

# Production of FeNi from high iron nickel ores

ERIK SVÄNÅ\*  
ROALD YSTEB

## Abstract

*The paper deals with the operation of FeNi-Furnaces when smelting high grade FeNi from ores containing more than 20% Iron oxide.*

*Principles of operation have been discussed and compared to the operation of furnaces producing low grade FeNi in the well known non-selective smelting process.*

## FeNi-SMELTING

The Rotary Kiln — Electrical Furnace (RKEF) Process for the production of ferronickel was developed in the pilot plant of Elkem's R & D Center in 1953-54. The process was first applied commercially to the treatment of garnieritic ores in New Caledonia, and has later been adopted by Ferronickel producers in several countries. Through continued smelting tests over the last 25 years, various types of nickel ores have been investigated with improved techniques for raw material preparation, preheating and prereluction. Experience has been gathered, and satisfactory process operation has been demonstrated for production of ferronickel with Ni-contents up to 50 percent.

A list of Elkem furnaces in commercial operation for the smelting of nickel ores in New Caledonia, Japan, Brazil, Indonesia, Guatamala and Columbia is presented in table — 1.

In the operation of the first RKEF plants coarse ( — 100 mm ) garnieritic ores of relatively high grade ( % Ni > 2,5% ) were fed directly to the rotary kiln. The ores were preheated and calcined in the kiln before transferred to the

smelting furnace. The reductants, coarse crushed low volatile coals ( —30 mm ), were added to the smelting furnace where all the reduction of iron and nickel oxides took place. The furnace operation was fairly smooth, but slag boil did occur mainly due to incomplete calcination of the ore in the rotary kiln<sup>1</sup>.

As time went by and the process was adopted in more plants, more experience with different ores and reductants was obtained both in commercial and pilot plant operation. Several improvements in the RKEF process concept were introduced. Principally these included higher preheating temperatures and a more complete calcination, high volatile coals and partial reduction in the kiln, treatment of small sized ores and fines prior to the kiln and different smelting techniques to suit the different ore types and product specifications<sup>2,3</sup>.

Based on the experience from commercial operation and pilot plant tests the RKEF process may today be adapted to virtually any known ore and product specification. Ferro Nickel grades from 12 to 50 percent Nickel and discharge slags up to 75% FeO content are feasible.

The future trends within the RKEF process

\*ELKEM A/S Engineering Division, Norway.

Table — 1. LIST OF ELKEM FURNACES IN COMMERCIAL OPERATION

Product	MVA	Type	Start-up	Company name	Country
Ferronickel	04.8	C/S	1962	Morro do Niquel S. A.	Brazil
Ferronickel	07.5	C/S	1965	Pacific Metals Co. Ltd.	Japan
Ferronickel	12.0	C/S	1968	Pacific Metals Co. Ltd.	Japan
Ferronickel	13.5	C/S	1958	S. A. Le Nickel	New Caledonia
Ferronickel	13.5	C/S	1959	S. A. Le Nickel	New Caledonia
Ferronickel	13.5	C/S	1959	S. A. Le Nickel	New Caledonia
Ferronickel	13.5	C/S	1960	S. A. Le Nickel	New Caledonia
Ferronickel	13.5	C/S	1963	S. A. Le Nickel	New Caledonia
Ferronickel	13.5	C/S	1966	S. A. Le Nickel	New Caledonia
Ferronickel	13.5	C/S	1969	Morro do Niquel S. A.	Brazil
Ferronickel	13.5	C/S	1969	S. A. Le Nickel	New Caledonia
Ferronickel	13.5	C/S	1969	S. A. Le Nickel	New Caledonia
Ferronickel	14.0	C/S	1968	Sumitomo Metal Mining Co.	Japan
Ferronickel	14.0	C/S	1969	Sumitomo Metal Mining Co.	Japan
Ferronickel	15.0	C/S	1970	Nihon Kogyo K. K.	Japan
Ferronickel	16.0	C/S	1970	Showa Denko K. K.	Japan
Ferronickel	17.0	C/S	1983	Emp. de Desenvolve. de Rec. Minerals 'Codemin'	Brazil
Ferronickel	17.0	C/S	1982	Emp. de Desenvolv. de Rec. Minerals 'Codemin'	Brazil
Ferronickel	18.0	C/S	1967	Pacific Metals Co. Ltd.	Japan
Ferronickel	20.0	C/S	1976	P. T. Aneka Tambang	Indonesia
Ferronickel	25.0	C/S	1969	Pacific Metals Co. Ltd.	Japan
Ferronickel	25.0	C/S	1971	Sumitomo Metal Mining Co.	Japan
Ferronickel	25.0	C/S	1973	Sumitomo Metal Mining Co.	Japan
Ferronickel	30.0	C/S	1971	Nihon Kogyo K. K.	Japan
Ferronickel	40.0	C/S	1970	Pacific Metals Co. Ltd.	Japan
Ferronickel	45.0	C/S	1979	P. T. Int. Nickel Indonesia	Indonesia
Ferronickel	45.0	C/S	1980	P. T. Int. Nickel Indonesia	Indonesia
Ferronickel	45.0	C/S	1983/84	Kombinat Kosovo	Yugoslavia
Ferronickel	45.0	C/S	1984	Kombinat Kosovo	Yugoslavia
Ferronickel	51.0	C/S	1982	Cerro Matoso S. A.	Colombia
Ferronickel	60.0	C/S	3)	Pacific Metals Co. Ltd.	Japan

line will be a continuous development of the metallurgical aspects of the process to suit an ever wider range of ores, and to reduce the energy and operation costs.

