# OPERATION OF AN 81 MVA HIGH CARBON FERRO-MANGANESE FURNACE AT SAMANCOR'S MEYERTON WORKS

---

By F. J. Potgieter*
(presented by Mr. Potgieter)

SYNOPSIS

This paper deals with the construction and operation of a large high carbon ferro-manganese furnace, with special reference to process control.

The conclusion reached is that South African manganese ores can be used with great success at loads above 45 MW.

## 1. Introduction

The Samancor Group first manufactured high carbon ferro-manganese in 1938 in a 3 m diameter blast furnace. In 1942, the first electric furnaces were commissioned. These had rectangular shells of size 6 m x 2 m, were fitted with 3 single phase 1 MVA transformers and operated on 3 in-line 840 mm diameter Söderberg electrodes.

Samancor at present operates 30 submerged arc reduction furnaces. These furnaces range in size from 4,5 MVA to 81 MVA and are situated at three locations in South Africa and at one location abroad.

Samancor has concentrated on mastering techniques required in the optimum utilisation of South African raw materials and has accumulated considerable expertise over the years.

The last decade of Samancor's history can be divided into three distinct phases as far as furnace size is concerned.

Prior to 1970 the largest furnace operating in the Group was a 15 MVA ferro-silicon furnace at the Group's Witbank Works.

In 1970, the decision to build a 48 MVA ferro-silicon furnace at Witbank launched the Group on an expansion programme which ended in 1974 with the completion of a fifth 48 MVA furnace. Of the latter four furnaces, two produced high carbon ferro-chrome at the Witbank Works, and two high carbon ferro-manganese at the Meyerton Works. Hereafter followed a three year period of consolidation and experimentation as it was soon discovered that an operating error which could be regarded as a minor mishap on a small furnace, often turned out to be a major catastrophe on a large unit.

In 1976, Samancor having gained valuable experience in the operation of larger units, was in a position to embark upon the design, erection

---

* Samancor, Meyerton, South Africa

and commissioning of the largest submerged arc ferro-manganese furnace in the world, heralding the beginning of the third phase of development. It was decided at that stage to build a furnace rated at 81 MVA, which decision resulted in furnace M12 at Meyerton Works being brought into operation on the 30th July, 1978.

After initial teething problems were solved, the furnace reached an operating load in excess of 40 MW and it consistently produces more than 11 000 tonnes of high-carbon ferro-manganese per month.

The main factors contributing to the outstanding success of the furnace are :

1. Advanced design and careful commissioning;

2. Sound electrode management;

3. Exploitation of the characteristics of Samancor ores;

4. The development of a control strategy based primarily on electrical behaviour.

## 2. Design and construction

A comprehensive study by Samancor indicated that the optimum siting of the new plant was at the Meyerton Works 50 km south of Johannesburg.

After project approval was granted in July, 1976, a Samancor design and construction team under the guidance of a Construction Manager was formed. This team included the designated Production and Maintenance Managers as members, thus ensuring that operating information used in the planning and design phase was the latest available.

The main design parameters are given in Table I, and the plant layout is shown in the aerial photograph in Figure I.

It is considered that the successful operation of M12 is in no small measure a result of effective communication systems that were brought into effect during the design and construction phases. The skillful blend of the metallurgist's art and the designer's science lead to the construction of a plant geared to withstand the harshest possible operating conditions whilst utilizing the most delicate control systems available.

Elapsed time from turning the first sod to switch-in was two years. During this period the furnace and its auxiliary equipment were constructed and tested before commissioning. The furnace proper was designed jointly by Samancor and Tanabe Kakoki. The other facilities including the ore bedding plant, screening plant, casthouse and all buildings were designed and installed by Samancor's Project Management Division. On the 30th July, 1978, the furnace was switched-in and predictions were for a smooth run to 25 MW after 30 days and then to the design load of 38 MW after 60 days.

## 3. Commissioning :

### 3.1 Training :

Operating personnel were appointed some months prior to commissioning and "dry-run" training was done piece-wise on equipment as it was being completed. Training on the furnace was done by means of a computer simulator coupled to the furnace instruments.

3.2 Testing :

Before the plant was handed over as an operating unit, the construction team tested all items of equipment under operating conditions for a period of three months. This testing was carried out on a 24 hours/day basis and thus also provided for fault finding and "fine tuning".

3.3 Performance :

The first month of operation provided no surprises and the furnace and auxiliary equipment performed as expected. The furnace was on a load of 25 MW when the first sign of the problems to come was perceived. An electrode was roughly handled during a test on the control circuits and the furnace was melted down thereafter to measure electrodes. This caused the first electrode break. During the following 4 months, 12 more breaks occurred with disastrous results on furnace output.

The fluctuating furnace load resulting from electrode problems aggravated the eruptions that were occurring to such an extent that frequent shutdowns were necessary to repair damage. Only the extreme robustness of the furnace and its surroundings prevented serious damage to equipment during this period.

