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CHARGE CHROME AND FERRO CHROME PRODUCTION IN INDIA

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A B S T R A C T

CHARGE CHROME AND FERRO CHROME PRODUCTION IN INDIA:

India is emerging as an important source for supply of charge chrome and ferro chrome to the world market.

This paper outlines the chrome ore reserves in India, their production, export, and utilisation and the need for beneficiation of lower grades for optimum utilisation of the reserves. Large quantities are available for exploitation of disseminated ores, run-of-mine ore rejects, low grade fines and friable lumpy ores. Considerable work has been done on beneficiation of chrome ores by FACOR. Low Grade chrome ores containing Cr_2O_3 15 to 25% have yielded chrome concentrates with 46-54% Cr_2O_3 content with a recovery of 75-85% of Cr_2O_3.

Briquetting of chrome ore concentrates and chrome ore fines using molasses and hydrated lime as binders, is considered as an appropriate technology for the agglomeration for their subsequent use in Electric Smelting Furnaces. Chrome ore briquettes having requisite physical strength and smelting characteristics have been produced, tested in the production of charge chrome and high carbon ferro chrome and are now being regularly used at FACOR as a component in the carge mix.

The paper then deals with salient aspects of smelting characteristics of Indian chrome ores and chrome ore briquettes and gives operation data for the production of charge chrome and high carbon ferro chrome with particular reference to selection and use of carbonaceous reductants to obtain requisite low phosphorus and sulphur contents in the metal.

A new Charge Chrome Plant with 50,000 tons per annum capacity has been set up at Randia in Orissa State based on the beneficiation, agglomeration and smelting technology developed at FACOR.

Finally the infrastructural facilities available for the production and export of high carbon ferro chrome and charge chrome in India to ensure its emergence as a stable supplier of chrome alloys to the world market, particularly the Japanese market in view of the geographical advantage is described.

Institutions and the same are being continued. According to the latest published data the revised estimates by Geological Survey of India along with other agencies have placed the reserves as at about 120 million tonnes[2]. The distribution of chrome ore reserves[3] is indicated in Table 1.

As stated above, Orissa holds the major ore reserves in the country. The mines are located in Cuttack, Dhenkanal and Keonjhar Districts. The most productive area is SUKINDA area in Cuttack district. Chromite deposits are located near the tri-junction of Cuttack, Dhenkanal and Keonjhar districts in Orissa. Sukinda ultramafic complex is a large chromiferous ultramafic body of about 40 Sq. KM and extends over a length of about 15 KM from the village Kansa on the east to the village Marubale on the West[4]. The main chrome ore mines in this area are SUKINDA (Bhimtanagar Block), the Kalarangi, Sarubil, Kamarda, Gurjang, Kaliapani, Kalarangi, Talangi, Kamarda, Kamarda-Balipada. The Baula-Nausahi Chromite deposits of Keonjhar district[5] are next in importance to the Sukinda deposits. This deposit is located in Boula forest on the Southern slope of Bhulinghore Huli range, about 48 KM east/north east of Sukinda field. The three mines operated are Boula, Nausahi and Bangur.

The Geological Survey of India undertook further intensified proving operations jointly with Directorate of Geology and Mining, Orissa; Orissa Mining Crorporation Mineral Exploration Corporation of India etc. The recently computed results on exploration data show extensive reserves. The provisional estimate has been placed at 112.6 million tonnes[6] in the Five Blocks of the Sukinda-Nausahi Chromite Belt. The five blocks comprise Bhimtanagar (Upper (Brown Zone and Lower Brown Zone), Kaliapani-Bhimtanagar (retrenched blocks A & B), Sukerangi Block, Saruabil Block, Nausahi, Baula Block as indicated in Table 2.

These estimates include all grades of chromite ores containing minimum 30 percent Cr_2O_3. Further exploration work, proving operations, compilation of data on grades and types are under progress and the final outcome will yield a more clear picture by 1985. However, from the estimates available now, it is observed that India is very comfortably placed in chrome ore resources.

PRODUCTION, EXPORT AND CONSUMPTION OF CHROMITE IN INDIA

Mining of chromite in India is started in 1903. Since there was no ferro chrome production till 1968 the chrome ore was mainly exported. Presently about 60 percent of the ore produced is exported. So far, right from 1903 to 1980 India has export 3.84 million tonnes. The current production of chromite in India is about 0.3 to 0.4 million tonnes per annum.[7] It reached the maximum in 1975 when there was export boom of 0.35 million tonnes. Nearly about 1,20,000 tonnes is consumed in India, out of which the Ferro Chrome Industry consumes about 60,000 tonnes, the Refractory Industry about 50,000 tonnes and the Chemical Industry consumes about 10,000 tonnes.[8]

Till recently the production capacity of ferro chrome was about 20,000 tonnes per annum only. This situation will change with the commencement of production of charge chrome. The requirement of chrome ores for refractory and chemical industries has also been estimated to progressively increase and reach to 86,000 tonnes per year and 82,000 tonnes per annum respectively in the year 2000 AD[9].

CHROME ORE CHARACTERISTICS

The types of chrome ores available are hard lumpy, friable and fines in all grades. More than 80% ores are of medium and low grade, which occur as lumps and fines. The various types of chrome ores are indicated in Fig-1.

Lumpy high grade ore containing more than 48.0% Cr_2O_3 and high chromium to iron ratio more than 2.8/1 are very limited. Whereas the same grade ores in friable form and fines are quite extensive. Such friable type ore and fines occur in Sukinda and Kaliapani Mines. While lumpy ores can be used directly in Electric Smelting Furnaces, the latter require agglomeration before use.

There are considerable reserves of medium grade ore with Cr_2O_3 35-45%, and chromium to iron ratio 2.0 to 2.6. These are available as hard lumpy, friable, as well as ore fines. The lumpy ores are directly used in HighCarbon Ferro Chrome production after blending with high grade ores. The ores fines of this grade have not been utilised till now.

The low grade chrome ores both in form of lumps and fines are available. There are considerable quantities dumped unutilised at the mines. Considering the total quantity mainly of higher grade chrome ores mined from 1903 to 1981 as 6.96 million tonnes and assuming an equal proportion as the quantity of lower grade chrome ores left unutilised, the same can be recovered for use now.

FACOR'S CHROME ORE SOURCES

FACOR's requirement for the plant at Shreeramnagar of high grade chrome ores amounts to about 1,00,000 tonnes per year. FACOR is having its mining leases at Kathpal and Boula in Orissa. There is also another mining lease at Kondapalli in Andhra Pradesh, with a small reserve. Most of the ores mined in Boula are of medium grade and low grade. Presently the mining is carried out by open cast method after removal of over burden by crawler mounted track shovels and dumpers. The ore raising is carried out mannually to avoid its mixing with surrounding rock. The annual quantity of ore raised is 70 - 80,000 tonnes. But with setting up of charge chrome plant at Orissa the total requirement of chrome ores is 2,30,000 tonnes per year either in lumpy form or agglomerated form. This necessiated utilisation of very low grade disseminated chrome ores earlier being discarded.

With the assistance of Mining Experts, further development and planning for economic mining to achieve targetted production at mines has been executed including underground mining. The underground mining will help in avoiding removal of huge quantities of overburden. After proper drilling and exploration the reserves have been proved as 4.87[10] million tonnes at Boula Mines and 0.54 million tonnes at Kathpal Mines[11]. The gradewise reserves are given in Table 3

TABLE : 3

GRADEWISE RESERVES AT BOULA MINES
(LEASED BY FACOR)

	% Cr_2O_3	Million Tons
Lump	+ 45	1.3
	40-45	0.93
	30-40	1.19
	25-30	0.10
Disseminated	25-30	0.45
	20-25	0.35
Old dumps	8-15	0.55
TOTAL :		4.87

The different types of chrome ores mined at Boula are:

		Cr/Fe	Proportion
Type 1	Hard, lumpy high grade with Cr_2O_3 45-50%	2.8	25 %
Type 2	Hard, lumpy medium grade with Cr_2O_3 35-45%	2.0-2.4	40 %
Type 3	Hard, lumpy low grade with Cr_2O_3 25-40%	0.8-1.6	35 %

Besides these, while mining, large quantities of disseminated ore and low grade ore fines and R O M rejects are obtained which contain Cr_2O_3 about 15%. At present all quantity of hard lumpy ores available at Boula with chromium to iron ratio of 2.8 are blended with hard lump ores at Kathpal having chromium to iron ratio 3.2 for the production of H.C.Ferro Chrome.

In addition FACOR utilises purchased chrome ores from other mines for the production of high and low carbon ferro chromium.

Keeping abreast with the technological change in the world requirement for chrome alloys it was felt that charge chrome would be an appropriate product to utilise optimally, all the available chrome ores in FACOR's mining lease areas. The lumpy ores of low grade and low chromium to iron ratio can be used for charge chrome and the very low grade wastes can be utilised after beneficiation.

With this concept investigations on beneficiation[12-16] were carried out on typical samples of low grade ores at FACOR. The tests indicated that though the chromium to iron ratio cannot be substantially improved upon, the Cr_2O_3 content could be enriched in a low grade ore from 27.8% to 52.0% as a result of removal of the gangue constituents. Encouraged with the results obtained on the preliminary investigation on different chrome ore samples at FACOR, a pilot chrome ore beneficiation plant based on gravity separation with crushing, grinding and tabling units was put up at Shreeramnagar Works. The flow sheet of the beneficiation plant at Works is indicated in Fig.2. Since erecting this pilot plant, various chrome ores were tested and the results are given in Table 4.4

The first category from serial Nos.1 to 6 are chrome ore chips upto about 25 mm size and were treated in the beneficiation plant mainly to bring down the SiO_2 content from 7-12% to less than 4.5%.

