15°C.,	67,9
Carbon wt., %	84,05
Hydrogen wt. %	15,95
Sulphur wt. %	0,104
Nickel wt. %	Nil
Vanadium wt. %	Nil
Ash wt. %	0,0001
Carbon/Hydrogen weight ratio	5,27/1
Initial Boiling Point, °C	42
Distillation Evaporation Basis °C, 90%	131
Molecular weight	95 - 115

THEORETICAL CONSIDERATIONS OF NAPHTHA INJECTION

For regular and smooth descent of the burden and the control of chemical analyses of hot metal within the acceptable limits, the temperature of the smelting zone should not widely fluctuate. It is well known that the chilling effect caused by the introduction of auxiliary fuels at about room temperature to the smelting zone at 1850 - 1875°C and their endothermal dissociation to CO and H_2 in relation to the heat released by the combustion of preheated coke, can be compensated by raising the temperature of the hot blast and/or enriching the blast with oxygen. In view of the high fluidity of naphtha, no preheating is necessary and is in fact avoided. The heat of dissociation of the hydrocarbon depends on its hydrogen content. Due to its higher carbon-hydrogen ratio, the heat of formation of naphtha is accepted as -470 Kcal/kg in comparison with -320 Kcal/kg for the fuel oil. In the absence of any sensible heat in injected naphtha and on account of its higher heat of dissociation, it will obviously need higher blast temperature or oxygen enrichment for the compensation of endothermal dissociation. Since on weight basis naphtha releases more hydrogen, the percentage of indirect reduction in the furnace stack will be higher which should lead to lower coke rates.

In view of the limitations of raising the hot blast temperature in the metallic tube recuperator of the Low Shaft Furnace Pilot Plant [36], optimum oxygen enrichment of the air blast was investigated along with naphtha injection and requisite optimization thereof was investigated. The oxygen enrichment was made to the pre-heated air blast through the hot blast main. Due to the addition of oxygen at atmospheric temperature and its expansion, the temperature of the hot blast became slightly lower than in the base period.

From a suggested equation[39] for the calculation of the raceway adiabatic flame temperature, the chilling effects of injection of either fuel oil or naphtha and enrichment of the blast with oxygen were calculated[40] and the results are shown in Fig.6 A-D. In the absence of any blast additive, at a hot blast temperature of 560°C, the raceway adiabatic flame temperature (RAFT) is 1775°C (Fig.6 B) which is considered to be lower than that needed for blast furnaces operating on Indian raw-materials. The injection of fuel oil (30 kg/tonne of pig iron) or naphtha (18 kg/tonne of pig iron) lowers the RAFT by 15°C (Fig.6 B and D). The RAFT is increased by 40° per 1% enrichment of the blast with oxygen (Fig.6 A and C). The oxygen enrichment of 0,35% compensated the decrease in RAFT due to injection of auxiliary fuels and additional quantity assisted in raising the RAFT to the desired level and thereby improved the smelting conditions.