### NICKEL ORES

The Ni-ores are mainly composed of FeO, MgO and SiO<sub>2</sub> with small amount of Ni, 1—3%, and varying, but generally small amounts of Al<sub>2</sub>O<sub>3</sub>, 2 — 4%. The three-phase diagram of FeO — MgO — SiO<sub>2</sub> in figure 1 is therefore considered to be of great interest.

The most common type of nickel ore, in sense of distribution and size of the deposits, is the oxide-silicate. The oxide form, usually called laterite or limonite overlies the silicate form, garnierite or serpentine, which extends down to contact the unaltered rock. The laterite is characterized by a high iron content, and relatively low nickel content, which seldom exceeds about 1.5%. The serpentine which is also commonly known as a laterite, contains less iron and more magnesia, The garnierite ores are relatively low in iron and with a Ni content varying from 1.6 to as high as 3.5%

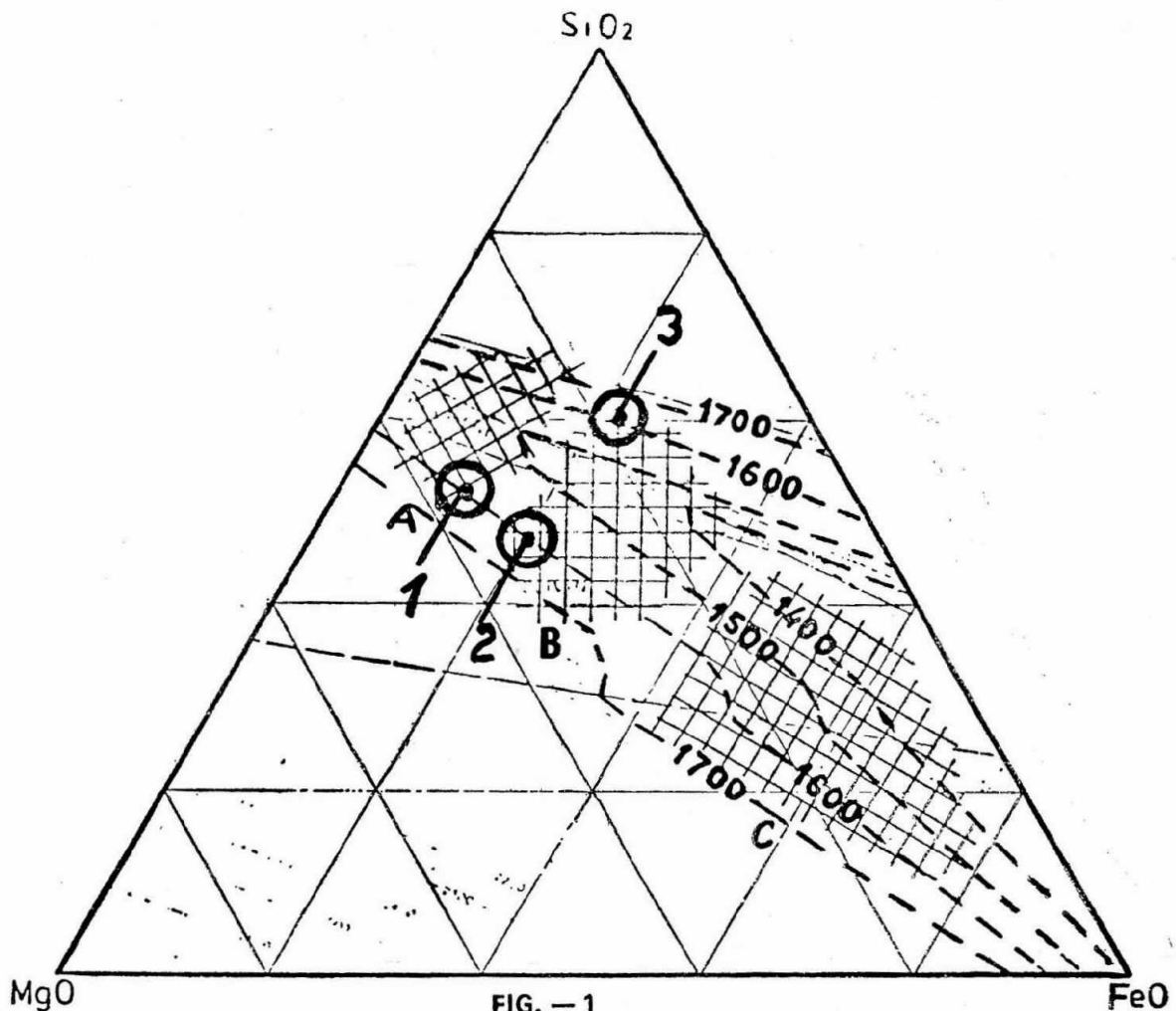


FIG. - 1  
Area for different types of Nickel ores.

- A : Garnierite ores
- B : Serpentine ores
- C : Laterite ores

The garnierite ores tend to be harder and coarser-grained than the laterites, but are also relatively easily mined by open pit methods. In figure 1 we have very roughly crosshatched the areas for the different types of ore.

In the same figure we have marked with circles the types of ores for which the smelting techniques will be specially discussed in this paper. Circle No. 1 indicate a low iron garnierite ore and circles No. 2 and 3 high iron garnierite ores. The major difference between the high iron ores are the silicon content.