When the plant was handed over by the Project Management Team to the Works as a production unit, all items of equipment had been proved under extreme conditions but the problems of electrode breaks (stump and green) and furnace eruptions had still to be solved.

4. Electrodes

Experience at various furnaces in the Samancor Group has led to the classification of electrodes in three sizes :

i Small electrodes have a diameter of up to 1 000 mm. These electrodes are generally found on small, open furnaces. Breaks occur mainly due to operational errors and are not too serious. Paste quality is not of prime importance and paste quality limits may be wide.

ii Medium electrodes range from 1 000 mm to 1 600 mm in diameter. Breaks can be very serious and care should be taken in electrode management. Paste quality is important. At Samancor these electrodes are found in furnaces up to 48 MVA.

iii Large electrodes of + 1 600 mm diameter are found in larger, closed furnaces. Paste of a consistently high quality with narrow limits is essential, and extreme care should be taken in electrode management.

The Söderberg paste originally used on M12 was made locally by a paste manufacturer partly owned by Samancor. This particular plant uses South African raw materials, of which the pitch is of good quality but the anthracite has ash contents which exceed 10 % and can be as high as 14 %.

With special reference to ferro-manganese furnaces, this paste proved to be satisfactory on the small and medium electrodes mentioned above. On large electrodes however, severe problems were encountered when using this high ash paste.

Two main problems were identified. Firstly, the baking rate was lower than the consumption. Secondly, the baked electrode was physically weak and unable to withstand thermal shocks. The result was that furnaces operated at lower than design loads and both green and stump breaks were a common experience.

4.1 Baking Rate :

When operating a furnace having high electrode consumption yet low paste baking rate the result of either continued long slips on the one hand or green electrode breaks on the other hand is anything but optimum. In order to eliminate green breaks the temperature of the paste in the contact clamps of each electrode is continuously monitored in two positions. This gives an accurate measurement of the location of the baking zone.

Slipping rate of the electrode is controlled by observing the position of the baking zone. Baking in of an electrode after a long slip is controlled in the same way.

The monitoring of the baking zones indicated an extremely low baking profile often with the 450$^{o}$ isotherm within 50 mm of the bottom of the contact clamp. Obviously faster slipping was not possible under these conditions.

In order to increase the baking rate of the paste an investigation resulted in a change of casing design. It was reasoned that with constant current in the electrode, a possible solution was to increase the resistance of the casing so as to increase the heat generation.

This change was made and the modified casings were first added to the electrode columns in January, 1979.

4.2 Physical Weakness

This problem could be mainly attributed to several factors; variable baking due to long slips, variable paste quality and low heat conductivity of the paste that lead to stresses in the electrode with temperature variations, were the most important. The first of these factors could be improved by the better baking expected with the new casings. The latter two, however, were overcome by changing to a paste with the required properties.

4.3 Results of Changes :

The incidence of electrode breaks on the furnace has reduced dramatically. In fact, the furnace operated for longer than a year without any long slips being taken. It can confidently be stated that, barring human errors, the electrodes have ceased to be a problem.

## 5. Raw materials

All raw materials are stacked in a blending plant before screening. Screening and sampling take place just before the proportioning house. Daily mass balances are performed on a feed forward basis to take variations between stockpiles into account. Table II lists the typical size range of raw materials fed to the furnace.

The computer controlled batching system has a total dynamic error of 0,03 % over 24 hours.

### 5.1 Ores

Samancor currently operates three manganese mines, the ores from two of which, namely Mamatwan and Wessels, are used on M12. Table III gives reserves of manganese ores in South Africa and Table IV the analysis of Mamatwan and Wessels ores.

Experience on existing furnaces showed that a combination of lumpy Mamatwan and Wessels ores has the following characteristics in an electrical furnace :

1. High furnace resistances are experienced leading to increased power input.

2. Deeper electrode penetration results in improved reduction and lower carbon consumption.

3. At high ratios of Mamatwan ore (i.e. greater than 50 % of the ore) gas volumes and power consumption increase.

4. Low phosphorous and alkali content enhances both alloy quality and furnace operation.

#### 5.1.1 High Furnace Resistance

It is possible to operate a furnace on a higher resistance on Mamatwan ore than on most other ores. This results in increased power input while maintaining electrode penetration. In the case of M12 this facilitated an increase from 38 MW to 45 MW without any adverse effects. Obviously allowance for the higher loads is required in shell design and materials handling facilities.

Table III illustrates the improvement in operating resistance with time.

#### 5.1.2 Electrode Penetration

Mamatwan ore, when used in conjunction with High $MnO_2$ containing ores can lead to a decrease in power consumption despite the apparent contradiction that exists as a result of the loss of exothermic heat. The mechanism of this reduction is postulated as follows :

When using high $MnO_2$ ores a proportion of $MnO_2$ reduction by solid phase C takes place. This leads to an increase in carbon requirements resulting in lower burden resistivity, lower operating resistance, decreased penetration and increased heat and vapour loss.