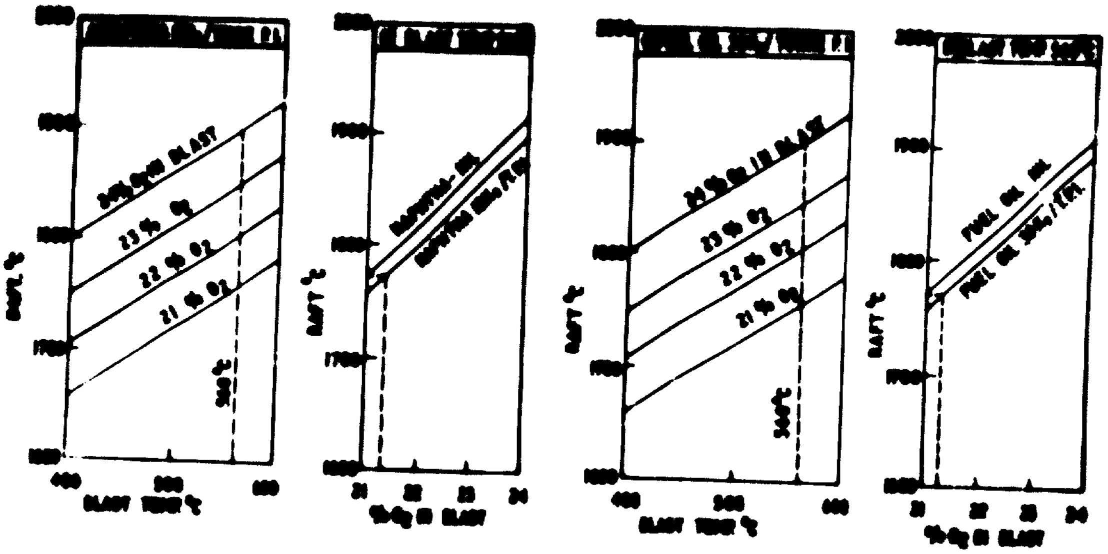
APPRAISAL OF OPERATIONAL VARIABLES

Blast Temperature and/or Oxygen Enrichment of the Blast

It has been mentioned that the endothermal dissociation of the injected material should not lower the raceway adiabatic flame temperature for maintaining the consistency of the hot metal analysis[41]. The attainment of optimum replacement ratio under specific burdening conditions depends on the employment of highest attainable air blast temperature. In these trials, limitations in blast heating facilities did not permit a study of variations in the blast temperature on coke rate and iron output at predetermined injection rates of either fuel oil or naphtha. The effect of variation of

Figure 6

Hot-blast temperature, blast additives and flame temperature



oxygen enrichment from 1 to 2 to 3% in three distinct stages on the smelting characteristics was therefore evaluated.

EXPERIMENTAL DETAILS AND OPERATIONAL RESULTS

Fuel Oil Injection

The chemical analyses of iron ore, low temperature carbonized coke and flux employed with the fuel oil injection trials are given in Table III. The screen analyses of raw-materials are recorded in Table IV. During the entire campaign, the calculated lime basicity degree of the slag $CaO/SiO_2 = P_1$ ranged between 1,20 to 1,25, dolomite was added to yield 6 - 8% MgO in the slag, and the blast pressure was maintained at 1800 - 1900 mmWG.

The investigations with either fuel oil or naphtha injection was subdivided into three stages in which the air blast was enriched with 1%, 2% and 3% oxygen respectively under practically the same operational conditions, until equilibrium conditions were obtained. The operational results with the fuel oil injection at different degrees of oxygen enrichment are summarised in Table V. In a previous trial, it was observed that the oxygen enrichment of the blast, in the absence of hydrocarbon injection was of marginal value.

In the absence of oil injection and oxygen enrichment of the air blast, the carbon requirement amounted to 1570 kg/tonne of pig iron and the daily output was of 7,3 tonnes or 1,0 tonnes/day/m^3. Oil injection at a rate of 30 kg/tonne of pig iron and enrichment of air blast with 1%, 2% and 3% oxygen in three different stages was observed to markedly improve the regularity of burden descent, increase the iron production and yield uniform analysis of the hot metal. In the first stage with 1% oxygen enrichment, fuel consumption was lowered to 1515 kg; in the second stage with 2% enrichment, it was lowered to 1505 kg; whilst in the 3rd stage, the fuel consumption was lowered to 1495 kg/tonne of pig iron produced, associated with a slag volume of 990 kg/tonne of pig iron. A conspicuous increase in productivity was observed at the oil injection rate of 30 kg/tonne of pig iron and the enrichment of the blast with 3% oxygen. It is considered that the oil injection rate of 30 kg/tonne of pig iron, and the low hot blast temperature of 560 - 575°C, the blast should be enriched by at least 3% oxygen to operate the furnace at the optimum RAFT. With increase of oxygen content of the air blast from 1 to 3% in stages, no

TABLE III - Chemical Analysis of Raw-materials

1. **Analysis of iron ore (Orissa)**

Fe %	SiO_2 %	Al_2O_3 %	S %	P %
59,92- 64,50	3,20- 6,34	4,10- 5,20	0,01- 0,29	0,02

2.i) **Analysis of limestone (Madras)**

CaO %	SiO_2 %	Al_2O_3 %	MgO %
54,31	0,88	1,23	1,01

ii) **Analysis of dolomite (Assam/West Bengal)**

CaO %	SiO_2 %	Al_2O_3 %	MgO %
31,30	0,63	0,40	20,70

3. **Analysis of Low Temperature Carbonized Coke (C.F.R.I.)**

Moisture %	V.M. %	F.C. %	Ash %	S %
5,80	4,60	61,60	26,00	0,23

4. **Ash Analysis of Low Temperature Carbonised Coke (CFRI)**

SiO_2 %	Al_2O_3 %	CaO %	MgO %	Fe %	P_2O_5 %	S %
56,31	22,00	3,45	2,20	7,61	1,83	0,27