## PRODUCTS

In the smelting operation the aim is to reduce the maximum NiO to metal.

With sufficient carbon present, both nickel and iron oxides tend to be reduced to metal at rates proportional to their relative concentrations

and selectivity is impossible. With a surplus of carbon in the charge combined with high temperature, the reduction of silicon will increase whereas the carbon content of the metal remains fairly constant. This describes the typical operation on low iron ores. With ores containing more iron, the Ni-grade will decrease in such an operation. To maintain a commercial grade FeNi in high iron ores, a certain degree of selectivity in the reduction is therefore required through decreased addition of carbon resulting in a higher Ni-grade and a low content of carbon in the metal. The silicon content may vary with the temperature and the composition of the slag as the Si-reduction is basically a function of temperature, heat concentration and acidity.

In table 2 analysis of metal and slag produced from the mentioned three different types of ores, are given. The product analysis are all from industrial size FeNi smelting furnaces.

Table — 2 ANALYSIS OF METAL AND SLAG

### 1. LOW IRON, LOW SILICA ORE.

METAL		SLAG	
Ni —	20 - 25%	Mgo	~ 37%
Si —	2 - 5%	SiO <sub>2</sub>	~ 53%
C —	2%	FeO	— 4 - 7%
S —	0.15 - 0.20%	Ni	— 0.05 - 0.12%
		MgO/SiO <sub>2</sub>	0.65 - 0.75

### 2. HIGH IRON, LOW SILICA ORE.

METAL		SLAG	
Ni —	45 - 50%	MgO	~ 35%
Si —	—	SiO <sub>2</sub>	~ 45%
C ~	0.050%	FeO	~ 15%
S ~	0.20%	Ni	~ 0.20%
		MgO/SiO <sub>2</sub>	0.75 — 0.85

### 3. HIGH IRON, HIGH SILICA ORE.

METAL		SLAG	
Ni —	40 - 45%	MgO	~ 19%
Si —	1.5 - 2.0%	SiO <sub>2</sub>	~ 60%
C ~	0.2%	FeO	~ 16%
S ~	0.4%	Ni	~ 0.20%
		MgO/SiO <sub>2</sub>	0.25 - 0.35

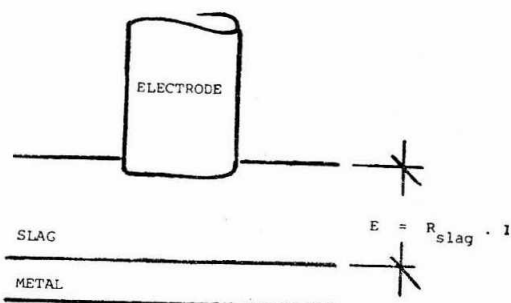
An increased Ni-grade will tend to increase the Ni-losses to the slag, but as can be seen from the analysis, even with metal grades of 40-50% Ni the Ni-recovery is good. The Ni-yield from the smelting furnace is varying between 92 to 96% depending on the ore grade.

## PRINCIPLES OF OPERATION

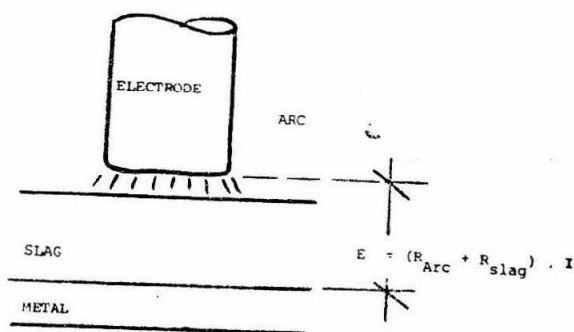
### General information :

A FeNi smelting furnace may principally be operated with the electrodes dipped into the slag or with the electrodes above the slag, (figure 2)

FIG - 2



CASE NO. 1



CASE NO. 2

In CASE 1, the electrodes have a good contact with the slag and the resistance may be considered as pure ohmic :

$$E = R_{\text{slag}} \cdot I \quad (R_{\text{arc}} = 0)$$

In the CASE 2 the current will go through the arc and into the slag :

$$E = (R_{\text{slag}} + R_{\text{arc}}) \cdot I$$

The total R of the furnace is calculated as  $R = \frac{P}{3I^2}$  where P is the load in KW and I is the electrode current in KA.

The two quite different methods of operation may occur at the same voltage and the same amperage because the resistance of the slag may vary considerably both in connection with a change in chemical composition or/and temperature,

The slag resistance may actually decrease by as much as 50 - 100 % as the temperature is raised by 100°C.

In a "standard" FeNi operation based on a low iron garnieritic ore, the two cases and of course all "in-between" cases may occur without problems as NiO and FeO is "completely" reduced and additional carbon will reduce SiO<sub>2</sub> which is a very slow reaction. The slag is saturated with carbon and there will be practically no chemical reaction between slag-oxides and the electrodes.

