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# FERROMANGANESE PLANT
# ABU ZENEIMA, SINAI

# STAGE I
# PREFEASIBILITY
# WORK REPORT

## APPENDIX 3,4,5 AND 6

*The Sinai Manganese Company*

SIMANG

PREPARED BY

**KAISER ENGINEERS AND CONSTRUCTORS, INC.**

in association with

ARAB CONSULTING BUREAU

REPORT NO. 80-57-RE
SEPTEMBER 1980

APPENDIX 3

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Raw Materials for FeMn (III.B.3)

- Natural Gas
- Crude Oil
- Dolomite
- Limestone
- Quartzite
- Ferrosilicon
- Coke
- Coal
- Sharm El Sheikh Manganese Ores
- Petroleum Coke
- Naphtha

Other Minerals, SMC Leases (III.B.4)

- Gypsum

APPENDIX 3

(III.B.3)

Raw Materials for FeMn

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Raw Materials:


- o Natural Gas
- o Crude Oil
- o Dolomite
- o Limestone
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- o Coal
- o Sharm El Sheikh Manganese Ores
- o Petroleum Coke
- o Naptha
- o Gypsum

# I. NATURAL GAS

Various contacts have been made with the Egyptian General Petroleum Corporation (EGPC) which is the governmental entity responsible for natural gas in Egypt.

During discussions with ACB, confirmed in the first attached letter, the production sector of EGPC provided preliminary reservoir information and gas analyses about two possible sources of natural gas which could be utilized in the production of ferromanganese at Abu Zeneima. They are the Petrobel oilfields and the Deminex oilfields currently owned by the Suez Oil Company.

In the second letter attached, EGPC confirmed the availability of quantities of natural gas from Belayim sufficient for plant operations at production levels predicated in this report.

TRANSLATION

June 12, 1980

Product General Manager
The General Authority of Petroleum
Cairo
Madient Nasr

Subject: Required Gas for FeMn Smelter at Abu Zeneima Sinai

During the meeting today with Engr. Fayez Awadalla at your office, the following topics were discussed.

- Petrobel Gas

  Petrobel Company, in its letter no. 8-1/29 dated April 4, 1980, stated it can supply from 10 to 18 million cubic feet/day of gas from Marine Belayim field from 1982 until the end of 1988. After that, less gas will be available unless new fields are found or existing fields extended.

  The gas analysis was submitted to Engr. Fayez.

- Deminex Gas

  The following is the gas analysis which was delivered to us.

Gas

Spread of Chemical Composition

| Component % Mole | P.T. No. 1 | P.T. No. 4 |
|---|---|---|
| Methane | 55.64 | 48.03 |
| Ethane | 20.08 | 19.16 |
| Propane | 11.81 | 13.06 |
| Iso-Butane | 0.95 | 1.04 |
| N-Butane | 2.51 | 3.09 |
| Iso-Pentane | 0.52 | 0.68 |
| N-Pentane | 0.62 | 0.87 |
| Hexane and Heavier | 0.83 | 1.03 |
| Oxygen | 0.00 | 0.00 |
| Nitrogen | 1.04 | 1.04 |
| Carbon | 6.00 | 12.00 |
| Total | 100.00 | 100.00 |
| Hydrogen Sulfide | Nil | Nil |
| S.G. by calculation (air = 1) | 0.9280 | 1.0174 |

Thanks.

Monir Ismail El Kholy

## GAS ANALYSIS FOR PETROBEL CONCESSIONS

| | Belayim Land | Belayim Marine |
|---|---|---|
| Methane | 66.82 | 71.72 |
| Ethane | 13.76 | 12.88 |
| Propane | 11.88 | 9.10 |
| I-Butane | 1.12 | 0.82 |
| N-Butane | 3.01 | 1.95 |
| I-Pentane | 0.64 | 0.43 |
| N-Pentane | 0.70 | 0.44 |
| Hexane | 0.61 | 0.30 |
| Heptane | 0.009 | 0.08 |
| Nitrogen | 0.80 | 1.08 |
| Carbon Dioxide | 0.65 | 0.37 |
| $H_2S$ | - | - |
| Gross Calorific value (k. cal/$m^3$) | 12861 | 12824 |
| Net Calorific value (k. cal/$m^3$) | 11705 | 11774 |
| Density at $0^oC$ 1 atm. (gm/cc) | 0.001094 | |
| Sp.gr. at $15^oC$ & 1 atm. | 0.855 | 0.788 |

المكتب الرئيسي :
٢ شارع موسى بن أبو علم - القاهرة
سجل تجاري : ١٨٤٩٨٢
سجل وكلاء تجاريين : ٧٧٦

# المكتب العربي الاستشاري

منير الخولي

AGB

التلكس : [illegible]
تلغرافيا : [illegible]
صندوق بريد : ٢٥٤٨ القاهرة
تليفون : [illegible]
٧٤٠١٥١

القاهرة فى ١٢ يونيو سنة ١٩٨٠

السيد / مدير عام الانتاج
الهيئة العامه للبترول
مدينة نصر - القاهرة

الموضوع : الغاز اللازم لمصنع الفيرومنجنيز بأبى زنيمة بسيناء :

تحية طيبه ... وبعد

فبالاشارة الى الاجتماع الذى تم صباح اليوم بينكم وبين المهندس/ فايز عبد الشهيد بمقر هيئتكم الموقرة بشأن الموضوع المشار اليه بعاليه .

نتشرف بان نثبت لكم ماتفضلتم مشكورين بموافاتنا به من بيانات بهذا الخصوص .

أولا : غاز شركة بترومل :

أفادت شركة بترومل بخطابها رقم 8 - 1/ 129 - OP المؤرخ ٢٨/٤/٨٠ بأنه يمكنها توفير كمية غاز تتراوح بين ١٠ و ١٨ مليون قدم٣ يوميا من غازات حقل بلاعيم البحرى وذلك أعتبارا من عام ١٩٨٢ وحتى نهاية عام ١٩٨٨ حيث سيتناقص الانتاج بعد ذلك فى حالة عدم حدوث أكتشافات جديدة أو امتدادات للحقول الحاليه . علما بأن تحليل هذا الغاز قد سبق أن سلمناه لكم .

ثانيا : غاز شركة ديمنكس :

فيما يلى بيان تحاليل غاز كشف ديمنكس كما ورد لنا من الشركة .

Gas

Spread of Chemical Composition

نادية [illegible]
[illegible]
٨٠/٦/٢٢

| Component % Mole | P. T. No 1 | P. T. No. 4 |
|---|---|---|
| Methane | 55. 64 | 48. 03 |
| Ethane | 20. 08 | 19. 16 |
| Propane | 11. 81 | 13. 06 |
| Iso-Butane | 0. 95 | 1. 04 |
| N-Butane | 2. 51 | 3. 09 |
| Iso-Pentane | 0. 52 | 0. 68 |
| N-Pentane | 0. 62 | 0. 87 |
| Hexane and Heavier | 0. 83 | 1. 03 |
| Oxygen | 0. 00 | 0. 00 |
| Nitrogen | 1. 04 | 1. 04 |
| Carbon | 6. 00 | 12. 00 |
| Total | 100. 00 | 100. 00 |
| Hydrogen Sulfide | NIL | NIL |
| S. G. by calculation (air=1) | 0. 9280 | 1. 0174 |

وإذ نشكر لكم صادق تعاونكم .

فاننا نرجو أن تتفضلوا بقبول خالص التحية وفائق الاحترام ...

المكتب العربي الاستشاري

١٩٨٠/٧/١٢

جيولوجي / منير اسماعيل الغولي

ACB

The Egyptian General
Petroleum Corporation
Osman Abdel Hafez Street-
Nasr City.
P.O.B. 2130-Cairo-
Tel. : 837388

July 3, 1980

Ref : 7/250

Mr. Monir El Kholy
Arab Consulting Bureau
2 Mohamed Sabry Abu Alam St.
Cairo.

Sub : The required gas for Ferro-manganese Factory at Abu Zeneima/Sinai.

Dear Mr Kholy,

Referring to your letter date 12.6.80 concerning the above mentioned subject. We beg to advise your goodself that Petrobel Co. had informed us that the available quantities of gas had been changed according to the new results of the drilling studies as follows :

| Year | The available quantity million cubic feet/day |
|---|---|
| 1981 | 31.60 |
| 1982 | 26.36 |
| 1983 | 25.86 |
| 1984 | 25.46 |
| 1985 | 26.08 |
| 1986 | 25.27 |
| 1987 | 24.22 |
| 1988 | 23.77 |
| 1989 | 22.97 |
| 1990 | 20.98 |
| 1991 | 19.42 |
| 1992 | 18.82 |
| 1993 | 18.16 |
| 1994 | 17.69 |
| 1995 | 16.84 |
| 1996 | 15.42 |
| 1997 | 14 34 |
| 1998 | 13.62 |
| 1999 | 12.82 |
| 2000 | 11.78 |

Best regards

Eng. B. Faragallah
General Director for
production

( نموذج ١٥/١٥١ - ٤٠٠ - ١٠٠×٣ - ٧٨/٤ )

THE EGYPTIAN GENERAL PETROLEUM CORPORATION
Osman Abdel Haliz Street - NASR CITY
P.O.B. 2130 CAIRO - Tel. 837388
Cable : PETMISR - Telex 92049

الهيئة المصرية العامة للبترول
شارع عثمان عبد الحفيظ - مدينة نصر
ص.ب: ٢١٣٠ - القاهرة - ت: ٨٣٧٣٨٨
تلغرافيا: بتميس - تيلكس: ٩٢٠٦١

ملف رقم ٧ / ٢٥٠ — Our Ref.
خطابكم رقم — Your Ref.
عدد المرفقات — No. of Encl.
التاريخ ١٩٨٠/٧/٣ — Date
الموضوع — Subject

السيد / منير الخولى
المكتب العربى الاستشارى
٢ ش محمد صبرى أبو علم - القاهرة

الموضوع : الغاز اللازم لمصنع الفيرومنجنيز بمنطقة زنيمة بسيناء

تحية طيبة وبعد .

بالاشارة الى خطابكم بخصوص الموضوع عالية بتاريخ ١٩٨٠/٦/١٢ ، نود الافادة بأن شركة بترول قد أفادت اخيرا بانه نتيجة لدراسة عمليات الحفر الحالية فان كميات الغاز المتاحة والتى يمكن توفيرها قد تغيرت طبقا لذلك ، وبالتالى فان الكميات المتوفرة بعد الاستخدام هى كالاتى :

| السنة | الكمية المتوفرة مليون قدم٣/ى | السنة | الكمية المتوفرة مليون قدم٣/ى |
|---|---|---|---|
| ١٩٨١ | ٣١٫٦٠ | ١٩٩١ | ١٩٫٤٢ |
| ١٩٨٢ | ٢٦٫٣٦ | ١٩٩٢ | ١٨٫٨٢ |
| ١٩٨٣ | ٢٥٫٨٦ | ١٩٩٣ | ١٨٫١٦ |
| ١٩٨٤ | ٢٥٫٤٦ | ١٩٩٤ | ١٧٫٦٩ |
| ١٩٨٥ | ٢٥٫٠٨ | ١٩٩٥ | ١٦٫٨٤ |
| ١٩٨٦ | ٢٥٫٢٧ | ١٩٩٦ | ١٥٫٤٢ |
| ١٩٨٧ | ٢٤٫٢٢ | ١٩٩٧ | ١٤٫٣٤ |
| ١٩٨٨ | ٢٣٫٧٧ | ١٩٩٨ | ١٣٫٦٢ |
| ١٩٨٩ | ٢٢٫٩٧ | ١٩٩٩ | ١٢٫٨٢ |
| ١٩٩٠ | ٢٠٫٩٨ | ٢٠٠٠ | ١١٫٧٨ |

وذلك للاحاطة .

وتفضلوا بقبول فائق الاحترام ،،،

مدير عام الهيئة للانتاج
مهندس / بطرس فرج الله

إن الانتاج هو المقياس الحقيقى للقوة الذاتية العربية

C.C. KE

ن / س

# II. CRUDE OIL

## A. Location

Crude oil sources closest to Abu Zeneima are:

- o Sinai crude oil, a mixture of the Assal, Sudr, and Metamir oilfields.
- o Belayim crude oil.
- o Deminex crude oil (Suez Oil Company).

## B. Availability

The production is as follows:

- o Sinai crude oil: 490 t/d (217.7 Assal, 208 Sudr, and 60 Metamir).
- o Belayim crude oil: 17,620 $m^3$/day.
- o Deminex: No regular production yet.

## C. Prices

Recent prices of the three kinds of crude oil are as follows:

- o Sinai crude oil: US$ 32.7, which is the price offered by the buyer, while the contracting price is expected to be higher.
- o Belayim crude oil: US$ 29.
- o Deminex crude oil: Not yet determined.

## D. Characteristics

The following table shows the characteristics of the three types of crude oil.

| Specifications | Deminex from field | Deminex after mixing | Belayim | Sinai (Mixture) |
|---|---|---|---|---|
| API gravity at 60°F | 36.3 | 24.1 | 26.3 | |
| Specific gravity at 60/60°F | 0.8433 | 0.9094 | - | 0.9223 |
| Density at 15°C in vacuum g/ml | 0.8428 | 0.9089 | 0.8962 | - |
| Density at 15°C in air g/ml | 0.8417 | 0.9078 | 0.8951 | - |
| Water content % Vol. | 0.70 | 0.05 | 0.10 | 1.8 |
| Salt content % Wt. | 0.030 | 0.005 | 0.005 | 0.026 |
| Sediment % Wt. | 0.01 | 0.01 | Nil | - |
| Sulphur content % Wt. | - | 2.20 | 2.32 | 1.9 |
| **Distillation** | | | | |
| Initial boiling point C | 97 | - | - | 90 |
| % Distilled at 100°C | 5 | - | - | 1 |
| % Distilled at 125°C | 8 | - | - | 3 |
| % Distilled at 150°C | 12 | - | - | 6 |
| % Distilled at 175°C | 16 | - | - | 10 |
| % Distilled at 200°C | 20 | - | - | 14 |
| % Distilled at 225°C | 23 | - | - | 18 |
| % Distilled at 250°C | 26 | - | - | 22 |
| % Distilled at 275°C | 29 | - | - | 27 |
| % Distilled at 300°C | 34 | - | - | 32 |

## E. Transport, Receiving and Storage

Crude oil from the three oilfields is transported by tankers. This method will utilize the service jetty of Abu Zeneima as the receiving point with special tank storage inside the industrial zone. However, trucking of crude oil directly to Abu Zeneima is also possible.

## III. DOLOMITE

Dolomite is widely available in the study area since it is a main constituent of the Middle Carboniferous Om Bogma Formation. The task was to specify a site of dolomite occurrence having three main specifications, namely:

- Good quality for the smelting process.
- The fewest difficulties in mining operations.
- A supply close to Abu Zeneima.

Therefore, an occurrence near the mouth of Wadi Khaboba was selected. This is 24 km from Abu Zeneima of which 20 km are on the asphalt road between Abu Zeneima and Abu Thor. Some 4 km lie along a desert track. The reserves can be estimated as over 100,000 tonnes. Surface mining, beginning a few meters above the wadi level, is proposed. Three horizons of different quality can be recognized:

- A sandy and coarsely crystalline lower horizon.
- A sandy and finely crystalline middle horizon.
- A coarse grained, locally stained by manganese oxide, upper horizon.

These beds dip southwest and have a maximum height above wadi level of 30 meters.

## IV. LIMESTONE

Limestone can be found very close to Abu Zeneima. They are mainly in the Cretaceous-Eocene succession, with varying degrees of purity and hardness. To the north, east and south of Abu Zeneima occurrences of limestones, and marly or sandy limestones are widespread.

Field studies base the optimum location site on three main criteria:

- Purity of the limestone (least sandy or clayey admixtures).
- Relative hardness of the rock.
- Least distance from Abu Zeneima.

The location selected is about 4 km south of Abu Zeneima and directly to the east of the asphalt road from Abu Zeneima to Abu Rudeis. Low topographic relief marks the quarry area. Reserves can be estimated at no less than 1 million tonnes.

## V. QUARTZITE

A highly consolidated quartzite required for the smelting process was located in the vicinity of Abu Zeneima. The location is at Wadi Tayiba, northeast of Gebel Musabba Salama, at some 17 km from Abu Zeneima. This deposit was determined as suitable for producing the required material.

Quartzite occurs at the top of the Upper Carboniferous sandstone (Abu Zarab Formation) in the form of a band a few meters thick. It has a relatively large horizontal extension and seems to be lens shaped. The deposit represents a near-surface cementation of sandstone by silica, highly stained with iron and manganese oxides. The rock is extremely hard and weathers to large blocks.

## VI. FERROSILICON

### A. Location

Ferrosilicon is currently produced by the Egyptian Chemical Industries Co. "KIMA" in its plants at Aswan. At present KIMA has no excess as their production meets the local market demand.

An Egyptian ferrosilicon plant for ferroalloys is under construction at Idfu, Aswan Governorate.

### B. Availability

KIMA is now supplying the total demands of the local market. When the Idfu plant starts production the surplus will be exported. Now KIMA has no surplus production for export.

The current operations under consideration will not require ferrosilicon consumption. If in the future there is a demand for low carbon ferromanganese or ferro-silico-manganese, then ferrosilicon would be consumed at Abu Zeneima and could be supplied by the Egyptian Chemical Industries (ECI) at KIMA, assuming that capacity there can be increased or from the Idfu plant when complete.

### C. Price

The ferrosilicon price at 75% Si is LE435 per tonne, exclusive of freight, loading, etc., at the Aswan factory in bulk, based on ECI letter M/N/80 of July 27, 1980.

### D. Characteristics

The Si content is usually 75% according to which the price is fixed. The specification of the standard FeSi is as follows:

| | |
|---|---|
| Si | 74-79% |
| S | 0.25% |
| Cr | 0.30% |
| Ti | 0.20% |
| C | 0.10% |
| Al | 1.50% |
| Ni | 0.10% |
| Ca | 0.75% |
| P | 0.035% |
| Mn | 0.40% |
| Cu | 0.10% |

The percentage of carbon and aluminum varies according to the specific requirements of each consuming industry.

# VII. COKE

## A. Location

Coke is currently produced in Egypt by El Nasr Co. for production of coke and basic chemicals. Plants exist at Tebin, Helwan and Cairo.

## B. Availability

The producer is provisionally ready to deliver to SMC ferro-manganese projects 1,500 tonnes per month at the rate of about 50 tonnes per day, starting in 1981.

## C. Price

The price of coke depends upon the price of imported coking coal. Therefore, annual contracts must be negotiated. The latest prices for the delivery of small quantities are as follows:

| Quality | Price/Tonnes, exclusive of freight, loading, etc., Factory,LE |
|---|---|
| plus-90-mm Coke | 193 |
| plus-40-mm Coke | 162 |
| plus-15 to minus-40 Coke | 136 |

## D. Characteristics

The characteristics of the locally produced coke are as follows:

| | |
|---|---|
| Ash | 9.5-10% |
| Fixed Carbon | 86% min. |
| Sulphur | 1.2% |
| Volatiles | 1.3% |
| Moisture | 5% |
| Calorific value | 7000 calorie/kg |

## E. Transport, Receiving and Storage

Coke could be trucked from the plants at Tebin, Helwan, or Cairo and received and stored in the industrial area of Abu Zeneima.

# شركة النصر لصناعة الكوك والكيماويات الاساسية

"التبين – حلوان – القاهرة"

العنوان التلغرافي "كيميكوك" حلوان - تليفون : ٣٩٩٥٤ - ٣٨٢٧١ - ٣٩٧٥٧ - ٣٨٥٩٨


السيد المهندس/ رئيس مجلس ادارة
شركة سيماء للمنجنيز
١ شارع قصر النيل - القاهرة

بعد التحية :

بالاشارة الى خطابكم الخاص بتوريد فحم كوك الى مصانعكم اعتبارا من عام ١٩٨١ وتساؤلاتكم بشأن امكانيات شركتنا فانى اوضح التالى :

اولا : الكميات يمكن توفيرها بواقع ١٥٠٠ طن شهريا بصفة مبدئية اى بواقع ٥٠ طن يوميا تقريبا .

ثانيا : المواصفات الكيماوية للكوك المنتج كما يلى :

| | | |
|---|---|---|
| رماد | ٩٫٥ | ١٠٪ |
| كربون ثابت | | ٨٦٪ (حد أدنى) |
| كبريت | ١٫٢ | ٪ |
| مواد متطايرة | ١٫٣ | ٪ |
| رطوبة | | ٥٪ |
| قيمة حرارية | ٧٠٠٠ ك كالورى/كجم . | |

ثالثا : سعر طن الكوك المنتج يرتبط بسعر الخام المشترى وهذا يتغير من عام لآخر ويتحدد طبقا لسعر استيراد الفحم الحجرى الخام من الخارج وعلى ذلك فان السعر يمكن تحديده عند التعاقد سنويا .

برجاء الاحاطة . مع تمنياتنا بتعاون مستمر لخدمة الوطن .

وتفضلوا بقبول فائق الاحترام ،

مدير قطاع الكوك والكيماويات
وعضو مجلس الادارة

(مهندس/ محمد عادل الموزى)

شركة النصر لصناعة الكوك والكيماويات
التبين ص.ب ١٤٩٢ القاهرة
٦ مارس ١٩٧٩
٢٥١ صادر

تحريرا فى : ١٩٧٩/٢/٤

El Nasr Co. for Coke & Basic Chemicals
El Tebin - Helwan - Cairo

February 4, 1980

Chairman of Sinai Manganese Co .

Referring to your letter for the supplying Coke to your factories at 1981, and to your quesstionnaire about the possibilities of our company.

We beg to inform your goodselves that;-

1- The quantities which may be available are 1500 ton / month i. e about 50 ton / day.

2- The chemical specifications of the produced coke are :-

| | | |
|---|---|---|
| Ash | 9.5 % | |
| Carbon | 86.0 % | Minimum |
| Sulphur | 1.2 % | |
| Volatiles | 1.3 % | |
| Moisture | 5.0 % | |
| Calorific Value | 7000 | Kilo calory / Kg . |

3- The price of the produced ton of coke depends on the price of purchase ore which changes from year to year according to the price of the imported Coal . So, the price could be calculated accordingly.

Best regards,

Eng. M. A. El Mousy
Manager of the Coke & Basic Chemicals Factory

# VIII. COAL

Coal was recorded before 1956 within the carbonaceous sediments of west central Sinai as thin bituminous carbonaceous interbeds.

Deep drilling prospection for oil revealed the presence of different types of coal and carboniferous matter. These were recorded at a depth between 418 and 2,960 meters in the Sinai. In 1959, prospection for coal began in the Sinai at Ayun Musa, Beida/Thora and Maghara, respectively, which led to the discovery of coal beds and carbonaceous matter. In 1966 exploration started for coal around the Maghara area. It ceased in June 1967, due to the war.

## A. Beida/Thora Coal Deposit

### 1. Location

Beida and Thora lie in the west central area of Sinai. The Beida deposit lies at Wadi Beida which is north of Gebel Om Rinna and east of Dibbet El Qeri. The Thora deposit lies at Wadi Om Thora, north of the El Qor area and south of Dibbet El Qeri.

### 2. Occurrence

The Egyptian Geological Survey exploration program for coal prospection lasted from 1959 to 1961. It included topographical surveying, surface geologic mapping, trenching, and adits totalling 240 linear meters. Also bore holes totalling 2,387 meters were drilled on widely spaced centers. Laboratory studies and tests were carried out.

Previous operations revealed coal lenses interbedded in carbonaceous shales passing into the subsurface. The KECI/ACR field team has recorded similar occurrences of coal seams interbedded in carbonaceous clays at one of the branches of Wadi Tayiba (Wadi Zuweibin) north of Gebel Musabba Salama. This occurrence seems worthy of some exploration work.

### 3. Reserves

The reserves were estimated at 75 million tonnes as follows:

- Proven reserves - 15 million tonnes of coal.
- Probable reserves - 60 million tonnes of coal and carbonaceous shale.

### 4. Properties

The reserves are the bituminous type, rich in volatile matter, with low coking ability.

## B. Ayun Musa Coal Deposit

### 1. Location

Ayun Musa lies on the eastern side of the Gulf of Suez 14 km south of El Shutt (facing Port Tawfik).