The addition of a percentage of Mamatwan ore however, reverses the above effect and leads to a reduction in power consumption via increased electrode penetration.

5.1.3 Increased Power Consumption

The advantages of increased penetration described above are off-set by increases in power consumption at higher proportions of Mamatwan ore. An optimum point is thus reached, and should be sought in the light of specific ore and power costs. Samancor has decided, in its unique position, on a high proportion of Mamatwan ore on M12 (i.e. approximately 70 %).

The most effective means of countering the high power consumption is by converting from lumpy ore to Mamatwan sinter, the advantages of which are discussed below.

5.1.4 Furnace Eruptions

Eruptions are inherent in ferro-manganese smelting, but become more violent when using a large percentage of high carbonate Mamatwan ore.

Careful control of the process can contain these eruptions to manageable proportions, but widely fluctuating loads such as can be caused by electrode problems, aggravate the eruptions to such an extent that these can degenerate into extremely dangerous uncontrollable explosions.

Various methods of solving the problem were tried but had limited success. An eruption could be predicted, for instance, by observing the loading rate of individual furnace loading chutes. By perturbing the electrode on which the feed is reduced, the eruption can be brought on. However, this is usually too late to minimize the force of the blow.

During investigations into the electrode problem, a method was developed to measure the pressure at the electrode trip. This pressure measurement was soon found to be invaluable in predicting blows.

As soon as bridging around any electrode starts, the pressure under that electrode increases. By moving the electrode when the pressure increase is observed, the bridging effect is minimized and only a minor eruption is experienced.

5.1.5 Ore Analysis

As is evident from Table IV, both Mamatwan and Wessels ore are ideal for the production of low phosphorous alloys. Furthermore, the low alkali levels of the ores facilitate burden permeability especially on larger furnaces.

5.2 Sintered Mamatwan Ore :

The advantages of using sintered ore in a ferro-manganese furnace has been reported on by various authors[1, 2].

Improvements obtained during a campaign on M12 with 60 % sintered ore were :

a) Resistance - increased 7 %

b) Reactance - decreased 3 %

c) Power consumption - decreased 15 %

d) Availability - increased 1 %

e) Reductant - decreased 10 %

f) Electrode consumption - decreased 10 %

These various advantages led to an increase in output of some 25 % to 14 000 tonnes per month.

5.3 Reductants

Metallurgical coke and a non-swelling coal is used in the ratio of 30/70.

This ratio is one of the most important control parameters on the furnace, and is used in conjunction with the total carbon requirements to stabilise the furnace electrical behaviour.

5.4 Flux

Quartz and dolomite are used to adjust the slag basicity which is expressed as (% CaO + % MgO) / % $SiO_2$ for day to day control. In fact the control over the slag analysis adheres to the principle examined by S. Selmer-Olsen[3] in 1974.

6. Operation

Investigations indicated that, in a ferro-manganese furnace with differential slag and metal tapping levels, a layer of almost pure MnO existed, as well as a coke layer[4]. Due to the long retention time caused by these two factors it is very difficult to control the operation by direct metallurgy. It has been determined that symptoms of metallurgical disturbances occur in the following order :

Firstly electrical behaviour, particularly furnace resistance, secondly gas ratio and material flow, and thirdly slag and metal analysis. The time lag between the first and second indications was found to be 8 to 24 hours, and between the first and third indications, three days. A control strategy has thus been developed based on electrical characteristics whilst monitoring metallurgical parameters.

6.1 Control Strategy

The control strategy is based on resistance and in order to achieve this, it is necessary to ensure an accurate relative measurement of the voltage between the electrodes and neutral. Careful planning of the routes taken by the measuring circuits will ensure a measured value which is satisfactory under all but the most unbalanced conditions.

The resistances are controlled by proportional controllers with a fixed deadband and time constants. The recording of the resistances indicates the stability of the resistances.

This stability has been correlated to the metallurgy of the furnace and has been found to be highly reliable as an early warning device.

Most other furnace parameters are plotted on time intervals ranging from 2 hourly to daily. The rates of change of these variables are all used for the overall control of the furnace. This method of control has been found to be so reliable that electrode lengths, for instance, have not been measured since December, 1978.

Model building for eventual total computer control has commenced and it is foreseen that this will be implemented in the future.

### 6.2 Results

Figures III. and IV. represent the 30 day moving average of the load and production on the furnace. The load is expressed as MWh/h and takes all stoppages into account. Production is the total production over the previous 30 days. Furnace availability is 98 %.

## 7. Conclusion

A production rate of 450 tonnes high carbon ferro-manganese per day, average over a period of a month, was achieved on the 81 MVA furnace at Meyerton during February, 1980.

This production rate was achieved utilizing the inherent advantages of Samancor's Mamatwan ore. Other factors contributing to the success where :

i A long and hard apprenticeship on medium sized furnaces.

ii Furnace and auxiliary equipment of robust and advanced design.

iii Advanced control procedures.