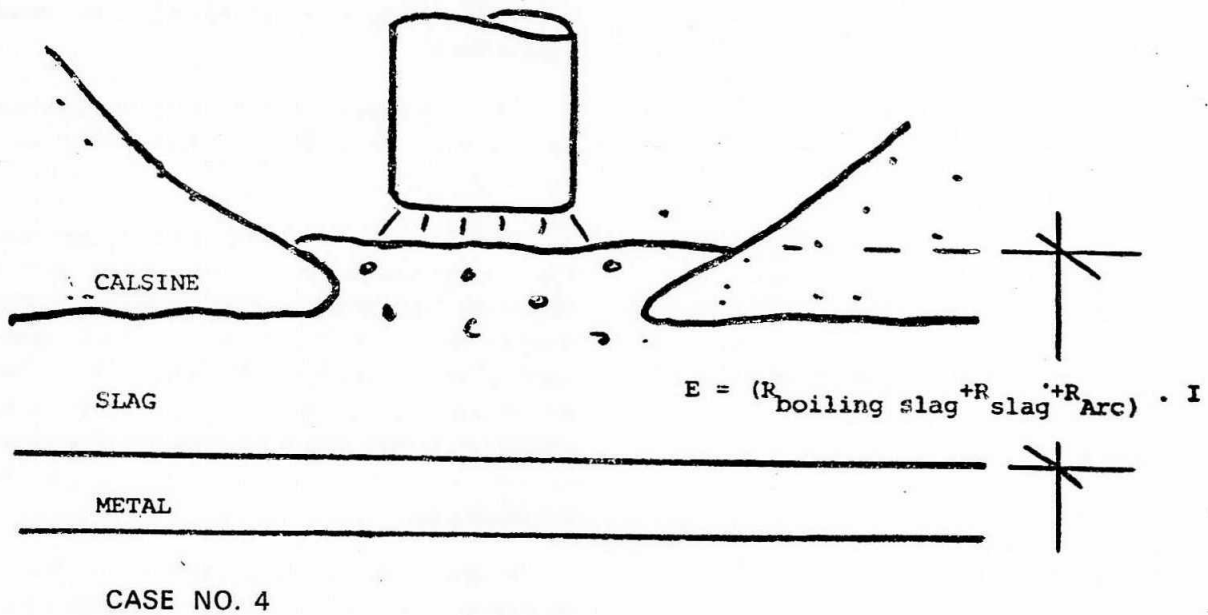
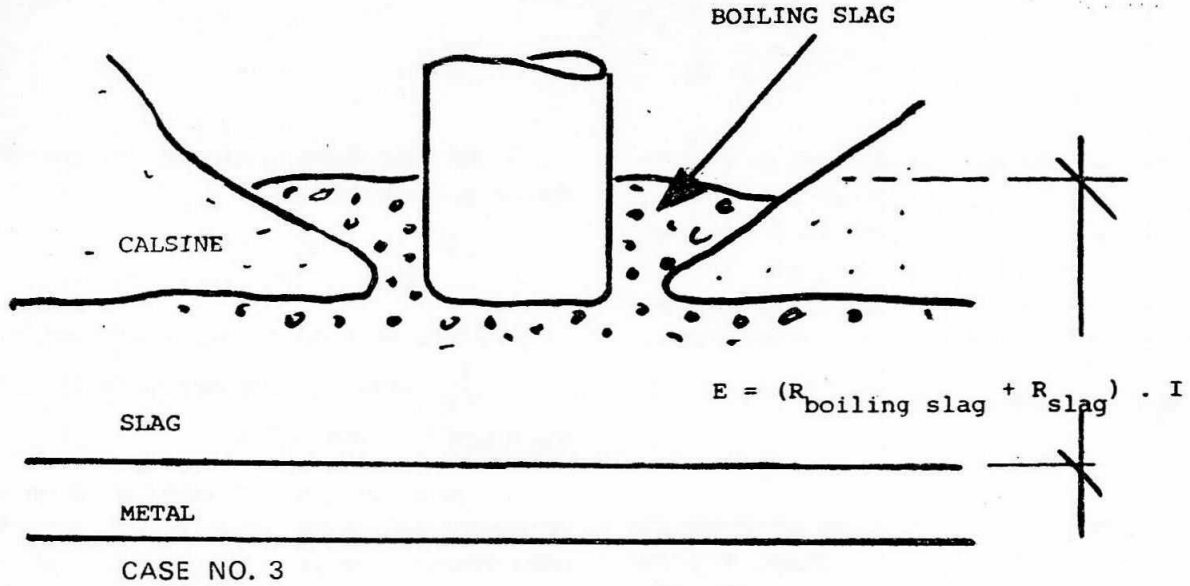
If the metal becomes too cold, Case 1 operation may be preferred until the metal temperature allows for an operation more like Case 2. The voltage may then be increased for maximum smelting efficiency.

### High FeO—slag operation.

In a high FeO-slag operation where we operate with a high degree of reduction of NiO and a partial reduction of FeO, we have the special problem with the Case 1 operation that the electrode reacts with surplus FeO in the slag resulting in additional gas formation in the slag.

The slag at a certain temperature and a certain viscosity is able to "release" a certain amount of reaction gases. If the amount of

FIG. - 3



gases in the slag for some reason exceeds this limit, the slag will start to foam or boil. Surplus gas is a result of surplus carbon in the calcine, high amount of combined water, reaction with the electrodes or a combination of these factors. The boiling will mainly occur around the electrodes. Such a situation may become more or less stable with a limited amount of boiling, but may also result in slag being "pushed" up and flow away from the electrodes and form a slag bath or a slag crust

on the top of the calcine.

If the furnace is operated with a choke feed such "boil-ups" of slag is rather bad as the crusts may form bridges followed by eruptions as bridges are "falling down".