### 2. Occurrence

In this area, a coal exploration program was carried out by the Egyptian Geological Survey from 1959 to 1963. This included 39 deep bore holes totalling 22,338 meters at depths ranging from 420 to 620 meters. A coal seam in the form of lenses was found in all holes within the Jurassic formations with a thickness of 60 to 170 cm. High pressure water, up to 60 atmospheres, was encountered at the coal horizon and overlying strata.

### 3. Reserves

Reserves were estimated at 18.5 million tonnes of probable coal.

### 4. Properties

The reserves are the bituminous type, rich in volatile matter, with low coking ability.

## C. Maghara Coal Deposit

### 1. Location

The Maghara area lies in the north Sinai province, southwest of El Arish, and 175 km from Ismailia.

### 2. Occurrence

The exploration program of the Egyptian Geological Survey started in 1959 by executing detailed geological mapping, drilling 91 bore holes for a total length of 19,000 meters. Mining and production development was started. Beneficiation and utilization tests were run.

All these investigations and exploratory operations are confined to the Bathonian sediments (Safa Formation) which are represented by intercalations of dark sandstones, shales, and marls. This succession encloses up to 10 coal seams of which only two, the main seam and the upper seam, can be economically exploited.

The upper seam is 8 to 10 meters above the main seam. The thickness of the main seam varies from 110 cm to 190 cm, while that of the upper seam is only 65 cm but with some thicker sections.

3. Reserves

The total reserves were estimated at 51.8 million tonnes in an area of 25 square kilometers as follows:

- o Proven coal reserves - 39.9 million tonnes.
- o Probable coal reserves - 11.9 million tonnes.

The mineable reserves are 35.6 million tonnes as follows:

- o Proven reserves - 27.8 million tonnes.
- o Probable reserves - 7.8 million tonnes.

These mineable coal reserves include:

- o 29.4 million tonnes from the main seam.
- o 6.2 million tonnes from the upper seam.

The area still needs additional drilling exploration.

4. Properties

These are homogenous sub-bituminous deposits having high volatile coal with fair coking properties.

## IX. SHARM EL SHEIKH MANGANESE ORES

The area of Sharm El Sheikh is at present inaccessible from the Egyptian side. Therefore, it was not possible for our field team to make any site visits.

It is useful, however, to site the data pertaining to Sharm El Sheikh manganese deposits obtained from previous reports. At Sharm El Sheikh, manganese and iron oxides are known to occur in association with 4-meter-thick sandstones and conglomerates. The area is cut by several faults running northwest to southeast, commonly filled with manganese minerals. It is believed that these deposits were formed by the action of percolating surface waters. The chemical analysis of two samples as reported by Hime (1906) is as follows:

| | Sample 1 | Sample 2 |
|---|---|---|
| $SiO_2$ + I.R. | 54.78 | 70.10 |
| $Al_2O_3 + Fe_2O_3$ | 2.32 | 12.92 |
| $MnO_2$ | 30.33 | 12.67 |
| CaO | Tr. | Tr. |
| MgO | - | Tr. |
| L.O.I. | 9.48 | 5.06 |
| | 100.75 | 96.91 |

In June 1961, SMC made a study trip to the area. At a site named Sharm Moba a 4-meter-deep old pit was found. The thickness of the ore here is about 3 meters and extends about 1500 meters toward the northeast.

Surface exploration was carried out by SMC in the area of Sharm El Sheikh, and several veins were discovered. Most important of these is the vein of Wadi Khoreita which extends for 200 meters with a thickness of 2 to 3 meters. Trenches across the vein strike were also executed to validate the vein extension and thickness variation. Another vein with a thickness of about 2 meters was discovered at Wadi Telet Fadda.

The results of chemical analyses of samples taken from these sites are reported as follows:

| Area | Sample No. | Mn % | Fe % | Remarks |
|---|---|---|---|---|
| Sharm Moba | 1 | 14.9 | 1.2 | At contact of vein with granite |
| | 2 | 24.8 | 24.8 | At middle of vein |
| | 3 | 13.4 | 1.6 | At contact of vein with sandstone |
| Wadi Khorate | 4 | 51.3 | 3.4 | At middle of vein |

The vertical downward extension of these veins has not been determined. Until now, the ore can only be classed as possible.

# X. PETROLEUM COKE

## A. Location

Petroleum coke comes from Suez refineries.

## B. Availability

Information from ACB telex 611 of August 18, 1980 advises that petroleum coke availability from production starting in 1983 will be over 20,000 t/y. The projected demand for the rehabilitated smelter is 15,000 to 20,000 t/y.

## C. Prices

In 1976 a contract was concluded with the Aluminum Complex at a price of US$ 50/tonne. The present price is about US$ 70/tonne.

## D. Characteristics

The following table shows the characteristics of the Belayim petroleum coke:

| | |
|---|---|
| Cube density | 0.960 |
| Sulphur % Wt. | 5.2 |
| $N_2$ % Wt. | 2.0 |
| Ash % Wt. | 0.4 |
| C/H Ratio | 87.2/4.3 |
| Volatile matter % Wt. | 14.5 |
| Calorific value (net calculated) | 15,000 btu/lb |
| Metal content ppm: | |
| Ca | 110 |
| Cr | 9 |
| Cu | 11 |
| Fe | 83 |
| Ni | 380 |
| Si | 410 |
| Na | 130 |
| V | 350-500 |
| Mg | 14 |
| Co | 0.8 |
| Mo | 2.0 |
| Pb | 3 |
| Ti | 14 |

## E. Transport, Receiving and Storage

Petroleum coke from the nearest refinery at Suez could be directly trucked to the coke stores at Abu Zeneima. It could also be transported by sea from Suez to the Abu Zeneima service jetty. From here it could be trucked to the coke storage within the industrial zone.

## XI. NAPTHA

The gas/liquids separation plants operated by Petrobel and Deminex will produce large quantities of naptha, which may be used for haul truck fuel. Specifications are attached as submitted by the EGPC. As yet, no confirmation on available quantities or costs has been received. Therefore, costs for truck haulage in this report were based on use of normal diesel fuel. The subject may be re-examined in Stage 2, when more information is available.

EGYPTIAN GENERAL PETROLEUM CORPORATION

# SPECIFICATIONS OF STRAIGHT RUN NAPHTHA FOR EXPORTATION FROM ALEXANDRIA (& Suez)

| TEST | | | METHOD | RESULT |
|---|---|---|---|---|
| Specific Gravity at 60/60 | °F | | ASTM D - 1298 | 0.690-0.73 |
| Colour | | | By inspection | Colourless |
| R V.P. $Kg/cm^2$ at 100 | °F | (Max) | ASTM D - 323 | 0.70 |
| Sulphur content % wt | | (Max) | ASTM D - 1266 | 0.05 |
| Gum content (mg/100 ml) | | (Max) | ASTM D - 381-70 | 2.0 |
| Lead content | | (Max) | ASTM D 3116/72 | 50 P.P.B. |
| Octane NO. (Motor Method) | | (Min) | ASTM D 2700/75 | 50 |
| Distillation : | | | ASTM D 86/67 | |
| I.B.P | °C | | | 35 - 55 |
| 10 % distilled @ | °C | (Max) | | 80 |
| 50 % distilled @ | °C | (Max) | | 130 |
| 90 % distilled @ | °C | (Max) | | 165 |
| F.B.P. | °C | (Max) | | 175 |
| PONA Analysis : | | | ASTM D 1319/70 & UOP 273 | |
| Olefins % vol. | | (Max) | | 0.5 |
| Naphthenes % vol. | | (Min) | | 22.0 |
| Aromatics % vol. | | | | 4.0 - 8.0 |
| Paraffins % vol. | | | | Balance |



21/5/1980

CATERPILLAR TRACTOR CO.

Peoria, Illinois 61629

August 28, 1980

Mr. George Aiken
Chief Mining Engineer
Kaiser Engineering
P. O. Box 23210
Oakland CA 94623

Dear George:

This is to followup our telephone conversation of today in which we had discussed the Suez Refinery naptha fuel product as a Caterpillar diesel engine fuel.

We concluded, based on the information that you have provided, that the fuel would not be acceptable for use in Caterpillar diesel engines. The limiting factors would most likely be the cetane number and viscosity. Both of these values were not provided but based on the distillation data that was supplied, we believe the cetane number would fall below our minimum requirements of 35 for precombustion chamber engines and 40 on direct injection engines. The viscosity, likewise, would probably be below our minimum requirement of 1.4 cst @ 100$^{o}$ F.

We must also caution against the blending of this fuel with No. 2 diesel fuel. Fuel blends having flash points lower than 100$^{o}$ F can create extremely volatile air/fuel mixtures in storage or service fuel tanks. I have included a copy of an article that we have recently published to further explain this safety hazard.

George, I apologize for the delay in answering your inquiry, and I hope that this is the information you were looking for.

Very truly yours,

James E. Williams

Service Engineering G.O.

JEWilliams
Telephone: (309) 675-6149
plf/attach.

CATERPILLAR

# SERVICE MAGAZINE

February 11, 1980

## Warning: Avoid Use Of Fuel Mixtures Of High Volatility. If You Are Exposed To Such Mixtures, Be Aware Of The Hazards Involved And Take Proper Precautions

**1280**

Diesel fuels combined with gasoline, naphtha, or other highly volatile fuels can be dangerous. BECAUSE OF THE SAFETY HAZARDS INVOLVED, CATERPILLAR DOES NOT RECOMMEND THE USE OF GASOLINE/DIESEL FUEL OR NAPHTHA/DIESEL FUEL BLENDS. Extreme caution must be exercised when these volatile fuel mixtures are present.

Gasoline and naphtha are light aromatic distillates of petroleum. When either of these fuels are combined with diesel fuel (No. 1 or No. 2) or kerosene, fuel blends of high volatility can result. The volatility of these blends could lie in a dangerous range even if a small percentage of gasoline or naphtha is added to the diesel fuel.

In a fuel tank, the vapor in the air space above pure diesel fuel is too lean to be a hazard at normal ambient temperatures. The vapor in a tank that contains pure gasoline or naphtha is too rich. However, when diesel fuel is mixed with gasoline or naphtha, the vapor-to-air ratios can be explosive. This vapor above the fuel in the fuel tank can be ignited by sparks, flames, electric arcing, and even static electric charges.

There are several reasons why such fuel blends are used. The most common is probably to combat fuel filter plugging problems (waxing) experienced in cold temperatures. Also in some areas, diesel fuel may be in short supply while gasoline or naphtha is readily available. Users may blend the fuels to extend the diesel fuel supply.

Mechanically, Caterpillar engines can accept certain proportions of gasoline or naphtha blended with diesel fuel without major effects on performance or engine life.

With this in mind, it is quite possible that hazardous fuel blends will be used by diesel equipment owners and operators—especially during periods of cold temperatures. It is for this reason, personnel who work with, on, or near diesel-powered equipment should be made aware of the safety hazards involved. SAFETY PRACTICES WHICH MAY HAVE WORKED WELL WHEN IN CONTACT WITH PURE DIESEL FUEL WILL NOT BE ADEQUATE WHEN DEALING WITH THESE BLENDS.

As it will be difficult at times to detect the usage of a fuel blend, we recommend that the following precautions be observed by personnel in contact with diesel fuels and diesel-powered equipment:

1. Do not smoke in areas where fuels are handled or used.

2. Keep heat sources, flames, sparks, electric arcing, etc. well away from storage or service tanks.

3. Prevent careless handling, fuel spillage, and tank leakage and exercise the above precautions if accidental spillage does occur.

4. Handle all fuels only in well ventilated areas.

5. Make sure that storage tanks are vented outside of buildings or enclosures and never into unventilated areas.

6. When transferring fuels from one tank to another, ensure that both tanks are grounded to a common ground or that they are electrically connected or bonded.

7. Always keep first aid and fire extinguishing equipment that is suitable for use on oil fires maintained and within easy access.

We recommend that this information be brought to the attention of all personnel who have contact with diesel fuels and diesel-powered equipment.

Refer to the articles "Fuel Heaters Are Now Available For Field Installation", SERVICE MAGAZINE, January 7, 1980 and "General Information—Diesel Fuels In Cold Temperature Operation", SERVICE MAGAZINE, December 17, 1979, for practical and safe solutions to cold temperature operation problems.

**WARNING**

THE USE OF FUEL HEATERS IN COMBINATION WITH HAZARDOUS FUEL BLENDS SHOULD BE AVOIDED. FUEL VOLATILITY INCREASES AS FUEL TEMPERATURE INCREASES. ■

## New Bearing Retainer Plate Is Used In Carrier Rollers

**4154**

**D9H and DD9H Tractors; 594H Pipelayers**

DESCRIPTION OF CHANGE: A new bearing retainer plate is used in the carrier rollers on D9H and DD9H Tractors, and 594H Pipelayers. This new bearing retainer plate is heat treated for added strength and longer service life. It was possible for the former bearing retainer plate to bend. The result is a loss of seal face load and a loss of oil.

ADAPTABLE AS: The new 9G7037 Bearing Retainer Plate is a direct replacement for the former 3P3401 Bearing Retainer Plate, which is canceled. ■

## New Gasket Gives A Better Seal Between The Flywheel Housing And Cylinder Block

**1157, 1201**

**D8K Tractors; 583K Pipelayers**

DESCRIPTION OF CHANGE: A different gasket is now used between the flywheel housing and the cylinder block on D8K Tractors and 583K Pipelayers. The new gasket is narrower than the former gasket in the area near the bore for the camshaft. This gives more load on the gasket in this area to prevent oil leaks.

ADAPTABLE AS: The new 8N9575 Gasket is a direct replacement for the former 2M7961 Gasket which is canceled. ■

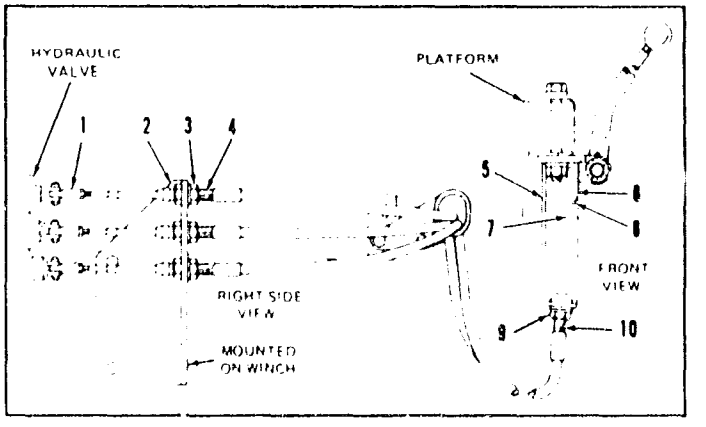
## Correct Procedure For Adjustment Of Hydraulic Valve Control Cables

**5063**

**528 Grapple Skidders (78W)**

According to field reports, wrong adjustment of the hydraulic valve control cables on some 528 Grapple Skidders has caused short cable service life and/or prevented good performance of the grapple. For maximum performance and cable service life, use the procedure that follows to adjust the control cables. This procedure will be added to the Service Manual at the time of the next revision.

CONTROL CABLE ADJUSTMENT: Reference numbers are shown in the illustration.




Hydraulic control cables. 1—Eyes. 2—Bracket. 3—Nuts. 4—Cable housing ends. 5—Bracket. 6—Rod ends. 7—Cable ends. 8—Nuts. 9—Nuts. 10—Cable housing ends.

1 Install nuts (8) and rod ends (6) on the ends of the cables (7) so the cable ends are all the way through the threads of the rod ends, and are even with the inside of the rod ends. Tighten the nuts (8) against the rod ends (6).

2 Fit the cable housing ends (10) into the center of slots in bracket (5) and tighten nuts (9).

3 Assemble bracket (5) to platform with bolts through the slotted holes in the bracket.

**NOTE**

The slotted holes in the bracket permit adjustment to limit cable travel (movement) if necessary. At the initial (first) assembly, slide the bracket to move the levers as far as possible away from the platform, and permit maximum lever movement.

4 Install cables through the rear of the platform and the cable guides.

5 Fit the cable housing ends (4) into center of slots in bracket (2) and tighten nuts (3).

6 Assemble the eyes (1) and nuts on the cable ends. Adjust each eye so the valve stem moves 10.2 mm (.40") when the control lever is moved against the platform.

# XII. GYPSUM

## A. Location

Gypsum and anhydrite form huge lenselike formations in Miocene rocks which extend along the western margins of the Sinai Peninsula from the Bitter lakes to the proximity of El Tor. The thickness and extension of these deposits vary greatly from one locality to another, but the reserves are huge. The most prominant locality for gypsum-anhydrite production in Sinai is Ras Malaab near Wadi Gharandal, in the eastern coast of the Gulf of Suez, some 100 km south of Suez.

## B. Geology

At Ras Malaab, the gypsum-anhydrite deposit developed during the Miocene Age. In some cases, the gypsum is covered by contorted and squeezed beds of foliated shales and anhydrite. The latter forms generally an outer layer surrounding the gypsum deposit, or as fillings of fracture planes cutting across the gypsum in a random manner. This indicates that gypsum is transformed into anhydrite through the action of weathering agents.

The evaporite succession lies unconformably over tilted lower Miocene basal conglomerates intercalated with day bands. This unconformity separates between the lower open sea sediments and the upper evaporite closed basin deposits.

## C. Ore Types

Three main types are distinguished in the deposit of Ras Malaab:

- Alabaster gypsum, massive and banded.
- Micaceous gypsum; coarsely crystalline and foliated.
- Anhydrate, massive and hard.

## D. Mode of Occurrence

The three main beds can be distinguished from top to bottom by:

- Bed $G_1$: with a thickness of 20-25 meters. It is composed of either alabaster, micaceous gypsum or anhydrite.

- Bed $G_2$: with about 5-meter thickness. It is composed mainly of micaceous gypsum.
- Bed $G_3$: with a thickness variable from 10 to 50 meters. It is composed of alabaster and micaceous gypsum.

These beds show variable degrees of lateral variation in ore type and thickness. Moreover, contorted and squeezed beds of green foliated shales are frequently intercalated either between these beds or still within one of them.

## E. Method of Extraction and Haulage of Ore

The extraction was being carried out until 1967 by open-pit methods from quarry faces. The rock was extracted by compressed air drilling and blasted. The ore was selected in the quarry and had been transported by trucks to the jetty stockpiles. The one-$m^3$ mine cars carry the ore to be loaded to lighters which carry it out to the ships at anchorage where it is off loaded from the lighters. Another haulage method was suggested to haul the ore from the quarries using bi-cable tramways and the lighter to ship-loading method. However, this was never implemented.

## F. Ore Reserves

The ore reserves have been calculated by blocks and beds and are differentiated into three ore types: alabaster, micaceous gypsum and anhydrite. The table below summarizes the distribution of ore reserves:

Ore Reserves of Gypsum and Anhydrite

in Ras Malaab Area

| Block No. | Bed | Type | Average Area $m^2$ 0005 | Average thick (meters) | Tonnes 000,000's | Working Method | Transport Method | Availability |
|---|---|---|---|---|---|---|---|---|
| $A_1$ | $G_3$ | Alabaster | 12 | 10 | .25 | D & B | Road | Immediate |
| $A_2$ | $G_3$ | Alabaster | 150 | 20 | 6 | D & B | R'way 1 | 3 years |
| $A_3$ | $G_3$ | Alabaster | 200 | 10 | 4 | D & B | R'way I | 20 years |
| $A_4$ | $G_3$ | Alabaster | 960 | 25 | 48 | D & B | R'way III | +20 years |
| $A_5$ | $G_3$ | Alabaster | 560 | 50 | 56 | D & B | R'way V | 2 |
| $A_6$ | $G_3$ | Alabaster | 540 | 30 | 32 | D & B | Road | 3 months |
| $A_7$ | $G_1$ | Alabaster | 10 | 20 | .4 | D & B | Road | 4 months |
| $M_1$ | $G_1$ | Micaceous | 20 | 20 | .8 | D & B | Road | 2 months |
| $M_2$ | $G_2$ | Micaceous | 25 | 5 | .25 | Rip | Road | 1 year |
| $M_3$ | $G_2$ | Micaceous | 30 | 5 | .30 | Rip | Road | 1 year |
| $M_4$ | $G_3$ | Micaceous | 200 | 10 | 4 | Rip | R'way 1 | 3 years |
| $M_5$ | $G_3$ | Micaceous | 200 | 20 | 8 | Rip | R'way III | + 20 years |
| $M_6$ | $G_3$ | Micaceous | 840 | 10 | 17.0 | Rip | R'way IV | 50 years |
| $M_7$ | $G_3$ | Micaceous | 270 | 20 | 11.0 | D & B | R'way II | 20 years |
| $An_1$ | $G_1$ | Anhydrite | 20 | 25 | 1 | shovel | R'way I | 3 years |

D- drilling B- blasting R'way = roadway

The total ore reserves reach 188 million tonnes of which 146 millions are Alabaster, 41 millions are micaceous gypsum and 1 million are anhydrite.

## G. Grade and Composition of Ore

Thirty samples have been selected for various types of analyses. From the samples, the table below indicates the quality of both gypsum and anhydrites.

| | Gypsum | | | | Anhydrite | |
|---|---|---|---|---|---|---|
| Element | Minimum | Max | Average Min 9 samples | | Map | Average 3 samples |
| $SiO_2$ | 0.09 | 0.50 | 0.24 | 0.27 | 1.22 | 0.72 |
| $Al_2O_3$ | - | - | - | - | - | - |
| $Fe_2O_3$ | - | 0.08 | 0.04 | 0.05 | 0.08 | 0.07 |
| CaO | 31.09 | 32.66 | 31.67 | 38.13 | 39.52 | 38.72 |
| MgO | - | 0.40 | 0.10 | - | 1.00 | 0.64 |
| $Na_2O$ | - | 0.03 | 0.01 | 0.03 | 0.92 | 0.46 |
| $K_2O$ | - | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 |
| $TiO_2$ | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| MnO | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| $H_2O^-$ | 14.22 | 15.61 | 14.99 | 0.17 | 1.04 | 0.68 |
| $H_2O^+$ | 4.43 | 5.69 | 5.17 | 1.45 | 2.75 | 2.14 |
| $CO_2$ | 0.14 | 0.82 | 0.57 | 0.56 | 2.43 | 1.31 |
| $SO_3$ | 45.72 | 48.86 | 47.32 | 53.16 | 56.11 | 54.78 |
| Cl | - | 0.01 | 0.01 | - | 2.18 | 0.99 |

The average total of $CaO.+ SO_3 + H_2O^- + H_2O^+$ for gypsum is 99.15% and for anhydrite is 96.32%. This is indicative of the high purity of gypsum and the relative purity of anhydrite. In anhydrite, chlorinem sodium carbon dioxide and silica are the main contaminents. For example, halite, dolomite and quartz are present in small amounts in the gypsum samples.

The X-ray powder diffraction analysis corroborates presence of these small amounts of contaminants. The average specific gravity of gypsum is 2.18, while that of anhydrite is 2.56. The average value for Vickers hardness for gypsum is 23.89, while for anhydrite it is 13.

APPENDIX 4

(III.B.4)

Other Minerals, SMC Leases

TABLE OF CONTENTS


- Minerals Currently Being Exploited
- Other Potential Minerals Not Currently Exploited

# I. MINERALS CURRENTLY BEING EXPLOITED

## A. Clays

### 1. General

The clays currently exploited by SMC in west central Sinai include three main varieties: kaolin, white clay, and carbonaceous (semi-fatty) clay. According to the documents delivered by SMC, the kaolin occurs in the Upper Carboniferous succession at Abu Natsh, Shalal (Wadi Budra), Abu Kafas, and Geni. The white clay is included in the deposits of the Nubia Formation at Musabba Salama, Wadi Khaboba, Dehissa, Farsh El Guzlan, and Om Eleigan as well as in the region of Gebel El Tih. The semi-fatty (carbonaceous) clay occurs in the Upper Carboniferous at Khaboba, Dababat, and Wadi Talha, with variable shades of dark coloration according to the content of carbonaceous material.

However, the results of the various analyses carried out on samples of these clay varieties indicate that the clay of the Nubia Formation belongs to the category of kaolin. Clays of the Upper Carboniferous are either white (fatty) or carbonaceous (semi-fatty).

### 2. Kaolin Clays

#### a. Historical

During World War II exploration for kaolin started. This resulted in the discovery of the deposits at Musabba Salama, Mezar El Qor Wadi Natsh, Wadi Budra and Wadi Faran. Individual private sector activities began in 1955 by engineers E. El Alfi at Wadi Abu Natsh, M. El Sabaa at Gebel Musabba Salama, and by G. Awad and M. Soliman. At the end of 1959, the Helwan Portland Cement Company applied for a prospecting license for kaolin in the Abu Natsh District.