The second category of benefication tests from Sl.Nos. 7 to 10 have been done on minus 6 mm screen rejects (- 6 mm) obtained while feeding the chrome ores to plant for the production of high carbon ferro chrome. These usually get contaminated with coke, coal and fluxes, and fines as a result these materials being fed through the same conveyor system. These fines used to be thrown out as waste previously. Since establishment of the beneficiation plant, these are treated to recover the chromite concentrates. The weight recovery was found to be a function of the contamination of the chrome ore rejects. The concentrates obtained under 1 & 2 category could be successfully utilised in the production of Low Carbon Ferro Chrome.

The third category comprising from Sl.Nos.11 to 19 are mainly low grade chrome ores and waste dumps from Boula Mines in which the Cr_2O_3 is less than 30% which were fed for the removal of gangue and the improvement of Cr_2O_3 (with Cr_2O_3 recovery 48 to 78%) using different feed materials. It can be noted from the results obtained in the beneficiation of these low grade chrome ores and waste dumps that the Cr_2O_3 content in the concentrates obtained is 44-54% and SiO_2 could be brought down to less than 5%. An improvement in Cr/Fe ratio is also noticed depending on the type of chrome ore. The ores containing iron in the form of hydrated oxides of iron and associated with clay are easily amenable to removal of iron thereby improving Cr/Fe ratio.

Based on the results and the process parameters collected a beneficiation plant with 36 tons per hour feed capacity has been designed and is being erected at the Boula Mines with an investment of Rs.35 million for production of the concentrates.

AGGLOMERATION OF CONCENTRATES AND ORE FINES

The concentrates obtained after benefication are below one mm size and therefore cannot be utilised directly in electric Smelting Furnace and are to be agglomerated into lump form. Several agglomeration process [17,18] followed throughout the world were considered in detail; like nodulizing, sintering, pelletisation and briquetting. At FACOR Mines, as it has already been indicated, the lumpy chrome ores mined constitute more than 70% . Hence the feed to furnace in the form of agglomerattion would be only about 30 percent. After evaluating various agglomeration processes it was decided to adopt briquetting technology. The briquetting process was considered to have the following advantages over the pelletisation process which was considered as the nearest alternate process.

1. The results in Pilot Plant beneficiation tests proved that liberation of the mineral is almost total on grinding to 400 micron size. The concentrates obtained show about 75% above 75 microns. Whereas pelletisation process requires further grinding of the concentrates to obtain about 85% minus 75 microns. The briquetting proces can utilise coarse grain concentrates directly. Therefore by adopting the briquetting process there will be saving in the capital and revenue cost involved in further grinding.

2. The briquetting process can accept grain size upto 6 mm, hence it is possible to blend the concentrates with natural chrome ore fines before briquetting, permitting wider flexibility of utilising various types of ore fines available in the region with different chemical composition.

3. Chrome ore fines or concentrates with high SiO_2 content can be used. In pelletisation process the high SiO_2 content can cause ring formation or bridging in rotary kiln or shaft furnaces used for heat hardening of the pellets.

4. Thermal energy need not be expended to get the required physical strength as in the case of pellets. Curing for 6 to 12 hours in the atmosphere is sufficient to obtain briquettes with desired strength.

5. The proportion of briquettes would constitute 30 to 40 percent in the furnace charge mix. Thus alongwith lumpy chrome ore of size 10-75 mm, briquettes would provided more permeability in the burden inside smelting furnace compared to the permeability obtained if the same size lump ores and pellets 8-20 mm size are used.

6. The porosity in the briquettes is higher than in pellets therefore the rate of reduction is higher.

7. It is easily possible to vary briquettes sizes as desired by changing the poket size in the rolls of the press.

8. Lower handling losses and lower dust losses in fumes because of coarser grain size in case of briquettes.

9. The plant equipments required are simpler and easily maintained compared to pelletisation process where apart from elaborate grinding equipment, heat hardening facilities are required.

Besides the above distinct advantages, it will not be out of place to mention that as in case of pellets the briquette can also be stored for several months without any deterioration.

Also further experimental work is being carried out to produce composite briquettes containing chrome ore concentrates/fines, flux and carbonaceous reducing agents. The possibility of preheating and pre-reduction of composite briquettes is also under study for energy conservation in the smelting process.

BRIQUETTE PRODUCTION AT FACOR

The flow sheet of the briquetting plant is given in Fig. 3

Molasses and hydrated lime are used as binders. The specifications of binders is given in Table 5, and 6

TABLE :5

MOLASSES SPECIFICATIONS

Quality	Grade A
Total reducing Sugar	50% (Min)
Brix value	80% (Min)
Polarisation	52% (Min)
Specific gravity	1.35 (Min)

TABLE :6

SPECIFICATIONS OF HYDRATED LIME

Constituents	Percent
CaO	65-70
SiO_2	6 max.
L.O.I.	22-25
Size	
100% Below	400 microns
70% Below	75 microns
Bulk density	800 kg/m^3

Briquettes of requisite strength and smelting properties could be produced. The physical properties of the briquettes produced is given in Table7. Till date a total quantity of 12,000 tonnes has been produced and utilised in the production of high carbon ferro chrome. The properties of the briquettes after storage for eight months are included in Table which clearly indicates that the briquettes retain their properties after long duration. Once the curing is over the briquettes retain their properties even when exposed to heavy rain.

There is some breakage during stock piling and reclaiming process for feeding to furnace charging system. There is a 6 mm screen in the feeding circuit to furnace day bins. The fines of minus 6 mm returned to the bri~~e~~quetting plant from this are about 15 percent.

TABLE : 7

PHYSICAL PROPERTIES OF CHROME ORE BRIEQUETTES

		After curing for 24 Hrs	Briquettes stored for 8 months
Size in mm		54 x 36 x 27	
shape		Almond	
Average weight per briquette gm		60-68	63-68
Apparent density gm/cc		3.3-3.6	3.3-3.6
Bulk density kgs/m^3		1830-1850	1830-1850
Angle of repose		31^o 51'	
a) Green strength of briquettes - kgs/briquette		15-26	-
b) Strength of cured briquettes - kgs/briquette		70-80	70-80
Drop strength (dropped 1 kg of material from a height of 3 meter on concrete floor) %			
Five drops*	+ 25 mm	95.05	98.50
-25	+ 12 mm	0.70	0.25
-12	+ 6 mm	0.85	0.25
- 6	+ 3 mm	0.65	0.50
- 3		2.75	0.50

*Five drops have been considered for testing to withstand handling from briquetting plants and furnace storage hoppers.

FERRO CHROME PRODUCTION AT FACOR

The Ferro Chrome Plant at FACOR was commissioned in December 1968. It consists one 12,000 KVA open submerged arc furnace and one 8,000 KVA moving & tiltable arc furnace. The smelting furnace is used for the production of Ferro Chrome Silicon and HC Ferrochrome. Tilter is used for the melting of lime and chrome ore for making slag utilised in the production of LC Ferrochrome by Silico-Thermic reduction. Subsequently with the growth of the mini-steels plants having electric arc furnaces diversifying their production to alloy & stainless steel, the domestic demand for LC Ferrochrome has increased.

Also there is some increase in demand for high carbon ferro chrome. This necessiated FACOR to convert one of their three 7.5 MVA furnaces, for high carbon ferrochrome production after incorporating suitable modifications. In this furnace, trial production of charge chrome was undertaken in 1979. Subsequently this furnace is being used for production of high carbon ferro chrome, utilising chrome ore briquettes, to meet the domestic requirements of high carbon ferro chrome. Another furnace with 16,000 KVA transformer rating was commissioned on 25th Sept.,1981 to coincide with FACOR's Silver Jubilee. Production of high carbon ferro chrome from this furnace is mainly exported.

The parameters of the smelting furnaces producing ferro chrome at FACOR are indicated in Table 8.

TABLE : 8

SMELTING FURNACES AT FACOR TO PRODUCE FERRO CHROME

Particulars	Unit	Furnace-3	FCE-4	FCE-5	FCE-6
Type of furnace		Open rotating	Open rotating	Open stationery	Open moving & tiltable
Transformer rating	KVA	7500	12000	16000	8000
Primary volts 50Hz	KV	11	11	11	11
Primary current	AMPS	400	700	800	242
Secondary volt.	V	80-130	100-170	100-201	142-242
Sec.current max.	KA	45	60	64.95	25.8
Electrode dia	MM	1050	1050	1100	800
Electrode distance	MM	2311-2692	2200-2350	2350-2850	1516-1645
Shell diameter	MM	7050	7900	8400	5300
Shell height	MM	4097	4600	4875	2200
Insidehearth dia	MM	5080	5920	5920	3500
Hearth depth	MM	2185	2600	3085	1250
No.of tapholes	-	3	3	4	Lip pouring

Various smelting campaigns were done to establish the feasibility of charge chrome production making use of chrome ore briquettes, with lumpy ores in different proportions.

The chemical composition of the various chrome ores, fluxes and briquettes used in the production of high carbon ferro chrome and charge chrome are indicated in Table 9. The operation data while producing different chrome alloys in various furnaces are indicated in Table 10.