TABLE IV - Screen Analyses of the Raw-materials employed, in %

Raw-materials	-50,8mm +25,4mm	-25,4 +12,7 mm	-12,7 + 6,35 mm	-6,35 +3,17 mm	-3,17mm mm
Low Temperature Carbonized Coke (C.F.R.I.)	59,50	37,50	Nil	Nil	3,00
Iron Ore (Orissa)	Nil	2,00	49,85	42,25	5,90
Limestone (Madras)	93,00	4,75	1,60	0,50	0,15
Dolomite (Assam)	15,95	79,80	4,00	Nil	0,25

conspicuous change in the oxygen content of the top gas was noticed, but the CO/CO_2 ratio was slightly altered.

Naphtha Injection

The chemical analyses of iron ore, fluxes, and low-temperature carbonized coke are given in Table III.

The operational results of each steady stage period of smelting are summarised in Table VI in which the data for consistent operation without wide fluctuations in chemical analyses of pig iron and slag were considered. In the base period the blast additives like naphtha and oxygen were not employed. The injection of naphtha with simultaneous enrichment of the air blast with oxygen was noticed to increase the productivity with appreciable decrease in coke rate.

TABLE V - Operational Results of Fuel Oil Injection and Oxygen Enrichment of the Blast.

Period	Base	1st stage	2nd stage	3rd stage
1. Quantity of Fuel oil/ tonne of pig iron, kg	Nil	31.0	30.7	30.6
2. Average oxygen enrichment, %	Nil	1	2	3
3. Production rate tonnes/day	7.3	7.7	8.3	8.8
4. Productivity tonne m^3/day	1.0	1.06	1.14	1.2
5. Increase in daily production, %	-	5.50	13.70	20.50
6. Corrected Fuel rate F.C./ tonne of pig iron, kg	1570	1515	1505	1495
7. Slag Volume kg/tonne of pig iron	1045	1029	1010	990
8. Replacement ratio	-	1.8	2.1	2.42
9. Hot blast temp. °C	575	565	570	560
10. Top Gas Temp. °C	385	360	335	295
11. Hot Blast Volume, Nm^3/hr.	2400 - 2600	2400 2500	2400 2600	2500 2600
12. Blast pressure mmWG (average)	1800	1800	1800 1850	1800 1850

TABLE V cont'd.

Period	Base	1st stage	2nd stage	3rd stage
13. Metal Analysis, %				
C	2.5	2.8	2.6	2.70
Si	3.5	4.12	3.30	3.20
S	0.07	0.07	0.08	0.09
Mn	0.18	0.04	0.14	0.12
14. Slag Analysis, %				
CaO	34.30	31.60	32.27	34.70
SiO_2	35.60	38.48	35.08	37.10
Al_2O_3	22.80	22.50	20.40	21.20
MgO	3.80	4.30	4.01	4.82
FeO	1.20	1.60	1.80	1.40
15. Top Gas Analysis, %				
CO	26.00	26.10	26.90	27.20
CO_2	4.30	4.50	4.80	5.30
CH_4	3.60	3.10	3.00	3.00
H_2	0.60	0.57	Nil	Nil
CO/CO_2 ratio	6.00	5.80	5.50	5.10

In order to ascertain the effect of the fuel employed for smelting on the operational characteristics with naphta and oxygen additions, nut coke was employed instead of low-temperature carbonised coke used in the previous preliminary trial (TABLE VI).

TABLE VI - Operational Results with Naphta Injection and enrichment of the Blast with Oxygen.

Data on	Base period (without naphta of O_2	Naphta Injection Enrichment of Blast with 1% O_2	 Enrichment of Blast with 2.5 % O_2
Daily production, tonnes	6.85	7.94	8.08
Increase in production, %	-	15.90	17.70
Naphta Injection rate kg/tonne of pig iron	-	33.00	33.00
Replacement ratio	-	2.10	2.70
Analysis: Pig Iron			
Si %	2.5 - 3.5	2.6 - 3.75	2.5 - 3.0
S %	0.05 - 0.08	0.05 - 0.07	0.05 - 0.07
Slag %			
CaO	34	35	36
SiO_2	33	32	32
FeO	1.5	1.3	1.2
Top Gas, %			
CO	23 - 34	25 - 26	24 - 25
CO_2	3.5 - 4.0	4.7 - 5.0	4.8 - 5.6
H_2	0.1	0.2 - 0.6	0.2 - 0.7
CH_4	3 - 3.5	3.5 - 3.7	3.5 - 3.75

The chemical and physical characteristics of fine grained iron ore, nut coke and blended fluxes employed for smelting in this campaign are recorded in Tables VII and VIII respectively. The operational results in the base period and simultaneous injection of naphta with oxygen are recorded in Table IX.