SMC started to prospect for kaolin in Wadi Natsh for the Helwan Portland Cement Company. These prospecting operations which had been done in Wadi Natsh included 260 linear meters of tunnel and 500 cubic meters of trenches. The Egyptian Mining Authority entrusted SMC to execute a prospecting program in the Carboniferous for kaolin. This included trenching in the district El Qor, El Saaho, Wadi Rakaiz, Budra, Wadi Geni, and Wadi Narsh. After completing the preliminary exploration, SMC concluded that the Wadi Geni kaolin bed was suitable for exploitation. The deposit had possible ore reserves of 25,000 tonnes while the other districts gave negative results

due to the high percentage of iron in the kaolin. At the end of 1960, SMC kaolin prospecting activities extended to the Cretaceous in Wadi Om Allian, Farsh El Guzlan, El Harabiat Wad El Fidfafa, and El Riyaina. The results of SMC's exploration operations indicated that the Dehissa district and Farsh El Guzlan had good kaolin prospects. The prospecting operations done in this district included 2,000 cubic meters of trenches and a few inclined shafts.

As a result of the kaolin prospecting work done by SMC, the total probable ore reserve was reported to be 75,000 tonnes. Great quantities of kaolin were discovered but it was not exploitable due to the high percentage of silica and iron. The kaolin samples taken were tested by:

- The National Research Center - studied the possibility of purification of the ore to suit the paper industries. The results using the wet process were negative.

- Rakta Company, Dr. Grant.

- Dr. CH. Shukri Girguis - studied the possibility of purification of the ore to suit the paper industry by using hydrochloric and nitric acids and chlorine.

- (G.O.F.I.) - tested kaolin for the use in aluminum extraction.

- Japan and England - conducted experiments to get rid of the impurities and to determine whether kaolin could be upgraded to be suitable for various industries. They also investigated the possibility of erecting a grinding unit at the Sinai mines. In November 1961, the tests which had been carried out by Dr. Robertson in England gave good results in the separation of the silica from the ore. Dr. Robertson's report stated the following:

  "The ore must be milled in a Super Micron Mill in which it is possible to separate the materials by air."

  The pulverizing operation was done in two stages and produced three grades of material.

  - To pulverize the ore to 200 - 300 mesh.

  - To pulverize the ore to 0.5 micron.

  The metallurgical analysis of the final product was as follows:

| | |
|---|---|
| Kaolinite Clay | 89.1% |
| Feldspar | 6.1% |
| Bohmite | 2.8% |
| Aratese | 1.5% |
| Goethite | 1.2% |
| Solubles | 0.2% |
| | 100.3% |

The differential thermal analysis showed that the kaolin ore is in a complete crystalline condition. It does not contain free aluminum hydrate or hallusite and the iron oxide is present in the form of hematite and not goethite.

Engineer El Sabaa commented that the mill had separated the free silica only and did not do any separation of the iron. Due to the pulverizing operation there was a 12% loss of ore. It was proposed to continue experiments on all the clays.

The chemical analysis of the samples of Cretaceous kaolin after burning is shown in the following table:

| | Original | 1st Product | 2nd Product | |
|---|---|---|---|---|
| "Non Burnt" Alumina | 36.7 | 35.18 | 39.04 | 40.00 |
| Silica | 46.6 | 17.11 | 46.08 | 43.94 |
| Alumina | 43.07 | 42.38 | 45.50 | 47.05 |
| Iron | 1.0 | 1.0 | 0.90 | 1.00 |
| Water | 15.97 | 17.00 | 14.38 | 14.88 |

This analysis shows that by using the Micron Mill separator we can get rid of free silica. Due to these previous experiments, SMC decided to erect a pilot plant for grinding kaolin in Abu Zeneima which was planned to include the following units:

- One Hosokawa grinding mill.
- One magnetic separator.
- One Shimadzu sedimentograph.
- One Hosokawa impeller breaker.

- One 21-inch-dia dust collector high efficiency cyclone fitted with dust storage hopper.

In April 1962, the Geological and Mining Prospection Department carried on experiments and analysis for kaolin samples. These consisted of primary and seondary crushing, grinding in a ball mill for one hour, and then leaching by 5% diluted hydrochloric acid for two hours while heating to 80°C. The results were as follows:

- Decrease of ferric oxide from 0.69% to 0.64%.
- Humidity: 1.27%
- Combined water: 12.25%
- Specific gravity: 2.6
- The degree of whiteness was not determined.

The kaolin deposits exploited by SMC in the study area occur in the form of beds intercalated within the Nubia Formation. They were exploited until May 1967 in four main leases:

- Musabba Salama West
- Musabba Salama East
- El Dehissa
- Farsh El Guzlan

b. Geology and Mode of Occurrence

A common geological feature for all the kaolin deposits mentioned above is that the economic clay beds occur as intercalations in the upper part of the Nubia Formation. The beds are some meters below the conformable contact with the overlying Cenomanian rocks. Rocks of the Nubia Formation are relatively common in the study area particularly in the northern parts. However, the kaolin deposits are limited to the vicinity of contact with the Nubia Formation/Cenomanian that only outcrops along the western borders of the area. This primarily is due to the fact that the relatively elevated Precambrian-Carboniferous terrain forming the major part of the study area does not include any younger formations. It is only along the downthrown western peripheral zones that the Nubia Formation and the younger rocks are outcropping; moreover, towards the north in the direction of the general dip, a gradual passage of the Nubia

Formation below the surface takes place not far from the southern foothills of Gebel El Tih. Any further prospecting work should be carried out along the western zone to the north of Gebel Sarbut El Gamal and particularly along the upper reaches of Wadi Insakar and on the western borders of Gebel El Iseila. This recommended prospecting area is limited on the west by the main fault parallel to the Gulf of Suez marking the fault contact between Miocene and older rocks. The same possibilities of finding kaolin are valid for the foothills of the Tih escarpment, representing the northern limit of the recommended prospecting area; however, mining and transport conditions are more difficult. Prospecting in the southwestern zones of the study area around Wadi Budra and Farsh El Guzlan should be equally initiated. However, it is believed that the possibilities in this area are relatively limited.

Specifically, two areas are recommended to be geologically studied and mapped for kaolin prospecting. The first area is limited by latitude 29° 13' N and longitude 33° 11' E and 33° 13' E and includes Wadi Insakar and Wadi Iseila. The second area is limited by latitude 28° 55' N and 28° 57' N and longitude 33° 17' E and 33° 19' E and mainly includes Farsh El Guzlan. Reconnaissance work in the northern zones of the area at the foothills of El Tih should be eventually undertaken as part of a continuing kaolin prospecting program.

Kaolin deposits occur in the form of two main beds:

- The upper bed, which is the economically exploitable one, with a thickness varying from 120 - 190 cm.

- The lower bed, separated from the upper one by 8 - 10 meters of sandy and silty clays. The average thickness is about 125 cm and it contains a relatively high content of quartz and iron oxides, making it non-marketable and consequently unexploitable.

The upper economic bed lies some 40 meters below the conformable contact surface between the Nubia Formation and the overlying Cenomanian succession. The general strike in the whole area is N 30°-32° west and the dip varies from 18°-25° southwest.

At the mine of Musabba Salama west, the upward continuation of the ore bed is represented by 40-50 cm of siliceous clay, usually not mined, followed by a few centimeters of marker band of ferruginous sandstone and most probably a hiatus surface.

c. Kaolin Reserves

According to SMC documents the kaolin reserves on May 1, 1967, reported as white clay, are as follows:

| Proven | Probable | Possible |
|---|---|---|
| 27,610 tonnes | 25,000 tonnes | 28,000 tonnes |

The company did not perform any exploration work from January 1, 1966, to May 1, 1967. Consequently, no new reserves were added or any upgrading of old reserves achieved.

The above reserves are those included in the SMC leases. SMC did not carry out any significant exploration efforts outside these leases. In 1958, Salizgeter carried out studies in west-central Sinai and projected very large amounts of reserves that need to be verified as to quality and quantity by a detailed long-term program.

3. White Clays

The white clay deposits exploited by SMC in the study area occur in the form of beds intercalated with the upper Carboniferous sandstone succession (Abu Zarab Formation). They have been exploited under the name of kaolinitic clays from several mines until 1967. These locations are:

- Wadi Budra (lease)
- Abu Natsh (lease)
- Abu Kafas (lease)
- Wadi Geni (lease)

a. Geology and Mode of Occurrence

All the occurrences of white clays in the study area show common geological features. Three clay beds can be recognized:

- The upper bed lies at about 4 to 5 meters below the upper contact of Abu Zarab Formation with the covering basalt sheets. The clay is only 40-60 cm thick and is unsuitable for economic exploitation.

- The middle bed lies 4 to 6 meters below the upper bed and about 10 to 12 meters below the upper contact of the Abu Zarab Formation. The thickness of the bed varies from 60 to 125 cm with an average thickness of

about 85 cm. This bed is the economic one and was previously exploited.

- The lower bed is separated from the middle economic bed by 6 to 8 meters of sandstone. Its thickness reaches 80 cm on the average, but the quality is poorer than the overlying economic bed. The lower bed has not been previously exploited.

The general strike of the beds in the area is northwest to southeast dipping southwest, up to 10 degrees.

During the current field work occurrences of white clays have been recorded at many locations of the study area, e.g., El Qor, Marahil, and Farsh El Azraq. It is recommended that the clays be prospected by following their stratigraphy. A large number of samples should be collected from many areas and be tested chemically and physically. The prospects for increasing known clay reserves are excellent.

b. Clay Reserves

According to SMC documents the white clay reserves on May 1, 1967, reported as kaolinitic clay, are as follows:

| Proven | Probable | Possible |
|---|---|---|
| 23,418 tonnes | 39,000 tonnes | 37,000 tonnes |

As for kaolin, SMC did not carry out any exploration work during the years 1966 and 1967. The above given reserves are those included within the SMC leases. In a 1948 report prepared by Salizgater huge reserves were indicated to be verified by further exploration.

4. Carbonaceous Clay

Carbonaceous clays were exploited by SMC only at Wadi Khaboba but occurrences were also recorded at Dababat and Wadi Talha. During current field work other locations have also been recorded, e.g., Wadi Sih Sidri in the south and Wadi Om Zaweibin to the north of Musabba Salama.

The carbonaceous clays occur in the Upper Carboniferous sandstones forming the Abu Zarab Formation. Their stratigraphic level lies immediately below that of white glass sands, i.e. 15-20 meters below the level of white clays. During the field studies it was noticed that there is a marked lateral variation in the content of carbonaceous matter in these clays. Thus carbonaceous clays may pass laterally into black clays not far from low grade coal.

However, the actual relation between these carbonaceous clays and the coal deposits of Budra and Thora, which seem to occupy rather the same stratigraphic level, is still under inspection and no conclusions can be made at present.

5. Production of Clays

Production of kaolin and clay was undertaken by underground room and pillar methods except the carbonaceous clay of Khaboba. The total production of clays from 1962 until 1967 was as follows:

| Year | 1962/63 | 63/64 | 64/65 | 65/66 | 66/67 |
|---|---|---|---|---|---|
| Tonnes | 9,092 | 29,000 | 46,472 | 25,950 | 30,154 |

6. Transport and Packing of Clays

The clay was transported exclusively by trucks from the various mines to Abu Zeneima and by ships or motor schooners from Abu Zeneima to Suez. From Suez it was trucked to the various consumers. The clay was packed in 50-kg secondhand jute sacks to prevent contamination and facilitate the loading and unloading processes. Sacks also reduced in-transit losses.

7. Marketing and Prices of Clays

Most of the kaolin and clay produced was being consumed by the local market. Limited quantities were exported to Serma Company, Italy. An amount of 12,000 tonnes was contracted for during the year 1966/1967, but only 6,340 tonnes were delivered before the 1967 war. The following table displays quantities, local prices, franco consumer and FOB export prices for 1965-1967.

| | 1965/66 | | | 1966/67 | | |
|---|---|---|---|---|---|---|
| | Quant. (tonnes) | Value/ LE | Price/ tonne LE | Quant. (tonnes) | Value/ LE | Price/ Tonne LE |
| Local Market | 18,274 | 142,950 | 7,822 | 24,998 | 187,939 | 7,518 |
| Foreign Market | 8,726 | 42,759 | 4,900 | 6,340 | 31,056 | 4,898 |
| Total | 27,000 | 185,609 | | 31,338 | 218,995 | |

8. Sinai Clay Stocks - 1967

There are 25,693 tonnes of white and carbonaceous clay at various mine sites and 7,904 tonnes of white and carbonaceous clay at Abu Zeneima, for an overall total of 32,597 tonnes.

B. Glass Sand

1. Mining Rights

White sands suitable for glass industry were exploited at Khaboba, Abu Natsh, and Abu Kafas.

## 2. Geology

The glass sands form part of the Abu Zarab Formation occupying a horizon about four meters below the bottom of the lower bed of white clays. The thickness of this glass sand varies from 8 to 12 meters, but is commonly about 10 meters thick.

This white sand horizon has been recorded at many locations where the Abu Zarab Formation outcrops, but only in a few cases do the particular specifications justify its suitability for the glass industry. The chemical purity, mechanical grain size, and relative homogenity have to be tested carefully to certify suitability for the glass industry in general and particularly glass tableware.

Therefore, large scale sampling of the white sand horizon is recommended for future programs. Through selective analytical assays of the collected samples it may be possible to verify new findings of large quantities of high quality glass sand.

## 3. Quality

The following table gives the chemical analysis of the glass sands produced from Khaboba and Abu Natsh as given in SMC documents:

| Element | Khaboba | Abu Natsh |
|---|---|---|
| $SiO_2$ | 97.5-98.5 | 98.0-99.0 |
| $Fe_2O_3$ | 0.02-0.04 | 0.02-0.06 |
| $TiO_2$ | Traces | Traces |
| $Al_2O_3$ | 0.09-0.10 | 0.0-0.10 |
| L.O.I. | 0.02-0.25 | 0.15-0.30 |

## 4. Production of Glass Sand

The production of glass sand during the period 1962-1967 is shown in the following table:

| Year | Tonnes |
|---|---|
| 1962/1963 | 3,842 |
| 1963/1964 | 18,000 |
| 1964/1965 | 11,130 |
| 1965/1966 | 21,252 |
| 1966/1967 | 25,484 |

The following table shows the mechanical analysis:

| Mesh | Khaboba | Abu Natsh |
|---|---|---|
| + 30 | 1-6 % | 1-2 % |
| + 40 | 12-20% | 6-20% |
| + 50 | 7-15% | 20-46% |
| + 60 | 8-14% | 14-20% |
| + 80 | 25-50% | 14-50% |
| +100 | 6-11% | 1-2 % |
| +110 | 10-12% | 1-2 % |
| -110 | | |

5. Stocked Quantities of Glass Sand

On May 31, 1967, there were 1,681 tonnes stocked in the quarries and 29 tonnes at Abu Zeneima.

6. Marketing and Prices of Glass Sand

Previous glass sand production was directed to the local market. Quantities of sand sold and the price to consumers during the two years before 1967 are as follows:

| | 1965/66 | 1966/67 |
|---|---|---|
| Quantity Tonnes | 18,695 | 24,170 |
| Value LE | 111,900 | 148,847 |
| Price/tonne LE | 5.986 | 6.158 |

C. Turquoise

Since the 4th Dynasty, turquoise was exploited by the ancient Egyptians from the Sinai. The old mines included Gebel Maghara and Sarabet El Khadim. At the present time, the local Bedouins engage in limited exploitation of turquoise from the old mines. Extraction is by primitive hand methods requiring extensive manual sorting of barren material.

Turquoise occurs in the form of small concretions along cracks and voids in the sandstones of the Adedia Formation. It is commonly accompanied by iron oxides which are taken as indicators of turquoise. It is believed that turquoise was formed by

percolating surface waters. However, any organized exploitation of turquoise in the Sinai should be preceded by a statistical study to indicate the distribution and intensity of mineralization at each of the proposed sites. The results of this could be used to determine the viability of commercial operations.

## II. OTHER POTENTIAL MINERALS NOT CURRENTLY EXPLOITED

### A. Copper

In the southern Sinai prospects for copper mineralization should not be neglected in future planning for a mining industry. Support for the validity of such a statement includes three main topics:

- Ancient Egyptian copper mining and smelting activities occurred at Bir Nassib. It is known to be famous for its heaps of copper slags produced from primitive ancient Egyptian smelters. Although the field team could not find absolute evidence of old copper mines in the area, many collapsed underground workings, e.g. at Om Rinna, with relics of smelting copper near the entrances are thought to represent ancient copper mines. The ore is thought to have been produced from disseminated carbonate copper ores of the lower sandstone underlying the Om Bogma Formation. However, previous exploration for copper in the lower sandstone by Egyptian Geological Survey was negative.

- Shows of oxidized primary copper mineralization in the genisses of Wadi Fairan have been recorded. No significant work has been directed to these to define their possible extension and economic value.

- Copper deposits in Cambrian sandstones are known to be actually under exploitation along the Gulf of Aqaba. They are represented by secondary copper minerals, mostly carbonates, disseminated in the sand. This formation is comparable with the Sarabet El Khadim Formation, believed to be Cambrian, identified recently by El Shazly in the study area.

Considering the strong evidence for economic copper mineralization, extensive exploration programs in southern Sinai are warranted.

### B. Ornamental Stone

The main ornamental stone in the Om Bogma district is the granite of the Om Bogma batholith. One of the best occurrences of this granite is at Wadi Shelal to the east of Area 45 and north of Gebel Moneiga. This granite has a nice appearance when polished; however, two main factors have to be carefully studied before planning for its extraction as an ornamental stone. The first factor is the relative frequency of cracks which would hinder the production of large-sized blocks. The second factor is the elevation of sites by detailed and accurate examinations of the area.

## C. Construction and Building Stone

Limestones, hard quartzitic sandstones, and basalts are very common in the study area. Gravels, conglomerates and loose sands are also common. These represent the main raw materials for construction and building stone.

Different varieties of limestones suitable for construction are common in several rock facies. These belong to various geologic ages, particularly the Cretaceous and the Eocene. These limestones can be used for construction purposes, production of lime, road pavement, chemical industries, etc.

Sandstones suitable for construction purposes can be produced from beds in the Nubia Formation, as well as in the Carboniferous rocks.

Clays that are potentially usable in manufacturing clay bricks are well represented in the Cretaceous and Eocene rocks close to Abu Zeneima.

Part of the gypsum deposits of Ras Malaab can be used for the manufacture of cement, whose raw materials are easily supplied from the area.

## D. Fluorspar

During the field work, the KECI/ACB team found some signs of fluorspar in veins associated with granites. Prospecting fluorspar deposits should be directed to the Om Bogma pink granite batholith. This is most likely to contain the fluorspar mineralization needed for industrial purposes. Inspection of shear and fault zones cutting across the granitic rocks and affiliated younger granitoids can be expected to reveal fluorspar mineralization.

## E. Feldspar

The Om Bogma granite batholith may contain pegmatitic bodies from which feldspar can be extracted. Only few examples of small pegmatitic bodies could be recognized during the current field work. Specialized exploration should be directed toward feldspar deposits, based on small scale geologic mapping of areas of acidic basement rocks.

## F. Quartz

Quartz, either in the form of veins or as associated feldspar in larger pegmatitic bodies should be looked for in the Om Bogma pink granite batholithic intrusion. The exploration for quartz should be integrated with any programs for fluorspar and feldspar.

APPENDIX 5

(III.C)

Mining & Ore Transport

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o Description of Existing Conditions

# I. DESCRIPTION OF EXISTING CONDITIONS

## A. Previous Production

The production of manganese ore was mainly from underground workings. These supplied 80% of the total production, and 20% of the total production was produced from surface workings with overburden not exceeding 4 meters in thickness.

Table III.C-1 in Section III.C of the main text shows SMC production from the first operating year, 1918, until the last in June, 1967. The average analysis of the production is shown as manganese, iron, total (manganese + iron) silica and humidity.

Table III.C-1 also shows the average manganese and iron analyses and their combined percentages from 1918 until 1967. Based on these data, the following can be concluded:

- The manganese + iron percentage is about 57%.
- The manganese grade is decreasing.
- The iron grade is increasing.
- The manganese + iron percentage was nearly constant since 1953.
- The silica is gradually increasing.
- The manganese to iron ratio started at 3:1, fell to about 1:1, and ended as 2:3.

## B. Mining Operations

Underground and Surface Mining Systems were employed in the Om Bogma mines.

### 1. Underground Mining Methods

Room and pillar methods were used in Om Bogma manganese deposits. This mining method was employed since 1918, the beginning of the extraction of manganese ores in the Om Bogma district.

Attempts to use other methods instead of room and pillar were tried but never fully developed. A modified short-wall method was tried but abandoned because the hanging wall could not be sufficiently well controlled and timber consumption was high. This was due to extensive faulting in the area.

The room and pillar method was used for the following reasons:

- o Familiarity of the method by the miners.
- o A simple and flexible method.
- o Safety.
- o Little timber used.
- o Mining losses not great.

The disadvantages of the room and pillar method, as applied by SMC, were high explosive consumption and poor planning which did not comprehend a centralized mechanical approach to mining.

a. Room and Pillar Mining by SMC

Drilling and blasting of the face was done by three men and six laborers. The ore was loaded for mucking in one tonne rail cars pulled by diesel locomotives of 30 hp. Track gauge was 60 cm between the mine and ropeway bunkers. The ropeway, aerial tram, hauled the ore to Depot No. 2 from where the ore was moved by 130 hp diesel locomotives to bunkers and stockpiles at Abu Zeneima. Main line track gauge was 75 cm for 5-tonne ore cars.

After the ore between pillars was completely extracted, a retreat system was used to extract the pillars. Supported open stopes used timber props during retreat for roof support. Where timber could be recovered safely or was not used in the retreat, the roof was allowed to collapse. Timber props were all imported and no steel was used. Some timber had been removed, probably by local inhabitants over the abandoned years.

The headings normally used a cross section of 2 meters by 2 meters. The advance per round was about one linear meter and the heading rarely required support. Headings were done in the prospection period in order to maintain the ore reserves. As required, halageways for ore were through the development headings.

(1) Drilling

Because manganese dust has injurious effects on the health, water flushing was used in drilling. All water was pumped to the mines from the El Markha well. The drilling was done by three men or one man with an airleg. Lightweight, 24-kg percussion drills were used. After 1960 based on a Demag suggestion,

some small, hand-held rotary drills of 12 kg were operated, but they failed in the hard ore.

In Area No. 8 the thickness of the manganese deposit is about four meters. Miners required wood scaffolds to drill the higher part of the ore, and the timberman needed scaffolds to set headers for the posts. Wooden scaffolds are commonly seen in the mine indicating that scaffolds were still being used until June 1967.

The drilling pattern used was the ordinary or pyramid cut. The drill round was about 1.0-1.15 meters. The advance per round was 0.9 meter. Cut holes were connected at the bottom because of safety fuse and cap use. This ensured successful detonation of all holes.

(2) Blasting

Blast hole spacing, dependent on the hardness of the manganese rock, was about 50 cm in headings and 120 cm in stopes. The length of the charge per hole was about 65% of the bore hole length. No electrical firing was used except for experimental work in driving tunnels.

Domestic explosives were used as follows:

- o Gelatine dynamite, 80% strength, No. 5
- o Cartridge of 30-cm length by 30-mm diameter (or 7/8-in. diameter)
- o Detonators, No. 6 and No. 8
- o Safety fuse, detonating cord

(a) Main Explosive Magazines

SMC had 2 main explosive magazines, each of 8-tonne capacity.

- o Depot No. 2, Explosive Magazine. A tunnel in the area of Depot No. 2. The tunnel is plastered but the doors are missing.
- o Lease 8 (lower), Explosive Magazine. In similar condition to the magazine at Depot No. 2.

(b) Auxiliary Explosive Magazines

SMC had 17 auxiliary explosive magazines of 1-tonne capacity located in various mining areas.