The operation for high carbon ferro chrome production with various chrome ores has indicated that in general the chrome ores are of easy smelting and not of highly refractory nature, therefore requiring extreme precautions to prevent fusion and slagging in the upper levels of the furnace. It has been also observed that if the MgO/Al_2O_3 ratio in the ore is not suitably adjusted it results in increased losses of Cr_2O_3 in the slag. This is particularly noted with chrome ores of SUKINDA area containing MgO/Al_2O_3 ratio of 0.85 - 0.90. While smelting these ores we observed lower recovery of chromium to metal. Usually magnesite is used as a controlling flux addition to improve the slag fluidity and attain higher chromium recovery. The slag volume is a direct function of gangue content inthe chrome ores and also of the ash content in the reducing agents. Since the ash content is high in the Indian carbonaceous reducing agents, it contributes to a comparatively larger portion of the slag volume. However it do not exceed the requisite slag volume necessary for easy tapping of metal and slag. It ofcourse always is the objective to employ the minimum flux by suitable blending of chrome ores to make the blend self-fluxing. It is also contemplated to make use of composite briquettes having the requisite fluxes incorporated in the briquettes so that external additions can be avoided.

PHOSPHORUS AND SULPHUR CONTROL

Small size cokes which are not useful for their own purpose are sold by the integrated steel plants in India as "Pearl Coke " and Mixed Coke". These cokes contain 0.16 to 0.18% phosphorus and are not suitable for ferro chrome production because of the very low limits of phosphorus permitted in charge chrome and high carbon ferro chrome for stainless steel making. The transfer of phosphorus to metal is 65-75% of the input. Chrome ores are almost phosphorus free. Therefore main control is exercised by selecting the suitable carbonaceous reductants like low phosphorus premium coke from Giridih, low temperature carbonised coke made from low phosphorus non-coking coals, carbonised lignite briquettes, low volatile semi-anthracite coal and non-coking coals.

After extensive investigations and actual trials we could attain the most optimum use of various reducing agents which could satisfy the phosphorus as well as sulphur specifications because some of the reductants like carbonised lignite while very low in phosphorus has a high sulphur content. The Indian coals and coke are mostly low in their sulphur content and do not pose any problem regarding sulphur.

However the control of sulphur requires apart from selection of suitable carbonaceous reducing agents proper control of the slag bascity to attain maximum sulphur partition co-efficient (sulphur in slag/sulphur in metal) The detailed specifications of the different carbonaceous reductants employed have been given in table 9.

CHARGE CHROME PRODUCTION

The charge chrome production was undertaken as a trial to establish the feasibility of using lumpy chrome ores available at Boula Mines as well as the chrome ore briquettes produced from concentrates obtained after beneficiation of low grade chrome ores. It could be established that briquettes upto 85% in the charge mix could successfully be utilised in the production of charge chrome.

While using the briquettes in the production of charge chrome, it was observed that there were improved permeability conditions in burden and resulted in smoother of operation of the furnace. The results obtained are presented in Table 10.

Based on the results of the smelting campaign in furnace No III a charge chrome plant with 50,000 tonnes per annum has been set up at Randia in Orissa.

CLEAN METAL SEPARATION BY IMPROVED CASTING SYSTEM

As improved casting system was introduced at FACOR in the production of high carbon ferro chrome. The previous practive was to tap metal and slag together into preheated refractory lined ladles and then cast the molten metal into chill moulds after decantation of the slag. This practice was resulting in more losses of metal due to skull formations in the ladle and in the decanted slag. Also a large proportion of metal with porus structure was obtained particularly in the metal with low silicon content.

This has been changed by tapping the metal and slag directly into suitably designed chill moulds such that the overflow from one mould will be received by the next one and the final slag flows into slag pots. Because of this practice, the slag almost free of metallic overflows and separates. After solidification this slag layer on top of metal can be easily removed and thus facilitates forcleaner and better metal separation. Also irrespective of silicon in the metal a dense and compact structure in metal is obtained.

This improved metal casting resulted in (a) an increase of about 5% metal recovery (b) avoided the usage of furnace oil for preheating of the refractory lined ladles (c) a dense metal structure (d) cleaner metal with less slag and non-metallic inclusions, and (e) reduced quantity of remelts which arose from ladle skulls and decanted slag from ladles. The system has posed more problems in crushing and sizing of metal particularly with lower chromium (60-62%) which is harder and denser and in thicker casts. However provision of suitable equipments would help to overcome this difficulty.

INDIA AN IMPORTANT SOURCE OF CHARGE CHROME TO WORLD MARKET

India has geared up to be an important source for charge chrome and ferro chrome to the world market. This situation has arisen recently due to the change in pattern of requirements in the world market for more charge chrome than high carbon ferro chromium and due to the recently increased proved chrome ore reserves in India. As already indicated the intensified exploration carried out by Geological Survey of India from 1977 has proved a much higher quantity of chrome ore reserves in Orissa. The change in technology of stainless steel production making it possible to use charge chrome with 50-55% chromium instead of high carbon ferro chrome with 65-70% chromium has permitted utilisation of lower Cr_2O_3 containing chrome ores with lower Cr/Fe ratio that is medium grade and low grade ores. The beneficiation processes need the simple gravity separation for the removal of gangue and improvement in Cr_2O_3 content without the task of improving chromium to iron ratio. Thus the vast low grade ores, fines, dumps, cotaining less than 20% Cr_2O_3 content, R O M Ore rejects etc. can be beneficiated to produce chrome ore concentrates and these can be agglomerated into briquettes or pellets.

This strategy has been pioneered by FACOR in India and has been implemented in their Works at Shreeramnagar and the newly established Charge Chrome facilities.

At FACOR about 30,000 tonnes high carbon ferro chrome and 10,000 tonnes of low carbon ferro chrome are produced at Shreeramnagar.

FACOR's charge chrome plant at Randia in Orissa has a production capacity of 50,000 tonnes per annum and this is totally earmarked for export. A second charge chrome plant is being set up by Orissa Mining Corporation at Bamnipal in Keonjhar district of Orissa with a capacity of 50,000 tonnes per annum. There is also another Letter of Intent granted to the Indian Metals & Ferro Alloys Ltd to set up a charge chrome plant in Orissa to produce

50,000 tonnes per annum. Thus the total availability of charge chrome will be 1,50,000 tonnes per annum for 1985-90. The production of high carbon ferro chrome will continue to be about 30,000 tonnes per annum. In India most of the alloy steel and stainless steel making is being done by conventional process in the electric arc furnace and they utilise low carbon ferro chrome. Recently one plant has installed facilities for VOD/VAD process, but their requirements of high carbon ferro chrome may be met by their own production. Another stainless steel plant expects to put VAD/VOD facilities by 1985-86. Hence the pattern of consumption in India is not expected to change widely till 1986. Some small producers have started VOD process application but their requirements are being met by high carbon ferro chrome presently produced. Hence estimated demand of high carbon ferro chrome and charge chrome for internal consumption would be about 30,000 tonnes per annum by 1985-86. Thus about 1,50,000 tonnes charge chrome is expected to be available for export. As India is already exporting high grade friable chrome ores and fines, these exports are likely to continue depending on internal requirements. The Government of India has permitted to establish three charge chrome plants for utilisation of the low grade chrome ores, which will benefit the consuming industries by way of freight and India can earn more foreign exchange The new charge chrome plants have got the full support of infrastructural facilities like rail and road transport, power availability and port facilities. In Andhra Pradesh the installed power generation capacity is planned to be increased to 4034 MW by 1984-85 and in Orissa State, it is being increased from the present 914 MW to 1474 MW by 1984-85. Also a new Super Thermal Project and several other Hydel Projects will be commissioned which will add nearly 3,000 MW during the seventh Five Year Plan. The export of charge chrome can be conveniently handled at the nearest Paradip Port. It has a deep draught of 11.89 metres and berthing facilities for bulk carriers upto 80,000 DWT. Being a developing State with vast mineral resources, the State Government of Orissa is providing all financial incentives for promotion of mineral based industries which raise the State economy. Thus India will be able to cater to the demand of charge chrome to a substantial extent for the stainless steel makers in Japan, Europe and USA.

India is advantageously placed geographically for quicker transport and deliver to the consuming centre especially Japan. The political stability as well as the policy of the Government is conducive to the export of charge chrome. Thus India has emerged as a dependable and regular source of supply.

C O N C L U S I O N

Once the resources of chrome ores in India was considered very meagre and the specification of chrome ores was also stringent for profitable exploitation in the production of ferro chrome alloys. The break-through in the technology in stainless steel making demanding more charge chrome and the increased reserves of chrome ores after reassessment has created impetus to optimally utilize all grades of chrome ores mined in India. FACOR pioneered the beneficiation of very low grade ores and waste dumps on industrial scale for obtaining concentrates and adopted briquetting technology for utilizing the same in the smelting of high carbon ferro chrome and charge chrome. The Indian Government has encouraged setting up charge chrome plants to export in the world market. India can be considered as a dependable supplier of chrome alloys.