A "boiling" operation may look somewhat like indicated as Case 3 in figure 3.

$$E = (R_{\text{boiling slag}} + R_{\text{slag}}) \cdot I \quad (R_{\text{Arc}} = 0)$$

The resistance in a boiling slag is relatively high and if the operation continues on the same voltage and the same current, this Case 3 situation may just continue for days with the obvious dis-advantages of an unstable furnace, high heat evolution and heat losses from the boiling slag, reduced smelting efficiency and an undesirable heat distribution in the furnace.

A relatively quick solution of such a situation is to lift up the electrodes to the top of the boiling slag and increase the voltage in order to create an arc as indicated as Case No. 4 in figure 3.

$$E = (R_{\text{boiling slag}} + R_{\text{slag}} + R_{\text{Arc}}) \cdot I$$

The arc will heat up the slag from the top and the gas in the slag will be released. The warm and gasfree slag will sink back into the furnace. The electrodes will follow and as  $R_{\text{boiling slag}}$  is reduced to zero, the voltage may be reduced to normal operating voltage.

#### Operating parameters for a high FeO-slag

The voltage drop in a normal arc operation will then be :

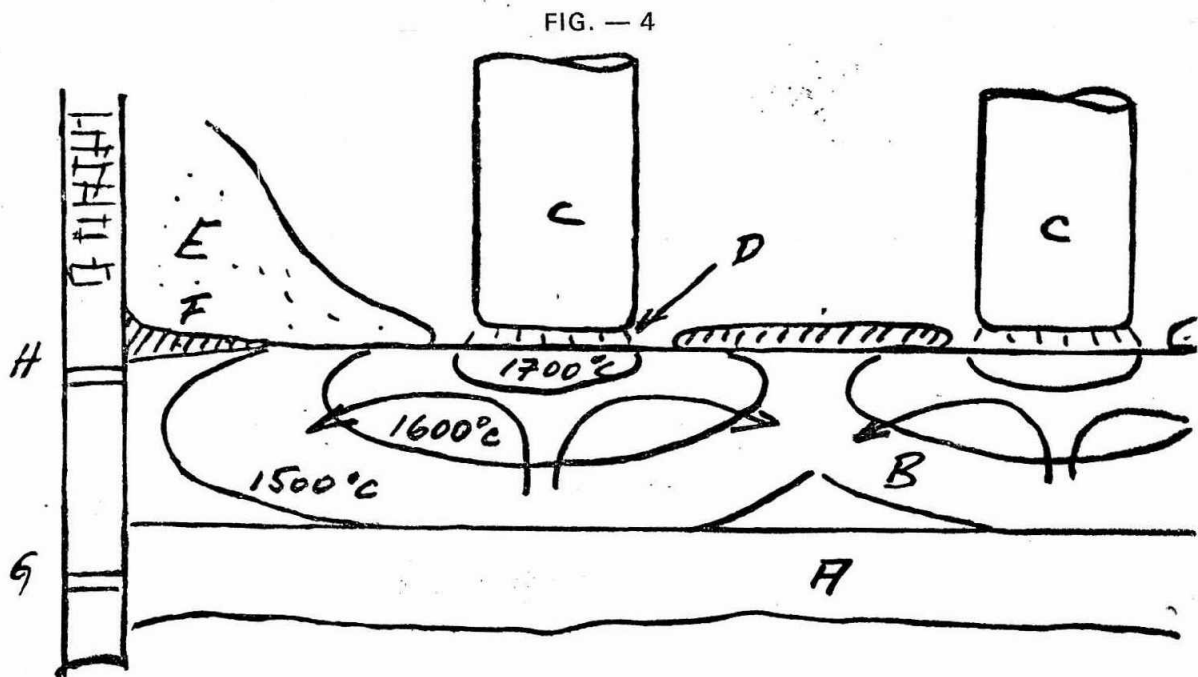
$$E = (R_{\text{slag}} + R_{\text{Arc}}) \cdot I$$

where  $R_{\text{slag}} = f(\text{temperature, composition})$

and  $R_{\text{arc}} = f(\text{atmosphere, temperature, electrodes, charge pressure etc.})$

In an arc operation we prefer a minimum distance between the electrode and the slag bath surface as the only reason for an arc operation is to avoid contact between the electrode and the high FeO slag.

In fig 4 we have indicated the isothermes which should be expected in the slag. This isothermes are effected by the energy concentration around the arc and the dynamic forces of the pinch effect. The pinch effect is



EXPECTED ISOTHERMES IN THE SLAG

A — METAL BATH  
B — SLAG BATH  
C — ELECTRODES  
D — ELECTRIC ARC

E — CALCINE  
F — CRUST FROM SLAG/CALCINE  
G — METAL TAPHOLE  
H — SLAG TAPHOLE

due to a concentration of parallel conductors which are conducting the current in the same direction. When the conductor is liquid slag, the slag will be moved towards the tip of the electrode and the resulting overpressure will push the slag towards the surface and radially away from the electrode. This force is tional to the electrode current.

In fig. 4 the arrows in the slag bath indicate movement of the slag due to the pinch effect. The sketch should also indicate that we prefer a maximum of heat in the slag and a minimum of heat losses to the air from the open arc. The overheated slag underneath the electrode should be moved efficiently towards the calcine where the surplus heat is used for melting. As long as sufficient amounts of calcine is available the surplus heat of the slag will be consumed. The slag reaching the lining should be close to the liquidus temperature and relatively harmless to the lining as such a slag is easy to freeze.

The conclusion of the above considerations is that we want to operate with a minimum of total furnace resistance, but always maintaining an arc.