- Area 45 Auxiliary Explosives Magazines
  - A 10-meter x 2-meter tunnel with door missing.
  - A 3-meter x 1-meter tunnel at Abu Natsh.
  - A magazine building of 7-meter x 43-meter dimension but with no doors. It is in the Tobia area.
- Area Abu Thor Explosives Magazines
  - A tunnel 38-meters x 2-meters without doors.
  - A tunnel 6-meters x 2-meters without doors.
- Area Abu Hamat Yemin Explosives Magazines
  - A tunnel 22-meters x 2.5-meters without door.
  - A tunnel 1.5-meters x 1.5-meters without door.
- Area Abu Hamat Shemal Explosives Magazine
  - A tunnel 15-meters x 2-meters without door.
  - A tunnel 5-meters x 1.5-meters without door.
- Om Bogma District Explosives Magazines
  - Area 10 has 2 magazines, 2 tunnels and missing doors.
  - Area 9 has 3 magazines and 3 tunnels. Two of them are missing doors while the third is complete with doors.
  - Area 8 has 3 magazines, 3 tunnels and doors missing.

b. Miner's Lamps

Underground work was lit by acetylene lamps also called carbide lamps. Commercial carbide yields 4.6 $ft^3$ of gas per pound of calcium carbide. A lamp will burn for 7 hours on 1/4 kg of carbide.

c. Mine Drainage

No underground water was recorded in the mines or tunnels. Surface inflow occurred through outcrops due to the moderate rainfall. This was especially noticed while mining to an outcrop adjacent to large drainage basins. This phenomenon was noticed in El Alluga and El Hessania adits. One of these is still full from occasional inflow. It was also noticed in all the inclined shafts and pits as at Abu Zarab. All these inflows were accumulated during the period of occupation when the mines were not maintained.

d. Mine Ventilation

No mechanical ventilation was used, since natural ventilation was sufficient. At times, it was necessary to use fans to drive headings.

e. Piping

The compressed air lines along the main production roads were 3 or 4 inches in diameter. Major branch lines were 2 inches with minor branch lines 1 inch to the various driving and working points.

The total lengths found in SMC's mines are as follows:

| Diameter (inches) | Length (meters) |
|---|---|
| 4 | 1,900 |
| 3 | 1,870 |
| 2 | 3,290 |
| 1½ | 2,640 |
| 1 | 1,960 |
| Total | 11,660 meters |

About 95% of these pipes are in good condition.

f. Trackage

The 60-cm gauge used track was mostly 12 kg/m (25 lb/yd). The switches were 7 kg/m (15 lb/yd). The total of measured, used track in the mines is as follows:

| Weight | Quantity |
|---|---|
| 12 kg/m | 10,620 m |
| 9 kg/m | 1,160 m |
| 7 kg/m | 330 m |
| 18 kg/m (used for the winch incline on Hill No. 8) | 100 m |

The total of used switches found in the mines is as follows:

| Weight | Quantity |
|---|---|
| 12 kg/m | 11 |
| 9 kg/m | 1 |
| 7 kg/m | 38 |

g. Mine Cars

Two types of side tipping mine cars were found, V-shaped and U-shaped. Cars were found with capacities of 0.75, 1.00 and 1.40 tonnes.

The total number of mine cars found is as follows:

| Quantity | Specifications |
|---|---|
| 71 | Capacity 1.0t - complete |
| 31 | Capacity 0.75t - complete |
| 38 | Box only - 1t |
| 1 | Box only - 1.4t |
| 9 | Chassis only |

h. Mine Locomotives

Mine locomotives, 60 cm gauge, were powered by diesel engines of 30-35 hp. The 13 locomotives found had the body only with engine drives and some parts missing. All are considered scrap.

i. Air Compressors

Air compressors used in mines were mainly mobile type with diesel engine drives. All seven air compressors found in the mines were scrap.

2. Surface Methods

Surface mining was used when the overburden was less than 4 meters or when the overburden to the ore was not more than 0.5:1 on a volume basis.

In some locations surface mining was used initially until the overburden reached 4 meters thick. At this point underground mining was started. These operations can be seen in Lease 267, Abu Kafas, and Hill No. 5, Lease 286.

Consumption of explosives was low in surface mining and the overall mining costs were low.

3. Ore Loading

Loading of ore to either the mine cars or motor trucks was done manually by means of a hoe and iron baskets. These were carried on the head from minefaces to ore cars.

4. Labor

Laborers who worked in exploration and mining of manganese ores were mostly from El Khatara village. Some were from El Hegaza and Koft villages. The three villages are in the Kena Governorship of Upper Egypt. Laborers were engaged under contract for a period of 5 months work. After this they returned to their villages for a period of 3 to 4 months before returning for another 5 months work.

The company, according to the labor laws, supplied houses for married miners and furnished rooms for single miners. The company also subsidized housing and provided free medical services.

a. Labor Classifications

Laborers were divided into three groups according to the following classifications:

(1) Contract

Drillers, timbermen, muckers, trammers, road construction and maintenance.

(2) Permanent

Truck drivers, bulldozer operators, grader operators, winch men, locomotive drivers, pipe fitters, gandy-dancers, blasters, mechanics and electricians.

(3) Native

Guards, drivers, hand sorting teams for the various high grade metallurgical manganese and manganese dioxide ores.

b. Output Per Man Shift

Using 10-tonne cars (i.e. 10 tonnes) per mucker per shift on shift contract and three drillers without airleg drills providing muck for 6 to 8 muckers per shift, average productivity was about 5.4 t/shift, which included muckers, drillers and timbermen.

Other productivity figures include 3.1 t/man shift at the mine bunker and 0.75 t/man shift overall mine production at Depot No. 2, end of aerial tramway.

c. Headings - Labor Requirements

Labor required for driving one meter of heading was:

| Man Days/Meter Heading | Classification |
|---|---|
| 2.26 | Muckers |
| 2.63 | Drillers |
| 0.33 | Blasters |
| 0.32 | Locomotive drivers |
| 0.33 | Fitters |
| 0.30 | Assistant Rais |
| 1.20 | Others |
| 7.39 day/meter drivage | |

Average meters/man shift = 0.135 m

The labor required for 100 tonnes of production of manganese ore delivered to the cable-tramway-bunker was:

| Man Days/100 Tonnes | Classification |
|---|---|
| 10.00 | Muckers |
| 6.00 | Drillers |
| 2.50 | Timbermen |
| 2.85 | Blasters |
| 3.35 | Locomotive drivers |
| 1.43 | Fitters |
| 1.52 | Bin workers |
| 1.00 | Rais |
| 4.00 | Others |
| 32.65 day/100 tonnes production | |

Average tonnes/man/shift delivered to bunkers = 3.1t

5. Production Costs for Manganese Ore

a. Manganese Ore Production Cost (for 1950 through 1953)

Costs per tonne for manganese ore production are in milliems and were abstracted from old records from 1950, 1951, 1952 and 1953 at Abu Zeneima:

| Year | 1950 | 1951 | 1952 | 1953 |
|---|---|---|---|---|
| Direct Costs | 540 | 773 | 626 | 756 |
| General Charges & Maintenance | 508 | 534 | 552 | 521 |
| Overhead Charges | 537 | 662 | 620 | 739 |
| Total FOB Abu Zeneima | 1,585 | 1,969 | 1,798 | 2,016 |

(1) Direct Costs include:

- o Average mining costs.
- o Tramway (men, transport cost and repairs).
- o Railway (men, repairs to locomotive and cars, operating costs and loading).
- o Abu Zeneima (unloading, handling, bagging and sorting for fines and pyrolusite).
- o Ship loading (loading, repairs, screening plant, etc.).
- o Accident compensation.
- o All costs of sampling and analysis.

(2) General Administrative and Maintenance Costs include:

- o Om Bogma (European houses, workmen houses, kitchen, bakery, mine building, water pipeline of Suez supply and of wadi supply, etc.).
- o Tramway (general maintenance, ore bunker, insurance, engineer and crew).
- o Railway, maintenance of ways.
- o Abu Zeneima (loading, power plant, water lines, telephone, etc.).
- o Casualty damage.
- o Messing and facilities.

(3) Overhead Charges include:

- o European staff (salaries, subsistence allowance, travel, hotels, sundries).
- o Egyptian staff (salaries and wages for Abu Zeneima and Om Bogma, survey assistants, labor recruiting, travel expenses, guards).
- o Medical and sanitary (salaries of doctor and nurses, hospital, drugs and dressings in Abu Zeneima and Om Bogma).
- o Sundry services (domestic lighting in Abu Zeneima and Om Bogma, ice plant, domestic water supply from Suez and wadi).

- Freight loading and unloading (loading and discharging vessels, stores handling charges, loading and running motor vehicles at Abu Zeneima and Om Bogma).

- General expenses (telephone, telegrams, post, bank charges, rent licenses and fees, taxi, agency fees, legal expenses in Egypt, insurance, sundries).

- Motor road.

- Motor vehicle renewals.

b. Manganese Ore Production Costs for 1964/1965 and 1965/1966

For the years 1964/1965 and 1965/1966, the manganese ore production costs per tonne in milliems are abstracted from geologist Abu El Eneim's Report:

| Years | 1964/1965 | 1965/1966 |
|---|---|---|
| Mining Cost | 663 | 674 |
| Abu Zeneima Services Cost | 1,107 | 976 |
| Cairo Services Costs | - | 650 |
| FOB Abu Zeneima | 1,770 | 2,300 |

c. Manganese Ore Production - Daily Average

The average daily production of manganese ore for 1950 through 1953, 1964/1965 and 1965/1966 was:

| Year | 1950 | 1951 | 1952 | 1953 | 1964/1965 | 1965/1966 |
|---|---|---|---|---|---|---|
| Average Daily Production (tonnes) | 510 | 514 | 622 | 670 | 585 | 611 |

As the above statistics indicate, mining costs remain the same despite elapsed time, increased materials cost, and the changes in the labor laws which affected salaries, wages and overhead expenses. This may be due to the increased production from surface mines offsetting underground costs. Production from 1950 to 1953 was mainly from underground mine Leases 8, 9 and 10. These produced 660 t/d from 12 tunnels and 3 open-cuts in 1960.

d. Previous Production Costs - Summary

After 1960 other minerals were produced, including gypsum from Ras Malaab, kaolin, white clay and glass sand. All these minerals shared in the overhead, general and maintenance expenses. Accordingly, the cost of the manganese

ore was affected. Complete amortization of the ropeway, railway and the main facilities of Abu Zeneima and Om Bogma occurred earlier. Therefore, the cost of the manganese ore did not bear any portion of amortization.

The prospecting work executed in 1953 amounted to 742 meters and increased the ore reserves by 34,500 tonnes at a rate of 46.49 t/m. From 1960 through 1967 this rate changed considerably. Prospecting work in 1964/1965 was executed in the following mines:

| Mine | Linear Meters |
|---|---|
| Gebel 8 | 38.5 meters |
| El Korb | 27.0 meters |
| Gebel Fouad | 24.6 meters |
| Abu Hamat Yemir | 137.0 meters |
| Abu Hamat Shemal | 377.7 meters |

Areas that were mined first exhausted their ore reserves before 1967. Hence, it appears that these prospecting costs were excluded from the true mining cost.

Abu Zeneima overhead costs for 1964/1965 and 1965/1966 were higher than those for 1950 through 1953. The Cairo overheads in the 1964/66 period were the same as in the latter four years.

## 6. Transportation

The transport of the manganese ore extracted from Om Bogma district to Abu Zeneima was difficult due to the very rugged topography. The German Company, the first operator, found that the best method to bridge the mountain conditions was a bi-cable tramway. The first system was installed by Messrs. Bleichert, a German company, in 1913. The bi-cable tramway extends from Om Bogma manganese deposits to a bunker, Depot No. 2, located near the coast of the Gulf of Suez. From the bunker, a railway line extended to the Abu Zeneima stockpiles. Material was moved from the stockpiles by belt conveyor to the ship loader.

### a. Underground Hauling

Manganese ores were transported by side tipping mine cars of one tonne capacity, and were pulled by diesel locomotives of 30 hp. The railroad moved ore from the development work and mining operations to the tramway bunkers. Track was 60 cm gauge and weighed 12 kg/m. Existing track in the mines is:

| | | |
|---|---|---|
| 10,620 meters | 12 kg/m | with 11 switches |
| 1,160 meters | 9 kg/m | with 1 switch |
| 330 meters | 7 kg/m | with 38 switches |
| 100 meters | 18 kg/m | |

All of the thirteen 30-hp diesel locomotives utilized before the war are now scrap. Mine cars existing today are:

| | |
|---|---|
| 71 cars complete | 1 tonne capacity |
| 38 cars, boxes only | 1 tonne capacity |
| 9 cars, chassis only | 1 tonne capacity |
| 31 cars complete | 3/4 tonne capacity |

b. The Bi-Cable Tramway

Ore was transported from the bunkers of the production areas to the terminal bunker, Depot No. 2, by the main bi-cable tramway. Another small bi-cable tramway exists on Hill No. 5. The main tramway reaches from Station No. 8 to Depot No. 2 and is called the main tramway with a length of 11,855 meters. Haulage on the main tramway moves the ore by gravity to Depot 2. However, the section to Ras El Homarra requires power.

Tramway Leg I is the extension from Station No. 9 to Station No. 8 or Hill No. 8. The tramway extension from Station No. 8 to Abu Hamat Shemal Station is called Leg 2 and this part moves ore against gravity for a length of 1,520 meters. The difference in elevation between the stations is 188 meters.

The main tramway was planned to extend from Abu Hamat Shemal Station to Abu Hamat Yemin Station, Leg 3-a, which would have been against gravity. This 1,300-meter span was under construction in 1967.

(1) Cables

The main bi-cable tramway consists of the following mixture of cables:

- Two track cables of non-stranded smooth coil. The cable diameters in the main tramway are 42 mm for the loaded carriers cable and 30 mm for the empty carrier cable. The diameters in Leg 2, Leg 3-a, and the cables from Station No. 9 to Station No. 8 are 35 mm for the loaded carriers cables and 25 mm for empty carrier cables.

- The endless stranded traction rope for moving the loads has various diameters. The main tramway is 24 mm, and for Leg 2, Leg 3, Station No. 9 to Station No. 8 (both upper and lower) it is 19 mm. The speed of the traction rope was 2.8 m/s.

(2) Carriers

Each carrier consisted of:

- o Carriage (trolley) with four wheels to run on the track cable.
- o Gravity-operated grip for seizing the traction rope.
- o Bucket with a capacity of 685 kg of manganese ore equal to 3.5 hl. The bucket top dimensions are 106 cm x 70 cm with a bottom width of 42 cm and a height of 57 cm.

There are tank carriers to transport water to the stations and personnel carriers for station inspections of the towers and cables. Tramway cars spaced 171 meters apart could be moved at the rate of 59 per hour.

(3) Stations

The main tramway stations are:

- o The terminal stations No. 8 (lower) for loading ore and Depot No. 2 for discharging the carriers or tramway cars.
- o The 9 intermediate stations which are tension stations, break-over stations, transfer stations and angle stations.

The other tramway stations are geographically distributed as follows:

- o Leg 1 has one loading station at Station No. 8 upper (Hill 8) and Transfer Station No. 9.
- o Leg 2 has one terminal station for loading carriers at Abu Hamat Shemal. At 187 meters before Abu Hamat Shemal, there is an intermediate equilibrium station. At Station No. 8 (upper), there is a transfer station.
- o Leg 3 has one terminal station for loading at Abu Hamat Yemin and one transfer station at Abu Hamat Shemal.

(a) Stations Between Station No. 8 and Depot No. 2

The names and functions of these stations are summarized as follows:

| Stations | Description |
|---|---|
| Depot No. 2 | Discharges carriers to bunker. |
| No. 5 | After tower No. 18, a tension station. |
| No. 6 | After tower No. 25, a tension station. |
| No. 7 | Station No. 7 is an operating and control station between Depot No. 2 and Station No. 10. |
| El Shami | After tower No. 30, a tension station. |
| El Sence | After tower No. 44, a double anchor. |
| No. 11 | After tower No. 52, an angle station. |
| Zaki | After tower No. 50, a tension station. |
| No. 10 | After tower No. 62, an operating control and tension station. |
| No. 9 | After tower No. 67, a transfer, tension and angle station. Station No. 9 has 2 branches with one line to Hill No. 8, Abu Hamat Shemal, and on the Abu Hamat Yemin. The other branch is to Area No. 8. |
| No. 8 | After tower No. 69, a terminal for loading. |

(b) Stations Between Station No. 9 and Abu Hamat Yemin

| Stations | Description |
|---|---|
| No. 9 | Discharge station from Upper Lease No. 8, and a tension station. |
| No. 8 | Transfer station at Upper Lease No. 8. |
| Abu Hamat Shemal | Tension, transfer and angle station. |
| No. A | Tension station. |
| No. B | Tension station. |
| No. C | Equilibrium station. |
| Abu Hamat Yemin | Loading terminal. |

(4) Towers

Towers between the stations are for supporting track cables and the traction ropes. There are 69 towers between Depot No. 2 and Station No. 8. There are 14 towers from Station No. 9 to Abu Hamat Yemin.

These towers are of steel latticed construction with saddles and traction pulleys on the top for supporting the track and traction ropes.

(5) Bunkers

There are seven bunkers with different capacities. Four bunkers are between Station Area No. 8 and Depot No. 2. There are three bunkers between Station Area No. 9 and the station at Abu Hamat Yemin.

Capacities of the seven bunkers are:

| Bunker No. | Capacity (Tonnes) |
|---|---|
| Depot No. 2 | 2,000 |
| Station No. 10 | 450 |
| Station No. 9 | 1,200 |
| Lower 9 | 800 |
| Hill No. 8 | 450 |
| Abu Hamat Shemal | 750 |
| Abu Hamat Yemin | Under construction (1967) |

(6) Overall Tramway Capacity

On the basis of 300 working days per year, 2 shifts of 7 hours each, the tramway could handle 35-50 t/h or 500-600 t/d. The daily capacity includes the overall efficiency. Station Hill No. 8 to Abu Hamat Shemal Station is 1,520 meters. Abu Hamat Shemal Station to Abu Hamat Yemin Station is 1,300 meters.

(7) Hill No. 5, Small Bi-cable Tramway

A second small bi-cable tramway, or Jigback, was used in the transportation of the ore from Hill No. 5 downhill to the bunker in Lease 9. From the bunker the ore was transported by side dump mine cars pulled by locomotives of 35 hp to the bunker of Station No. 9. From here the ore was transported by main bi-cable tramway to Depot No. 2.

The small bi-cable tramway has one tower and two bunkers, one at Hill No. 5 and the other at Lease 9. The cable diameter on both tracks is 20 mm.

c. Present Condition of the Tramway

Tramway Components

| Description | From Depot No. 2 to Area 8 (lower) | From Station No. 9 to Abu Hamat Yemin | Hill No. 5 | Total |
|---|---|---|---|---|
| Number of Stations | 11 | 7 | 2 | 20 |
| Number of Towers | 74 | 14 | 1 | 89 |
| Number of Bunkers | 4 | 3 | 2 | 9 |
| Number of Loaded Carriers | 78 | 25 | 1 | 104 |
| Number of Empty Carriers | 74 | 22 | 1 | 97 |
| Number of Carriers Stand-by | 19 | - | - | 19 |
| Number of Water Carriers | 6 | - | - | 6 |
| Number of Labor Carriers | 1 | - | - | 1 |

(1) Stations

(a) Depot No. 2 Stations

The main receiving station has no rail, none of the 26 carrier discharge components, and no grease points. The Depot No. 2 Station needs:

- Replacement of all missing parts.
- Cleaning of rust and repainting.
- Inspection of the saddles, sleaves, attachers and detachers.
- Reconstruction of the laborers' buildings.
- Reconstruction of 2 water tanks and their connections to provide water to the water carriers.

(b) Station No. 5

The station skeleton is complete on its steel structure base, but requires:

- o Removal of corrosion and repainting.
- o Replacement of grease points.
- o Replacement of some saddles.

(c) Station No. 6

The station is complete on its concrete base, but requires:

- o Removal of corrosion and repainting.
- o Replacement of the grease points.

(d) Station No. 7

The steel station of the skeleton is complete, but needs:

- o The brake repaired.
- o Reconstructing the station, labor building and the station roof.
- o A generator.
- o Completion of the greasing system.
- o Removal of corrosion and repainting.
- o Repairing the workshop.

(e) El Shamy Station

The steel skeleton of the station is on a concrete base and needs:

- o Removal of corrosion and repainting.
- o Completion of the greasing system.

(f) Zaki Station

The steel skeleton of the station is on a concrete base and needs:

- o Removal of corrosion and repainting.
- o Completion of the greasing system.

(g) Ras El Homarra Station

This station needs:

- o Rebuilding the residence of the labors and generator house.
- o New water tanks.
- o A generator.

(h) Station No. 10

This station consists of the drive machinery for moving the cable line to Depot No. 2 and to Station No. 9. The station lacks the line speedometer, some parts of the brakes, the generator, the air compressor and all the equipment and tools needed by the station workshop. In addition, Station No. 10 requires:

- o Reconstruction of the station roof.
- o Six new water tanks for machine cooling.
- o Removal of the corrosion and repainting.

(i) Station No. 9

This station requires:

- o Reattaching some angle iron.
- o Generator and machine drive.
- o Some new wood planks for the floor.
- o Reconstruction of the water cooling tanks.

(2) Tramway Add-on Sections

(a) Leg No. 1

The Leg No. 1 span from Station No. 9 to Hill No. 8 is 800 meters long. The cable diameters are 35 mm on the load side, 25 mm on the empty side, and 19 mm on the moving cable.

Ore from Hill No. 8 is received at Station No. 9 and is transferred to the bunker serving the main tramway to Depot No. 2. This part of Station 9 is complete.

(b) Leg No. 2

This leg spans the distance between Hill No. 8 and Abu Hamat Shemal for a length of 1,520 meters. Cables are the same size as in Leg No. 1. The Abu Hamat Shemal station needs new drive machinery.

(c) Leg No. 3-A

This connection is between Abu Hamat Shemal and Abu Hamat Yemin with a length of 1,300 meters. Cables are similar to those on Leg Nos. 1 and 2. Leg No. 3-A has four stations:

- o Abu Hamat Shemal Station (previously mentioned)
- o Station A
- o Station B
- o Station C

Abu Hamat Yemin Station was under construction.

(3) Towers

There are 69 towers from Depot No. 2 to Station No. 8. All 69 towers of the main tramway need paint, greasing and new saddles. Towers 55, 57, 58, 59, and 60 need their ladders replaced or repaired. According to the present physical condition of the towers, each is classified into one of the four categories below:

(a) Towers 60% Usable

1 - 2 - 4 - 5 - 7 - 11 - 12 - 13 - 14 - 15 - 16 - 19 - 20 - 22 - 23 - 24 - 25 - 26 - 28 - 32 - 33 - 36 - 37 - 38 - 39 - 43 - 44 - 46 - 49 - 52 - 53 - 62 and 66.

Total = 33 towers

(b) Tower 50% to 60% Usable

3 - 6 - 8 - 18 - 27 - 29 - 30 - 31 - 34 - 35 - 40 - 41 - 42 - 45 - 47 - 48 - 50 - 51 - 54 - 56 - 61 - 64 - 68 and 69.

Total = 24 towers.

(c) Towers 40% to 50% Usable

9 - 17 - 21 - 55 - 57 - 58 - 59 - 60 - 63 - 65 and 67.

Total = 11 towers.

(d) Towers 30% to 40% Usable

Total one tower.

In addition, there are 14 towers in Leg Nos. 1, 2 and 3-A. Their present physical condition is:

- Two towers only on Leg No. 1 from Station No. 9 to Hill No. 8 and they are in good condition.
- The 9 towers of Leg No. 2 from Station Hill 8 to Abu Hamat Shemal are in good condition.
- The 3 towers of Leg No. 3-A from Abu Hamat Shemal to Abu Hamat Yemin were under construction and all the components appear to be at the sites.

(4) Aerial Tramway Cables

To prevent corrosion and decrease wear, the aerial tramway cables need regular lubrication and periodic shifting on the saddles. But due to the period of about 13 years when no maintenance was carried out, all the cables deteriorated to the point of requiring complete replacement.

