INFACON 7, Trondheim, Norway, June 1995
Eds.: Tuset, Tveit and Page
Publishers: FFF, Trondheim, Norway

STRATEGIC PLAN TO ABATE POLLUTION AND TO BENEFICIATE LOW GRADE MANGANESE ORE AT SMIORE'S METAL AND FERROALLOYS PLANT

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ABSTRACT

The development strategy to abate pollution in SMIORE's 15-MVA and two 20-MVA submerged arc furnaces for FeMn and FeSi are discussed. Initially, technological alternatives for recovering the potential heat energy in the flue gas were examined but found uneconomical. Thus, it became imperative to install bag house filters for air pollution. Their design, layout and commissioning problems are highlighted. To meet future demand, upgrading of manganese ores by roast reduction-magnetic separation route is discussed. A 2-tph pilot plant to carry out research and development work for setting up a commercial module of 50 kt/yr of sinter for growth up to 135 kt is envisaged. Meanwhile, a 35-tpd pan sintering facility has been installed to use filtered dust.

INTRODUCTION

When ferroalloy plants were set up on green field sites in the 1970s and 1980s, the concept of effectively "closing" the submerged arc furnace (SAF) by providing a refractory dome would have meant using the potential energy of waste gas for (1) power generation, (2) preheating of raw materials, or (3) storing and flaring the excess CO-rich gas after preheating metal launders or ladles. All three options entailed capital investment, which a sunrise industry could ill afford. Moreover, the need for the first two options was hardly felt because electricity was available cheaply (0.37 cents/kWh). The third option would have been a wasteful exercise, because of very limited use of gas for a single-furnace plant or for export.

But, in a developing country with cheap electricity and low priority for environmental protection on the industrial agenda, entrepreneurs were eager to take off to meet the ferroalloys demand of the foundry and steel industries, SMIORE did not idle.

Today, the scenario in India has changed dramatically. The ferroalloy industry is facing multiple problems such as high power tariff, inadequate supply of power; manganese ores and reductants; high cost of pollution control. New entrants are compounding these problems by overproduction in a stagnant steel industry producing 15 million tonnes. Although the installed capacity of the bulk ferroalloys are 550 kt of FeMn/SiMn, 150 kt of FeSi, 480 kt of FeCr, including 200 kt of charge chrome for export, barely 50% meets the domestic demand. Survival under such circumstances must depend on pioneering zeal and pragmatic approach.

Conscious of its industrial and social responsibilities, SMIORE is addressing these issues professionally. An attempt is, thus, made in this paper to present the development strategy to abate pollution in its 15-MVA and two 20-MVA SAFs smelting FeMn/SiMn and FeSi, respectively; also, to create selfsufficiency in manganese ore sinter for smelting manganese alloys in the future. On-going research and development (R&D) efforts to set up a pilot plant for roast reduction of Mn ore (2 tph) in a rotary kiln followed by magnetic separation and sintering are discussed. Prospects of scaling up tenfold so as to reach ultimately a target of 135 kt of sinter per year are examined.

BACKGROUND

Although mining of manganese ores started as early as 1907, SMIORE entered the field as a private company in 1954, and became a public limited in 1964. Prior to 1954, a Belgian company produced 3.72 million tonnes of ore. By systematic and scientific mining during 1954-94, total production reached 6.18 mt.

These ferruginous ores of Precambrian origin contain pyrolusite (MnO_2), cryptomelane (MMn_8O_{16}) or psilomelane (Hydrous Mn manganate), closely associated with hematite (Fe_2O_3) and goethite ($Fe_2O_3 . H_2O$).

The present yearly production of SMIORE ore is 285 kt comprising 85 kt of FM grade (Mn/Fe > 4.66); 100 kt each of A (38-46% Mn) and C (30-38% Mn) grades. Their typical analyses are given in Table 1. Plans are afoot to raise this level of production to 540 kt. With 200 kt of FM-grade ore, the Ferroalloy Plant would be fully geared to produce 85 kt of hot alloy (THA) from its three SAFs.

Table 1. Chemical Analyses of SMIORE Ore

Grade	Analyses, %				
	Mn	Fe	Al_2O_3	SiO_2	P
FM	45.54	9.50	7.73	2.22	0.010
A	42.16	17.41	5.23	1.69	0.011
C	36.84	21.64	5.75	2.75	0.011

Because of low P with Mn + Fe ranging from 55-60%, the A-grade ores have been traditionally exported for blending with richer ores, but higher P, and as a source of Mn for blast furnace iron. But the C-grade ore, produced in equal amount, has a limited market. Thus, SMIORE initiated dialogues with various agencies in Norway, Finland, the erstwhile USSR, and other research and development institutions within the country for upgrading leaner ores; also to insure against future scarcity of captive FM-grade in a mineable reserve of 18.8 mt.

Besides, SMIORE was seriously concerned with conservation of the environment and the method of combating air pollution.

CLEAN AIR LAWS

With growing public awareness, the Environmental (Protection) Act, 1986, empowered the State Control Boards to penalise any industry violating the National Standards. These stipulated that (1) suspended particulate matter (SPM) shall not exceed 150 mg/Nm^3, (2) the minimum stack height shall be 30 meters, but even higher according to specifications (Table 2), and (3) the ambient air quality shall not exceed the limits given in Table 3.

Although the last two standards were easily satisfied, the first was difficult since the SPM in the gas emissions averaged 1907 mg/Nm^3 for FeMn and 1202 mg/Nm^3 for FeSi. This compelled SMIORE to seriously examine the pollution control options, especially in view of the Government's deadline of December 1993.