R E F E R E N C E S

1. Chromite A Market Survey MS 4
   Indian Bureau of Mines, Nagpur, Dec.1977 pp 121.
2. "Monograph on Chromite" mineral, Facts and problem
   No.6 in series. Indian Bureau of Mines, Nagpur
   March 1982 pp 166-189
3. ibid pp 182
4. ibid pp 97
5. Mukherjee (S) Geology, Mineralogy and geochemistry
   of the chromite deposits of Nausahi, Keonjhar district,
   Orissa, Qtr. J.Coal Min.Metal. Soc.India No.1,
   Vol.34. 1962.
6. Monograph on chromite-Facts and problems No.6
   in series IBM Nagpur Mar. 1982 pp 189
7. ibid pp 208-210
8. ibid pp 383
9. ibid pp 185
10. Narasimham, G.A., Tibrewala G.R.Report on Gradewise
    Reserves of FACOR Boula Chromite Mines - Internal
    Report.
11. Report on the assessment of reserves of Boula and
    Kathpal Chromite mines by Nagpur commissioned by FACOR.
12. Subramanian M, Seetharamayya O, et al, Beneficiation
    of Low Grade Chrome Ores in Pilot Plant at FACOR.
    Various Internal Reports of M/s.Ferro Alloys
    Corporation Ltd., Shreeramnagar 1978, 1979, 1980
    unpublished.
13. Reddy, P.S.R.Rao R.B. et al.
    "Beneficiation of Chromite from Boula Mines"
    An Internal Report by Regional Research Laboratory,
    Bhubaneswar, India 1980 unpublished.
14. H.Tuovinen, Viitamen et al Preliminary study for
    processing of Indian Chromite ores for FACOR by
    OUTOKUMPU OY, Metallurgical Research Centre, Pori,
    Finland, May 5, 1978, unpublished.
15. Test Work on a Low Grade Chromite ore sample of
    M/s.Ferro Alloys Corporation Ltd., Shreeramnagar
    by Sala International, Sweden, Oct. 1979 unpublished.
16. Sen Gupta, S.K.Ranganathan, M.V. et al Beneficiation
    studies on chrome ore samples for M/s.Ferro Alloys
    Corporation Ltd., Shreeramnagar. Internal Report
    No.IR 1045/80 National Metallurgical Laboratory,
    Jamshedpur March 1980.
17. Harman C.N. & Subramanian M, Seetharamayya O., et al
    Agglomeration of chrome ore fines by briquetting and
    the performance of briquettes in the smelting of
    high carbon ferro chrome and charge chrome symposium
    volume International symposium on recent advances
    in Beneficiation and agglomeration of minerals organi-
    sed by IIM&RRL Bhubaneswar,Jan.1981,pages 3.20.1-3.2017
18. Comparison of various agglomeration process.Internal
    Report of Ferro Alloys Corpn.Ltd.,S/Nagar '79unpublishd

TABLE : 1

DISTRICT-WISE AND GRADE-WISE RESERVES OF CHROMITE IN INDIA

DISTRICT	GRADE	RESERVES IN '000 TONNES			TOTAL
		Proved	Probable	Possible	
ANDHRA PRADESH					
Krishna	Medium	120.00	-	2,000.0	2,120.0
BIHAR					
Singhbhum	Low	-	-	47.7	47.7
	Unclassified	-	-	88.7	88.7
KARNATKA					
*Hassan	Low	-	1,200.0	-	1,200.0
	Unclassified	-	700.0	-	700.0
MAHARASTRA					
Bhandara	Unclassified	-	-	685.0	685.0
Ratnagiri	Low	-	-	61.2	61.2
MANIPUR					
Tengnoupal	High	-	0.9	-	0.9
****ORISSA**					
Cuttack	High	2,209.3	3,135.4	657.0	6,001.7
	Medium	231.7	115.8	119.0	466.5
	Low	1,449.6	804.1	455.8	2,709.5
	Unclassifed	2,124.2	1,519.2	554.1	4,197.5
Keonjhar	High	234.4	312.1	347.7	894.2
	Medium	23.6	-	-	23.6
	Low	-	276.3	254.1	530.4
	Unclassified	-	22.2	616.9	639.1
TAMILNADU					
Salem	Unclassified	-	9.8	202.0	211.8
		6,392.8	8,095.8	6,089.2	20,577.8
**Additional reserves of Cuttack & Keonjhar districts.					98,700.0
TOTAL RESERVES					119,277.8

TABLE : 2

RESERVE FIGURES OF FIVE BLOCKS IN SUKINDA-NAUSAHI BELT.

(In million tonnes)

Name of the block	Grade	Drill proved	Proya-ble	Possi-ble	Total
1. Bhimtanagar block.	Met.gd.	8.87	14.78	20.79	44.44
	Ch.Cr.gd	7.63	11.06	9.87	28.56
	Inf.gd.	2.81	3.61	2.53	8.95
	Total	19.31	29.45	33.19	81.95
2. Saruabil & Kamardah blocks.	Met.gd.	1.65	0.81	3.29	5.75
	Ch.Cr.gd.	0.24	0.13	0.25	0.62
	Inf.gd.	--	--	--	--
	Total	1.89	0.94	3.54	6.37
3. Sukerangi block.	Met.gd.	0.07	0.70	0.99	1.76
	Ch.Cr.gd.	0.39	0.90	1.11	2.40
	Inf.gd.	0.39	0.53	0.66	1.58
	Total	0.85	2.13	2.76	5.74
4. Kaliapani & retrenched blocks of Bhimta-nagar i.e. South Kaliapani	Met.gd.	2.48	5.23	2.16	9.87
	Ch.Cr.gd.	0.92	2.15	1.27	4.35
	Inf.gd.	0.44	0.82	0.64	1.90
	Total	3.84	8.20	4.07	16.11
5. Nausahi/ Boula block	Met.gd.	-	-	-	0.15
	Ch.Cr.gd.	-	-	-	0.43
	Inf.gd.	-	-	-	1.86
	Total	-	-	-	2.44
Grand Total of 5 Blocks.		25.89	40.72	43.56	112.61

TABLE : 4

TEST RESULTS AT FACOR ON BENEFICIATION OF VARIOUS CHROME ORES

S. No.	YEAR	ORE	FEED					CONCENTRATE					RECOVERY	
			Dry wt in Tons	Cr_2O_3	FeO	SiO_2	Cr/Fe	Dry wt in Tons	Cr_2O_3	FeO	SiO_2	Cr/Fe	Wt.	Cr_2O_3
1.	1978	Kathpal Chips	1899	52.76	13.74	7.21	3.38	1666	57.71	14.20	4.35	3.57	87.74	95.98
2.	1979	-do-	327	52.96	15.09	7.94	3.09	2275	57.78	14.37	3.69	3.54	84.07	91.69
3.	1980	-do-	628	52.96	14.73	7.14	3.16	529	58.01	15.80	3.40	3.23	84.30	92.34
4.	1981	-do-	1594	51.09	12.93	8.40	3.51	1312	55.34	14.37	4.29	3.39	82.30	89.08
5.	1978	Boula chips	301	52.44	15.27	6.60	3.02	262	56.88	14.37	3.69	3.48	87.05	94.42
6.	1980	Tisco chips	75	46.37	12.93	12.40	3.15	49	58.02	15.80	2.92	3.23	64.68	80.93
7.	1978	Undersize Rejects	884	49.37	14.39	9.58	3.02	676	56.61	14.85	4.18	3.35	76.47	87.69
8.	1979	-do-	1130	41.30	12.93	15.27	2.81	790	55.37	15.11	4.71	3.22	69.86	93.65
9.	1980	-do-	2663	39.78	14.01	13.86	2.50	1676	54.44	15.57	5.01	3.08	62.93	86.11
10.	1981	-do-	879	40.03	12.19	13.97	2.89	564	52.09	15.52	5.39	2.95	64.20	83.54
11.	1980	Kondapalli	97	38.26	19.40	16.60	0.74	61	47.89	17.97	6.40	2.34	62.75	78.54
12.	1981	-do-	614	38.26	15.80	17.34	2.13	431	47.89	17.97	6.40	2.34	70.23	87.90
13.	1978	Boula dump	219	13.51	15.56	40.70	0.76	30	48.89	24.59	4.60	1.78	13.52	48.83
14.	1980	-do-	169	25.18	14.10	34.50	1.57	44	52.96	21.55	4.70	2.16	25.80	54.26
15.	1981	-do-	131	29.13	17.23	17.23	1.49	59	50.93	16.53	6.68	2.71	45.01	78.69
16.	1981	Lowgrade dump lot-1	67	30.15	25.14	11.62	1.05	26	54.48	16.80	5.30	2.85	39.67	71.68
17.	1981	-do lot-2	78	31.16	21.46	12.00	1.28	31	53.46	17.34	4.84	2.71	39.77	68.23
18.	1982	Boula dump rejects	629	8.61	12.22	39.00	0.61	77	47.13	20.58	8.10	2.01	12.16	66.56
19.	1982	Gangapit	100	23.32	32.33	19.20	0.60	45	39.53	36.65	7.00	0.95	45.10	76.45

NOTE: CATAGORIES CLASSIFIED AS UNDER :
Sl.No.1 to 6 : I, Sl.No.7 to 10 : II, Sl.No.11 to 19 : III.