The old GMC program was to extend the tramway, after completing the bunker of Abu Hamat Yemin and its leg to Abu Zarab and to El Alluga, as follows:

| | |
|---|---|
| Abu Hamat Shemal to Abu Hamat Yemen | Leg 3-A = 1.3 km |
| Abu Hamat Yemin to Abu Zarab | Leg 3-B = 1.0 km |
| Abu Zarab to El Alluga | Leg 3-C = 1.6 km |
| Abu Hamat Shemal to El Ramsy | Leg 4 = 2.5 km |

All these extensions were proposed to carry loaded buckets uphill and to consume extra power.

d. Railroad Transport

Ore was transported from the final station of the tramway called Depot No. 2 to the Abu Zeneima area either to the

bunker or to the stockpile. Side dump railway cars, 5 tonne capacity each, were used. The cars were pulled by a 130 hp locomotive. The railroad has a total length of 16.5 km. A single line was doubled for 500 meters. At Abu Zeneima, there is a branch to the stockpile and one to the bunker. The railway gauge is 75 cm (2.5 ft) and the weight of the rails is 18 kg/meter, with wood sleepers.

The present physical condition of the railway is described as follows:

(1) The Embankment

More than 10 km of the embankment had been destroyed.

(2) The Sleepers

The sleepers are unsuitable because they are old and wooden.

(3) The Railway Line

The buried length of the 3,155 meter line needs removal of the overburden to test whether the rails are in working condition or not. The sleepers must be changed and the 10 km embankment must be reconstructed.

(a) Locomotives

There were German G. and F. diesel locomotives of 120-150 hp which were working on the railway between Depot No. 2 and the main bunker at Abu Zeneima. All of these locomotives are beyond repair.

(b) Railway Cars

Egyptian-made SIMAF ore cars (5-tonne capacity) were used. These ore cars were V-shape, side dump type. There were 50 cars used to transport the manganese ore. Only 15 complete cars exist and they are scattered in various places. To be usable, they would have to be collected and reassembled. There are also 35 car-boxes without frames or wheels and are likely to be scrap. Cars were 2.30 meters long and 1.74 meters wide with a depth of 0.86 meters. Manual hand brakes were provided.

(4) Present Condition of the Railroad - Summary

More than 10 km of the side slopes on the right-of-way have been destroyed and nearly all sleepers are beyond use. Should the railroad ever be used in the future, which is unlikely, 3,355 meters will have to be dug out from slide material covering the tracks. About 3,535 meters of rail is completely missing and 2,050 meters is present but in an unusable state. Any replacement would require consideration of drainage to prevent washouts.

Summary of Railroad Condition

| Location | Distance (meters) | Track Removed | Line Track Present but Unusable | Line Track Buried | Track Undestroyed and Usable |
|---|---|---|---|---|---|
| From km 0 to km 1 | 1,000 | - | - | - | 1,000 |
| From km 1 to km 2 | 1,000 | 780 | 50 | - | 170 |
| From km 2 to km 3 | 1,000 | - | - | 190 | 810 |
| From km 3 to km 5 | 2,000 | 405 | - | 285 | 1,310 |
| From km 5 to km 6½ | 1,500 | - | - | 880 | 620 |
| From 6½ to km 7 | 500 | - | - | 500 | - |
| From km 7 to km 7½ | 500 | - | - | - | 500 |
| From km 7½ to km 9 | 1,500 | 200 | - | 1,300 | - |
| From km 9 to km 12 | 3,000 | 2,150 | - | 200 | 650 |
| From km 12 to km 13 | 1,000 | - | 1,000 | - | - |
| From km 13 to km 14 | 1,000 | - | - | - | 1,000 |
| From km 14 to km 14½ | 500 | - | 500 | - | - |
| From 14½ to km 15 | 500 | - | 500 | - | - |
| From 15 to km 16½ | 1,500 | - | - | - | 1,500 |
| 16½ km | 16,500 | 3,535 | 2,050 | 3,355 | 7,560 |

e. Truck Transport

Trucks have been used to transport the manganese ore from deposits not served by the tramway. The present roads connecting the Om Bogma mines are not suitable for heavy trucks. To handle trucks up to 20 tonne capacity, all the roads need extensive upgrading. Truck transport to carry the high grade ores and manganese dioxides was used from the following truck transport leases:

- El Shalal, Lease 292, to Abu Zeneima stockpile.
- Abu Kafas, Leases 266 and 267, to Abu Zeneima stockpile.
- Abu Thor, Leases 293, 401 and 402, to Abu Zeneima stockpile.
- Wadi El Gassib, Lease 312, to Abu Zeneima stockpile.
- Abu Hamat Yemir to Abu Hamat Sheral tramway bunker.
- El Alluga, Leases 353 and 354, to Abu Zeneima stockpile.
- Om Pinna to Abu Zeneima stockpile.

f. Belt Conveyors

The belt conveyors were used for loading ships and stockpiling the screened fines of manganese ores. From the main bunker of Abu Zeneima, mine cars of one tonne capacity were loaded and manually trammed to the hand operated rotary dumper. This transferred the ore to an inclined 66-meter long belt conveyor. This belt conveyor transported the ore to the jaw-crusher in open circuit with a vibrating screen of 6 mm or ¼ inch.

The undersize went to a belt conveyor for stockpiling of fines at the northern part of the ship loading plant. The oversize goes to a horizontal conveyor 82.25 meters long. From this horizontal conveyor, the ore goes to an inclined 37-meter long belt conveyor. At this point, ore was transferred to a 10-meter long conveyor loading through a cylindrical chute. All conveyors are 90 cm wide. Ship loading was done at 60-70 t/h for ore over 6 mm or ¼ inch and 120-150 t/h for non-screened ore. A scale was available for weighing the loaded ore, and ships were loaded 14 hours daily in two shifts.

The draft of the port at the loading dock is 27 feet which is suitable for loading 15,000-tonne ships. All motor drives of all conveyors are missing but the steel frames are in good condition. Conveyor rehabilitation would require:

- Removing standing water and improving drainage at conveyor and dumper.
- Replacing all belts.
- Reinstalling drivemotors, controls and associated electrical parts.

g. Previous Direct Costs for Transport

| Year | 1950 | 1951 | 1952 | 1953 | 1961 | 1962/63 |
|---|---|---|---|---|---|---|
| Method | (1) | (1) | (1) | (1) | (2) | (2) |
| Rope LE/Tonne | 0.1345 | 0.120 | 0.11825 | 0.141 | 0.053 | 0.059 |
| Railway LE/Tonne | 0.0975 | 0.120 | 0.13858 | 0.067 | 0.066 | 0.079 |
| Belt conveyor LE/Tonne | 0.0299 | 0.0447 | 0.02866 | 0.029 | 0.046 | 0.054 |
| Trucks LE/Tonne | - | - | - | - | 1.360 | 1.025 |

The above data is from old accounting books found in Abu Zeneima. The data were extracted from SMC Annual Reports and yearly budgets as submitted to the Assemblies of the Mining Organization. In our opinion these costs are underestimated and are not representative of the actual costs.

h. Roads

(1) Main Roads

There are two main roads from Abu Zeneima to the mines of Om Bogma. The present condition of these roads is:

(a) El Tarik El Daiiri Road

This road connects Wadi Muttala, Dibbet El Qeri, Wadi Nassib, Abu Thor, Abu Hamat Yemin, El Beida, Area No. 8, Area No. 9 and Area No. 10. This road is called the circular road or El Tarik El Daiiri, and its length is 59 km. The following lengths make up the 59-km road.

| From | To | Total/km | Asphalt Road/km | Track/km |
|---|---|---|---|---|
| Abu Zeneima | Bir Nassib | 39.00 | 35.5 | 3.5 |
| Bir Nassib | Abu Thor area | 2.00 | - | 2.0 |
| Abu Thor area | Abu Hamat - El Beida | 11.20 | - | 11.20 |
| El Beida | Area No. 8 | 2.50 | - | 2.50 |
| Area No. 8 | Area No. 9 (mosque) | 1.50 | - | 1.50 |
| Area No. 9 (mosque) | Area No. 10 | 2.80 | - | 2.80 |
| Total lengh of the road from Abu Zeneima to Area No. 10 | | 59.00 km | 35.5 km | 23.50 km |

The asphalt road was broken down in many places by the flow of rainwater. Side slopes need to be restored. At one end of the road, passing through a cut, the base course material should be completely replaced. Repaving of the road sections can be improved by motor grader work to provide a good surface for trucks and cars.

(b) Wadi El Shalal Road

The second access road passes by Depot No. 2, Wadi Baba, El Dehissa, Area No. 45, Wadi El Shalal to Om Bogma, Area No. 10. This road goes directly to Area No. 10 without passing through the other Om Bogma mines. Its length is 38.2 km. The following lengths make up the 38.2-km road:

| From | To | Total/km | Asphalt/km | Unpaved Track/km |
|---|---|---|---|---|
| Abu Zeneima | Entrance of Wadi Baba | 18.0 | 18.0 | - |
| Entrance of Wadi Baba | Area No. 45 | 12.5 | 12.5 | - |
| Area No. 45 | Start at incline | 4.7 | - | 4.7 |
| Incline to Area No. 10 | | 3.0 | - | 3.0 |
| | | 38.2 km | 30.5 km | 7.7 km |

The first 18 km are in good condition. The next 12.5 km, from the entrance of Wadi Baba to Area No. 45, needs to be rebuilt. Water erosion has removed the base course of the road. Today this part is paved. However, this part of the road needs to be fully reconditioned. The road from Area No. 45 to the start of the incline is closed due to side hill rubble washed down on various parts of the road. This part of the road should be reopened for transport of the ore from El Hessenia, El Saaho and Om Ratam, and to shorten the route to Abu Zeneima.

(2) Branch Roads

(a) Abu Zarab Road

At Kilometer 43, El Tarik El Daiiri, the circular road, begins a branch road of 4.1 km to the Abu Zarab area. This branch is unpaved. Via this branch road and El Tarik El Daiiri it is 47.1 km from Abu Zeneima to Abu Thor and 2 km further to Abu Zarab. The Abu Zarab road is about 500 meters long and, due to slides from the sidehill, has been cut into 5 parts.

(b) El Alluga Road

The road which goes to El Alluga area begins from Bir Nassib and goes to Wadi Nassib and the El Alluga area. Its length is 4.5 km. A part of the road is very rocky and unpaved with a length of about one kilometer. This part needs to be resurfaced with clay or shales, while the other parts need only reworking with a grader.

(c) El Ramsy Road

This road branches from the circular road (El Tarik El Daiiri) at kilometer 34.0 and passes to Wadi Baba and on to the Ramsy area. This branch has a length of 6.0 km, and one kilometer has a very soft base due to the accumulation of sand.

(d) Abu Hamat Road

This unpaved road is a branch from the circular road (El Tarik El Daiiri) near Abu Hamat Yemin and goes to Abu Hamat Shemal. It has a length of 1.2 km and needs to be repaired.

(e) El Hessenia Four Branch Roads

This area is reached by 4 branch roads as follows.

There is one branch road from the circular road, from Bir Nassib passing by Alluga and then up an incline to El Lahian Wadi. From here it goes south to El Marahil and Wadi El Saaho, El Hashash, and to the El Hessenia area (Om Sylat). The length from El Alluga to the Hessenia area is 13 km. It is a very bad road and extremely difficult for a truck to pass.

Another branch road is at the end of the asphalt road, part of the circular road passing the Wadi El Sih to Wadi El Lahian and to El Hessenia. The road is very bad and difficult to use by trucks for ore transportation.

The shortest road is a branch from El Shalal Road (Area 45) through El Shalal to El Hessenia. Its present physical condition was not investigated due to a blockage of the El Shalal Road.

There is a 1.7 km branch road from Area 9. This road is under construction. It was roughed in but never completed. Once completed, this road could be utilized to transport the ore by trucks to the tramway station of Area 9.

(f) Ras El Homarra Road

Ras El Homarra Road runs 2.00 km from Area 10 to the tramway station. The road's condition is very bad due to slides. This road needs to be completely repaired.

(g) Abu Kafas Road

The Abu Kafas Road is a continuation of the main road to El Shalal from Area 45. It extends for 3.3 km to Abu Kafas mines. About 300 meters of this branch road is damaged by 6 cuts due to slides. About two kilometers from Area 45, there is 100 meters of the branch road in need of repair.

(h) Abu Kasar/Wadi Budra Road

This branch road is 1.8 km long. This road is parallel to the Abu Kafas branch road.

(i) Om Rinna Road

This branch road leaves the Om Rinna asphalt road and leads to the mine working sites. This road needs some minor repairs. It has a length of 8.5 km from the asphalt road section to past the highest point of the hill.

(j) V-Shaped Hill Road

This road is a branch from the circular road 100 meters from the asphalt end; for example, at kilometer 35.6 going east through the Wadi El Sih to the downgrade of the V-shaped hill for a distance of about 3 km. Thus, the total distance to the V-shape hill is 38.6 km from Abu Zeneima.

APPENDIX 6

(III.D.)

METALLURGICAL REFERENCES

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# RAW MATERIALS AND PRODUCTS

The following tables indicate projected analyses, and some actual analyses, for raw materials used and products made in the various processes considered for this project.

TABLE 6-1

PROJECTED ASSAYS

ORE RESERVE DATA

| Case | Mn/Fe | Mn | Fe | $SiO_2$ | $Al_2O_3$ | CaO | MgO |
|---|---|---|---|---|---|---|---|
| I (1) | 1.03 | 27.40 | 26.71 | 4.0 | 1.0 | 3.0 | 1.0 |
| II (2) | 2.00 | 33.0 | 16.5 | 5.0 | 1.0 | 4.0 | 1.0 |
| III (3) | 3.00 | 39.0 | 13.0 | 4.0 | 1.0 | 3.0 | 1.0 |

(1) Data on Mn, Fe and Mn/Fe ratio from proven reserve data - gangue oxides assumed.

(2) Data projected from overall cumulative figures of total ore reserves.

(3) Data projected from cumulative reserves having a Mn/Fe ratio of approximately 3 to 1.

TABLE 6-2

PROJECTED ASSAYS

LOW GRADE ORE (1) AND BLENDS (2)

| Mn/Fe Ratio | Mn | Fe | $SiO_2$ | $Al_2O_3$ | CaO | MgO |
|---|---|---|---|---|---|---|
| 0.6 | 21.5 | 36.0 | 5.80 | 2.38 | 0.78 | 0.10 |
| 1.0 | 24 | 24 | 10 | 5 | 4 | 3 |
| 2.0 | 32 | 16 | 9 | 4 | 4 | 3 |
| 3.0 | 36 | 12 | 9 | 4 | 4 | 3 |
| 4.0 | 39 | 9 | 9 | 4 | 4 | 3 |
| 5.0 | 40 | 8 | 9 | 4 | 4 | 3 |

(1) Low grade ore is Om Bogma mine run with 0.6 Mn/Fe ratio.

(2) The 1.0 to 5.0 Mn/Fe ore blends are assumed from dolomite-bearing new areas ore with enhancement from existing higher grade ore deposits having a predominantly acid gangue.

TABLE 6-3

PROJECTED ASSAYS - REDUCED ORES (1)

LOW GRADE ORE (2) AND BLENDS (3)

| Mn/Fe Ratio | Mn | Fe | $SiO_2$ | $Al_2O_3$ | CaO | MgO | Wt Rec |
|---|---|---|---|---|---|---|---|
| 0.6 | 28.5 | 48.0 | 7.7 | 3.2 | 1.0 | 0.1 | 75.22 |
| 1.0 | 31.0 | 31.0 | 12.9 | 5.2 | 5.2 | 3.9 | 77.46 |
| 2.0 | 43.1 | 20.6 | 11.6 | 5.2 | 5.2 | 3.9 | 77.63 |
| 3.0 | 45.7 | 15.2 | 11.4 | 5.1 | 5.1 | 3.8 | 78.71 |
| 4.0 | 49.0 | 11.3 | 11.3 | 5.0 | 5.0 | 3.8 | 79.53 |
| 5.0 | 50.1 | 10.0 | 11.3 | 5.0 | 5.0 | 3.8 | 79.80 |

(1) 93% metallization of iron contained

(2) Low grade ore is Om Bogma mine run with 0.6 Mn/Fe ratio.

(3) The 1.0 to 5.0 Mn/Fe ore blends are assumed from dolomite-bearing new areas with enhancement from existing higher grade ore deposits having a predominantly acid gangue.

TABLE 6-4

RAW MATERIALS

PROJECTED ANALYSES

| | % |
|---|---|
| **Coke** | |
| Fixed Carbon | 75.0 |
| Volatiles | 2.0 |
| $H_2O$ | 12.0 |
| $SiO_2$ | 5.0 |
| $Al_2O_3$ | 3.0 |
| $Fe_2O_3$ | 2.0 |
| S | 1.0 |
| | 100.0 |
| **Quartzite** | |
| $SiO_2$ | 99.0 |
| $Al_2O_3$ | 1.0 |
| | 100.0 |
| **Limestone** | |
| CaO | 55.0 |
| $SiO_2$ | 1.8 |
| $CO_2$ | 43.2 |
| | 100.0 |
| **Dolomite** | |
| CaO | 30.2 |
| MgO | 21.0 |
| $SiO_2$ | 2.0 |
| $CO_2$ | 46.8 |
| | 100.0 |

TABLE 6-5

LOW GRADE ORE
COMPLETE ANALYSIS

SMC - January 30, 1979

| Constituent | Percent | |
|---|---|---|
| $MnO_2$ | 32.76 | |
| MnO | 0.97 | |
| $Fe_2O_3$ | 51.52 | (1) |
| FeO | nil | |
| $SiO_2$ | 5.80 | |
| $Al_2O_3$ | 2.38 | |
| $TiO_2$ | nil | |
| CaO | 0.78 | |
| MgO | 0.10 | |
| BaO | 0.40 | |
| $BaSO_4$ | 0.90 | |
| CuO | 0.05 | |
| PbO | 0.07 | |
| CoO | trace | |
| NiO | trace | |
| ZnO | trace | |
| $Na_2O$ | 0.10 | |
| $K_2O$ | 0.30 | |
| $As_2O_3$ | 0.02 | (2) |
| $P_2O_5$ | 0.236 | |
| S | 0.09 | (2) |
| $CO_2$ | 0.12 | |
| $H_2O$ | 3.25 | |
| Undetermined | 0.154 | |
| TOTAL | 100.000 | |
| Mn | 21.46 | |
| Fe | 36.03 | |
| P | 0.103 | (3) |
| Mn/Fe | 0.60 | |

(1) Based on 36.03% total Fe as $Fe_2O_3$.

(2) Assumed based on 42 and 48% grade and fine ore analysis.

(3) From 0.236% $P_2O_5$.

TABLE 6-6

HIGH GRADE ORE
COMPLETE ANALYSIS

SMC - January 30, 1979

| Constituent | | Percent |
|---|---|---|
| $MnO_2$ | | 67.77 |
| MnO | | 11.18 |
| $Fe_2O_3$ | | 9.79 |
| FeO | | nil |
| $SiO_2$ | | 1.16 |
| $Al_2O_3$ | | 0.90 |
| $TiO_2$ | | 0.033 |
| CaO | | 1.45 |
| MgO | | 0.35 |
| BaO | | 1.30 |
| $BaSO_4$ | | 0.15 |
| CuO | | 0.05 |
| PbO | | trace |
| CoO | | trace |
| NiO | | 0.01 |
| ZnO | | 0.55 |
| $Na_2O$ | | 0.30 |
| $K_2O$ | | 0.41 |
| $As_2O_3$ | | 0.025 |
| $P_2O_5$ | | 0.185 |
| S | | 0.09 |
| $CO_2$ | | 0.30 |
| $H_2O$ | | 3.90 |
| Undetermined | | 0.097 |
| | TOTAL | 100.000 |
| Mn | | 51.51 |
| Fe | | 6.85 |
| P | | 0.081 |
| Mn/Fe | | 7.52 |

TABLE 6-7

REDUCED PRODUCT
LOW GRADE ORE
PROJECTED ANALYSIS

| Constituent | Percent | |
|---|---|---|
| $MnO_2$ | - | |
| MnO | 36.83 | |
| $Fe_2O_3$ | - | |
| FeO | 4.31 | |
| Fe | 44.55 | (1) |
| $SiO_2$ | 7.71 | |
| $Al_2O_3$ | 3.16 | |
| $TiO_2$ | - | |
| CaO | 1.04 | |
| MgO | 0.13 | |
| BaO | 1.32 | |
| CuO | 0.07 | |
| NiO | - | |
| CoO | - | |
| PbO | - | |
| ZnO | - | |
| $Na_2O$ | 0.01 | |
| $K_2O$ | 0.04 | |
| $As_2O_3$ | 0.003 | |
| $P_2O_5$ | 0.314 | |
| S | 0.01 | |
| $CO_2$ | - | |
| $H_2O$ | - | |
| C | 0.30 | |
| Undetermined | 0.203 | |
| TOTAL | 100.000 | |
| Mn | 28.49 | |
| Fe | 47.85 | |
| P | 0.137 | |
| Mn/Fe | 0.60 | |

(1) 93% metallization

TABLE 6-8

REDUCED PRODUCT
HIGH GRADE ORE
PROJECTED ANALYSIS

| Constituent | Percent | |
|---|---|---|
| $MnO_2$ | - | |
| MnO | 83.65 | |
| $Fe_2O_3$ | - | |
| FeO | 0.78 | |
| Fe | 8.01 | (1) |
| $SiO_2$ | 1.46 | |
| $Al_2O_3$ | 1.13 | |
| $TiO_2$ | 0.042 | |
| CaO | 1.82 | |
| MgO | 0.44 | |
| BaO | 1.76 | |
| CuO | 0.06 | |
| NiO | 0.01 | |
| CoO | - | |
| PbO | - | |
| ZnO | 0.06 | |
| $Na_2O$ | 0.04 | |
| $K_2O$ | 0.05 | |
| $As_2O_3$ | 0.004 | |
| $P_2O_5$ | 0.234 | |
| S | 0.01 | |
| $CO_2$ | - | |
| $H_2O$ | - | |
| C | 0.30 | |
| Undetermined | 0.140 | |
| TOTAL | 100.000 | |
| Mn | 64.78 | |
| Fe | 8.62 | |
| P | 0.102 | |
| Mn/Fe | 7.52 | |

(1) 93% metallization

TABLE 6-9
PRODUCT ASSAYS

| | FeMn | Pig Iron | Semi Steel | SiMn |
|---|---|---|---|---|
| % Mn | 75.0 | 4.0 | 0.44 | 65.0 |
| % Fe | 16.0 | 90.0 | 98.24 | 17.0 |
| % C | 6.5 | 4.0 | 0.04 | 2.0 |
| % Si | 1.5 | 1.0 | - | 16.0 |
| % Other | 1.0 | 1.0 | 1.28 | - |

# DESIGN CRITERIA

The following tables indicate the design criteria developed and used for the metallurgical balances and production schedules for the processes and types of ore considered.

The criteria developed includes:

- carbon reduction reactions
- Metal to products recoveries.
- Specific power consumptions.
- Electrode consumptions.

TABLE 6-10

CARBON REDUCTION REACTIONS

A. $Fe_2O_3 + \underset{12}{C} = \underset{144}{2FeO} + CO$

B. $Fe_2O_3 + \underset{36}{3C} = \underset{112}{2Fe} + 3CO$

C. $FeO + \underset{12}{C} = \underset{56}{Fe} + CO$

D. $MnO_2 + \underset{24}{2C} = \underset{55}{Mn} + 2CO$

E. $MnO_2 + \underset{12}{C} = \underset{71}{MnO} + CO$

F. $MnO + \underset{12}{C} = \underset{55}{Mn} + CO$

G. $SiO_2 + \underset{24}{2C} = \underset{28}{Si} + 2CO$

H. $P_2O_5 + \underset{60}{5C} = \underset{62}{2P} + 5CO$

TABLE 6-11
SUMMARY
METAL TO PRODUCTS
BASE RECOVERIES

FeMn Smelting

70% of Mn in burden to metal

SiMn Smelting

80% of Mn in burden to metal

Pig Iron Smelting

92% of Fe in burden to metal

Semi-Steel Melting

100% of metallic Fe in burden to metal
93% metallization of Fe in burden

Process Recovery

95% in metal
95% in slag
5% losses - vaporization, dust, spillage and recycle

TABLE 6-12
SUMMARY

SPECIFIC POWER CONSUMPTION

| | Metal Requirement kWh/t | Slag Requirement |
|---|---|---|
| **FeMn Smelting** | | |
| High grade Mn ore | | |
| 40% MnO slag | 2,000 | 0.5 |
| 20% MnO slag | 2,500 | 0.5 |
| High Mn slag | | |
| 20% MnO slag | 2,500 | 0.5 |
| **Iron Smelting** | | |
| Pig iron | 1,200 | 0.5 |
| Semi-steel | 600 | 0.5 |
| **SiMn Smelting** | | |
| Low Mn slag | 4,000 | 0.5 |

TABLE 6-13
ELECTRODE CONSUMPTION

| Consumable Electrodes | kg/t |
|---|---|
| FeMn Smelting | 25 |
| SiMn Smelting | 35 |
| Pig Iron Smelting | 15 |
| **Graphite Electrodes** | |
| Steel - Slag Melting | 7 |

(1) Reference Industrial Electric Furnaces by J. Persson and V. Paschkis Interscience Publishers, N.Y. 1960

# DEMAG TEST PROGRAM

Smelting testwork conducted by Demag at Lauffenburg in West Germany in 1959 has been reviewed and metallurgical balances calculated from the data generated. The metallurgical balances and summary tables from the testwork are included in the appendix for reference purposes. A discussion of the Demag process data is as given in the following.