## 8. Acknowledgement

The author wishes to thank Samancor Limited for permission to publish this paper. J.S. Stanbury is thanked for his enthusiastic help and technical advice.

## REFERENCES

1. HOOPER, R.T. "The production and smelting of Manganese Sinter". Presented at the 36th Electric Furnace Conference Toronto, 1978.

2. NARUSE, W. "The production of manganese alloys by the sintering process". Presented at Infacon 74, Johannesburg, 1974.

3. SELMER-OLSEN, S. "Slag - Metal relations in Metalloys' High Carbon ferromanganese furnaces". Presented at Infacon 74, Johannesburg, 1974.

4. BARCZA, N.A. *et al.* "The "Dig out" of a 74 MVA high carbon ferromanganese electric smelting furnace". Presented at the 37th Electric Furnace Conference, Detroit, 1979.

TABLE I.

| SPECIFICATIONS OF PLANT | | |
|---|---|---|
| **FURNACE** | | |
| Transformer capacity | | 81 MVA |
| Frequency | | 50 Hz |
| Primary voltage | | 33 KV |
| Electrode diameter | | 1 900 mm |
| Crucible depth | | 5 700 mm |
| Pitch Circle diameter | | 2 742 mm |
| Shell diameter | | 15 500 mm |
| Shell depth | | 8 200 mm |
| Crucible diameter | | 12 600 mm |
| Tapholes | | 2 x metal |
| | | 2 x slag |
| **GAS CLEANING PLANT** | | |
| Type | | Double Venturi scrubber |
| Capacity | | 17 000 $nm^3/h$ |
| Availability | | 98 % |
| Standby | | 100 % |
| **PRODUCT** | | |
| High carbon ferro-manganese | Mn | 77 % |
| | Fe | 15 % |
| | Si | ,15 % |
| | P | ,08 % |
| | S | ,01 % |
| **GUARANTEES** | | |
| Availability | | 97 % |
| Reactance | | 1,1 millions ohm (total furnace reactance from primary side of transformers). |
| Production | | 110 000 tonnes p/a (under the condition that resistance will be kept at 0,7 million ohm minimum and power consumption 2 700 kWh/tonne). |

TABLE II.

## TYPICAL SIZE RANGE OF FURNACE FEED

| RAW MATERIAL | SIZE (mm) |
|---|---|
| Mamatwan Ore | 65 x 25 |
| Wessels Ore | 65 x 10 |
| Quartz | 70 x 30 |
| Dolomite | 70 x 30 |
| Coal | 40 x 25 |
| Coke | 40 x 25 |

TABLE III.

RESERVES OF MANGANESE ORES IN SOUTH AFRICA (TONNES X $10^6$)

| Type | Mn content % | Mn and Fe % | Samancor Reserves | | | Inferred. other producers | Total |
|---|---|---|---|---|---|---|---|
| | | | Proved | Inferred | Total | | |
| Wessels | + 44 | 60 | 191 | | | 120 | 311 |
| | 40 - 44 | 60 | 18 | | | 12 | 30 |
| | 36 - 40 | 40 - 45 | 11 | | | 7 | 18 |
| | 30 - 40 | 35 - 50 | 19 | | | 12 | 31 |
| TOTAL WESSELS | | | 239 | | 239 | 151 | 390 |
| Mamatwan | 38 - 40 | 43 - 45 | 328 | 105 | 433 | 894 | 1 327 |
| | 30 - 38 | 40 - 45 | 614 | 2 166 | 2 780 | 2 943 | 5 723 |
| | 20 - 30 | | 200 | 1 660 | 1 860 | 3 266 | 5 126 |
| TOTAL MAMATWAN | | | 1 142 | 3 931 | 5 073 | 7 103 | 12 176 |
| Ferrugeneous | 30 | 20 | | 10 | | 5 | 15 |
| GRAND TOTAL | | | 1 381 | 3 941 | 5 322 | 7 259 | 12 581 |

SOURCE : Mining Division, S.A. Manganese Amcor Limited

TABLE IV.

## ANALYSIS OF ORES

| COMPONENT | WESSELS | MAMATWAN |
|---|---|---|
| Mn | 48,2 | 38,06 |
| Fe | 11,53 | 4,01 |
| $SiO_2$ | 6,06 | 4,66 |
| $Al_2O_3$ | ,36 | ,27 |
| CaO | 5,3 | 14,4 |
| MgO | ,45 | 3,65 |
| $Na_2O$ | ,03 | ,025 |
| $K_2O$ | ,01 | ,015 |
| P | ,022 | ,015 |
| BaO | 0,37 | ,08 |
| $CO_2$ | 1,2 | 16,5 |
| Combined Water | ,48 | ,37 |
| S | ,11 | 0,02 |
| Total metallics | 59,7 | 43,6 |