Table 2. Minimum stack height for various plants

Plant type	Minimum Stack Height, meter
All plants except thermal plants	30
Plants where SO_2 is Q in kg/h	$(14Q)^{0,3}$
Plants where SPM is Q in t/h	$74\ (Q)^{0,27}$

Table 3. Ambient Air Quality

		Concentration, µg/m^3			
Category	Area	SPM	SO_2	NO_x	CO
A	Industrial & mixed use	500	120	120	5000
B	Residential & rural	200	80	80	2000
C	Sensitive	100	30	30	1000

TECHNOLOGICAL OPTIONS

Before deciding a pollution control system, it was necessary to examine technical feasibility of upgrading the C-grade ore by one of the three routes: (1) blast furnace smelting (BF), (2) submerged arc smelting (SAF), or (3) roast reduction - magnetic.

A theoretical analysis showed that it would not be possible to produce high-manganese slag in a BF. A Chinese plant which had claimed [1] production of Mn-rich slag confirmed that it had discontinued the process. Trials in SMIORE's SAF were unsuccessful. However, it seems technically feasible provided (1) a specially designed SAF is installed with facilities to handle large volume of slag (120 kt/yr), (2) 25 MVA power is available, one-third through captive generation, and (3) 54 kt of Spiegel is sold in a virtually non-existent market. These options were not viable economically. In contrast, the roast reduction route was preferred because it was less dependent on power (9 MVA).

Dependency on Product Mix

To develop a technological strategy for pollution control, SMIORE had to commit to a product mix based on its innate strength and on the changing marketplace. The 15-MVA SAF (No. 1) has a capacity to produce 33 kt/yr of FeMn72, while each of the two 20-MVA ELKEM SAFs (No. 2 & 3) has a capacity to produce 12 kt/yr of FeSi73. Because of oversupply of FeSi, production of FeMn was imperative in these SAFs at short notice. Thus, metal separation and slag granulation facilities were created for production of FeMn/SiMn at 50% re-rated load, or 8 MW. Also, the pollution control system was designed to serve either all three SAFs on FeMn or two SAFs on FeMn and one on FeSi.

With this flexibility, the choice of "closing" SAFs 1 or 3 or both for FeMn while leaving SAF-2 "open" for FeSi had to be made. The scheme developed in Fig. 1 focuses attention on project capital based on Rupee-US$ parity for the respective years. If SAF-1 alone were to be "closed", venturi scrubbers would have become inevitable, compelling recovery of waste gas energy.

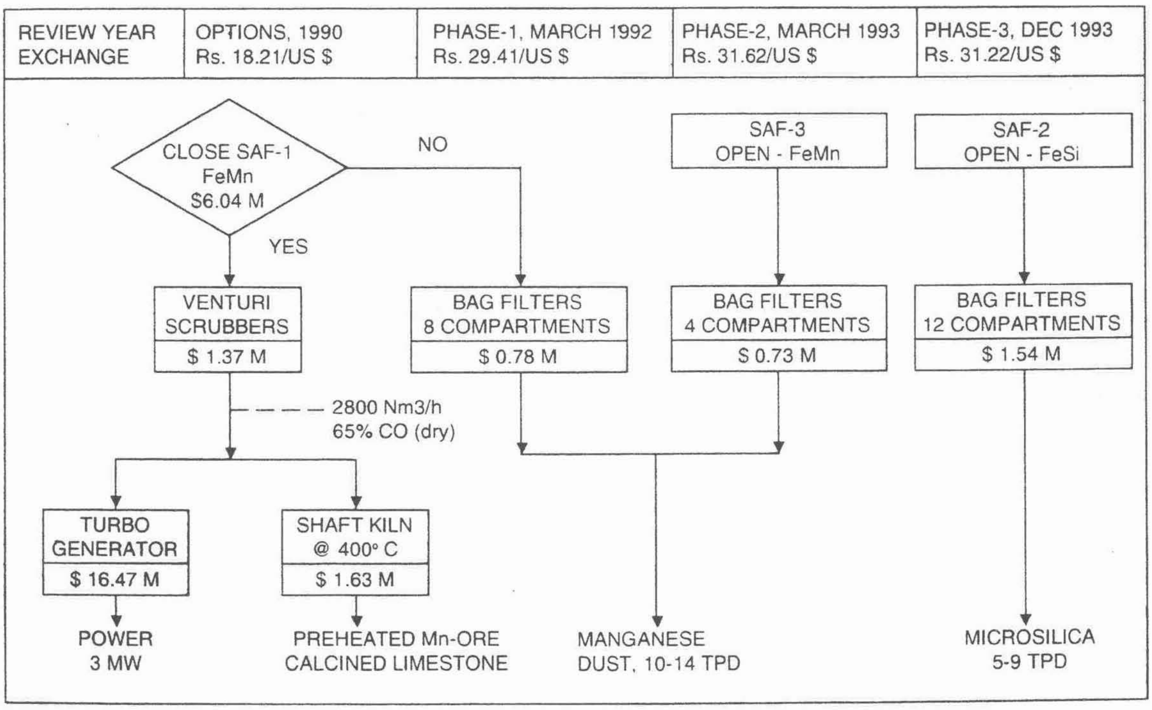


Figure 1. Capital for Technological Options for Gas Usage and Phased Pollution Control System.

Power Generation by Waste Heat Recovery

The flue gas could generate electric power through the boiler-turbo-generator route. Estimates (1991) showed that power generation system alone would be US$16.47 m to generate maximum 30% of the SAF load, or 3 MW. This meant a capital-output ratio of $1.81 m/MW for thermal plants and $1.02 m/MW for minihydel projects in India. Also, interrupted power supply was a deterrent. Thus, the power generation option was ruled out.