TABLE:9 CHROME ORES, BRIQUETTES, FLUXES

	Chemical analysis in percent							Screen analysis in percent				
	Cr_2O_3	FeO	SiO_2	MgO	Al_2O_3	CaO	Cr/Fe	-75mm +50mm	+25mm	+12mm	+6mm	-6mm
Boula chrome ore	49.6	14.8	10.3	14.5	10.5	0.7	2.95	65	31	2.0	1.0	1.0
Boula low grade	36.1	15.1	20.1	11.0	13.0	1.0	2.10	55	30	10.0	3.0	2.0
Kathpal chrome ore	45.3	12.85	9.0	15.0	11.0	0.7	3.10	55	26	8.0	8.0	3.0
TISCO chrome ore	40.5	18.00	9.5	12.0	14.0	1.0	1.98	18.0	50	15.0	7.0	10.0
OMC Fines	56.2	14.4	5.0	13.5	10.0	0.6	3.43	-	59.0	16.0	8.0	17.0
Chrome ore briquettes	43.8	15.80	4.5	12.06	9.0	5.5	2.44	24.0	86.0	25.0	4.0	11.0
FLUXES:												
Quartz	-	0.3	98.0	0.20	0.50	0.3	-	8.0	70.0	18.0	4.0	-
Magnesite	-	1.0	6.0	45.0	-	2.0	-	12.0	65.0	19.0	4.0	-

CARBONACEOUS REDUCTANTS

	FC	VM	Ash	P	S	Fe_2O_3	SiO_2	CaO	MgO	Al_2O_3	TiO_2	+50mm	+25mm	+12mm	+6mm	-6mm
Giridih																
Coke	70.0	1.5	23.0	0.04	0.3	1.4	16.1	0.8	0.2	3.7	0.3	2.0	60.0	20.0	8.0	10.0
Semi-Anth. coal	68.0	9.0	23.0	0.01	0.4	1.5	13.7	0.3	0.1	7.0	n.d.	-	15.0	20.0	70.0	5.0
LTC coke	56.0	14.0	30.0	0.01	0.6	1.7	19.0	5.5	2.1	4.5	1.5	-	30.0	40.0	22.0	8.0
Noncoking coal	45.0	35.0	20.0	0.03	0.7	2.2	18.1	0.7	0.4	7.6	0.4	8.0	30.0	24.0	20.0	18.0
Lignite carbonized coke	72.0	18.0	10.0	0.01	1.5	0.7	2.1	2.7	0.6	1.7	0.1	-	33.0	44.0	11.0	12.0

TABLE : 10

OPERATION DATA FOR PRODUCTION OF HIGH CARBON FERRO CHROME AND CHARGE CHROME

PARTICULARS	UNIT	FURNACES						
		No.III			No.IV			No.VI
PRODUCT		H.C. FeCr	Charge Chrome		Highcarbon Ferrochrome			Highcarbon FeCr
CAMPAIGN		1	2	3	4	5	6	7
Period	Days	92	6	6	30	15	59	91
Briquettes	%	nil	33.33	66.66	nil	28	-	6.6
Production	T	2873	197	186	937	566	3261	4449
Per ton of alloy								
Kathpal lump	kg	535	-	-	869	1094	53	20
Boula lumps	kg	1398	1533	747	1326	551	1137	1182
Tisco lumps	kg	344	-	-	-	-	1199	1105
Briquettes	kg	-	680	1323	-	641	-	171
OMC Ore	kg	-	-	-	-	-	-	110
Total	kg	2277	2213	2070	2195	2286	2389	2588
Magnesite	kg	46	-	-	15	2	12	22
Quartz	kg	78.3	-	32	124	95	153	113
Giridih coke	kg	115	464	419	521	431	232	233
TalcherCoal	kg	488	272	263	295	398	300	198
Leco Briquettes	kg	142	-	54	-	-	98	78
Semi-anthracite coal	kg	188	-	-	-	-	182	288
Power consumption (10-150mm)	KWH	4345	3880	3893	4495	4373	4060	4156
Cr recovery	%	88.06	91.74	92.65	85.26	90.38	84.60	79.0
Slag (calculated)	kg	870	1041	1054	909	901	1150	976
Analysis of Metal	%							
Cr		65.90	56.46	55.52	69.10	68.08	61.87	62.10
Si		2.70	3.15	3.60	2.50	4.20	3.40	4.50
C		6.45	7.47	7.38	6.80	6.70	6.65	6.80
P		0.028	0.038	0.038	0.038	0.036	0.03	0.037
S		0.037	0.013	0.012	0.04	0.038	0.037	0.038
Analysis of slag	%							
MgO		32.0	29.78	30.41	32.00	33.48	24.40	27.50
Al_2O_3		23.0	24.44	22.15	24.50	25.01	26.57	25.90
SiO_2		33.4	31.94	33.50	34.70	33.20	35.25	32.70
Cr_2O_3		6.40	6.67	5.79	5.00	5.00	8.55	8.90
CaO		2.80	4.31	6.00	1.70	1.16	2.33	2.34
FeO		2.40	2.28	2.15	2.00	2.15	2.22	2.56

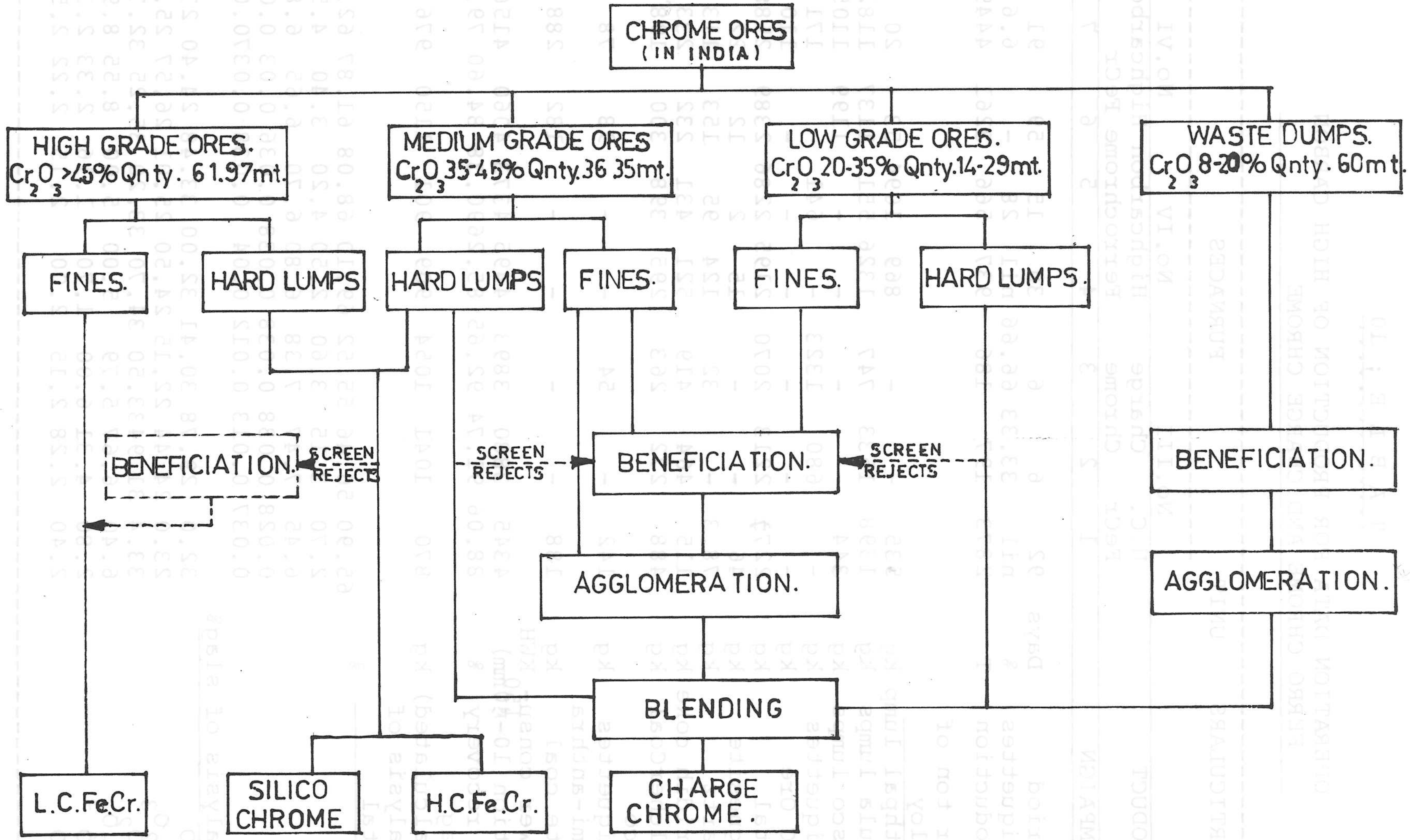

Fig. 1. Types of chrome ores & A strategy for optional utilization.