FIGURE I

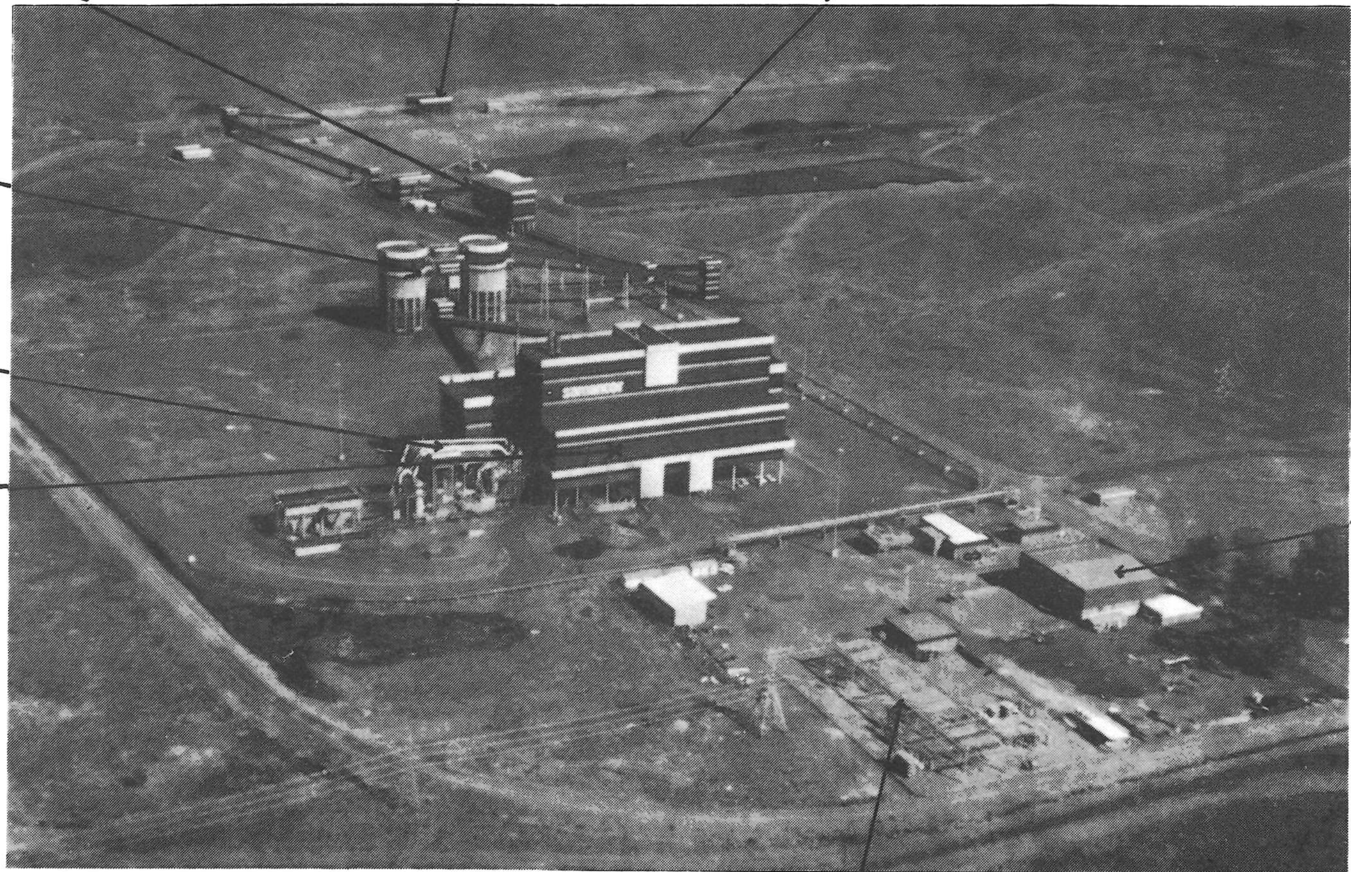

SCREENING FACILITY
RAIL CAR TIPPLER
RAW MATERIAL BLENDING PLANT
WEIGHING AND MIXING BUNKERS
GAS CLEANING PLANT
FURNACE BUILDING
WORKSHOPS
ELECTRICAL DISTRIBUTION YARD

FIGURE II.