TABLE VII - Chemical Analyses of Raw Materials

1. **Proximate Analysis of nut coke, %**

F.C.	V.M.	Mn	Ash	S
74.70	2.50	0.20	22.90	0.50

2. **Analysis of coke ash, %**

CaO	SiO_2	MgO	Al_2O_3	Fe	P
3.8	52.08	2.12	33.0	6.0	0.69

3. **Analysis of iron ore (Orissa Mineral), %**

Fe	SiO_2	Al_2O_3	S	P
64.14	3.28	4.57	0.01	0.02

4. **Analysis of Limestone (Madras), %**

CaO	MgO	SiO_2	Al_2O_3	S	Fe
54.1	1.00	0.88	1.2	0.027	-

5. **Analysis of Dolomite (Andhra), %**

CaO	MgO	SiO_2	Al_2O_3	S	Fe
32.20	25.00	0.30	0.56	0.55	N.D.

TABLE VIII - Screen Analyses of Raw-Materials

Material	-50.8 mm	-50.8 +25.4 mm	in % -25.4 +12.7 mm	-12.70 + 6.35 mm	-6.35 +3.175 mm	-3.175 mm
Nut coke	-	53.0	30.0	5.48	2.98	8.54
Orissa Mineral ore	-	-	5.95	46.50	39.00	8.55
Andhra Limestone	-	7.35	62.00	12.25	7.50	10.90
Madras Limestone	21.27	35.00	18.23	7.91	8.07	9.66

TABLE IX - Operational Results with Naphta Injection and Enrichment of the Blast with Oxygen.

Data on			Base period	Naphta injection with 2 % Oxygen enrichment
Daily production, tonnes			5.86	6.33
Increase in production, %			-	8.00
Naphta injection rate, kg/tonne of pig iron			-	38.00
Replacement Ratio			-	2.60
Dust rate, % of raw-material			3.90	4.06
Analysis:	Pig Iron,	Si%	3.80	3.0
		S%	0,06	0.08
	Slag,	CaO %	38.00	35.00
		SiO_2 %	32.00	33.00
		FeO %	1.50	2.50
	Gas	CO %	26.00	25.80
		CO_2 %	5,60	5.80
		CH_4 %	2.30	4.10

After completion of these preliminary trials (Tables VI and IX) further trials were oonducted with identical raw-materials as in the fuel oil injection trials, such as iron ore fines, (in particle size range of 50% -12+6 mm and 42% - 6+3 mm), limestone (79% -25+12 mm) and low temperature carbonised coke -50+25 mm, 38% - 25+12 mm) (Tables III and IV); to critically assess the technical and industrial possibilities of injection of naphtha in place of furnace oil, and the results are summarised in Table X.

The injection of auxiliary fuels normally reduces the coke rate, the replacement ratio 3/1 to 2/1 of coke by injeoted fuel should be obtained; along with increased production rates. It may be observed from Table XI that with the progressive increase in oxygen enrichment of the blast, the fuel rate was progressively lowered associated with increase in iron production. The reduction in coke rate was attributed tc the better exchange of heat and improvement in the indirect reduction as evidenced by the lower CO/CO_2 ratio. Fig.7 shows that in either case higher replacement ratio was attained with increase in enrichment in the blast with oxygen.[34,35] The beneficial effect of oxygen enrichment of the smelting efficiency has been recognized.[42,43] This can be accounted for by the compensation of endothermal dissociation of the hydrocarbon fuel by the oxygen enrichment of the blast. It may be seen that with hot blast temperatures of 550 - 600°C, about 3% oxygen enrichment is essential to maintain the raceway adiabatic flame temperature at 1850°C (Fig.6). The increase in replacement ratio was slightly higher with naphtha than for fuel oil. The replacement ratios were some what higher than those obtained with the fuel oil injection in the industrial scale. It has been mentioned earlier that the oxygen enrichment of the blast was essential for the compensation of the endothermal dissociation of the injected fuels. Significant increase in iron production by simultaneous injection of oil and oxygen has been reported.[20,35,36,43]. The enrichment of the blast with oxygen progressively increased the daily output as illustrated in Fig.8; 3% oxygen enrichment resulting in 20% increase in production. The rate of increase of production with oxygen enrichment was higher with naphtha injection, presumably due to its complete combustion in the tuyere zone. Naphtha injection rates of 33 kg/tonne (Table VI),