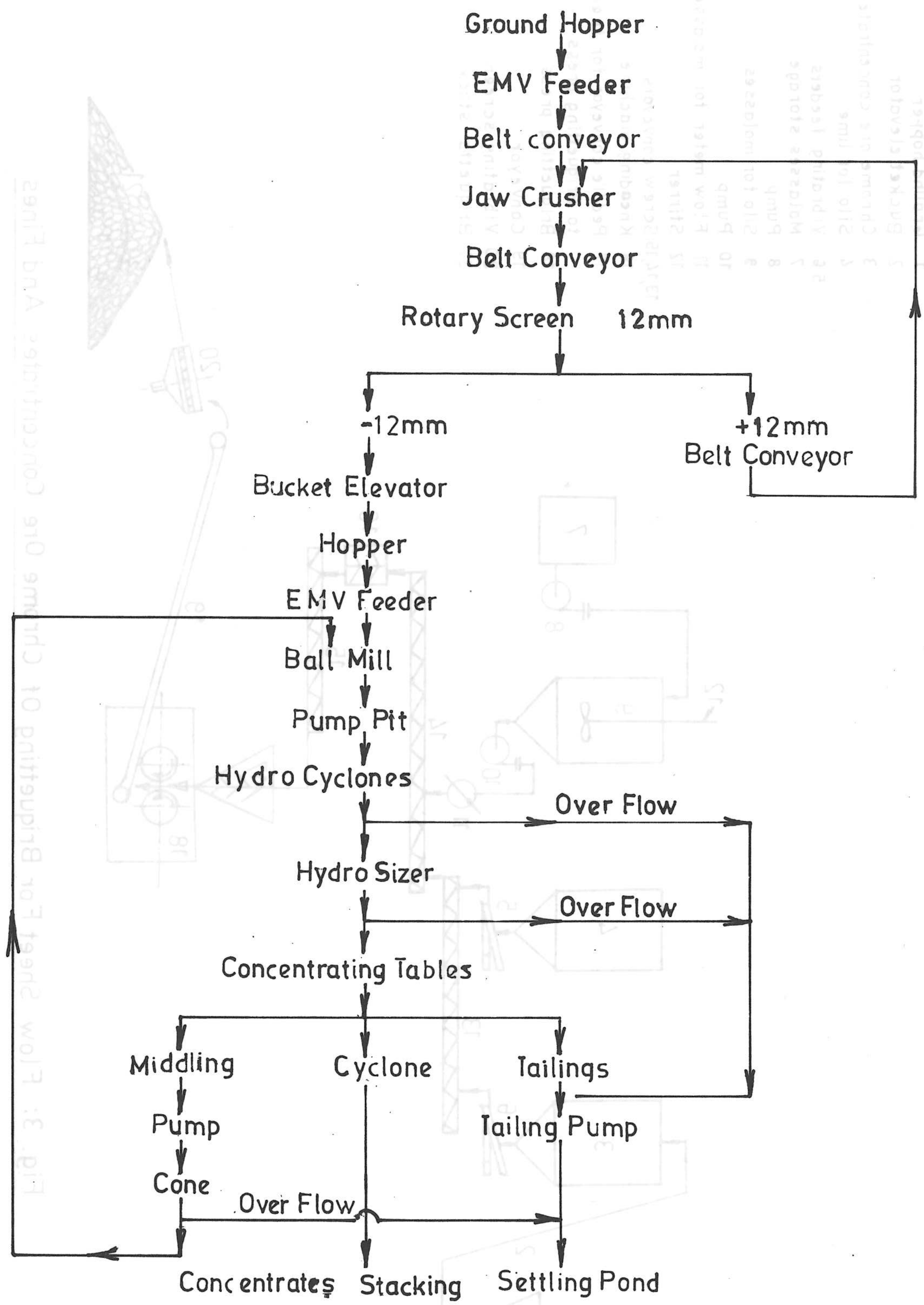

Fig. 2: Flow Sheet For Chrome Ore Beneficiation

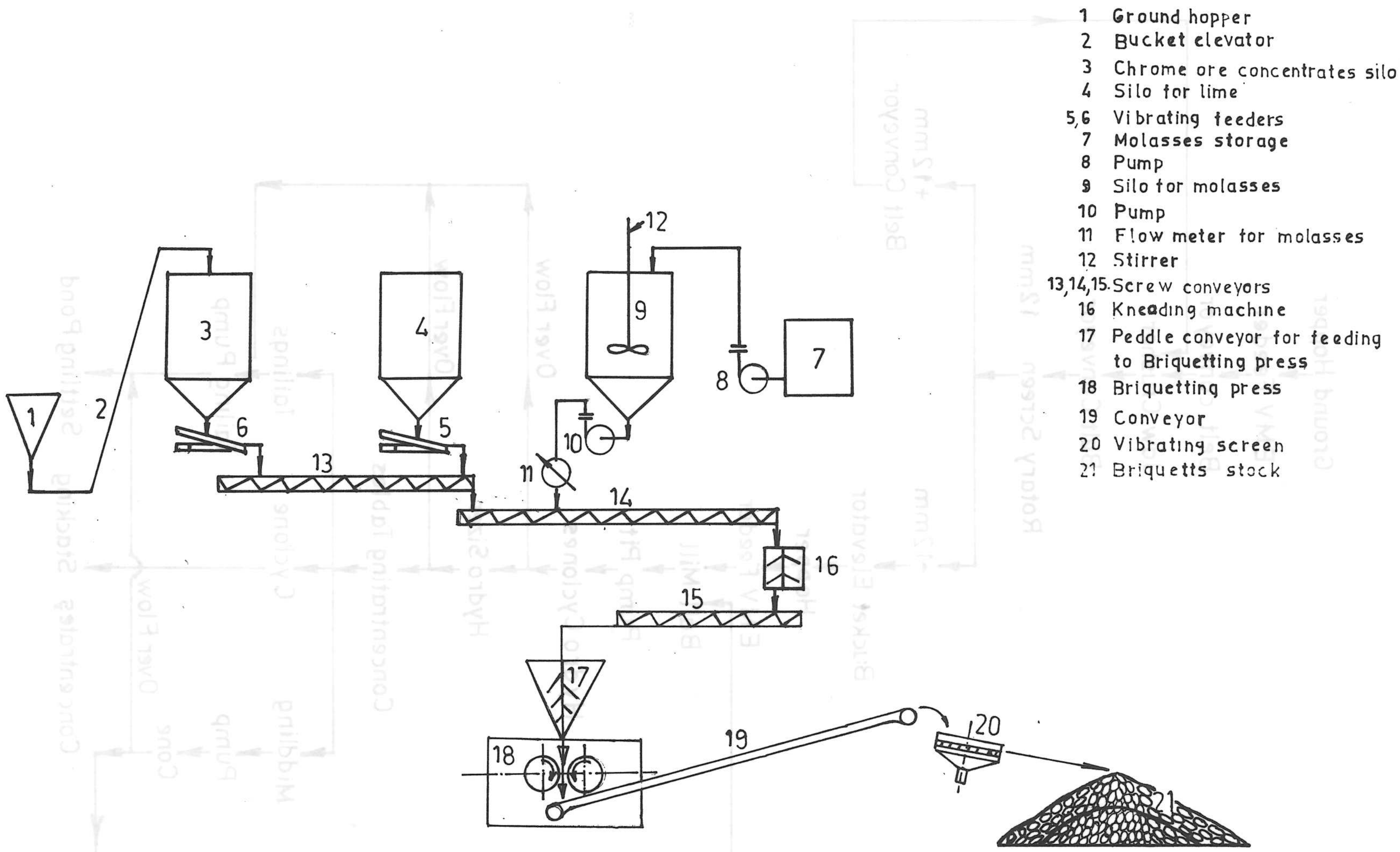

Fig. 3: Flow Sheet For Briquetting Of Chrome Ore Concentrates And Fines

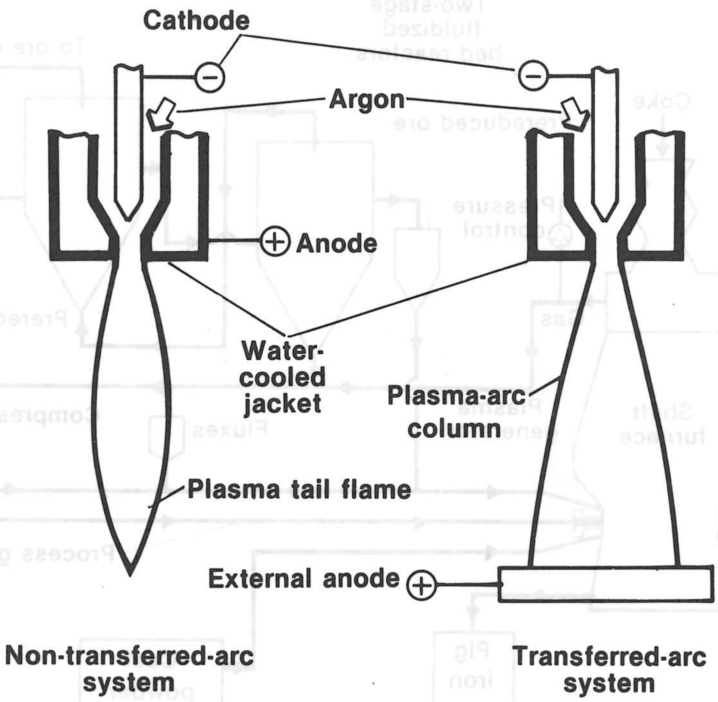

FIG. 1. Two plasma systems

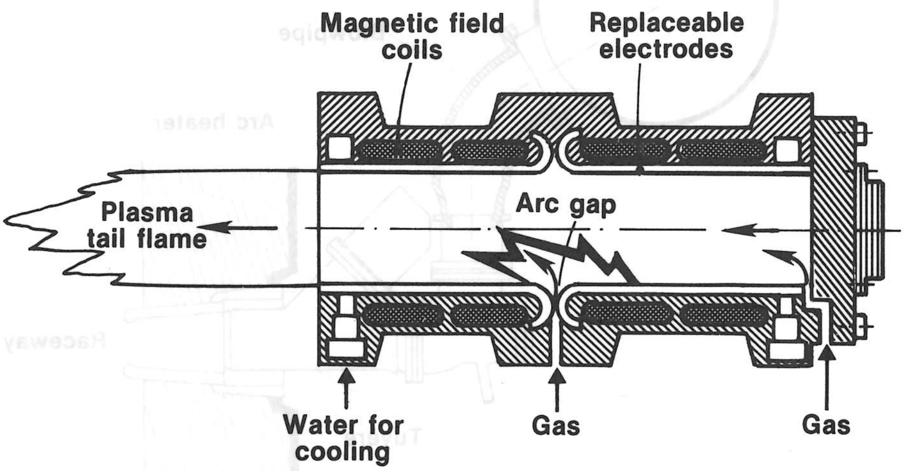

FIG. 2. A non-transferred-arc heater (after Fey and Melilli[3])