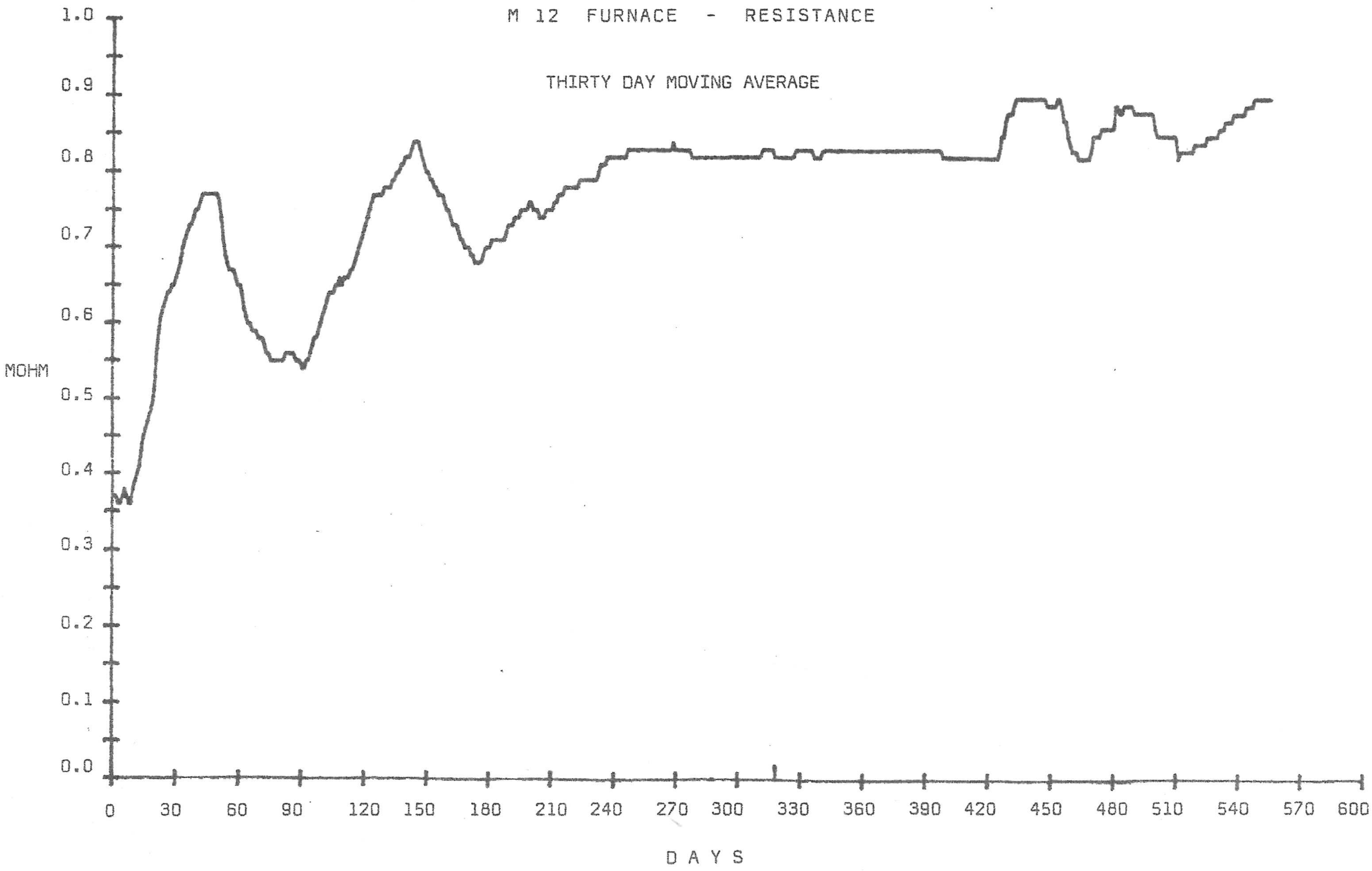

M 12 FURNACE - RESISTANCE
THIRTY DAY MOVING AVERAGE
MOHM
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0 30 60 90 120 150 180 210 240 270 300 330 360 390 420 450 480 510 540 570 600
D A Y S

FIGURE III.