Figure 7

Effect of oxygen enrichment of the blast on the replacement ratio

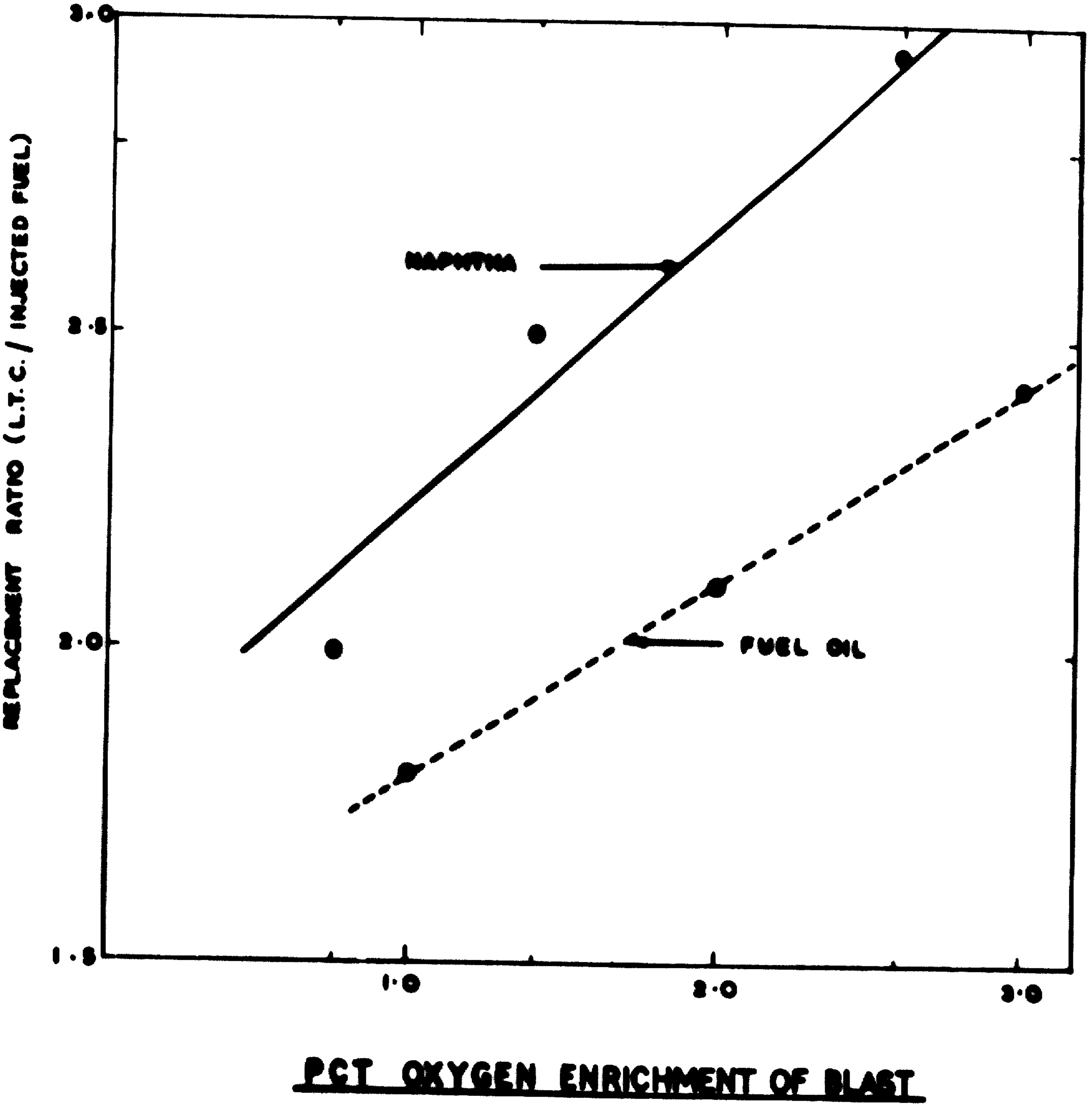
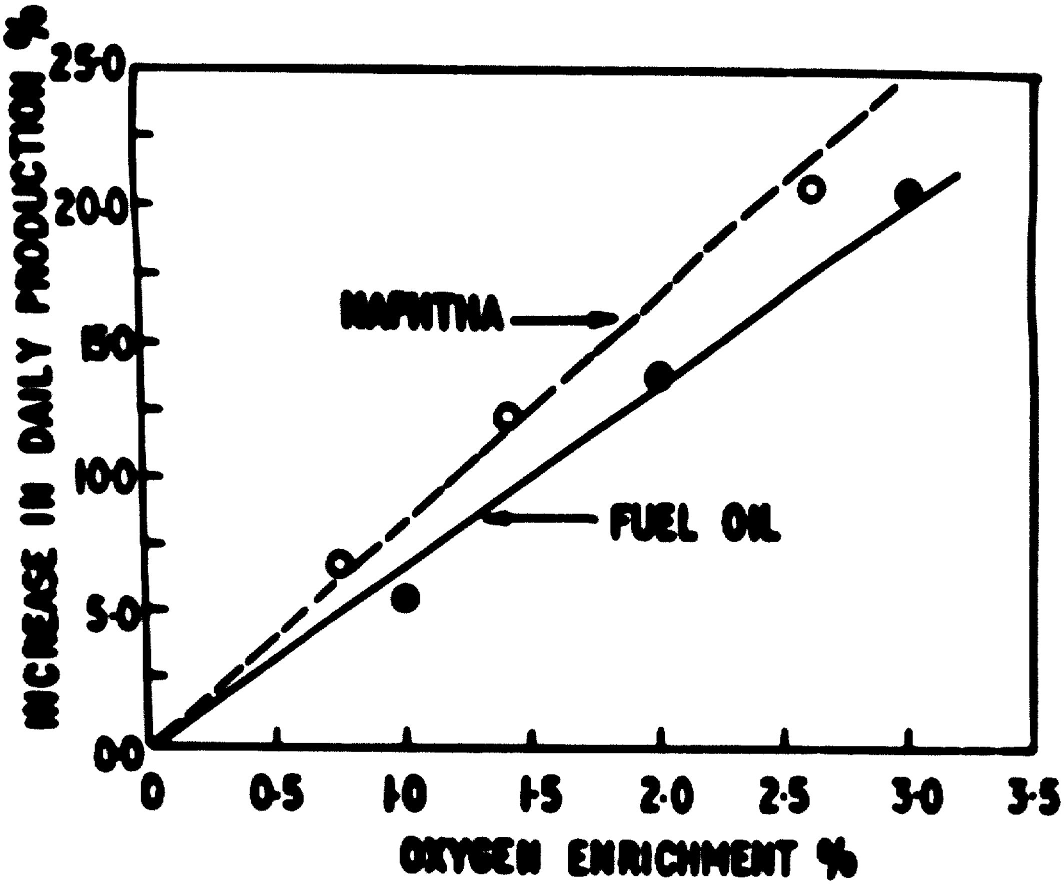