The process proposed by Demag is the least complex and involves direct charging of the ferruginous manganese ore to an open top smelter furnace along with coke and silica to produce a pig iron containing about 2.5% Mn and 4% C. The high Mn slag contains 52% MnO (40% Mn) and an 8 to 1 Mn/Fe ratio. The high Mn slag is subsequently smelted with coke, limestone, and dolomite to obtain standard 75% Mn ferromanganese and a low Mn slag. This direct approach to duplex treatment of the Om Bogma ores is considered the most effective because of simplicity of the operation.

The power consumption projected by Demag from the testwork at 2,700 kWh/t of FeMn is probably optomistic with the comparatively large slag volumes encountered. A more realistic value is in the range of 3,500 to 4,000 kWh/t depending on slag levels. In addition, a somewhat higher level of Mn can be expected in the pig iron if close carbon control is not observed.

TABLE 6-14
DEMAG TEST PROGRAM

SAEF

MN ORE - 0.6 MN/FE

PIG IRON + FEMN

METALLURGICAL DATA

| | High C FeMn | Pig Iron |
|---|---|---|
| Operating Load - kW | 9,000 | 9,800 |
| Operating Time - % | 96 | 96 |
| Avg. Load - kW | 8,640 | 9,400 |
| kWh/kg Alloy | 2.7 | 2.0 |
| kWh/t Alloy | 2,700 | 2,000 |
| % Mn in Metal | 75.0 | 6.0 |
| % Si in Metal | 1.5 | 0.5 |
| % C in Metal | 6.0 | 4.0 |
| Electrode Paste - kg/t | 15 | 8 |

TABLE 6-15

DEMAG TEST PROGRAM

SAEF

MN ORE - 0.6 MN/FE

PIG IRON + FEMN

CAMPAIGN PROGRAM

| | |
|---|---|
| 1000 kg low grade ore | 341 kg pig iron + 488 kg high Mn slag |
| 1000 kg high Mn slag | 335 kg FeMn + 926 kg low Mn slag |
| 335 x .488 | = 163 kg FeMn |
| 926 x .488 | = 452 kg low Mn slag |

HOURLY PRODUCTION

| | | | |
|---|---|---|---|
| Pig iron | 9400/2000 | = | 4.70 t/h |
| High Mn slag | 488/341 x 4.70 | = | 6.73 t/h |
| FeMn | 8640/2700 | = | 3.20 t/h |

7 MO PIG IRON + 5 MO FEMN

| | | | | |
|---|---|---|---|---|
| Pig iron | 215 x 24 x 4.70 | = | 24,252 t | |
| Slag | 215 x 24 x 6.73 | = | 34,727 t | |
| FeMn | 150 x 24 x 3.20 | = | 11,520 t | |
| Slag req'd | 11,520 x 488/163 | = | 34,489 t | balance 215/150 |
| Ore req'd | 24,252 x 1000/341 | = | 71,000 t | |
| Low Mn slag | 34,489 x 926/1000 | = | 31,937 t | |

TABLE 6-16
DEMAG TEST PROGRAM

SAEF

MN ORE - 0.6 MN/FE

PIG IRON + FEMN

Summary - Raw Materials Requirements

| Pig Iron | kg/ Batch | kg/t Pig Iron | t/d | t/Campaign 215 d 7 mos |
|---|---|---|---|---|
| Low grade ore | 1,000 | 2,930 | 331 | 71,100 |
| Coke | 240 | 700 | 80 | 17,200 |
| Quartzite | 100 | 290 | 33 | 7,100 |
| | 1,340 | 3,930 | 444 | 95,400 |
| Pig iron | 341 | 1,000 | 113 | 24,200 |
| High Mn slag | 488 | 1,430 | 161 | 34,700 |

| FeMn | kg/ Batch | kg/t FeMn | t/d | t/Campaign 150 d 5 mos |
|---|---|---|---|---|
| High Mn slag | 1,000 | 2,990 | 230 | 34,500 |
| Coke | 130 | 390 | 30 | 4,500 |
| Limestone | 500 | 1,490 | 115 | 17,250 |
| Dolomite | 100 | 300 | 23 | 3,450 |
| Scrap | - | - | - | - |
| | 1,730 | 5,170 | 398 | 59,700 |
| FeMn | 335 | 1,000 | 77 | 11,500 |
| Low Mn slag | 926 | 2,760 | 213 | 31,900 |

TABLE 6-17
DEMAG TEST PROGRAM
SAEF - MN ORE - 0.6 MN/FE - PIG IRON + FERROMANGANESE

| Material | Weight per Charge kg | $MnO_2$ %/kg | Mn %/kg | MnO %/kg | Mn %/kg | $Fe_2O_3$ %/kg | Fe %/kg | $SiO_2$ % | kg | $Al_2O_3$ % | kg | CaO % | kg | MgO % | kg | BaO % | kg | P % | kg | S % | kg | C % | kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Low Grade Ore | 1000 | 32.76 | | 0.97 | | 51.52 | 36.03 | 5.80 | 58 | 2.38 | 24 | 0.78 | 8 | 0.10 | 1 | 0.99 | 10 | 0.10 | 1 | 0.09 | 1 | | |
| | | 328 | 207 | 10 | 8 | 515 | 360 | | | | | | | | | | | | | | | | |
| Coke | 240 | | | | | 2.0 | | 5.0 | 12 | 3.0 | 7 | | | | | | | | | 1.0 | 2 | 75.0 | 180 |
| | | | | | | 5 | 6 | | | | | | | | | | | | | | | | |
| Quartzite | 100 | | | | | | | 99.0 | 99 | 1.0 | 1 | | | | | | | | | | | | |
| TOTALS | 1340 | | 207 | | 8 | | 364 | | 169 | | 32 | | 8 | | 1 | | 10 | | 1 | | 3 | | 180 |

Pig Iron Produced

| | Initial kg | kg | % |
|---|---|---|---|
| Fe | 340 | 318 | 93.25 |
| Si | 0.4 | 0.2 | 0.06 |
| P | 0.8 | 0.7 | 0.21 |
| Mn | 8.1 | 8 | 2.35 |
| S | 0.1 | 0.1 | 0.03 |
| C | 15.1 | 14 | 4.10 |
| Other | 0.5 | - | - |
| TOTAL | 365.0 | 341 | 100.00 |

Slag Produced

| | Initial kg | kg | % |
|---|---|---|---|
| $SiO_2$ | 157.2 | 156 | 31.97 |
| $Al_2O_3$ | 5.5 | 30 | 6.15 |
| CaO | 12.3 | 7 | 1.43 |
| MgO | 10.1 | 1 | 0.21 |
| MnO | 288.9 | 254 | 52.05 |
| FeO | 31.4 | 31 | 6.35 |
| BaO/Other | 24.4 | 9 | 1.84 |
| TOTAL | 529.8 | 488 | 100.00 |

Material Balances

| | kg Product/Feed | | Unit Recovery |
|---|---|---|---|
| Fe | 342/364 | = | 0.940 |
| Mn | 205/215 | = | 0.953 |
| $SiO_2$ | 156/169 | = | 0.923 |
| $Al_2O_3$ | 30/32 | = | 0.938 |
| CaO | 7/8 | = | 0.875 |
| MgO | 1/1 | = | 1.000 |
| C | | | |

| | |
|---|---|
| $Fe_2O_3/Fe$ | 109.2 |
| $Fe_2O_3/FeO$ | 2.6 |
| MnO/Mn | 1.7 |
| $MnO_2/MnO$ | 45.2 |
| $SiO_2/Si$ | 0.2 |
| $P_2O_5/P$ | 0.7 |
| C in Metal | 15.1 |
| TOTAL | 174.7 |

174.7/.75 = 233 Use 240 kg

Product Ratios

| | | |
|---|---|---|
| Slag/t | (488/341)1000 | = 1431 kg/t |
| Slag Ratio | MnO + FeO/$SiO_2$ | = 1.83 by wt |
| Coke/t | (240/341)1000 | = 704 kg/t |
| Coke to Mix (Percent) | (240/1340)100 | = 17.9 |
| $SiO_2$ to Mix (Percent) | (100/1340)100 | = 7.5 |
| $SiO_2$/t | (100/341)1000 | = 293 kg/t |
| Mn/Fe Slag | | 8.16 |

TABLE 6-18
DEMAG TEST PROGRAM
SAEF - MN ORE - 0.6 MN/FE - PIG IRON + FERROMANGANESE

| Material | Wt. per Charge kg | $MnO_2$ %/kg | Mn %/kg | MnO %/kg | Mn %/kg | $Fe_2O_3$ %/kg | Fe %/kg | FeO %/kg | Fe %/kg | $SiO_2$ % | $SiO_2$ kg | $Al_2O_3$ % | $Al_2O_3$ kg | CaO % | CaO kg | MgO % | MgO kg | BaO % | BaO kg | P % | P kg | S % | S kg | C % | C kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hi Mn Slag | 1000 | | | 52.05<br>521 | 404 | | | 6.35 | 64 | 31.97 | 320 | 6.15 | 62 | 1.43 | 14 | 0.21 | 2 | 1.84 | 18 | | | | | | |
| Coke | 130 | | | | | 2.00 | 2 | | | 5.00 | 7 | 3.00 | 4 | | | | | | | | | | | 75.00 | 98 |
| Limestone | 500 | | | | | | | | | 1.80 | 9 | | | 55.00 | 275 | | | | | | | | | | |
| Dolomite | 100 | | | | | | | | | 2.00 | 2 | | | 30.20 | 30 | 21.00 | 21 | | | | | | | | |
| TOTALS | 1730 | | | | 404 | | 2 | | 64 | | 338 | | 66 | | 319 | | 23 | | 13 | | | | | | 98 |

**FeMn Produced**

| | Actual kg | Actual % | Initial kg | Initial % |
|---|---|---|---|---|
| Mn | | | 251 | 75.0 |
| Fe | | | 54 | 16.0 |
| C | | | 22 | 6.5 |
| Si | | | 5 | 1.5 |
| P | | | - | - |
| S | | | - | - |
| Other | | | 3 | 1.0 |
| TOTAL | | | 335 | 100.0 |

**Slag Produced**

| | Actual kg | Actual % | Initial kg | Initial % |
|---|---|---|---|---|
| $SiO_2$ | | | 321 | 34.66 |
| $Al_2O_3$ | | | 63 | 6.80 |
| CaO | | | 303 | 32.72 |
| MgO | | | 22 | 2.38 |
| MnO | | | 187 | 20.19 |
| FeO | | | 12 | 1.30 |
| BaO | | | 18 | 1.95 |
| | | | 926 | 100.00 |

**Material Balances**

| | kg Product/Feed | Unit Recovery |
|---|---|---|
| Mn | 396/404 | = 0.980 |
| Fe | 63/66 | = 0.955 |
| $SiO_2$ | 332/338 | = 0.981 |
| $Al_2O_3$ | 63/66 | = 0.955 |
| CaO | 303/319 | = 0.950 |
| MgO | 22/23 | = 0.957 |
| C | | |

| | |
|---|---|
| MnO/Mn | 54.8 |
| FeO/Fe | 11.6 |
| $SiO_2$/Si | 4.3 |
| $P_2O_5$/P | - |
| C in Metal | 22.0 |
| | 92.7/.75 = 124 Use 130 kg |

**Product Ratios**

| | |
|---|---|
| Slag/t | (926/335)1000 = 2764 kg |
| Slag Ratio Molal | $\frac{CaO + MgO + MnO + FeO}{SiO_2} = 1.638$ |
| Coke/t | (130/335)1000 = 388 kg |
| Coke to Mix Percent | (130/1730)100 = 7.5 |
| L.S./Dol/t | (600/335)1000 = 1791 kg |
| LS/Dol to Mix % | (600/1730)100 = 34.7 |

# ELKEM TEST PROGRAM

Smelting testwork conducted by Elkem in Norway in 1960 has been reviewed and metallurgical balances calculated from the data generated. The metallurgical balances and summary tables from the testwork are included in the appendix for reference purposes. Discussion of the Elkem process is as follows:

In this duplex process the smelter furnace is preceded by a rotary kiln which preheats and calcines the furnace charge. The Mn ore, coke and fluxes are fed to the kiln and the hot, calcined product is fed directly to the smelter furnace. The furnace is covered with a refractory roof and is fed by gravity from multiple refractory-lined charge hoppers. With the covered furnace, CO gas is collected from the furnace top, scrubbed, and supplied to the rotary kiln to supply heat for preheating and calcining. Otherwise, operation of the smelter furnace is very similar to the previous process with pig iron and FeMn being produced on a campaign basis. When FeMn is being produced in the smelter, high Mn slag is fed to the preheat kiln along with the basic fluxes and Mn ore as required. Preheating of the smelter furnace charge with the kiln reduces power consumption by approximately 10% with the high slag volume operation.

Linking of the rotary kiln to the smelter furnace on a continuous basis and the hot charging system tends to complicate the smelter operation. The pig iron and FeMn products from the tandem kiln and furnace campaign operations are of the same quality as with smelter furnace alone. Overall coke consumption is approximately equivalent.

Comparison of the Elkem proposal with the metallurgical balances shows a higher tonnage of pig iron and a slightly lower tonnage of FeMn for the indicated feed mix. The higher pig iron and reduced FeMn production indicated by the metallurgical balances may be due to use of somewhat different analyses for the Mn ore, Mn fines, coke and flux materials than in the original proposal. Further, there are objections to operating a closed-top furnace with 64% of Mn fines in the smelter furnace feed as proposed.

TABLE 6-19

PH + SAEF - PIG IRON + FEMN

ELKEM TEST SMELTING

Metallurgical Data

| | High C FeMn | Pig Iron |
|---|---|---|
| Operating Load - kWh | 8,300 | 10,500 |
| Operating Time - % | 94 | 94 |
| Avg. Load - kWh | 7,752 | 9,883 |
| kWh/kg Alloy | 3.4 | 1.725 |
| kWh/t Alloy | 3,400 | 1,725 |
| t/h Alloy | 2.28 | 5.73 |
| % Mn | 69.9 | 5.9 |
| % Fe | 22.2 | 90.0 |
| % Si | 1.9 | 0.3 |
| % C | 6.0 | 3.5 |
| Electrode Paste - kg/t | 25 | 15 |

TABLE 6-20
SAEF

MN ORE - MN/FE

PIG IRON + FEMN

CAMPAIGN PROGRAM

| | |
|---|---|
| 1000 kg Mn Ore | 341 kg pig iron + 419 kg high Mn slag |
| 1000 kg high Mn slag | 364 kg FeMn + 857 kg low Mn slag |

HOURLY PRODUCTION

| | | |
|---|---|---|
| Pig Iron | 9883/1725 = | 5.73 |
| High Mn Slag | 5.73 x 419/341 = | 7.04 |
| FeMn | 7752/3400 = | 2.28 |

ANNUAL PRODUCTION: Pig Iron 215 d/7 mo FeMn 150 d/5 mo

| | | | |
|---|---|---|---|
| Pig Iron | 5.73 x 215 x 24 = | 29,567 t/y | |
| High Mn Slag | 7.04 x 215 x 24 = | 36,326 t/y | |
| FeMn | 2.28 x 150 x 24 = | 8,208 t/y | |
| Slag Required | 8,208 x 1000/364 = | 22,549 t/y | |
| Ore Required | 29,567 x 1000/341 = | 86,707 t/y | |
| Coke Required | 29,567 x 210/341 = | 18,208 | |
| | 8,208 x 126/364 = | 2,841 | |
| | | | 21,049 t/y |
| Low Mn Slag | 8,208 x 857/364 = | 19,325 t/y | |

TABLE 6-21

PH + SAEF - PIG IRON + FEMN

ELKEM TEST SMELTING

Summary - Raw Material Requirements

| Pig Iron | kg/Batch | kg/t Iron | t/d | t/campaign 215 d 7 mo |
|---|---|---|---|---|
| Low Grade Ore | | | | |
| Fine - 17% Mn | 466 | 1,367 | 188 | 40,405 |
| Coarse - 20% Mn | 466 | 1,367 | 188 | 40,405 |
| High Grade Ore - 43% Mn | 68 | 199 | 27 | 5,897 |
| Coke | 210 | 616 | 85 | 18,208 |
| Quartzite | 57 | 167 | 23 | 4,938 |
| | 1,267 | 3,716 | 511 | 109,853 |
| Pig Iron | 341 | 1,000 | 138 | 29,567 |
| High Mn Slag | 419 | 1,229 | 169 | 36,326 |

| FeMn | kg/Batch | kg/t FeMn | t/d | t/campaign 150 d 5 mo |
|---|---|---|---|---|
| High Mn Slag | 1,000 | 2,747 | 150 | 22,549 |
| Coke | 126 | 346 | 19 | 2,841 |
| Limestone | 588 | 1,615 | 88 | 13,256 |
| Scrap | 35 | 96 | 5 | 788 |
| | 1,749 | 4,804 | 262 | 39,434 |
| FeMn | 364 | 1,000 | 55 | 8,208 |
| Low Mn Slag | 857 | 2,354 | 129 | 19,325 |

TABLE 6-22
PREHEAT KILN + SAEF - MN ORE - PIG IRON + FEMN
ELKEM TEST SMELTING

| Material | Weight per Charge kg | $MnO_2$ %/kg | Mn %/kg | MnO %/kg | Mn %/kg | $Fe_2O_3$ %/kg | Fe %/kg | | $SiO_2$ % | kg | $Al_2O_3$ % | kg | CaO % | kg | MgO % | kg | BaO % | kg | P % | kg | S % | kg | C % | kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Low Grade Ore (fine) | 466 | 27.0 | 17.1 | | | 56.3 | 39.4 | | 6.54 | 30 | 0.8 | 4 | 1.25 | 6 | 0.35 | 2 | | | 0.08 | - | 0.28 | 1 | | |
| | | 126 | 80 | | | 262 | 184 | | | | | | | | | | | | | | | | | |
| Low Grade Ore (coarse) | 466 | 31.5 | 19.9 | | | 51.4 | 36.0 | | 4.04 | 19 | 2.2 | 10 | 1.88 | 9 | 0.94 | 4 | | | 0.05 | - | 0.33 | 2 | | |
| | | 147 | 93 | | | 240 | 168 | | | | | | | | | | | | | | | | | |
| High Grade Ore | 68 | 69.1 | 43.69 | | | 16.19 | 11.33 | | 3.0 | 2 | 1.5 | 1 | 1.7 | 1 | | | | | 0.09 | - | 0.15 | - | | |
| | | 47 | 30 | | | 11 | 8 | | | | | | | | | | | | | | | | | |
| Coke (SAEF + Prereducing) | 210 | | | | | 0.8 | | | 2.84 | 6 | 1.27 | 3 | 2.43 | 5 | 0.41 | 1 | | | 0.48 | 1 | 0.40 | 1 | 83.5 | 175 |
| | | | | | | 2 | 1 | | | | | | | | | | | | | | | | | |
| Quartzite | 57 | | | | | | | | 99.0 | 56 | 1.0 | 1 | | | | | | | | | | | | |
| TOTAL | 1,267 | 320 | 203 | | | 514 | 361 | | | 113 | | 19 | | 21 | | 7 | | | | 1 | | 4 | | 175 |

PIG IRON PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| Fe | 315 | 332 | 92.3 |
| Mn | 10 | 11 | 3.0 |
| C | 11 | 12 | 3.5 |
| Si | 4 | 4 | 1.0 |
| P | 1 | 1 | 0.2 |
| S | - | - | - |
| | 341 | 360 | 100.0 |

SLAG PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| $SiO_2$ | 99 | 104 | 23.6 |
| $Al_2O_3$ | 18 | 19 | 4.3 |
| CaO | 20 | 21 | 4.8 |
| MgO | 7 | 7 | 1.6 |
| MnO | 236 | 248 | 56.4 |
| FeO | 35 | 37 | 8.4 |
| BaO/Other | 4 | 4 | 0.9 |
| | 419 | 440 | 100.0 |

MATERIAL BALANCES

| | kg Product/kg Feed | Unit Recovery |
|---|---|---|
| Fe | 342/361 | = 0.948 |
| Mn | 193/203 | = 0.949 |
| $SiO_2$ | 108/113 | = 0.952 |
| $Al_2O_3$ | 18/19 | = 0.947 |
| CaO | 20/21 | = 0.952 |
| MgO | 7/7 | = 1.000 |

C

| | |
|---|---|
| $MnO_2/MnO$ | 44.1 |
| MnO/Mn | 2.4 |
| $Fe_2O_3/FeO$ | 38.6 |
| FeO/Fe | 71.1 |
| $SiO_2/Si$ | 3.4 |
| $P_2O_5/P$ | 1.0 |
| C in Metal | 12.0 |
| | 172.6 |

172.6/.835 = 206.7

Use 210 kg

PRODUCT RATIOS

| | | | |
|---|---|---|---|
| Slag/t | (419/341)1000 | = | 1229 kg |
| Slag Ratio | CaO + MnO + MgO/$SiO_2$ | = | 2.34 |
| Coke/t | (210/341)1000 | = | 616 kg |
| Coke to Mix % | (210/1267)100 | = | 16.6 |
| $SiO_2$/t | (57/341)1000 | = | 167 kg |
| $SiO_2$ to Mix % | (57/1267)100 | = | 4.5 |
| Mn/Fe Slag | | | 6.7 |

NOTE: Coke used in this calculation includes carbon required for reducing the ores.