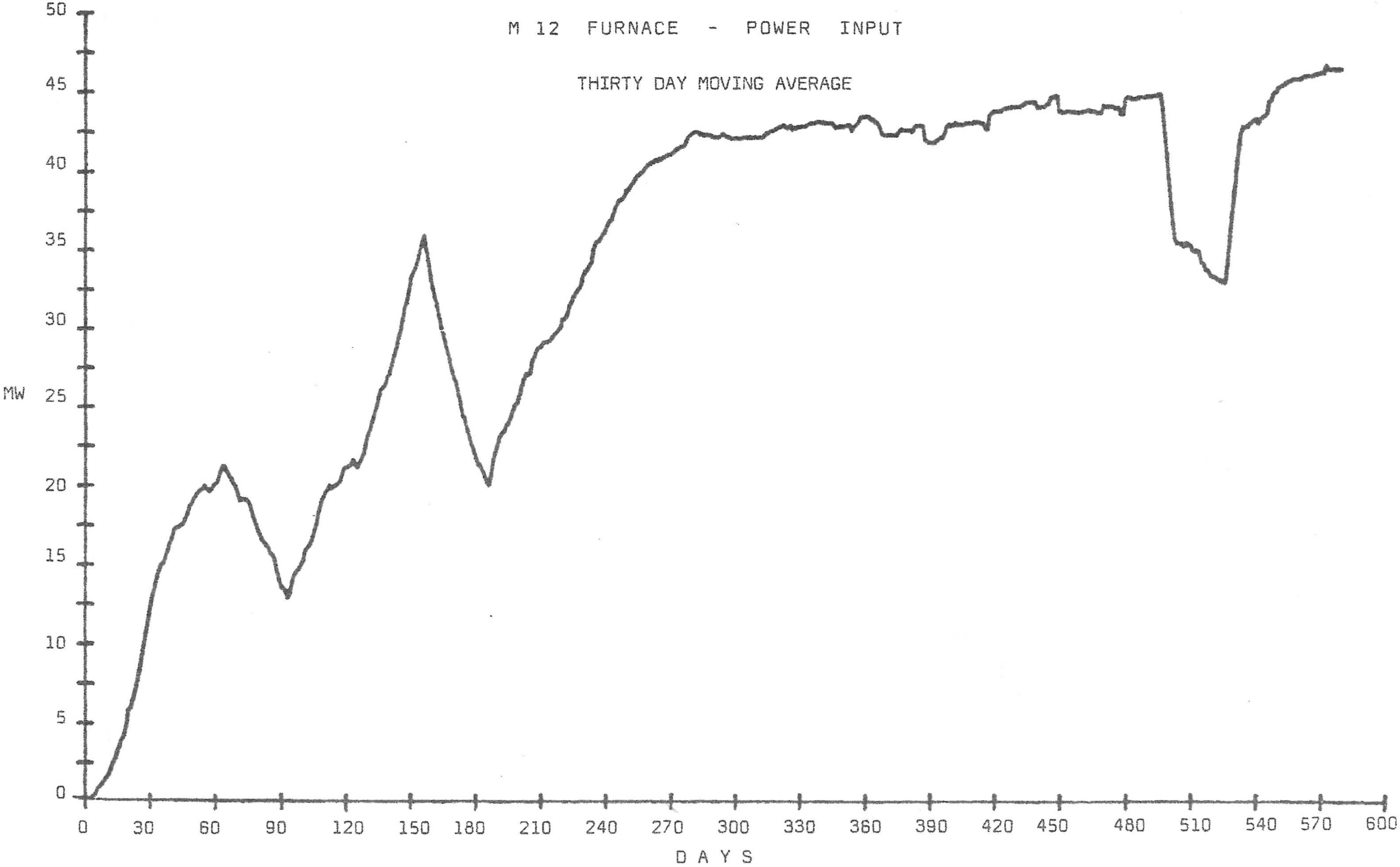
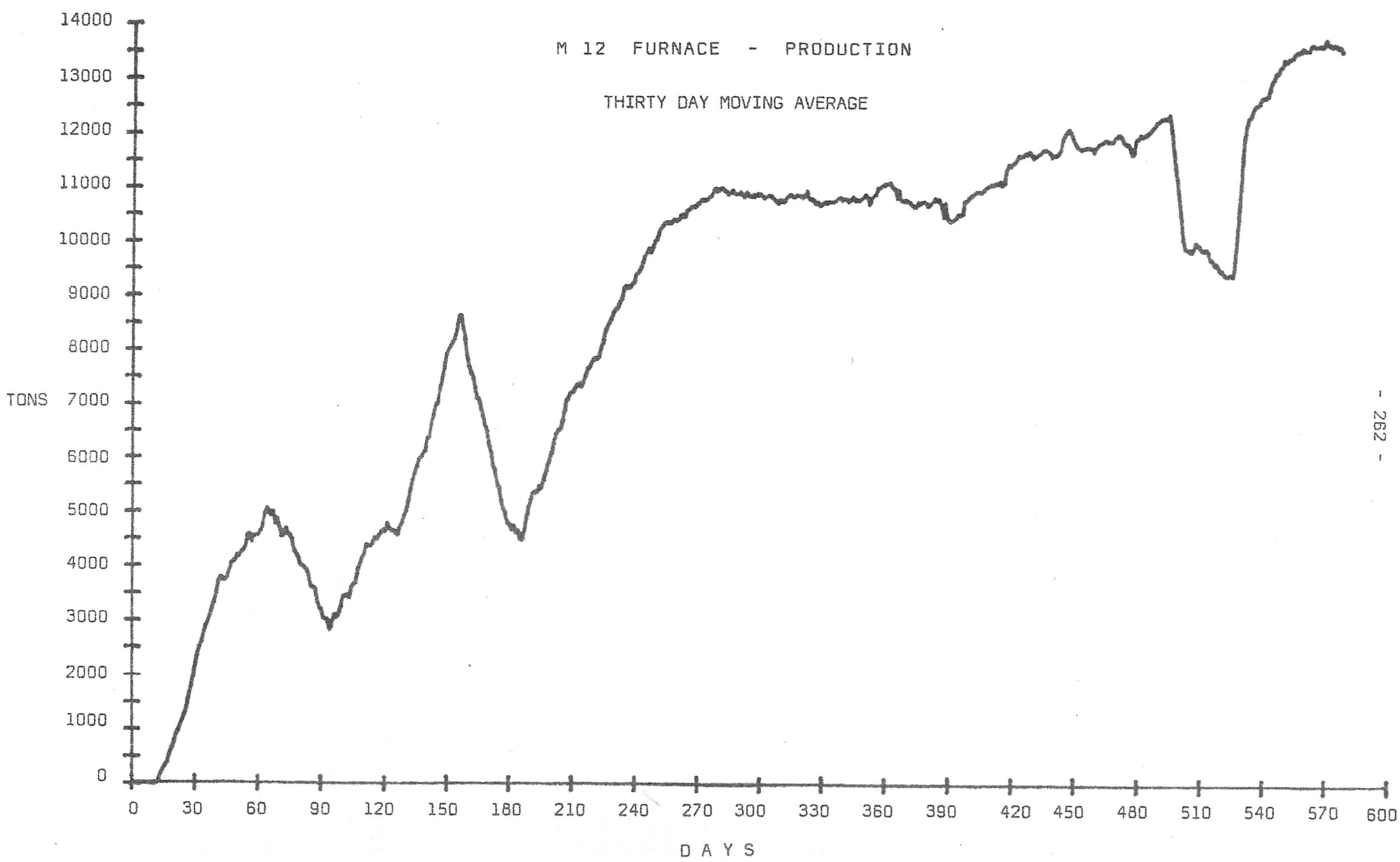