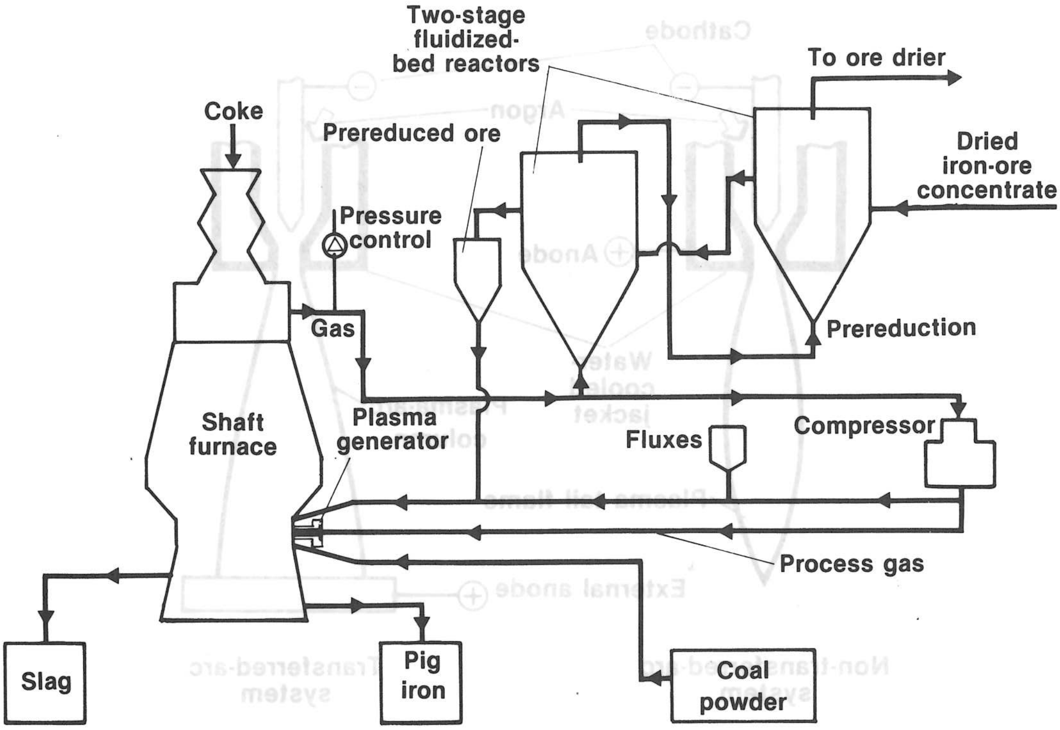

FIG. 3. The SKF PLASMASMELT process (after Santén[4])

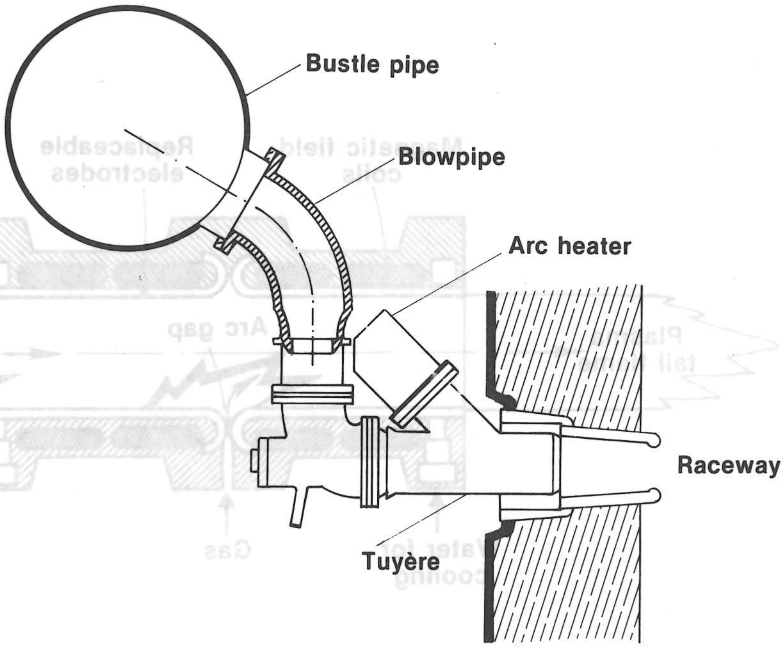

FIG. 4. Modified blowpipe and tuyère for attachment of an arc heater to a blast furnace (after Poos[18])

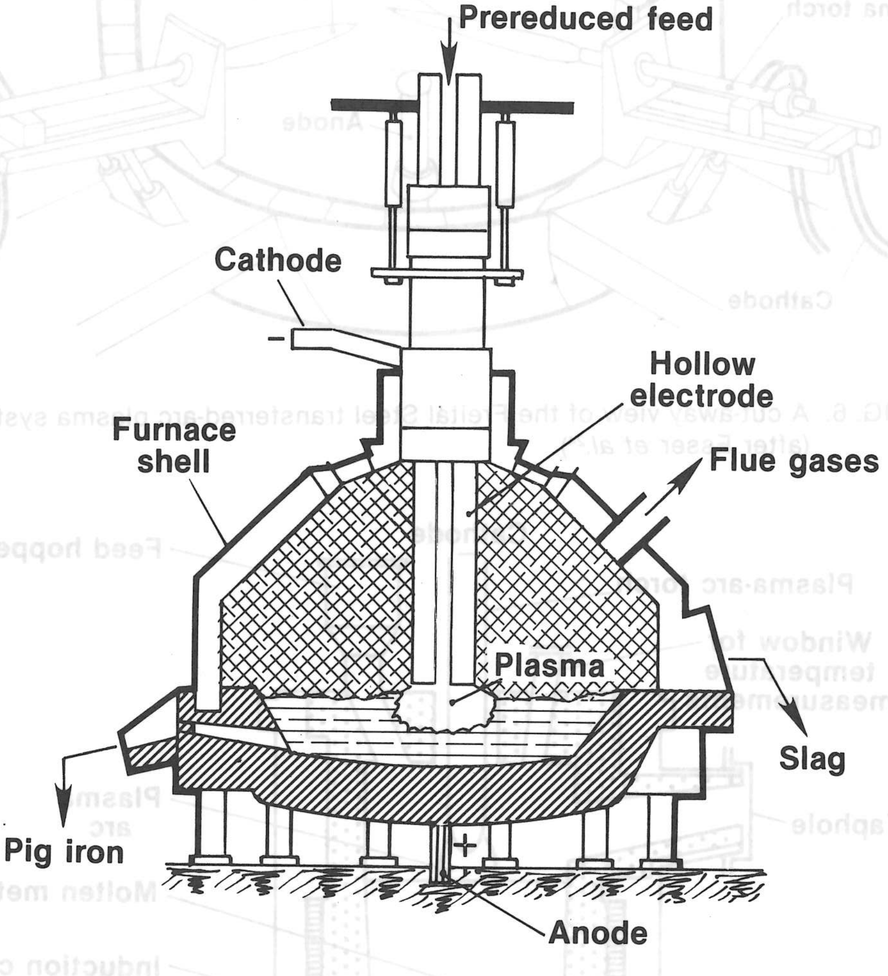

FIG. 5. The Elred smelting furnace (after Bengstsson and Widel[5])

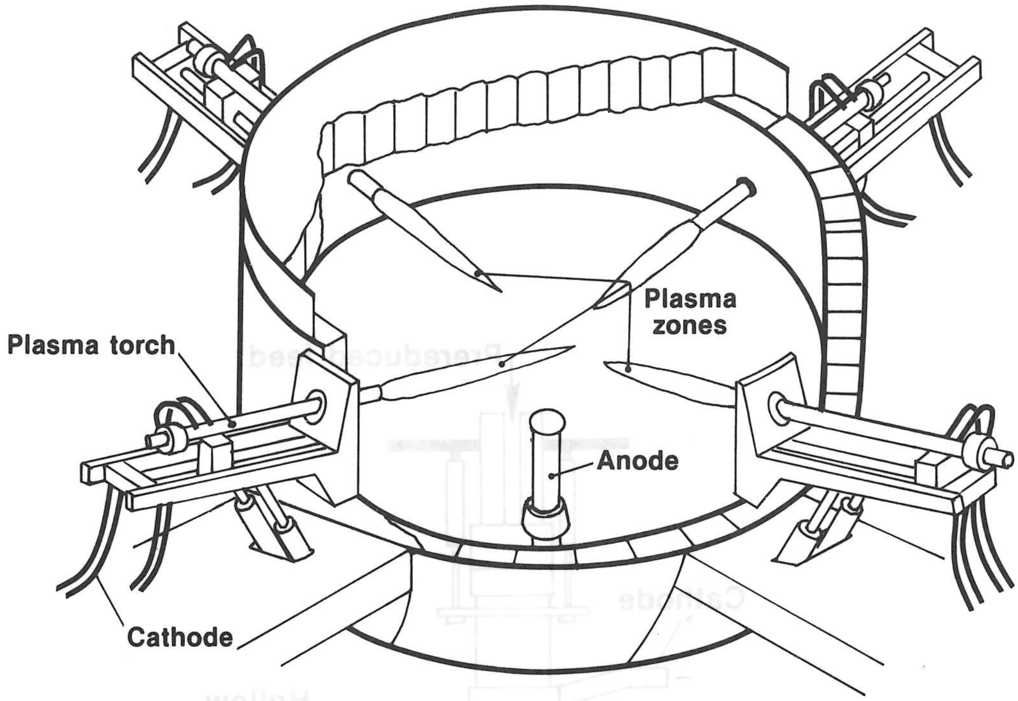

FIG. 6. A cut-away view of the Freital Steel transferred-arc plasma system (after Esser *et al.*[24])