Preheating Raw Materials

Although thermal dissociation of MnO_2 to Mn_2O_3 occurs above 450°C and Mn_2O_3 to Mn_3O_4 at 950°C, the reactions at 298°K in the presence of carbon monoxide are exothermic as shown below:

$$2MnO_2 + CO = Mn_2O_3 + CO_2 \; ; \quad \Delta H° = -0.20 \text{ GJ} \qquad (1)$$
$$3Mn_2O_3 + CO = 2Mn_3O_4 + CO_2 \; ; \quad \Delta H° = -0.19 \text{ GJ} \qquad (2)$$

These reactions contribute 630 ekWh/THA (2.27 GJ) in a SAF at 85% efficiency. If prereduction were to be carried out externally, say, in a high rotary kiln developed by Outokumpu, Finland, the specific energy would typically increase to 3300 kWh/THA from 2700 kWh/THA. Thus, the idea of retrofitting a kiln was abandoned.

Alternatively, preheating manganese ores to 400°C and calcining limestone at 900°C were examined. The potential energy saving was estimated at 209 kWh/THA for manganese ore and 126 kWh/THA for limestone (Table 4). The combined practical saving is estimated at 276 kWh/THA. Credit was taken for the sensible heats of H_2O and CO_2 if these were to be present in flue gases leaving the SAF at 700°C.

Table 4. Potential Energy Saving by Preheating Manganese Ores and Calcining Limestone

Process	Energy Saving, eKWh/THA	
	Theoretical	Practical*
Manganese ore:		
Preheating @ 400°C	166	137
Vaporization (2% moisture)	27	22
Nil H_2O in SAF top gas (700°C)	16	13
Limestone:		
Calcination @ 900°C	109	90
Vaporization (1% moisture)	1	1
Nil CO_2 in SAF top gas (700°C)	15	12
Nil H_2O in SAF top gas (700°C)	1	1
Total	335	276

*Thermal efficiencies assumed: SAF = 85%; preheating kiln = 70%

Some experts opined that the specific energy increases by 100 kWh/THA after "closing" a SAF, leaving a net saving of just 176 kWh/THA, or \$0.73 m/yr at 6.45 cents/kWh.

Further, the top gas (65% CO) has a calorific value of 3040 kWh/Nm^3 CO, which is equivalent to 0.375 kg carbon (0.63 kg coke) per Nm^3. Thus, if 26 million Nm^3 of CO from two SAFs were used for either preheating or roast reduction of Mn-ore, the equivalent coke saved would have been 16.4 kt/yr, valued at \$1.29 m. But, the combined saving of \$2.02 m was inadequate to service the financial cost at 25% of \$10 m capital (1992 est).

Once again the prospects of recovering waste energy proved uneconomical. Thus, it was decided to install bag house filter (BHF) to abate pollution which had assumed great urgency.

POLLUTION CONTROL SYSTEM

In "open" top SAFs, the gas flow with air ingress was 0.145 million Nm^3/h for SAF No. 1 smelting FeMn, and 0.245 million Nm^3/h for SAF No. 2 or 3 (three chimneys each) for smelting FeSi. Particulate size analysis showed that 80% of the dust was above 40 μm; while 2-5% for FeMn and 9.5% for FeSi were above 10 μm. This warranted installation of bag filters which can efficiently cope with sizes even down to 0.5 μm [2]. The large emissions warranted careful designing and planning.

Design and Layout

To reduce the gas flow to 0.163 million Nm^3/h, only two out of the three chimneys in each 20-MVA SAFs were connected to the main duct leading to the BHFs. Because of the larger flow from FeSi operation in SAF 2/3, a 2.2-m diameter duct was routed below the smaller 2.0-m duct for directing the gas to BHF-2 (Phase-3). Both were designed to accept the higher volumes at temperatures of 120°C-180°C at the chimney-duct junctions.

Figure 2 shows the general layout of the Plant. The two double row bag houses were accommodated between SAFs 1 & 2 in a phased manner (Fig. 3). BHF-1 for SAF-1 was sited nearer to SAFs-2 & 3 with the idea of expanding from 8 compartments to 12 (Phase-2) once SAF-3 on FeMn was connected to the BHF. This enables smelting of FeMn in SAF-2 when SAF-3 is off for reline.