TABLE X - Operational Results with Naphta Injection and Oxygen Enrichment of the Blast

Data on	Base period	1st stage	2nd stage	3rd stage
1. Quantity of naphta/ tonne of pig iron/kg	Nil	18.4	17.8	17.8
2. Average Oxygen enrichment, %	Nil	0.74	1.4	2.6
3. Production rate, tonne/day	7.3	7.8	8.2	8.8
4. Increase in daily production, %	-	6.8	12.3	20.5
5. Corrected fuel rate F.C./ tonne of pig iron, kg	1570	1536	1525	1517
6. Slag Volume ton/ tonne of pig iron	1045	1026	1014	995
7. Replacement ratio	-	2	2.5	2.95
8. Hot blast temp. °C	575	585	570	575
9. Top gas temp. °C	385	360	345	325
10. Hot blast vol. Nm^3/hr.	2400/ 2600	2400/ 2650	2500/ 2700	2600/ 2750
11. Hot blast pressure, mmWG (average)	1800	1800	1820	1800
12. Metal analysis: -				
C %	2.5	2.7	2.51	2.60
Si %	3.5	3.6	3.40	3.50
S %	0.07	0.07	0.064	0.05
13. Slag Analysis: -				
CaO %	34.80	33.90	36.20	36.50
SiO_2 %	35.60	35.70	35.80	35.60
FeO %	1.20	1.30	1.20	1.00
14. Top Gas Analysis:				
CO %	26.00	26.00	25.80	26.60
CO_2 %	4.30	4.50	4.67	5.30
CH_4 %	3.60	3.10	3.20	3.50
15. CO/CO_2 ratio	6.00	5.80	5.50	5.00

Figure 8

Oxygen enrichment in relation to increase in output



38 kg/tonne (Table X) were employed. Although the operational conditions were not precisely similar, the replacement ratio decreased with the increase in the injection rate.