In fig. 5 we have indicated the operating resistance for the three different types of ores. Ores no. 2 and 3 require an arc operation.

As can be seen, the ores indicated in circles 1 and 2 in fig. 1 are being smelted at practically the same furnace resistance which means that the combined slag and arc resistance for the high iron, low silica slag corresponds to the slag resistance of the low iron, low silica slag.

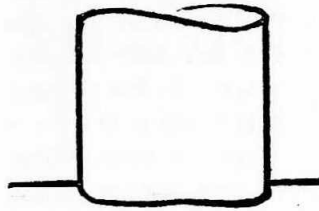
#### CONTROL OF OPERATION

For large furnaces it is not advisable to look into the furnace from the roof while operating, because of the high voltage operation.

These furnaces are also too large to inspect from the periphery of the roof as may be done in smaller furnaces.

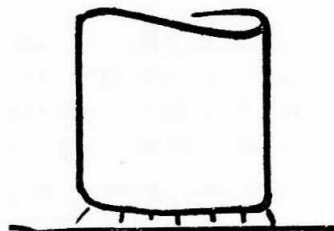
FIG. — 5 OPERATING RESISTANCE FOR THREE TYPES OF ORE

#### LOW IRON, LOW SILICA ORE



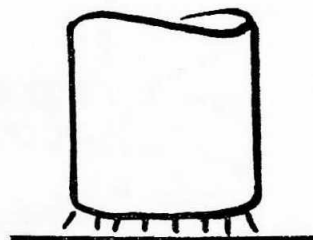
$$R_{\text{total}} = R_{\text{slag}} = 7 - 9 \text{ m}\Omega$$

#### HIGH IRON, LOW SILICA ORE



$$R_{\text{total}} = R_{\text{slag}} + R_{\text{Arc}} = 8 - 10 \text{ m}\Omega$$

#### HIGH IRON, HIGH SILICA ORE



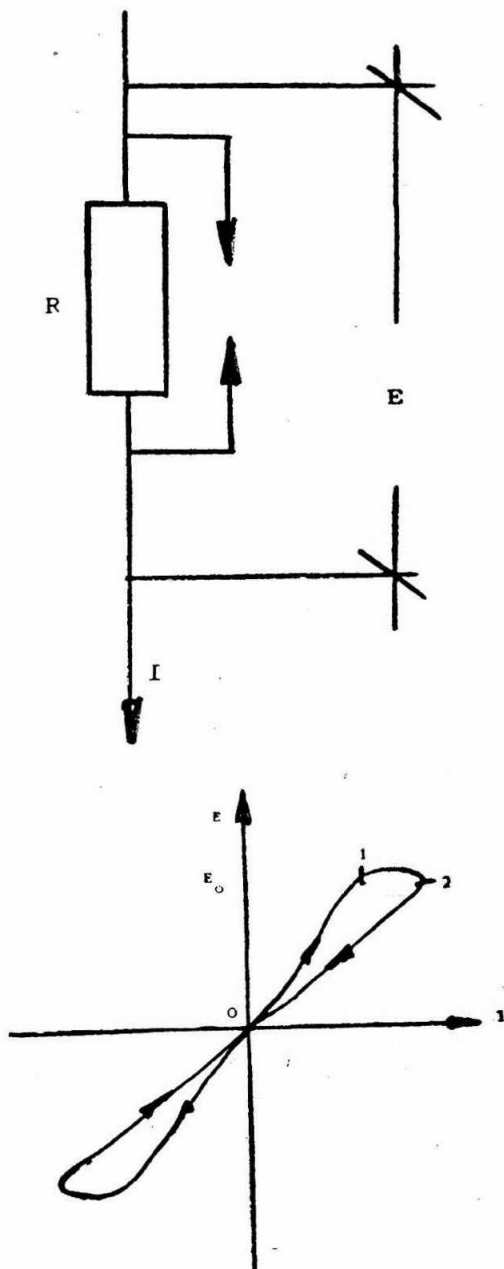
$$R_{\text{total}} = R_{\text{slag}} + R_{\text{Arc}} = 12 - 18 \text{ m}\Omega$$



As the possibility of visual control during operation is lost, we must look for other methods of information. We are specially interested, as have been previously explained, to know if we have an arc operation or a pure ohmic resistance operation.

We are also looking for tendencies i.e. if the furnace on arc operation have a tendency to

FIG. — 6 LISSAJOU CURVE — PRINCIPLES



change over to ohmic operation or vice versa at constant electrical operating parameters.

For this purpose we are using a type of equipment where it is possible to read the electrode voltage as a function of the electrode current on an oscilloscope where the lissajou-curve is formed.

This method will be explained here in principle.

In fig. 6 R represents the ohmic resistance in the furnace and the two arrows represents the arc. If we follow the curve from 0 to 1 in the diagram the current will go through the resistance R and the voltage will follow the formula  $E = R \cdot I$ .

At point 1 the arcing starts and the voltage remain fairly constant until the current has reached a maximum at point 2. Close to 0 the arc will extinguish and the curve repeats itself in the next half period.

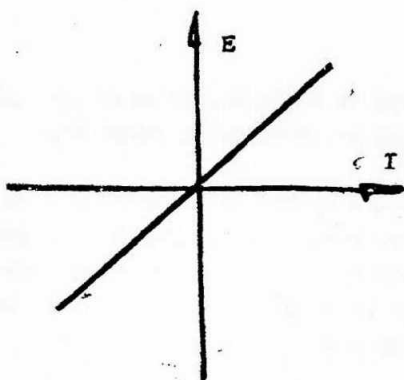
If we have no arcing and purely ohmic resistance, the curve will be a straight line.