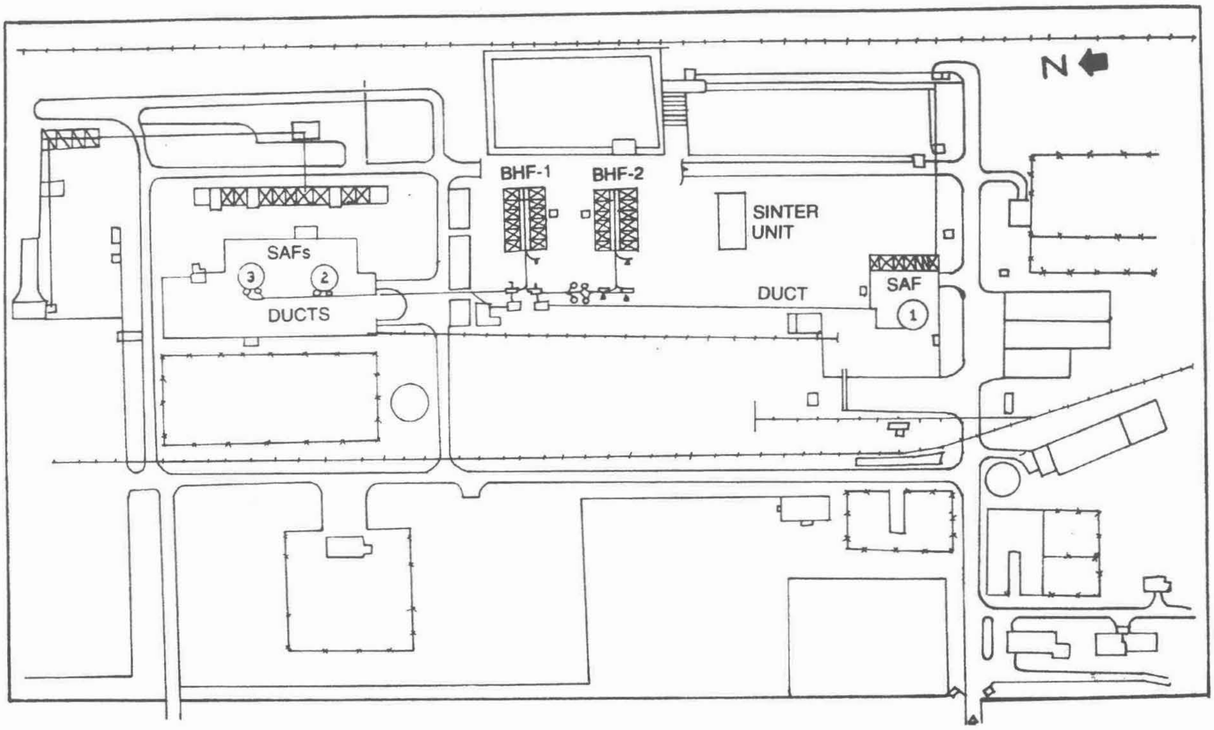
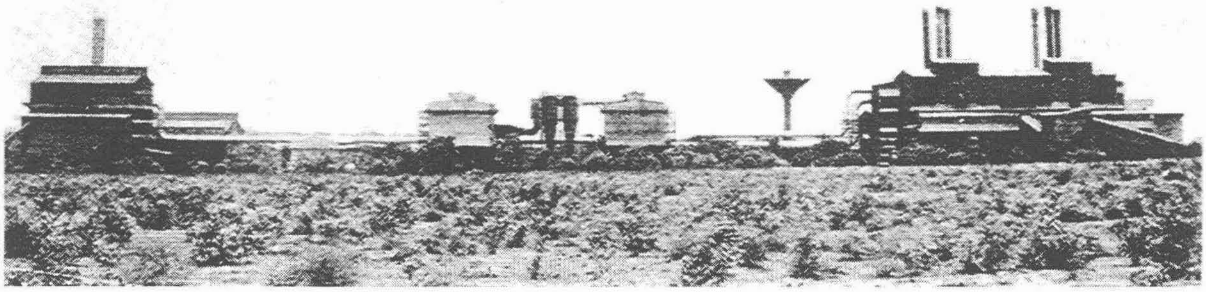


Figure 2. Plant Layout Showing Location of Bag House Filter & Sinter Unit Between SAFs



SAF-1 BHF-2 BHF-1 SAF-2 + 3

Figure 3. Bag House Installations Between SAFs.

The flow diagram of the filtering system is shown in Fig. 4. Emissions pass through a precollector or a multiclone which traps coarser particles. It also doubles as a spark arrestor to protect the fibre glass woven bags, which can withstand up to 260°C. The dust-laden gases are sucked through the ducts by 600-kW main fans and transported to each compartment via a tapered plenum. Filtered gases escape to the atmosphere with SPM of 10-15 mg/Nm^3, registering a drop of 99%. The bag house manganese dust (BHMD), collected in a silo after reverse air cleaning (RAC) is sent to the sinter unit. The dust rate was 0.23t/h for each SAF.

In Phase-1, 0.191 million m^3 of gas per hour was filtered at 120°C through eight compartments, each with 112 bags (292 mm dia x 10.2 m). Thus, the filtering velocity was 26 m/h in seven compartments while the eighth was on RAC cycle. In Phase-2, the number of bags was increased to 128 per compartment to cope with combined volume of 0.406 million m^3/h. Thus, the filtering velocity increased to 31 m/h with 11 active compartments