M 12 FURNACE - POWER INPUT
THIRTY DAY MOVING AVERAGE
MW
50
45
40
35
30
25
20
15
10
5
0
0 30 60 90 120 150 180 210 240 270 300 330 360 390 420 450 480 510 540 570 600
D A Y S

FIGURE IV.


M 12 FURNACE - PRODUCTION
THIRTY DAY MOVING AVERAGE
TONS
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450
480
510
540
570
600
D A Y S

## DISCUSSION

Mr. H. Parsons*

I have three questions that I would like to ask to Mr. Potgieter. In connection with the furnace electrodes, he refers to a long slip. I would like Mr. Potgieter just to give us an idea what he means by a long slip, how much is it and what does he regard as a normal slip? The second question I have is: He referred to the fact that they changed the electrode casing design. I assume he refers to the steel to paste ratio and I wonder whether Mr. Potgieter would like to give us some idea on what the ratio is between steel and paste? Then, the third question is: He refers to temperatures in the electrode. I would like to ask what these temperatures are, where they are monitored and how?

Mr. F.J. Potgieter:

(i) A normal slip is 10 mm; anything longer than that is a long slip;

(ii) Our casing parameters are classified information; I thus regret that the question cannot be answered;

(iii) Thermo couples are used to monitor the temperature in the bottom one-third of the contact clamps. The range of temperatures is between 450° and 600°C.

Mr. J. Sciaud**

Vous avez sur vos tableaux deux trous de coulée métal et deux trous de coulée laitiers. J'aimerais savoir si vous arrivez à couler le laitier séparément par les trous de coulée laitiers et le métal par les trous de coulée métal? D'autre part, deuxième question : Il semble que vos matières premières soient utilisées au-dessus de 25 mm. Est-ce que réellement vous criblez toutes vos matières premières, minerai et coke à 25 mm, et que faites-vous du 0.25 ?

Mr. F.J. Potgieter:

(i) As far as our slag and metal tapping is concerned, we always tap slag from the slag side and always tap metal from the metal side. We stop a tap immediately that slag appears at the metal taphole;

(ii) The sizes given in the table are nominal sizes and to ensure that no fines go into the furnace at all, we screen at 10 mm. The material fines are sometimes used in other, smaller furnaces, and sometimes sold.

Mr. A. Das Gupta***

Our Company has been engineering ferro-alloy plants since 1955 and we have done about a dozen. I note from Mr. Potgieter's paper that from July 1976 to July 1978, that means in just about 2 years' time, the entire project has been implemented, which is excellent. Our experience in India is that we need about 3 years' time from the day the decision is taken to "go-ahead".

---

* Infurnco (Pty) Limited, South Africa; ** SOFREM, France; *** M.N. Dastur & Company (P) Ltd, India

I would like to know if this 2 years' time includes any preliminary work because approval may mean anything: it may mean financial approval or it may mean that you have placed the order for the furnace, etc., or whatever stage it is. Secondly, I would like to know what steps you have taken in monitoring this project, such as CPM network or any other method?

Mr. F.J. Potgieter:

Planning for the project started early 1976, and preliminary planning was complete at the time of project approval. The project is monitored by using a P E R T network for construction and a financial program for costs.

Mr. A. Torres*

You mentioned that you have several eruptions. My first question is: Can you tell me what kind of safety measures you are taking to avoid accidents? My second question: In your opinion, what is the main difference between the operation of a two-level taphole furnace and a one-level taphole furnace?

Mr. F.J. Potgieter:

(i) As far as safety is concerned, the furnace floor is sealed off completely and nobody is allowed into that area while the furnace is in operation;

(ii) The experience at our Meyerton Plant is that the main difference is in the resistance of the furnace. You are able to run at a very much higher resistance without a slag layer, but the furnace is more unstable.

* Compania Minera Autlan S.A. de C.V., Mexico