In fig. 7 we have made several types of lissajou-curves resulting from different operating conditions.

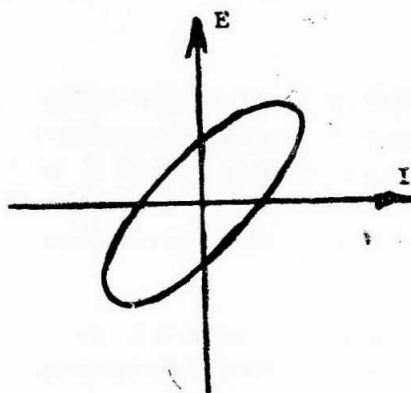
There are also other indications on the type of operation such as :

- If the furnace is being operated on arc with open bath around the electrodes or the electrode tips just being covered by charge, the arcing sound is quite clear.
- With an open bath arc operation the smoke from the smoke stacks seems more voluminous and dirty brown.
- When the furnace is checked inside during shutdown there will be none or only very small crusts around the electrodes and the legs of the electrodes will be quite clean if it has been an arc operation.

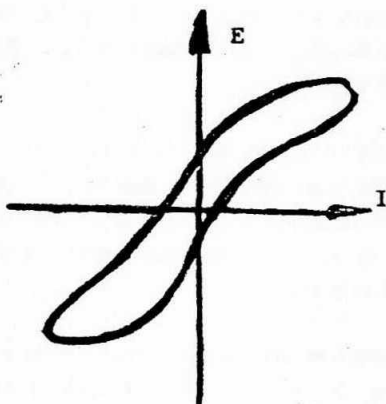
FIG.— 7 LISSAJOU CURVES



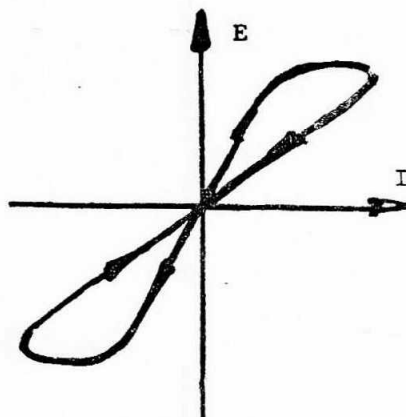
NO ARCING  
NO INDUCTIVITY  
RELATIVELY HIGH POWER FACTOR  
PURE RESISTANCE



NO ARCING  
INDUCTIVE AND RESISTANCE LOAD  
RELATIVELY LOW POWER FACTOR



ARCING  
NO INDUCTIVITY  
RELATIVELY HIGH POWER FACTOR  
ONLY RESISTIVE LOAD



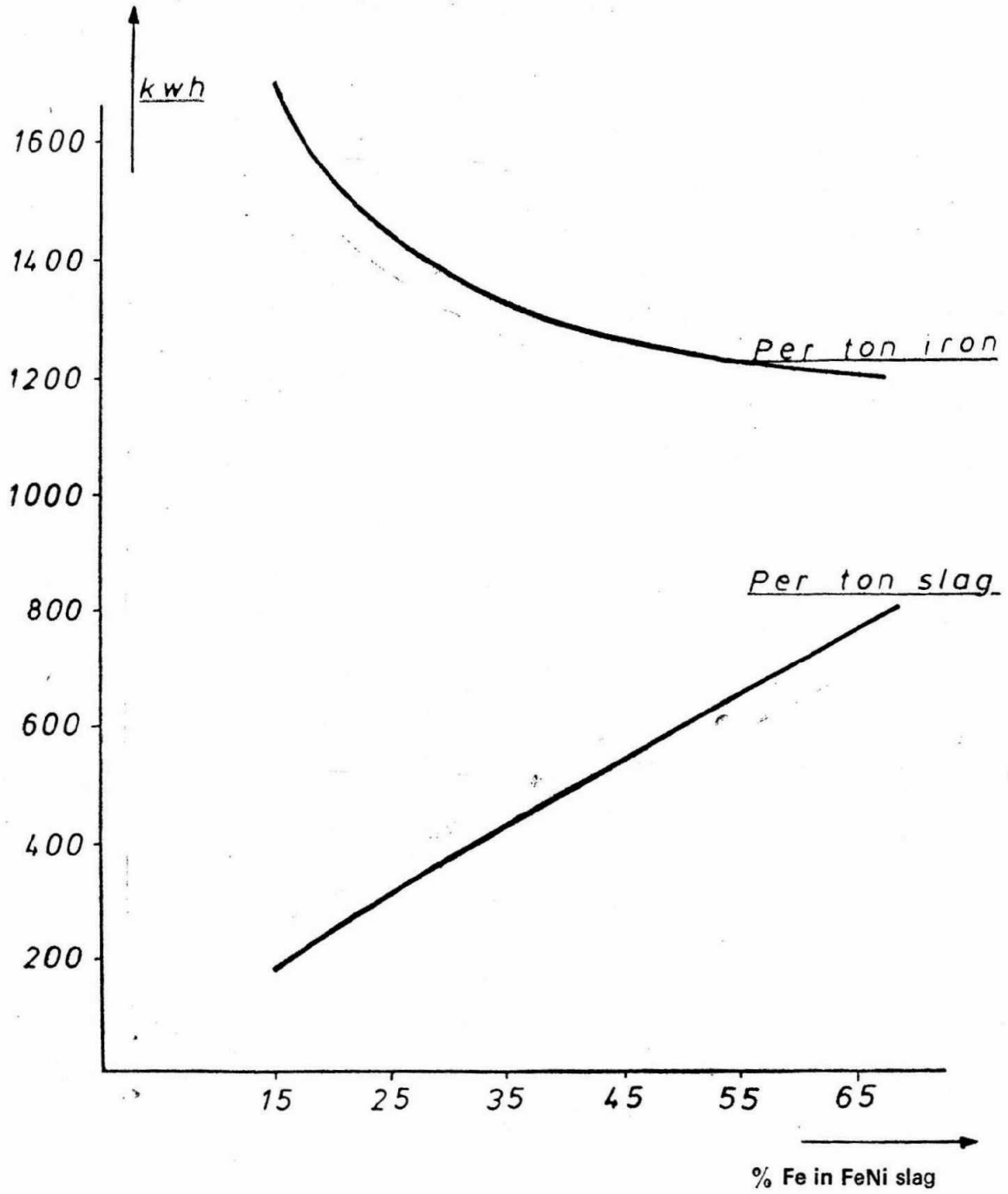
ARCING  
INDUCTIVE AND RESISTIVE LOAD  
RELATIVELY LOW POWER FACTOR

- When we have a pure ohmic operation with the electrodes dipped into the slag no arcing sound can be heard and the smoke from the stacks seems to be rather limited and the gas is burning with a pure, "bluish" flame.
- If it has been slag boiling and the furnace is checked inside it is normally possible to see quite a lot of crust formation. Some times the crust seems to be covered by calcine which may have been sliding towards the electrodes after the furnace have

been switched off. This makes the observation at times uncertain on this point.

- Another more clear indication of slagging connected to an "ohmic" operation is slag sticking on the legs of the electrodes.
- When the electrodes are dipped into the slag in an "ohmic" operation and the FeO in the slag reacts with the electrodes, the surplus gas in the slag will also move with the slag away from the electrodes towards the lining and during slag tapping the gas

FIG. — 8



Electric energy consumption per ton of slag and per ton of iron.

tries to get out and the furnace seems like it is belching. After a period of such operation it becomes increasingly difficult to tap slag.

## 6. OPEN ARC - OPEN BATH OPERATION

The two different types of high iron ores which so far have been discussed may be smelted in an open arc operation which have so far been the case in industrial size furnaces, or in a submerged arc operation which was the case during test smelting where the calcine contained a relatively limited amount of fines. When other types of high iron nickel ores are smelted the produced slag may have liquidus temperature very close to the liquidus temperature of the produced metal. Addition of fluxes to increase the liquidus temperature of the slag may be possible from a metallurgical point of view, but generally not economically due to a relatively high amount needed and consequently a reduced nickel yield.