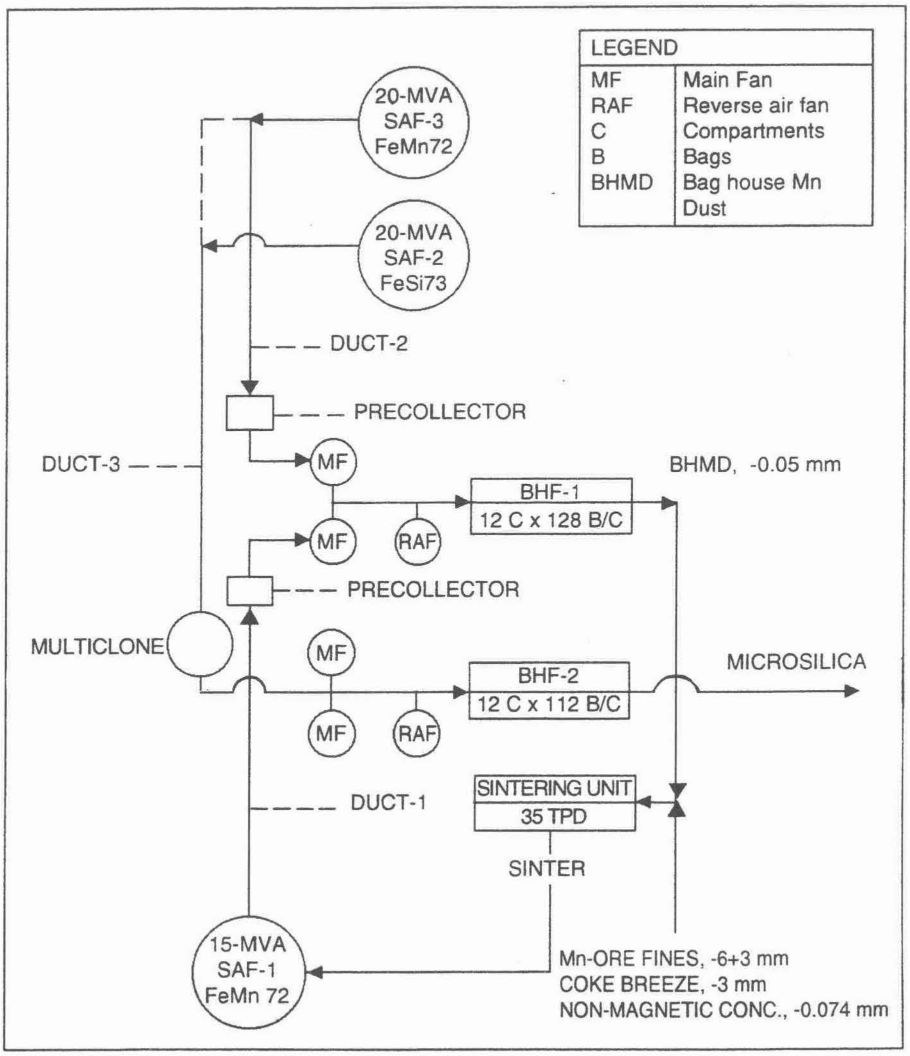


Figure 4. Schematic Flow Sheet of the Submerged Arc Furnaces - Bag House Filters - Sinter System.

Had the pulse jet air cleaning system been adopted, the flow velocity would have increased by a factor of 2.6 over smaller area of bag. To cope with these severe conditions, costlier temperature-resistant bags would have had to be employed. Also, high frequency of cleaning would have reduced the life of bags. These were important considerations in deciding the RAC system.

Commissioning Problems

While commissioning BHF-1, the two major problems encountered were (1) choking of screw feeders, and (2) sluggish flow of bag house manganese dust (BHMD).

As designed, the BHMD, falling through hoppers, located below each compartment of filter bags, was transferred by rotary feeders to two parallel screw conveyors which, in turn, were feeding the main screw conveyor running perpendicular to them. The BHMD was finally conveyed to a silo by a bucket elevator.

Choking of Screw Conveyors
It was soon realised that insufficient clearance between the 225-mm diameter trough and the 190-mm diameter flanges of the hanger bearings caused choking, thus overloading the motor. Finally, it was decided to increase the diameter of the screw from 200 mm to 450 mm; trough to 480 mm. For greater efficiency, the two screw conveyors below the compartments were replaced by 12 screw feeders connected to two screw conveyors on the central axis. These, in turn, discharged to a common conveyor transferring the BHMD downstream. The problem was, nevertheless, aggravated by moisture pick-up by the dust in the emissions.

Sluggish Flow of BHMD
Normally, the differential pressure across bags builds up gradually from 0-150 mm water gauge over a period of 60 minutes. But, during trial operations, the pressure exceeded the limit of 250 mm WG within eight hours. This was attributed to absorption of moisture by the BHMD during colder nights. Passing through a 160-m long duct, the gas temperature dropped from 140° at the chimney-duct junction to 70°C at the BHF. As a result, caking of bags occurred rapidly and the back pressure caused puffing of gases on the furnace floor. Also, BHMD, accumulated in the hoppers, was removed manually through the inspection windows.

Initially, the operation of the multi-louver damper (MLD), which controls the gas suction, was governed by the current setting of the main fan motor. However, the system ignored the effect of inlet temperature. Hence, a resistance-temperature detector (RTD) was introduced at the bag house inlet and the output signals were transmitted to the proportionate integrated derivation (PID) controller to regulate the MLD operations. This permitted the gas temperature to be maintained between 110° and 115°C to avoid early blinding of the filter bags. Nevertheless, RAC had to be repeated before sequential shifting to the next compartment. Moreover, the suction rate of the gases was reduced because of throttling (30-40%), resulting in puffing at the furnace floor.

To ensure rated performance, designers are now considering cladding both ducts with thermal insulating blankets.

Capital and Operating Costs

The capital cost was about $1.53 million for each BHF, totalling $3.05 m from 1991-94. The main- and reverse-air fans consume as much as 19 GWh per year. Figure 5 shows the distribution of variable and fixed costs for operating the BHFs. It is noteworthy that the cost of operating BHF-1 for two SAFs on FeMn is $1.22 m/year, approximating that of BHF-2 with just one SAF on FeSi. As a result, the cost of production increases by $24 and $97 per tonne of saleable FeMn and FeSi, respectively.

Costs are also sensitive to hikes in electricity tariff and poor quality of supply. This burden cannot be transferred directly to the consumer, mainly the steel plants who are themselves seeking cheaper sources. Small producers with low investment on installed capacities (below 7 MVA) and State power subsidies are offering fierce competition to the major units. Thus, to offset the costs, efforts are being made to use the BHMD for sintering and to find markets for microsilica.