The slight differences in the dust losses were insignificant. The descent of the burden was regular and no hanging was experienced. The absence of any carbonaceous deposits in the inner tube of injector lance showed that the rate of flow of naphtha was sufficiently high to prevent its cracking in the lance. The lances were not blocked, no back pressure was found to develop and lance cooling by the envelope of air was efficient. The position of the tip of the injector from the tuyere nose was adjusted to obtain optimum combustion of injected fuels. The combustion of either fuel oil or naphtha was satisfactory as no deposit was observed to accumulate at the orifice of the injector. Deposition of carbonaceous matter was also not observed in the gas cleaning system.

DISCUSSION

Both fuel oil and naphtha injection with simultaneous enrichment of the blast with oxygen appreciably lowered fuel and increased the production rates. For the same results, injection rate of naphtha was lower than for fuel oil and as such, oxygen enrichment of the air blast for the former was greater than in the case of the latter. Replacement ratio obtained with naphtha injection was better than that for fuel oil. At the current prices in India of fuel oil and naphtha, the utilization of naphtha is economically more attractive. Apart from the test results, the investigation has established the feasibility of injection of low flash point inflamable light petroleum product directly into the hearth of an iron smelting furnace without any operational hazards.

PRODUCTION ECONOMICS

The economics of fuel injection will largely depend on the local cost of the fuels viz. coke and the auxiliary fuels, the installation and operation of the injection system. In industrial plant, the temperature of the hot blast can be raised sufficiently to compensate the endothermal dissociation. A direct and preliminary assessment of the economics of oil injection can readily be made by calculating the difference between the cost of coke replaced by the cost of oil injected. At the current prices in India for coke of Rs.90/95 per tonne and for fuel oil of Rs.230/- per tonne, a weight replacement ratio of $\frac{\text{coke}}{\text{oil}}$ of about 2,6 will balance the higher cost of oil in a straight forward calculation, without allowing any other credits, for the additional benefits already mentioned. At the time of conducting the trial, the price of naphtha inclusive of excise duty, ocean freight, rail or rod transport delivered at the steel plant was about Rs.100/- per tonne. Assuming that the efficiency of the naphtha will at least be comparable to fuel oil for iron smelting, a weight replacement ratio of about 1,0 will strike the balance between the costs of coke saved and naphtha injected. The pattern of utilization of naphtha, either in the blast furnace, or as a feedstock in fertilizer or petrochemical industry will depend on economic factors.

SUMMARY AND CONCLUSIONS

Due to the surplus availability of naphtha from the petroleum refineries in India, investigations were conducted to assess the possibilities of direct injection of naphtha into the hearth of the low -shaft furnace for the partial substitution of coke for iron smelting purposes. In the absence of any published technical literature or reported data on the direct injection of naphtha through the tuyeres of a blast furnace, it was considered that facilities for both oil and naphtha injection should be provided, which will afford unique opportunity of comparison of performance with these two liquid injectants. The entire injection system was developed, designed, and fabricated indigenously without involving any foreign exchange. In view of the limitation of raising the hot blast temperature in the metallic tube recuperator of the low shaft furnace pilot plant, oxygen enrichment of the air blast was essential to compensate the endothermal dissociation of the injectants.

In order to obtain comparative results, identical operational conditions were maintained and data for the base period without oil injection were obtained. In the absence of hydrocarbon additives, the enrichment of blast with oxygen was of marginal consequence. With oil injection rate of 30 kg/tonne of pig iron, the blast was enriched with 1%, 2% and 3% oxygen in three different stages. In the final stage, the fuel rate was decreased by 75 kg/tonne and the production was increased by 20,5%. The simultaneous injection of oil and oxygen contributed towards regularity of the smelting operation and uniformity of the chemical analyses of pig iron produced.

After initial trials with fuel oil injection, the naphtha injection trials with simultaneous enrichment of the air blast with oxygen were conducted exercising adequate care during the operations. As far as practicable, the operational variables were maintained within narrow limits and a stable smelting operation was attained. At naphtha injection rate of 18 kg/tonne of pig iron and 3% oxygen enrichment, the fuel rate was lowered by 57 kg/tonne and the productivity was increased by 20,5%.