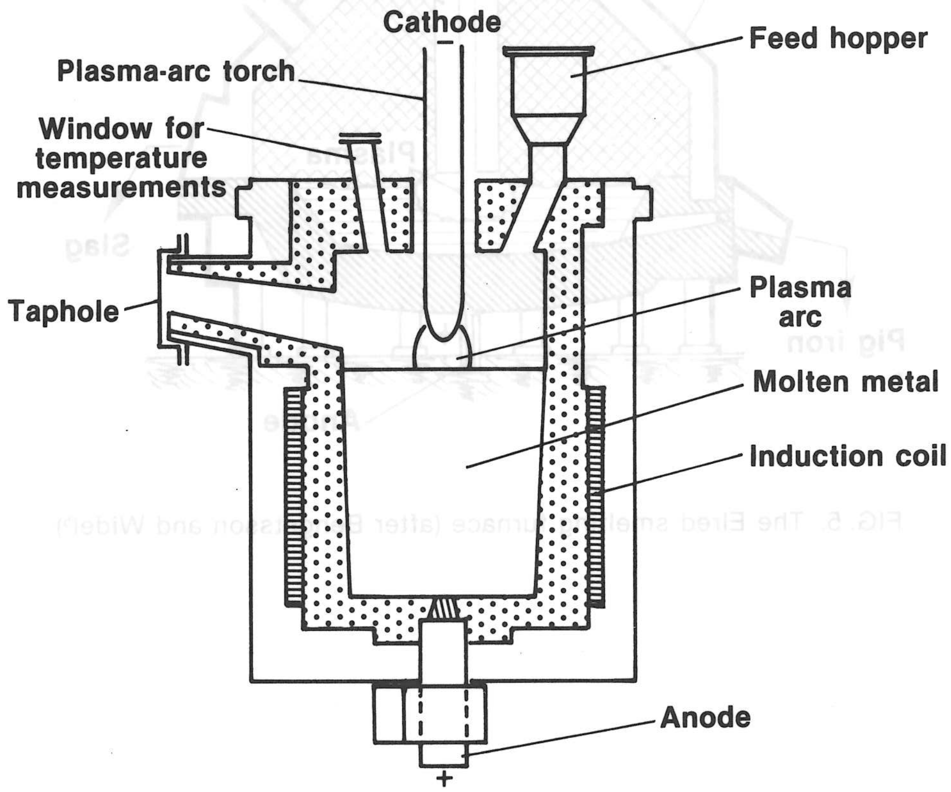

FIG. 7. A transferred-arc plasma furnace combined with an induction-heating furnace (after Asada and Adachi[25])

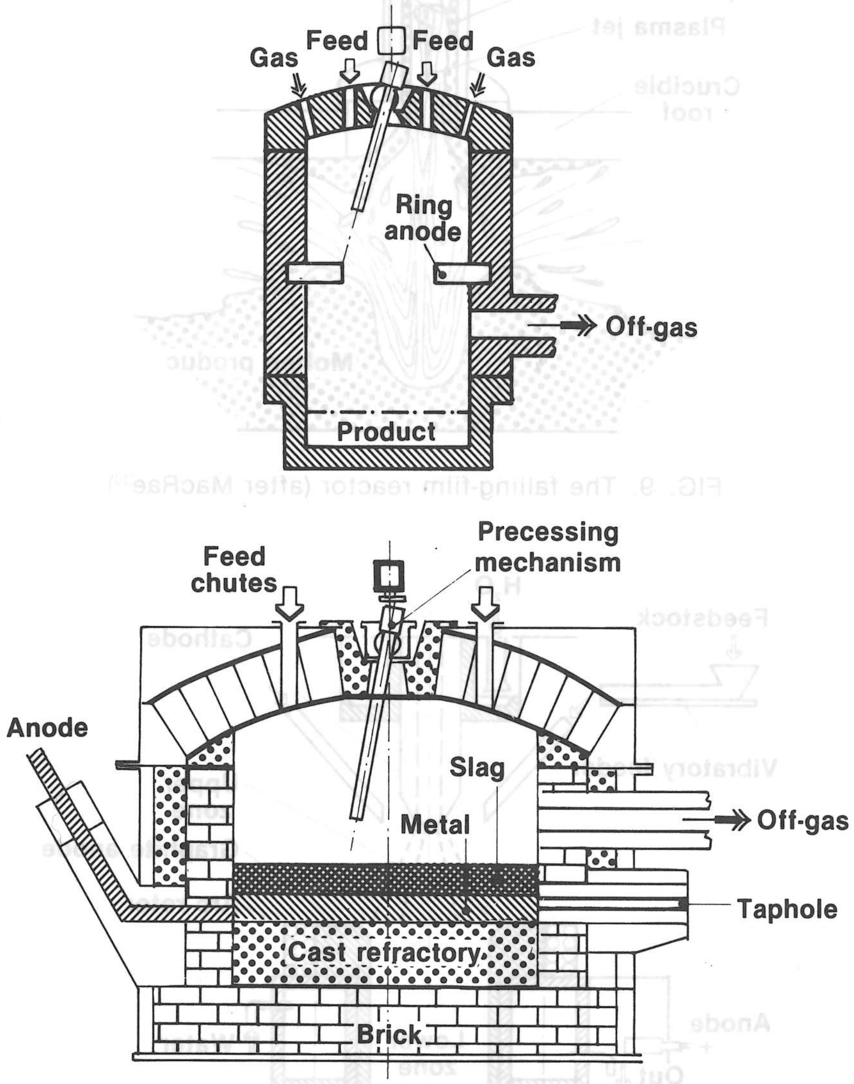

FIG. 8. The Tetronics Research and Development 'in-flight' and transferred-arc systems (after Tylko[27] and Page[28])

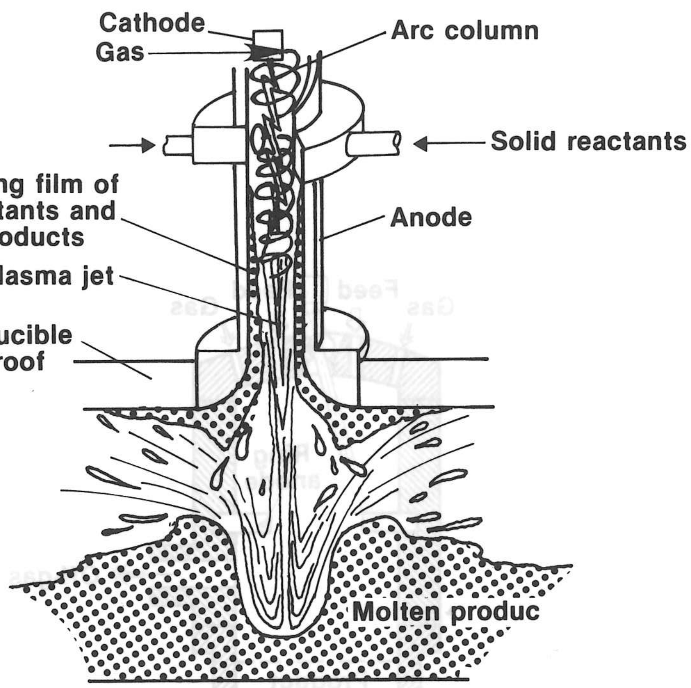

FIG. 9. The falling-film reactor (after MacRae[30])

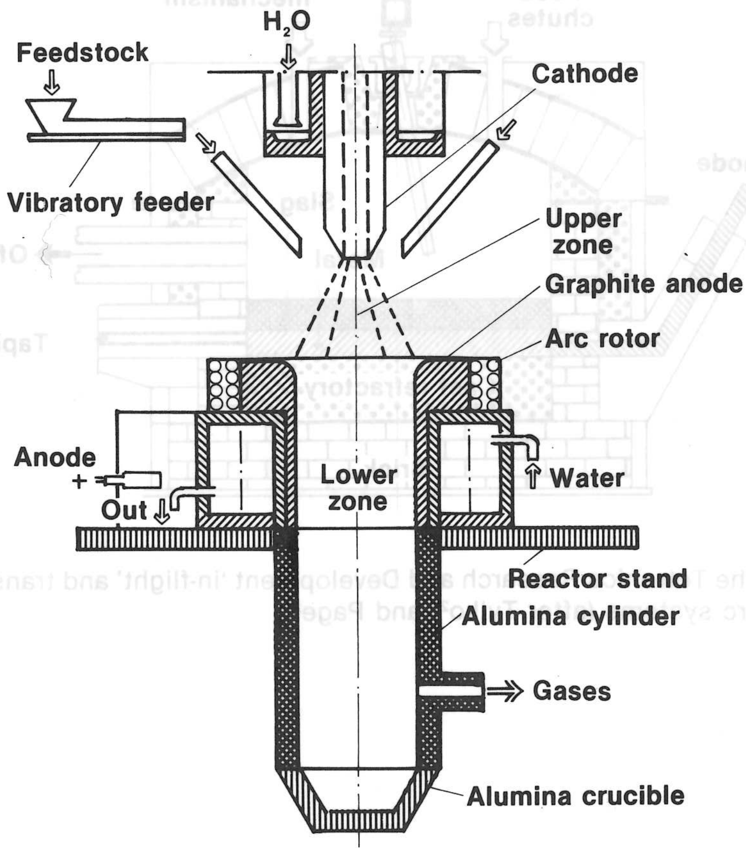

FIG. 10. The shock-wave plasma reactor (after Tylko *et al.*[33])