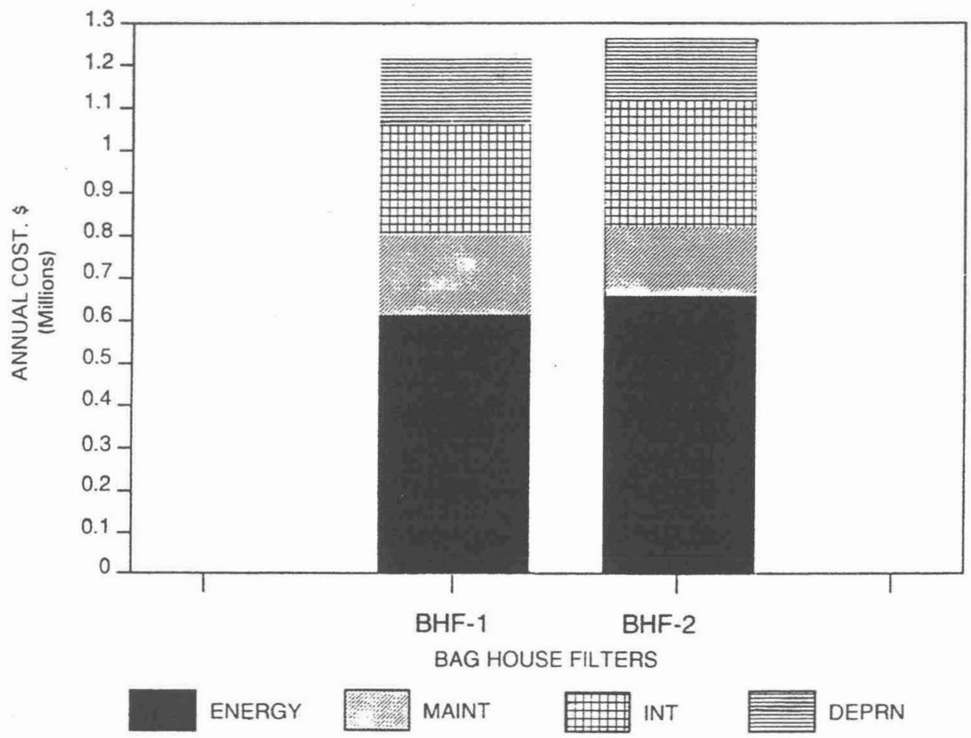


Figure 5. Variable & Fixed Costs for Filtering Flue Gas From SAFs Smelting FeMn and FeSi.

MANGANESE ORE BENEFICIATION

After careful investigations and consultation, both within and outside the country, it was decided that SMIORE's C-grade ore (31% Mn: 22% Fe) could be upgraded by roast reduction and magnetic separation. Budgetary estimates were made to comprehend the logistics and investments involved.

Plant Logistics

R&D results indicated it was possible to get Mn/Fe ratio of 5.04 at Mn recovery of 68%. The non-magnetic fraction was 53%. Thus, material balances were developed (Fig. 6) for obtaining Mn/Fe ratio of 7.42 with a sinter yield of about 30% of the C-grade ore used. A blend of sinter and C-grade ore was envisaged for smelting FeMn72; only sinter for FeMn78, meant for exports.

The cumulative yearly requirements of ore and sinter are projected in Figure 7. Sinter plant modules of 50 kt/yr are being considered in two or three phases, depending on the marketability. Conceptually, about 75% of the requirement could be met at 100 kt/yr capacity, probably coinciding with optimum sinter feed for the three SAFs; excess, if any, could be marketed.