ENGINEERS

TABLE 6-23
PREHEAT KILN + SAEF - MN ORE - PIG IRON + FEMN
ELKEM TEST SMELTING

| Material | Weight per Charge kg | MnO % | MnO kg | Mn % | Mn kg | $Fe_2O_3$ % | $Fe_2O_3$ kg | Fe % | Fe kg | FeO % | FeO kg | Fe % | Fe kg | $SiO_2$ % | $SiO_2$ kg | $Al_2O_3$ % | $Al_2O_3$ kg | CaO % | CaO kg | MgO % | MgO kg | BaO % | BaO kg | P % | P kg | S % | S kg | C % | C kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| High Mn Slag | 1,000 | 48.5 | 485 | | 376 | | | | | 7.6 | 76 | | 59 | 29.5 | 295 | 8.3 | 83 | 3.5 | 35 | | | | | | | | | | |
| Coke | 126 | | | | | 0.8 | 1 | | 1 | | | | | 2.84 | 4 | 1.27 | 2 | 2.43 | 3 | 0.41 | 1 | | | 0.48 | 1 | 0.40 | 1 | 83.5 | 105 |
| Limestone | 588 | | | | | | | | | | | | | 2.3 | 14 | 1.8 | 11 | 52.7 | 310 | 0.6 | 4 | | | | | 0.1 | 1 | | |
| Scrap | 35 | — | — | | | — | | 35 | | — | | — | | — | | — | | — | | — | | — | | — | | — | | — | |
| TOTAL | 1,749 | | 485 | | 376 | | 1 | | 36 | | 76 | | 59 | | 313 | | 96 | | 348 | | 5 | | | | 1 | | 2 | | 105 |

FEMN PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| Mn | 250 | 263 | 68.5 |
| Fe | 86 | 91 | 23.7 |
| C | 21 | 22 | 5.8 |
| Si | 7 | 7 | 1.9 |
| P | - | - | 0.1 |
| S | - | - | - |
| TOTAL | 364 | 383 | 100.0 |

SLAG PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| $SiO_2$ | 283 | 298 | 33.1 |
| $Al_2O_3$ | 91 | 96 | 10.6 |
| CaO | 331 | 348 | 38.6 |
| MgO | 5 | 5 | 0.6 |
| MnO | 139 | 146 | 16.2 |
| FeO | 5 | 5 | 0.6 |
| Other | 3 | 3 | 0.3 |
| | 857 | 901 | 100.0 |

MATERIAL BALANCES

| | kg Product/kg Feed | Unit Recovery |
|---|---|---|
| Fe | 90/95 | = 0.946 |
| Mn | 358/376 | = 0.951 |
| $SiO_2$ | 298/313 | = 0.952 |
| $Al_2O_3$ | 91/96 | = 0.948 |
| CaO | 331/348 | = 0.951 |
| MgO | 5/5 | = 1.000 |

| | |
|---|---|
| MnO/Mn | 57.4 |
| $Fe_2O_3$/FeO | 3.9 |
| FeO/Fe | 19.5 |
| $SiO_2$/Si | 6.0 |
| $P_2O_5$/P | - |
| C in Metal | 22.0 |
| | 108.8 |

108.8/.835 = 130.3

PRODUCT RATIOS

| | | |
|---|---|---|
| Slag/t | (857/364)1000 | = 2354 kg |
| Slag Ratio | $\frac{CaO+MgO+MnO}{SiO_2}$ | = 1.69 |
| Coke/t | (126/364)1000 | = 346 kg |
| Coke to Mix % | (126/1749)100 | = 7.2 |
| LS/$t_i$ | (588/364)1000 | = 1615 |
| LS in Mix % | (588/1749)100 | = 33.6 |
| Mn/Fe Slag | | 27.7 |

TABLE 6-24

PH + SAEF - PIG IRON + FEMN

PLANT DESIGN

Metallurgical Data

| | High C FeMn | Pig Iron |
|---|---|---|
| Operating Load - kWh | 10,000 | 10,000 |
| Operating Time - % | 94 | 94 |
| Avg. Load - kW | 9,400 | 9,400 |
| kWh/kg Alloy | 3.40 | 1.725 |
| kWh/t Alloy | 3,400 | 1,725 |
| % Mn | 75.0 | 5.0 |
| % Fe | 16.0 | 90.0 |
| % Si | 1.5 | 0.5 |
| % C | 6.5 | 4.0 |
| Electrode Paste - kg/t | 25 | 15 |

TABLE 6-25
PH + SAEF - PIG IRON + FEMN

PLANT DESIGN

CAMPAIGN PROGRAM

| | |
|---|---|
| 1000 kg Mn Ore | 342 kg pig iron + 447 kg high Mn slag |
| 1000 kg High Mn Slag | 386 kg FeMn + 811 kg low Mn slag |

HOURLY PRODUCTION

| | | | |
|---|---|---|---|
| Pig Iron | 9400/1725 | = | 5.45 t/h |
| High Mn Slag | 5.45 x 447/342 | = | 7.12 t/h |
| FeMn | 9400/3400 | = | 2.76 t/h |

ANNUAL PRODUCTION: Pig Iron 215 d/7 mo FeMn 150 d/5 mo

| | | | |
|---|---|---|---|
| Pig Iron | 215 x 24 x 5.45 | = | 28,122 t/y |
| High Mn Slag | 215 x 24 x 7.12 | = | 36,739 t/y |
| FeMn | 150 x 24 x 2.76 | = | 9,936 t/y |
| Slag Required | 9936 x 1000/386 | = | 25,741 t/y |
| Ore Required | 28,122 x 1000/342 | = | 82,228 t/y |

| | | | |
|---|---|---|---|
| Coke Required | 28,122 x 240/342 = 19,735 | | |
| | 9,936 x 150/386 = 3,861 | | 23,596 t/y |
| Low Mn Slag | 9,936 x 811/386 | = | 20,876 t/y |

TABLE 6-26
PH + SAEF - PIG IRON + FEMN
PLANT DESIGN

Summary - Raw Material Requirements

| Pig Iron | kg/Batch | kg/t Iron | t/d | t/Campaign 215 d/7 mo |
|---|---|---|---|---|
| Fine Ore - 19% Mn | 640 | 1,871 | 245 | 52,626 |
| Coarse Ore - 21% Mn | 280 | 819 | 107 | 23,024 |
| High Grade Ore - 48% Mn | 80 | 234 | 31 | 6,578 |
| Coke | 240 | 702 | 92 | 19,735 |
| Quartzite | 60 | 175 | 23 | 4,921 |
| | 1,300 | 3,801 | 498 | 106,884 |
| Pig Iron | 342 | 1,000 | 131 | 28,122 |
| High Mn Slag | 447 | 1,307 | 171 | 36,739 |

| FeMn | kg/Batch | kg/t FeMn | t/d | t/Campaign 150 d/5 mo |
|---|---|---|---|---|
| High Mn Slag | 1,000 | 2,591 | 172 | 25,741 |
| Limestone | 550 | 1,425 | 94 | 14,159 |
| Coke | 150 | 389 | 26 | 3,861 |
| Scrap | 10 | 26 | 2 | 258 |
| | 1,710 | 4,431 | 294 | 44,019 |
| FeMn | 386 | 1,000 | 66 | 9,936 |
| Low Mn Slag | 811 | 2,101 | 139 | 20,876 |

TABLE 6-27
PREHEAT KILN + SAEF - MN ORE - PIG IRON + FEMN - PLANT DESIGN

| Material | Weight per Charge kg | $MnO_2$ %/kg | Mn %/kg | MnO %/kg | Mn %/kg | $Fe_2O_3$ %/kg | Fe %/kg | $SiO_2$ % | kg | $Al_2O_3$ % | kg | aO % | kg | MgO % | kg | BaO % | kg | P % | kg | S % | kg | C % | kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fine Ore | 640 | 28.99 | 18.33 | 0.86 | 0.67 | 54.29 | 38.00 | 5.80 | 37 | 2.38 | 15 | 0.78 | 5 | 0.10 | 1 | 0.99 | 6 | 0.103 | 1 | 0.09 | 1 | | |
| | | 186 | 117 | 6 | 4 | 348 | 243 | | | | | | | | | | | | | | | | |
| Coarse Ore | 280 | 32.76 | 20.71 | 0.97 | 0.75 | 51.52 | 36.03 | 5.80 | 16 | 2.38 | 7 | 0.78 | 2 | 0.10 | - | 0.99 | 3 | 0.103 | - | 0.09 | - | | |
| | | 92 | 58 | 3 | 2 | 144 | 101 | | | | | | | | | | | | | | | | |
| High Grade Ore | 80 | 67.77 | 42.95 | 11.18 | 8.66 | 9.79 | 6.85 | 1.16 | 1 | 0.90 | 1 | 1.45 | 1 | 0.35 | - | 1.40 | 1 | 0.081 | - | 0.09 | - | | |
| | | 54 | 34 | 9 | 7 | 8 | 5 | | | | | | | | | | | | | | | | |
| Coke | 240 | | | | | 2.00 | | 5.00 | 12 | 3.00 | 7 | | | | | | | | | 1.00 | 2 | 75.00 | 180 |
| | | | | | | 5 | 3 | | | | | | | | | | | | | | | | |
| Quartzite | 60 | | | | | | | 99.00 | 59 | 1.00 | 1 | | | | | | | | | | | | |
| TOTALS | 1,300 | 332 | 209 | 18 | 13 | 505 | 352 | | 125 | | 31 | | 8 | | 1 | | 10 | | 1 | | 3 | | 180 |

PIG IRON PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| Fe | 308 | 324 | 90.0 |
| Si | 2 | 2 | 0.5 |
| P | 1 | 1 | 0.3 |
| Mn | 17 | 18 | 5.0 |
| S | - | - | 0.04 |
| C | 13 | 14 | 4.0 |
| Other | 1 | 1 | 0.16 |
| | 342 | 360 | 100.00 |

SLAG PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| $SiO_2$ | 115 | 121 | 25.7 |
| $Al_2O_3$ | 29 | 31 | 6.6 |
| CaO | 8 | 8 | 1.7 |
| MgO | 1 | 1 | 0.2 |
| MnO | 250 | 263 | 56.0 |
| FeO | 34 | 36 | 7.7 |
| BaO/Other | 10 | 10 | 2.1 |
| | 447 | 470 | 100.0 |

MATERIAL BALANCES

| | | |
|---|---|---|
| Fe | 334/352 | = 0.950 |
| Mn | 211/222 | = 0.950 |
| $SiO_2$ | 119/125 | = 0.952 |
| $Al_2O_3$ | 29/31 | = 0.936 |
| CaO | 8/8 | = 1.000 |
| MgO | 1/1 | = 1.000 |
| BaO | 10/10 | = 1.000 |

| | C |
|---|---|
| $Fe_2O_3$/FeO | 37.9 |
| FeO/Fe | 69.4 |
| $MnO_2$/MnO | 45.8 |
| MnO/Mn | 3.9 |
| $SiO_2$/Si | 1.7 |
| $P_2O_5$/P | 1.0 |
| C in Metal | 14.0 |
| | 173.7 |

173.7/.75 = 231.6 Use 240 kg

PRODUCT RATIOS

| | | | |
|---|---|---|---|
| Slag/t | (447/342)1000 | = | 1,307 kg |
| Slag Ratio | MnO + CaO + MgO/$SiO_2$ | = | 1.92 |
| Coke/t | (240/342)1000 | = | 702 kg |
| Coke to Mn % | (240/1300)100 | = | 18.5 |
| $SiO_2$/t | (60/342)1000 | = | 175 kg |
| $SiO_2$ to Mix % | (60/1300)100 | = | 4.6 |
| Mn/Fe Slag | | = | 7.3 |

TABLE 6-28
PREHEAT KILN + SAFF - MN ORE - PIG IRON + FEMN - PLANT DESIGN

| Material | Weight per Charge kg | $MnO_2$ %/kg | Mn %/kg | MnO %/kg | Mn %/kg | FeO %/kg | Fe %/kg | $Fe_2O_3$ %/kg | Fe %/kg | $SiO_2$ % | kg | $Al_2O_3$ % | kg | CaO % | kg | MgO % | kg | BaO % | kg | P % | kg | S % | kg | C % | kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| High Mn Slag | 1,000 | | | 56.0 | | 7.7 | | | | 25.7 | 257 | 6.6 | 66 | 1.7 | 17 | 0.2 | 2 | 2.1 | 21 | | | | | | |
| | | | | 560 | 434 | 77 | 60 | | | | | | | | | | | | | | | | | | |
| Limestone | 550 | | | | | | | | | 1.8 | 10 | | | 55.0 | 303 | | | | | | | | | | |
| Coke | 150 | | | | | | | 2.0 | | 5.0 | 8 | 3.0 | 5 | | | | | | | | | 1.0 | 2 | 75.0 | 113 |
| | | | | | | | | 3 | 2 | | | | | | | | | | | | | | | | |
| Scrap | 10 | | | | | | 10 | | | | | | | | | | | | | | | | | | |
| TOTAL | 1,710 | | | 560 | 434 | 77 | 70 | 3 | 2 | | 275 | | 71 | | 320 | | 2 | | 21 | | | | 2 | | 113 |

FEMN PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| Mn | 289 | 304 | 75.0 |
| Fe | 62 | 65 | 16.0 |
| C | 25 | 26 | 6.5 |
| Si | 6 | 6 | 1.5 |
| P | - | - | - |
| S | - | - | - |
| Other | 4 | 4 | 1.0 |
| | 386 | 405 | 100.0 |

SLAG PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| $SiO_2$ | 249 | 262 | 31.9 |
| $Al_2O_3$ | 67 | 71 | 8.2 |
| CaO | 304 | 320 | 36.5 |
| MgO | 2 | 2 | 0.2 |
| BaO | 20 | 21 | 2.5 |
| MnO | 160 | 168 | 19.2 |
| FeO | 9 | 9 | 1.5 |
| | 811 | 853 | 100.0 |

MATERIAL BALANCES

| | kg Product/Feed | | Unit Recovery |
|---|---|---|---|
| Fe | 69/72 | = | 0.958 |
| Mn | 413/434 | = | 0.952 |
| $SiO_2$ | 262/275 | = | 0.953 |
| $Al_2O_3$ | 67/71 | = | 0.944 |
| CaO | 304/320 | = | 0.950 |
| MgO | 2/2 | = | 1.000 |
| BaO | 20/21 | = | 0.952 |

C

| | |
|---|---|
| MnO/Mn | 66.3 |
| FeO/Fe | 13.9 |
| $Fe_2O_3$/FeO | 0.2 |
| $SiO_2$/Si | 5.1 |
| C in Metal | 26.0 |
| | 111.5 |

111.5/.75 = 148.7 Use 150 kg

PRODUCT RATIOS

| | | |
|---|---|---|
| Slag/t | (811/386)1000 | = 2101 kg |
| Slag Ratio | $\frac{CaO+MgO+MnO+BaO}{SiO_2}$ | = 1.89 |
| Coke/t | (150/386)1000 | = 389 kg |
| Coke to Mix % | (150/1710)100 | = 8.8 |
| LS/t | (550/386)1000 | = 1425 kg |
| LS to Mix % | (550/1710)100 | = 32.2 |
| Mn/Fe Slag | | 17.7 |

# PHYSICAL BENEFICIATION TESTWORK

During the period in which the Om Bogma area ores have been exploited, the main contaminant of the manganese ore has been the iron content. Normally the Mn and Fe oxides comprise about 80% of the ore. For standard commercial specifications, manganese ore contains about 48% Mn and has a Mn/Fe ratio of 7 to 1 or better, that is the ore contains less then 7% Fe.

Generally the Mn and Fe in the Om Bogma ores is extremely fine and intimately associated such that physical separation is difficult. Further, the oxide ores of manganese tend to create slimes on grinding which complicate the conventional beneficiation methods of sizing, gravity concentration, high intensity magnetic separation, and flotation.

Since dilution of the local ore by gangue minerals such as quartz, limestone, and dolomite is comparatively minor, the benefits of grinding the ore to liberation are small unless iron can be removed. Mineralogical studies show that the iron is finely disseminated through out the manganese minerals and is therefore difficult to liberate without extreme fine grinding.

As a means to improve the iron separation characteristics, magnetic roasting of the ferruginous manganese ores has been extensively tested in the laboratory at the National Research Center. Work conducted by the National Research Center from 1961 to 1973 applying magnetic roasting and dry low intensity magnetic separation techniques showed some promise of an improved method for separating the iron and manganese. As a result, testwork was undertaken by KECI/ACB at the Mineral Resources Research Center (MRRC) in 1980 to confirm and further evaluate the magnetic roasting and separating of iron from the ore using improved procedures for iron removal. Samples of ferruginous manganese stockpile fines and low grade bunker ore were obtained by KECI/ACB at Abu Zeneima in March, 1980, and forwarded to MRRC. The ore was chemically analyzed and a preliminary mineralogical examination was conducted for identification of ore constituents and for interpretation of the thermal gravimetric analysis (TGA) conducted. The TCA analysis provides information on roasting and weight loss characteristics of a particular ore in comparison to an inert standard.

Subsequently roasting testwork was conducted over a band of

temperatures ranging from 500° to 700°C. This temperature band brackets the most favorable temperature range of 600° to 650°C for roasting a nonmagnetic hematite (Fe203) to a stable magnetite (Fe304) without conversion to nonmagnetic wustite (FeO): The best results obtained by conversion of hematite to magnetite occurred at a roasting temperature of 700°C. The concentrates obtained were as follows:

Mn Ore Feed to Magnetic Separation After 700°C Roast to Fe304

| % Wt. | % Fe | % Mn | Mn/Fe | |
|---|---|---|---|---|
| 100.0 | 47.8 | 21.8 | 0.46 | Roasted Ore Analysis |

Magnetic Concentrate (Fe304)

| % Wt | % Fe | % Mn | Mn/Fe | % Fe Rec | % Sep Eff Fe-Mn |
|---|---|---|---|---|---|
| 63.0 | 65.1 | 4.3 | 0.07 | 85.6 | 73.2 |

Nonmagnetic Concentrate (MnO)

| % Wt | % Fe | % Mn | Mn/Fe | % Mn Rec | % Sep Eff Mn-Fe |
|---|---|---|---|---|---|
| 37.0 | 15.5 | 54.5 | 3.52 | 87.0 | 74.7 |

Rec = Recovery Sep Eff = Separation Efficiency

In a separate investigation the test temperature was increased and gas reduction was conducted at 1000°C to obtain sponge iron and to examine the magnetic concentration characteristics for separating metallic iron from MnO.

When magnetic separation was conducted on reduced ore in which the iron as hematite was converted to metallic iron at 1000°C, the results were as follows:

Mn Ore Feed to Magnetic Separation After 1000°C Reduction to Fe Metal

| % Wt | % Fe | % Mn | Mn/Fe | |
|---|---|---|---|---|
| 100.0 | 49.8 | 24.5 | 0.49 | Reduced Ore Analysis |

Magnetic Concentrate (Fe Met)

| % Wr | % Fe | % Mn | Mn/Fe | % Fe Rec | % Sep Eff Fe-Mn |
|---|---|---|---|---|---|
| 60.9 | 71.8 | 5.2 | 0.07 | 87.7 | 74.7 |

Nonmagnetic Concentrate (MnO)

| % Wt | % Fe | % Mn | Mn/Fe | % Mn Rec | % Sep Eff Mn-Fe |
|---|---|---|---|---|---|
| 39.0 | 15.5 | 54.5 | 3.52 | 87.0 | 74.7 |

Rec = Recovery Sep Eff = Separation Efficiency

The above data on magnetic and reduction roasting are preliminary and have been obtained from testwork on samples that are not necessarily representative of the low grade ore reserves.

The MRRC test report and detailed test results are included in the Appendix for reference purposes. The initial metallurgical results are significant enough to warrant further investigation in Stage 2 in order to determine whether there is application of physical beneficiation for the surplus high iron-bearing low Mn/Fe ratio ore reserves of the Om Bogma area. Additional bench scale testing of a wider range of samples would generate sufficient data to permit an economic analysis of the roasting and magnetic concentration approach.

Future concentration testwork to provide more definitive answers concerning the above improved beneficiation procedures should be conducted in Stage 2. This testwork will require 1,000 kg of a representative iron-bearing Mn ore sample.

# SINAI MANGANESE

# ORE STUDIES

FOR

KAISER ENGINEERS & CONSTRUCTORS, INC.

JULY 1980

BY

UNIVERSITY OF MINNESOTA

MINERAL RESOURCES RESEARCH CENTER

MINNEAPOLIS MINNESOTA

# SINAI MANGANESE ORE STUDIES

Two groups of ore samples were received for testing:

1. Hand specimens (unrepresentative).

Ten samples, each consisting of several lumps, some as large as two inches, were submitted for analyses of Fe and Mn and possible petrographic examinations.

2. Bulk ore samples, about 50 pounds each.

Lot 1: Fines
Lot 2: Fines
Lot 3: Coarse ore, 3-inch top size.

These samples were submitted for analyses of Fe and Mn, possible petrographic examination, and reduction-magnetic separation studies.

## HAND SPECIMENS

These samples were randomly sampled and analyzed, with the results as shown in Table 1. The assays were not consistent with the groupings suggested. All but two contained less than 2% Fe and more than 55% Mn. The other two were over 52% Fe and 7.4% Mn or less. The relatively high Loss-on-Ignition at 1000°C probably included adsorbed and combined water as well as oxygen released by manganese oxides.

Two lumps were cut and polished for microscopic examination with the following observations:

"Medium Grade" No. 2: Red streak. Grain size 0.01 to 0.25 mm. Manganese mineral appears to have crystallized out of surrounding hematite. Estimated composition:

| | |
|---|---|
| Hematite | 55-65% |
| Pyrolusite | < 30% |
| Gangue | 15-25% |

"High Grade" No. 2: Yellowish streak. Grain size 2-4 mm length. Composition: Primarily goethite, fibrous, with about 5% quartz.

Further work was unwarranted because these samples were not representative of defined ore quantities.

## BULK ORE SAMPLES

The particle size distributions of the three ore lots, as received, are given in Table 2. Because of the coarseness of Lot 3, it was crushed to minus 3/4 inch before further study to make better sampling possible.

Each lot was sampled and assayed, and the mineral densities were determined by liquid displacement. The LOI was determined at both 900°C and 1000°C (in air). The bulk densities and angles of repose of Lots 1 and 2 in the as-received condition and Lot 3 after crushing were determined. The internal porosities of the ore particles were estimated by comparing the mineral densities with the gross mean densities of the plus 8 mesh particles as obtained by mercury displacement measurements. These data are all reported in Table 3.

A thermal-gravimetric analysis was made on a 0.2-gram sample of Lot 2 at minus 150 mesh. Although the accuracy and precision of the test data were generally poor, the results did yield a qualitative picture of the thermal decomposition characteristics of the ore. The data, given in Table 4 and plotted in Figure 1, clearly show three stages of thermal decomposition: loss of free and adsorbed water is the most likely phenomenon below 300°C, dehydration of goethite between 300 and 350°C, and decomposition of pyrolusite, $MnO_2$, to lower oxides above 500°C. (Because of equipment deficiencies, the observed weight losses are only approximate.) From other considerations, such as the equilibrium partial pressures of oxygen over the various iron and manganese oxides, it was concluded that the manganese and iron oxides remaining after ignition at 900°C were hausmannite ($Mn_3O_4$) and hematite ($Fe_2O_3$), respectively.

Laboratory chemical reduction tests were performed on 100-gram samples of Lot 2 to explore the possibilities of separating the material into high manganese-low iron and low manganese-high iron fractions by subsequent magnetic separation. Reduction of iron oxides normally occurs in stages, the successive products being magnetite ($Fe_3O_4$), wustite (FeO), and, finally, metallic iron. The manganese oxides also reduce in stages, but manganosite (Mno) is the only stable end product to be expected upon reduction of a manganiferous iron ore. Magnetic separation of iron from manganese should be possible at either the magnetite or metallic iron stages but not at the wustite stage.

Past experience has shown that iron ores can be reduced to the magnetite stage in relatively dilute mixtures of carbon monoxide or hydrogen (or both) at temperatures between 450 and 700°C, with best results at 600 to 650°C. Magnetite formed at less than 600°C tends to be unstable in air, even after cooling below 100°C, and above 650°C, some over-reduction to the nonmagnetic wustite form begins to occur. Although metallic iron begins to appear even as low as 700°C, best results require reduction at 900°C or above. Still higher processing temperatures may be desirable, especially for very fine-grained ores, to promote grain growth or coalescence of the iron for better magnetic separation.

## Reduction Tests

A series of reduction tests at elevated temperatures was undertaken with the reductant gas consisting of approximately 30% hydrogen and 70% nitrogen, humidified by bubbling through water at room temperature. The formation of the nonmagnetic wustite should not pose a problem with such a mixture. The reduction temperatures were chosen arbitrarily at 500, 600, 700, and 1000°C. The reactions were carried out in a 2-inch diameter retort suspended from a balance in a vertical, electrically heated, tube furnace under the conditions listed in Table 5.

The time, temperature and weight-loss data are recorded in Tables 6-11 and plotted in Figures 2-7 to show the course of the reductions. The first four tests were made on 100-gram portions of the plus 8 mesh fractions of Lot 2. Tests 5 and 6 were made on 125-gram portions of the minus 8 mesh fines of Lot 2, agglomerated into half-inch diameter wet balls. The sample for Test 6 contained one percent crude sodium chloride.

## Magnetic Separation Tests

Portions of the reduced ores of Tests 1-4 were pulverized to minus 150 mesh for determination of their magnetic separation characteristics by means of the Davis magnetic tube separator. For each product, a series of three tube tests at successively more vigorous conditions was performed on identical 5-gram samples. The heads and magnetic concentrates were assayed for total iron and manganese. Although assays for metallic iron were also made on the head samples of Test 4 and Test 5 products, possible interferences by manganese have not been established and the values obtained may not be accurate. Manganese assays of the nonmagnetic tails - the manganese concentrates - were calculated from weight recoveries and assays of the magnetic concentrates. The magnetic separation test results are given in Table 12.

The results of the magnetic separation tests are shown graphically in Figures 8-11. The curves labeled Fe refer to grade and iron recovery of the magnetic fraction or iron concentrate, while those labeled Mn refer to grade and manganese recovery of the nonmagnetic fraction or manganese concentrate. A single-stage separation can separate only two components of a mixture; additional separation means would have to be applied to each of the products obtained by magnetic separation to remove unwanted gangue minerals.