The other alternative is to control and increase the temperature of the slag by decreasing the feed rate of the calcine, thus maintaining some of the superheat from the electrode area in the slag bath.

A superheated slag rich in iron will be extremely aggressive towards a traditional lining, which within a relatively short period may dissolve into the slag. To avoid this possibility, lining materials of high thermal conductivity must be used in the slag area. Enforced cooling will ensure a self lining of frozen slag on the inside as protection against the aggressive slag. Such linings are presently under evaluation and testing at our pilot plant in Norway. A relatively large open bath and at the same time arc operation will also result in a more heavy strain on the furnace cover. High gas temperature, radiation stresses and possible attack from melted dust makes it necessary to improve the design and high quality refractory materials will be required.

## IRON PRODUCTION FROM THE FERRO NICKEL SLAG

A slag rich in iron tapped from the ferro nickel furnace may in some cases be a very interesting basis for iron production, and at the same time provide combustible fuel to the calcining and prereducing unit in the ferronickel process line. Tests have proved that coal can be used as reductant and that the iron oxide content may be reduced to approximately five percent in the slag. The volatiles from the coal will add to the calorific value of the off-gas.

The process and furnace design is based on the same principle as for ferro nickel from ores high in iron. The slag is transferred in liquid state to the reduction unit, coal is added for reduction and electrical energy is used to provide the necessary reduction energy and to compensate for thermal losses. The iron produced in this process will be low in carbon and a good basis for steel production. Pig iron will not be possible to produce. Laboratory and pilot test smelting has been conducted at Elkem's R & D center and we are quite confident that such a process is feasible.

The economy of the process is very favourable. If the off gas replaces oil, as will be the case in the ferro nickel process line, most slags containing more than fifty percent iron should be considered. Fig. 8 indicates the electric energy consumption per ton of slag and per ton of iron depending on the iron content in the slag to be reduced.

### REFERENCES :

- 1) "Ferro-Nickel Smelting in New Caledonia" by C. G. Thurneysen, Journal of Metals, March 1960.
- 2) "Production of High Grade Ferronickel from Laterites Rotary Kiln - Electric Furnace Process" by A. A. Dor, Hans Skretting, Erik Svana — Paper No. A 74-40, The Metallurgical Society of AIME 345, East 47th Street, New York, N. Y. 10017.
- 3) "Ferro Nickel Smelting" by Erik Svana, International Symposium on Ferroalloys in Sibenik, Yugoslavia, September, 1975.
- 4) Various internal ELKEM reports.