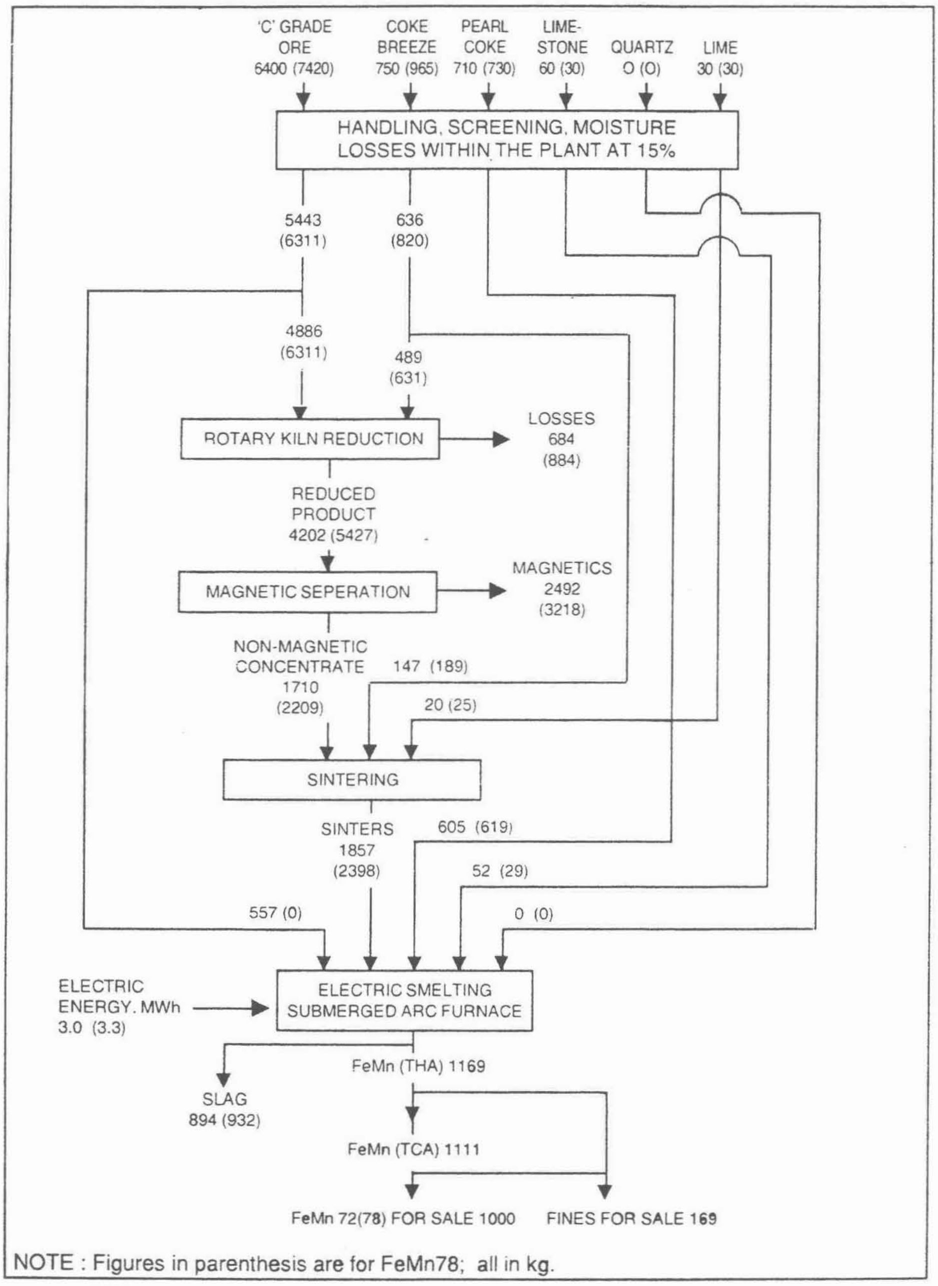


Figure 6. Material Flowsheet for Beneficiating and Smelting FeMn72 & FeMn 78.

Investment for Commercial Plant

Based on these concepts, preconstruction estimation of capital made in 1992 are given in Table 5. Considering today's status of process development, a 50-kt module was found to be reasonable. But, before committing to such a heavy investment in a pioneering venture, it was deemed prudent to establish the technical parameters in a pilot plant.

Table 5. Cost Estimate for Medium and Large Scale Plant

		Medium	Large
A.	Capacity:		
	Ore to Rotary Kiln, t/h	20	50
	Sinter, kt/yr	50	135
B.	Capital, $ million	16	27
C.	Capital to output ratio, $/t	320	200

Pilot Plant

By scaling down by a factor of 10, the size of the pilot plant was fixed at 2 tph ore feed to the rotary kiln. This would be equivalent to producing 17 tonnes of sinter per day. Because the bag houses were installed, a 35-tpd pan sinter facility at a cost of $ 126,984 was set up in 1994 to cope with 10-14 tpd of BHMD from two SAFs. Meanwhile, the design specifications of other facilities for roast reduction and magnetic separation were finalised. The budgeted capital has been restricted to $ 1.43 m.

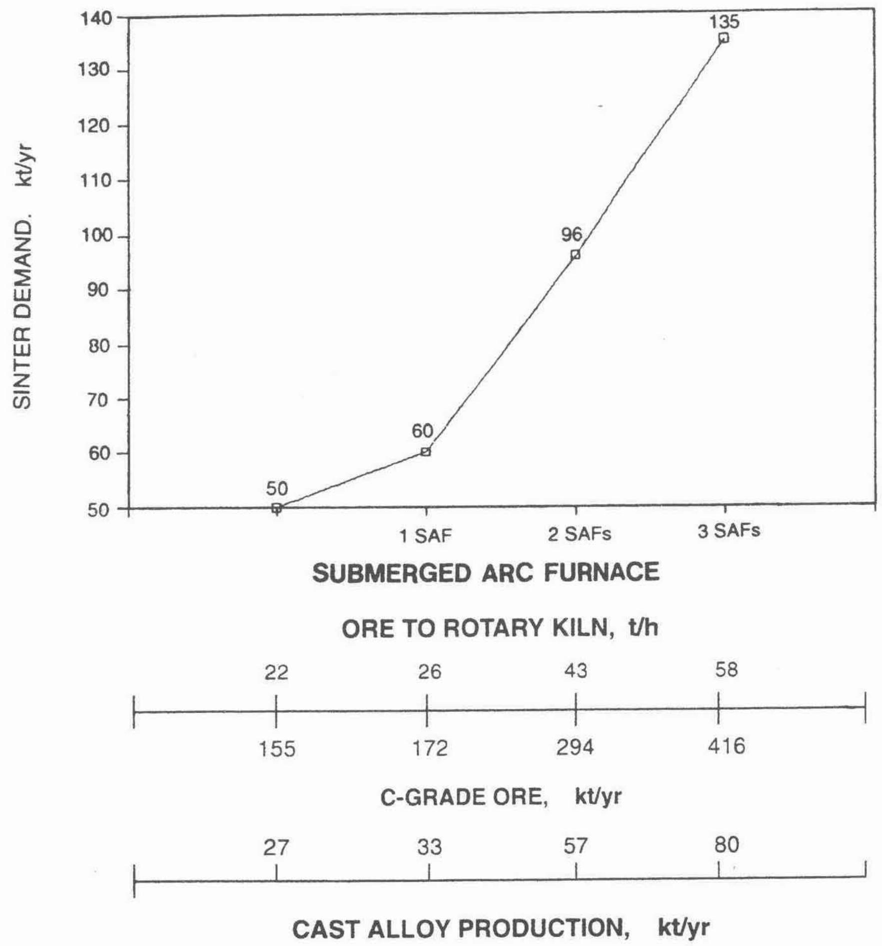


Figure 7. Logistics for Modular Growth of Sinter Plant

The process flow sheet to conduct the R&D is shown in Fig. 8. Roast reduction is carried out by feeding screened ore at 2 tph into a rotary kiln (1.6-m working dia x 20 m) with speed varying from 0.3-1.2 rpm. For attaining the desired temperature of 850-900°C, three air fans (1000 m^3 each) are mounted on the shells, and a fuel injector (300 kg/h) is provided at the discharge end. The hot reduced product, which passes through an externally water-cooled rotary cooler (1.5-m ID x 12 m), may exit at about 120°C. A heat-resistant belt conveyor transports it to the yard for processing. The gases escape through a post-combustion chamber before leaving the refractory-lined stack.