The injection rate of naphtha was lower than that of fuel oil and therefore, the oxygen enrichment of the blast in relation to the injection rate was higher. Under smelting conditions, the replacement ratio with the naphtha was better than that of fuel oil. Both the replacement ratios and the daily output improved with progressive oxygen enrichment of the blast. The combustion of either fuel oil or naphtha was satisfactory and the lances did not disclose any evidences of cracking of the hydrocarbon. It was found that naphtha can be successfully injected for iron smelting. Bearing in mind the present price structure of naphtha, furnace oil and coke in India, the use of naphtha is much more economically attractive than the furnace oil.

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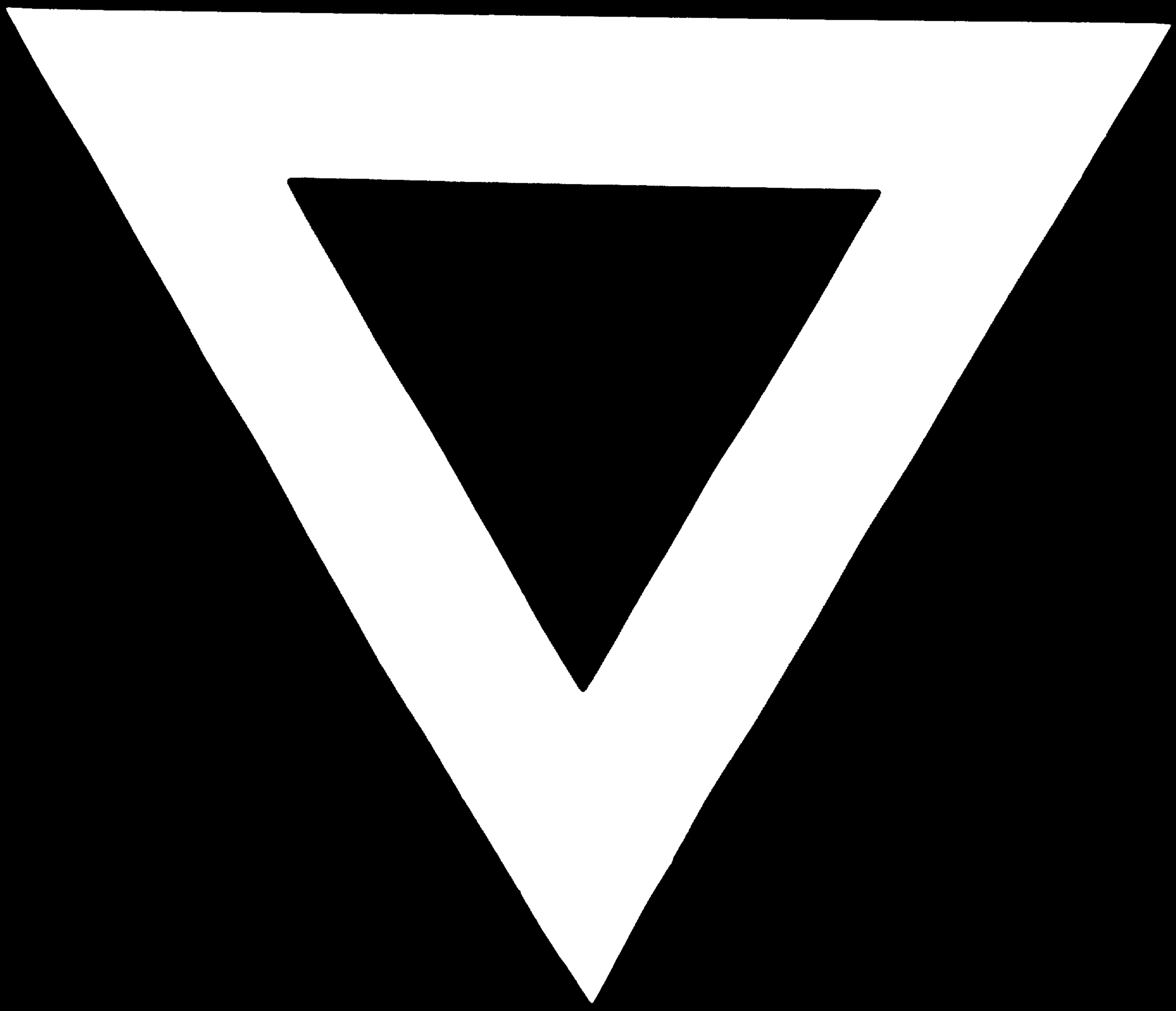

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