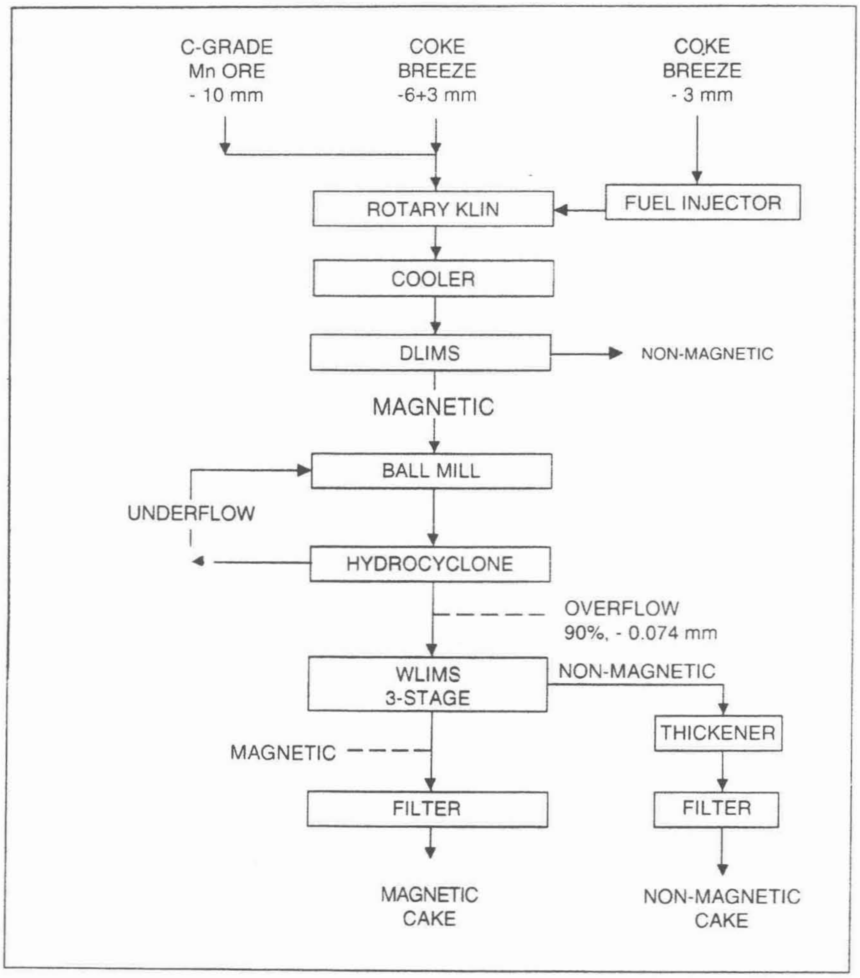


Figure 8. Flow Sheet for Mn-Ore Beneficiation Plant. DLIMS, WLIMS Denote Dry and Wet Low Intensity Magnetic Separation.

The reduced product is subjected to either dry low intensity magnetic separation or wet low intensity magnetic separation (1400-1500 Gauss) after grinding in a ball mill and passing through a hydrocyclone to obtain 90% below 74 microns. Flexibility is provided to obtain concentrates in one or three stages by WLIMS. Between each stage, the magnetic fraction is demagnetised before passing through a disk type vacuum filter. The non-magnetic concentrate goes to a thickener and a vacuum filter to obtain a cake having 12-14% moisture, suitable for sintering. While about 17 tpd of non-magnetic fraction would go for sintering, about 24 tpd magnetic fraction may go for coal washeries as suspension medium or for blast furnace feed after agglomeration.

Sintering Unit

To use the BHMD, the sinter plant was located near SAF-1 (Fig. 2). The major equipment such as ribbon blender, disc pelletizer (2-m diameter), sintering pans (2x4 m^2), cyclone, and wet scrubber are housed in a shed (300 m^2). An under-slung crane lifts the feed materials in a Steahler bin which discharges into a blender. The pan is filled to a bed height of 500 mm and sintering is done with a suction fan (13,000 m^3, 1130 mm WG). The pan is then lifted on to a tilting stand for unloading. The sinter is broken by impact on grizzlies and removed by rail-mounted tubs.

A blend of BHMD (38.6% Mn, 5.6% Fe) and screened Mn-ore fines (38.5% Mn, 14% Fe) was used to obtain a sinter of 39.6% Mn, 7.8% Fe. The tumbler index, 65% + 6.3 mm, was adequate for smelting.

SUMMARY

SMIORE examined various technological alternatives once end-1993 deadline was set for abating pollution. Investment for "closing" the SAFs smelting FeMn and use the potential energy in the waste gas either for power generation or preheating raw materials was uneconomical. Hence, installation of two bag house filters for FeMn and FeSi was decided. Their design and layout are discussed and commissioning problems highlighted.

Besides sintering bag house manganese dust, SMIORE is concerned with upgrading its low grade manganese ores to meet future scarcity of ores for smelting FeMn. Before launching commercial modules, it was decided to set up a pilot plant (2-tph ore basis) for roast reduction in a rotary kiln and magnetic separation. Meanwhile, the sintering facility is meeting present requirements.

ACKNOWLEDGEMENT

The author wishes to thank the management of the Sandur Manganese & Iron Ores Ltd. for permission to publish this paper.

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