## Metallic Iron Characteristics

If these ores were to be treated by reduction to the metallic iron state, the iron recovery could be greatly enhanced by coalescence of the metallic iron and promotion of its malleability during the reduction process. The reduced ores from Tests 4 and 5 did not exhibit such enhancement, but that of Test 6 did yield an increased proportion of malleable iron.

## SUMMARY AND CONCLUSIONS

The Sinai manganese ore samples were readily reduced to either the magnetite or metallic iron state with subsequent fair to good efficiency of separation by magnetic concentration. The experimental conditions employed were selected more or less arbitrarily. It is reasonable to expect that high grade concentrates of iron and of manganese could be produced from this ore under optimum process conditions which could be determined by additional research.

N. F. Schulz
Research Associate
July 30, 1980

TABLE 1. ANALYSES OF SINAI MANGANESE ORE HAND SPECIMENS

| Sample | % Fe | % Mn | % LOI, 1000°C |
|---|---|---|---|
| | Group Labeled "Low Grade" | | |
| 1 | 1.62 | 55.2 | 12.1 |
| 2 | 0.65 | 60.5 | 14.5 |
| 3 | 0.16 | 62.0 | 13.9 |
| | Group Labeled "Medium Grade" | | |
| 1 | 0.16 | 62.5 | 14.3 |
| 2 | 57.2 | 6.4 | 3.7 |
| | Group Labeled "High Grade" | | |
| 1 | 0.32 | 59.4 | 14.2 |
| 2 | 52.3 | 7.4 | 11.0 |
| 3 | 0.49 | 55.6 | 11.7 |
| 4 | 0.16 | 62.0 | 12.9 |
| 5 | 0.16 | 60.5 | 13.9 |

TABLE 2. PARTICLE SIZE DISTRIBUTIONS OF ORE SAMPLES

| Size Fraction, mesh | % Distribution | | |
|---|---|---|---|
| | Lot 1 | Lot 2 | Lot 3 |
| +4 | 16.1 | 15.6 | 71.9 |
| 4/8 | 22.0 | 20.0 | 10.7 |
| 8/14 | 15.9 | 16.2 | 5.6 |
| 14/28 | 12.9 | 12.5 | 3.5 |
| 28/35 | 6.5 | 5.5 | 1.3 |
| 35/48 | 4.4 | 4.9 | 1.2 |
| 48/65 | 6.3 | 4.9 | 0.8 |
| 65/100 | 7.4 | 9.4 | 0.9 |
| 100/150 | 4.4 | 5.7 | 0.9 |
| 150/200 | 2.2 | 2.7 | 0.7 |
| -200 | 1.9 | 2.6 | 2.5 |

TABLE 3. ASSAYS AND PHYSICAL CHARACTERISTICS OF THE THREE ORE LOTS

| | Lot 1 | Lot 2 | Lot 3 |
|---|---|---|---|
| Assays: | | | |
| % Fe | 38.1 | 39.4 | 36.8 |
| % Mn | 16.7 | 15.7 | 16.0 |
| % LOI: 900°C | 6.5 | 6.0 | 7.0 |
| 1000°C | 7.7 | 7.0 | 7.9 |
| Bulk density (loose pack) | | | |
| $lb/ft^3$ | 119 | 127 | 117 |
| $kg/m^3$ | 1900 | 2040 | 1870 |
| Mineral density $g/cm^3$ | 4.19 | 4.20 | 4.06 |
| Mean gross particle density $g/cm^3$ | 3.05 | 3.11 | 2.96 |
| Porosity of particles, % | 27.1 | 26.0 | 27.2 |
| Angle of repose, degrees | 40 ± 2 | 40 ± 2 | 38 ± 2 |

TABLE 4. THERMAL-GRAVIMETRIC ANALYSIS (TGA) OF LOT 2

| Time, minutes | Temperature °C | Weight Loss, % |
|---|---|---|
| 8 | 50 | 0 |
| 14 | 100 | 0.26 |
| 26 | 200 | 1.17 |
| 32 | 260 | 1.44 |
| 34 | 280 | 1.51 |
| 36 | 300 | 1.56 |
| 40 | 335 | 2.36 |
| 42 | 360 | 2.65 |
| 47 | 400 | 2.61 |
| 53 | 460 | 2.67 |
| 59 | 510 | 2.68 |
| 63 | 540 | 2.91 |
| 65 | 560 | 3.20 |
| 68 | 590 | 3.82 |
| 71 | 620 | 4.32 |
| 73 | 640 | 4.73 |
| 75 | 660 | 4.76 |
| 88 | 790 | 4.74 |
| 90 | 820 | 4.58 |

TABLE 5. REDUCTION TESTS: SUMMARY

| Test No. | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Reduction Temp., °C | 500 | 600 | 700 | 1000 | 1000 | 1000 |
| Preheat Period: | | | | | | |
| Time, min. | 165 | 70 | 90 | 140 | 225 | 205 |
| % Wt loss | 4.8 | 6.9 | 6.8 | 8.6 | 21.7 | 17.4 |
| Reduction Period: | | | | | | |
| Hydrogen, ℓ/min. | 1 | 1 | 1 | 1 | 1 | 1 |
| Time, min. | 60 | 90 | 360 | 270 | 210 | 210 |
| % Wt loss | 6.1 | 7.8 | 13.4 | 17.4 | 11.0 | 13.6 |

TABLE 6. TEST DATA, REDUCTION NO. 1
(100 g, +8 mesh, Lot 2)

| Time, min. | Gas rates, ℓ/min. $N_2$ | $H_2$ | Temp. °C | Weight Loss, % Cumulative | Reduction |
|---|---|---|---|---|---|
| 15 | 1.0 | 0 | 190 | 1.6 | - |
| 25 | 1.0 | 0 | 300 | 2.6 | - |
| 35 | 1.0 | 0 | 380 | 4.0 | - |
| 50 | 1.0 | 0 | 435 | 4.5 | - |
| 60 | 1.0 | 0 | 480 | 4.8 | - |
| 70 | 1.0 | 0 | 490 | 4.8 | - |
| 120 | 1.0 | 0 | 510 | 4.8 | - |
| 165 | 1.8 | 0 | 500 | 4.8 | - |
| Begin Reduction | 1.8 | 1.0 | 500 | 4.8 | 0 |
| 5 | 1.8 | 1.0 | 525 | 5.6 | 0.8 |
| 10 | 1.8 | 1.0 | 510 | 7.8 | 2.2 |
| 18 | 1.8 | 1.0 | 500 | 8.8 | 4.0 |
| 30 | 1.8 | 1.0 | 500 | 10.2 | 5.4 |
| 45 | 1.8 | 1.0 | 515 | 10.9 | 6.1 |
| 60 | 1.8 | 1.0 | 500 | 10.9 | 6.1 |
| (Cool in $N_2$) | | | | | |

TABLE 7. TEST DATA, REDUCTION NO. 2
(100 g, +8 mesh, Lot 2)

| Time, min. | Gas rates, ℓ/min. $N_2$ | $H_2$ | Temp. °C | Weight Loss, % Cumulative | Reduction |
|---|---|---|---|---|---|
| 10 | 1.8 | 0 | 210 | 1.5 | - |
| 20 | 1.8 | 0 | 400 | 3.3 | - |
| 30 | 1.8 | 0 | 535 | 4.4 | - |
| 40 | 1.8 | 0 | 600 | 5.8 | - |
| 50 | 2.2 | 0 | 600 | 6.6 | - |
| 60 | 2.2 | 0 | 600 | 6.8 | - |
| 70 | 3.0 | 0 | 600 | 6.9 | - |
| Begin Reduction | 3.0 | 1.0 | 600 | 6.9 | 0 |
| 5 | 3.0 | 1.0 | 600 | 8.1 | 1.2 |
| 10 | 3.0 | 1.0 | 600 | 9.5 | 2.6 |
| 20 | 2.5 | 1.0 | 600 | 11.2 | 4.3 |
| 30 | 2.2 | 1.0 | 600 | 12.4 | 5.5 |
| 40 | 2.2 | 1.0 | 600 | 13.0 | 6.1 |
| 50 | 2.2 | 1.0 | 610 | 13.4 | 6.5 |
| 60 | 2.2 | 1.0 | 600 | 13.8 | 6.9 |
| 70 | 2.4 | 1.0 | 595 | 14.2 | 7.3 |
| 80 | 2.4 | 1.0 | 600 | 14.4 | 7.5 |
| 90 | 2.4 | 1.0 | 600 | 14.7 | 7.8 |
| (Cool in $N_2$) | | | | | |

TABLE 8. TEST DATA, REDUCTION NO. 3
(100 g, + 8 mesh, Lot 2)

| Time, min | Gas rates, ℓ/min $N_2$ | $H_2$ | Temp. °C | Weight Loss, % Cumulative | Reduction |
|---|---|---|---|---|---|
| 10 | 1.8 | 0 | 125 | 0.4 | - |
| 30 | 1.8 | 0 | 500 | 3.4 | - |
| 45 | 1.8 | 0 | 645 | 5.4 | - |
| 60 | 3.3 | 0 | 720 | 6.5 | - |
| 77 | 2.6 | 0 | 695 | 6.7 | - |
| 90 | 2.6 | 0 | 695 | 6.8 | - |
| Begin Reduction | 3.3 | 1.0 | 705 | 6.8 | 0 |
| 5 | 3.0 | 1.0 | 695 | 8.2 | 1.4 |
| 10 | 2.6 | 1.0 | 698 | 9.7 | 2.9 |
| 17 | 2.6 | 1.0 | 700 | 11.4 | 4.6 |
| 24 | 2.6 | 1.0 | 700 | 12.4 | 5.6 |
| 30 | 2.6 | 1.0 | 700 | 12.8 | 6.0 |
| 45 | 3.0 | 1.0 | 705 | 13.9 | 7.1 |
| 60 | 3.0 | 1.0 | 703 | 14.5 | 7.7 |
| 75 | 3.3 | 1.0 | 703 | 14.9 | 8.1 |
| 90 | 2.6 | 1.0 | 690 | 15.3 | 8.5 |
| 105 | 2.6 | 1.0 | 695 | 15.7 | 8.9 |
| 120 | 2.6 | 1.0 | 693 | 16.1 | 9.3 |
| 135 | 2.6 | 1.0 | 700 | 16.5 | 9.7 |
| 155 | 3.0 | 1.0 | 715 | 17.1 | 10.3 |
| 210 | 3.0 | 1.0 | 700 | 18.2 | 11.4 |
| 250 | 3.0 | 1.0 | 695 | 18.8 | 12.0 |
| 270 | 3.0 | 1.0 | 700 | 19.1 | 12.3 |
| 310 | 3.0 | 1.0 | 700 | 19.5 | 12.7 |
| 360 | 3.3 | 1.0 | 700 | 20.2 | 13.4 |
| (Cool in $N_2$) | | | | | |

TABLE 9. TEST DATA, REDUCTION NO. 4
(100 g, + 8 mesh, Lot 2)

| Time, min. | Gas rates, ℓ/min $N_2$ | $H_2$ | Temp. °C | Weight Loss, % Cumulative | Reduction |
|---|---|---|---|---|---|
| 20 | 0.5 | 0 | 100 | 0.4 | - |
| 45 | 0.5 | 0 | 350 | 2.5 | - |
| 70 | 0.5 | 0 | 510 | 3.9 | - |
| 76 | 0.5 | 0 | 565 | 4.1 | - |
| 85 | 0.5 | 0 | 635 | 4.8 | - |
| 94 | 0.5 | 0 | 705 | 6.0 | |
| 99 | 0.5 | 0 | 750 | 6.3 | - |
| 105 | 0.5 | 0 | 795 | 6.6 | - |
| 113 | 0.5 | 0 | 850 | 6.9 | - |
| 126 | 0.5 | 0 | 920 | 7.2 | - |
| 131 | 0.5 | 0 | 960 | 7.4 | - |
| 138 | 0.5 | 0 | 1000 | 7.7 | - |
| 161 | 3.0 | 0 | 1000 | 8.2 | - |
| 195 | 3.0 | 0 | 1005 | 8.6 | - |
| Begin Reduction | 3.0 | 1.0 | 1005 | 8.6 | 0 |
| 5 | 3.0 | 1.0 | 1003 | 9.6 | 1.0 |
| 10 | 3.0 | 1.0 | 1006 | 10.5 | 1.9 |
| 15 | 3.0 | 1.0 | 1008 | 13.0 | 4.4 |
| 25 | 3.0 | 1.0 | 1005 | 15.2 | 6.6 |
| 35 | 3.0 | 1.0 | 1005 | 16.3 | 7.7 |
| 45 | 3.0 | 1.0 | 1006 | 17.4 | 8.8 |
| 60 | 3.0 | 1.0 | 1003 | 18.5 | 9.9 |
| 75 | 3.0 | 1.0 | 1010 | 19.7 | 11.1 |
| 90 | 3.0 | 1.0 | 1005 | 20.6 | 12.0 |
| 120 | 3.0 | 1.0 | 1000 | 22.5 | 13.9 |
| 150 | 3.0 | 1.0 | 1000 | 23.7 | 15.1 |
| 180 | 3.0 | 1.0 | 1010 | 24.6 | 16.0 |
| 210 | 3.0 | 1.0 | 997 | 25.3 | 16.7 |
| 240 | 3.0 | 1.0 | 1010 | 25.7 | 17.1 |
| 270 | 3.0 | 1.0 | 1005 | 26.0 | 17.4 |
| (Cool in $N_2$) | | | | | |

TABLE 10. TEST DATA, REDUCTION NO. 5
(125 g, -8 mesh, Lot 2, Balled)

| Time, min. | Gas rates, ℓ/min | | Temp. °C | Weight Loss, % | |
|---|---|---|---|---|---|
| | $N_2$ | $H_2$ | | Cumulative* | Reduction |
| 25 | 1.0 | 0 | 200 | 8.2 | - |
| 70 | 1.0 | 0 | 200 | 17.7 | - |
| 100 | 1.0 | 0 | 300 | 17.7 | - |
| 106 | 1.0 | 0 | 400 | 18.6 | - |
| 115 | 1.0 | 0 | 500 | 19.0 | - |
| 133 | 1.0 | 0 | 600 | 19.4 | - |
| 145 | 1.0 | 0 | 700 | 20.2 | - |
| 160 | 1.0 | 0 | 800 | 20.8 | - |
| 173 | 1.0 | 0 | 900 | 21.3 | - |
| 225 | 1.0 | 0 | 1000 | 21.7 | - |
| Begin Reduction | 3.0 | 1.0 | 1000 | 21.7 | - |
| 5 | 3.0 | 1.0 | 1000 | 23.0 | 1.3 |
| 10 | 3.0 | 1.0 | 1000 | 23.9 | 2.2 |
| 15 | 3.0 | 1.0 | 1000 | 24.6 | 2.9 |
| 30 | 3.0 | 1.0 | 1000 | 26.3 | 4.6 |
| 60 | 3.0 | 1.0 | 1000 | 29.3 | 7.6 |
| 90 | 3.0 | 1.0 | 1000 | 30.2 | 8.9 |
| 120 | 3.0 | 1.0 | 1000 | 31.8 | 10.1 |
| 150 | 3.0 | 1.0 | 1000 | 32.2 | 10.5 |
| 180 | 3.0 | 1.0 | 1000 | 32.7 | 11.0 |
| 210 | 3.0 | 1.0 | 1000 | 32.7 | 11.0 |
| (Cool in $N_2$) | | | | | |

*Cumulative weight loss includes balling moisture.

TABLE 11. TEST DATA, REDUCTION NO. 6
(125 g, -8 mesh, Lot 2, Balled,
1% NaCl added)

| Time, min. | Gas rates, ℓ/min | | Temp. °C | Weight Loss, % | |
|---|---|---|---|---|---|
| | $N_2$ | $H_2$ | | Cumulative* | Reduction |
| 25 | 1.0 | 0 | 150 | 4.0 | - |
| 70 | 1.0 | 0 | 200 | 12.7 | - |
| 89 | 1.0 | 0 | 300 | 12.7 | - |
| 92 | 1.0 | 0 | 350 | 13.4 | - |
| 101 | 1.0 | 0 | 450 | 14.0 | - |
| 110 | 1.0 | 0 | 500 | 14.6 | - |
| 120 | 1.0 | 0 | 600 | 15.0 | - |
| 130 | 1.0 | 0 | 700 | 15.8 | - |
| 147 | 1.0 | 0 | 800 | 16.4 | - |
| 156 | 1.0 | 0 | 900 | 17.0 | - |
| 205 | 1.0 | 0 | 1000 | 17.4 | - |
| Begin Reduction | 3.0 | 1.0 | 1000 | 17.4 | 0 |
| 10 | 3.0 | 1.0 | 1000 | 19.6 | 2.2 |
| 30 | 3.0 | 1.0 | 1000 | 23.3 | 5.9 |
| 60 | 3.0 | 1.0 | 1000 | 26.9 | 9.5 |
| 90 | 3.0 | 1.0 | 1000 | 27.5 | 10.1 |
| 120 | 3.0 | 1.0 | 1000 | 28.8 | 11.4 |
| 150 | 3.0 | 1.0 | 1000 | 29.7 | 12.3 |
| 180 | 3.0 | 1.0 | 1000 | 30.7 | 13.3 |
| 210 | 3.0 | 1.0 | 1000 | 31.0 | 13.6 |
| (Cool in $N_2$) | | | | | |

*Cumulative weight loss includes balling moisture.

TABLE 12. MAGNETIC SEPARATION TEST RESULTS

| | Magnetic Portion | | | | Metallic Fe | Nonmagnetic Portion | | | Separation Efficiency |
|---|---|---|---|---|---|---|---|---|---|
| | % Weight | % Fe | % Fe Unit Recovery | % Mn | | % Weight | % Mn | % Mn Unit Recovery | % Mn-Fe* |
| **Reduction Test No. 1, 500°C** | | | | | | | | | |
| Heads | - | 45.5 | - | 17.4 | - | - | - | - | - |
| Conc A | 71.6 | 54.0 | 85.0 | 5.4 | - | 29.4 | 47.7 | 77.7 | 62.7 |
| Conc B | 61.6 | 57.4 | 77.6 | 4.1 | - | 38.4 | 38.8 | 85.6 | 63.2 |
| Conc C | 43.6 | 61.1 | 58.5 | 2.9 | - | 56.4 | 28.7 | 92.9 | 51.4 |
| **Reduction Test No. 2, 600°C** | | | | | | | | | |
| Heads | - | 42.0 | - | 21.2 | - | - | - | - | - |
| Conc A | 43.4 | 59.3 | 66.6 | 2.7 | - | 56.6 | 37.3 | 94.1 | 59.6 |
| Conc B | 36.3 | 62.3 | 53.8 | 1.8 | - | 63.7 | 32.3 | 96.9 | 50.7 |
| Conc C | 31.6 | 63.9 | 48.2 | 1.3 | - | 68.4 | 30.5 | 98.1 | 46.4 |
| **Reduction Test No. 3, 700°C** | | | | | | | | | |
| Heads | - | 47.8 | - | 21.8 | 6.9 | - | - | - | - |
| Conc A | 63.0 | 65.1 | 85.6 | 4.3 | - | 37.0 | 51.6 | 87.6 | 73.3 |
| Conc B | 56.1 | 68.8 | 80.7 | 3.3 | - | 43.9 | 45.5 | 91.6 | 72.3 |
| Conc C | 45.5 | 72.6 | 69.1 | 2.3 | - | 54.5 | 38.1 | 95.1 | 64.3 |
| **Reduction Test No. 4, 1000°C** | | | | | | | | | |
| Heads | - | 49.8 | - | 24.5 | 31.9 | - | - | - | - |
| Conc A | 60.9 | 71.8 | 87.7 | 5.2 | - | 39.1 | 54.5 | 87.0 | 74.7 |
| Conc B | 57.8 | 74.5 | 86.5 | 4.6 | - | 42.2 | 51.8 | 89.1 | 75.6 |
| Conc C | 53.9 | 78.0 | 84.3 | 3.7 | - | 46.1 | 48.7 | 91.8 | 76.0 |

*Efficiency of separation of manganese from iron: $E_{Mn-Fe}$ = (Fe recovery in magnetics) - (100-Mn recovery in nonmagn

See: N.F. Schulz, "Separation Efficiency," Trans SME/AIME, 247, 81-87 (1970).

## REDUCTION TESTWORK

Evidence was developed by Elkem showing an increase in the output of the submerged arc furnace with preheating and partial reduction of the ferruginous manganese ore and hot charging of the preheated ore to the furnace. In addition the 1960 Birlefco proposal was based on solid carbon reduction of the iron-bearing manganese ore to sponge iron and MnO with subsequent melting of the reduced product in an open arc furnace to produce pig iron for marketing and a high manganese slag for FeMn production in the submerged arc electric furnace. The ore preparation procedures of Elkem and Birlefco were developed to increase the capacity of the SAEF and to improve its efficiency.

As means of enhancing the duplex smelter process, a further investigation was conducted by KECI/ACB to determine the effect of preheating and preproduction on high iron-bearing manganese ore. Ore samples were obtained at Abu Zeneima in March, 1980, and forwarded to Allis-Chalmers (A-C) Research Laboratories.

Initial tube test results conducted on an iron-bearing hand sample were favorable with metallization of the iron and reduction of the manganese to MnO. The initial results are summarized below. The detailed report including photomicrographs is included in the Appendix for reference purposes.

Lump Ore

| % Fe | % Mn | Mn/Fe | |
|---|---|---|---|
| 23.84 | 35.57 | 1.45 | Hand Sample |

Prereduced Product

| % Fe | % Mn | Mn/Fe | % $S_1O_2$ | % C |
|---|---|---|---|---|
| 30.64 | 52.29 | 1.71 | 1.65 | 0.30 |

Subsequently a larger scale test was conducted by A-C utilizing the 75-kg sample of stockpile fines and bunker ore acquired at Abu Zeneima in March, 1980. This test simulated conditions of gas preheating and prereduction in a commercial rotary kiln. The detailed report of the prereduction testwork including photomicrographs of feed and products is contained in Appendix 6. The prereduction test results are as follows:

Ore Feed

| $ Fe | % Mn | Mn/Fe | |
|---|---|---|---|
| 37.67 | 18.10 | 0.48 | Stockpile and Bunker Sample |

Prereduced Product

| % Fe | % Mn | Mn/Fe | % C |
|---|---|---|---|
| 52.27 | 19.38 | 0.37 | 0.30 |

The above test shows that gas prereduction of the iron-bearing manganese ores can be achieved with a high degree of metallization and a low carbon product. This test confirms the initial gas prereduction test results on the hand sample.

The above prereduced product is acceptable as feed for meltdown in a conventional open arc steelmaking furnace. The furnace products consist of a low-carbon low-manganese semi-steel and a high manganese slag. Quartzite is added to form the slag.

The combination of reduction kiln and open arc melting furnace allows the existing rehabilitated submerged arc furnace to operate full time on production of FeMn without pig iron production. With full-time operation the furnace capability is approximately 25,000 tonnes per year of FeMn.

As this approach with FeMn and semi-steel products may have superior economic and marketing benefits, further testwork is recommended on a larger representative sample of the iron-bearing Mn ore reserves. The testwork will provide data essential for design and economic analysis of commercial reduction and melting facilities.

PRELIMINARY DIRECT REDUCTION STUDIES

for

# KAISER ENGINEERS
## Oakland, California

on

# SINAI MANGANESE

## Phase II

## *ACCAR* Simulation

JUNE, 1980

Submitted by

ALLIS-CHALMERS
CEMENT, MINING &
METALS SYSTEMS

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## INTRODUCTION

This is the Phase II report of a preliminary direct reduction investigation on an ore furnished by the Sinai Manganese Company through Kaiser Engineers. The Phase I report was submitted in April, 1980. The work herein was at the request of Richard B. Greenwalt, Project Manager, Kaiser Engineers, Oakland, California.

The purpose of Phase II was to generate sufficient reduced (with respect to iron) product which would be used for subsequent induction furnace melting tests. The ore feed stock had an average chemistry of 18.10 percent manganese, 37.67 percent iron. The target quality for the product was +90 percent metallization (with respect to the iron) and less than 0.5 percent carbon.

This investigation consisted of crushing, grinding, screening, blending, pelletizing, induration, and ACCAR simulation tests. Account number 01-3537-72537 continued to be used for control purposes and all charges accured were billed against Kaiser purchase order 80012-002.

## SUMMARY AND CONCLUSIONS

1. Three separate samples, shipped from Egypt by Kaiser Engineers, were chemically analyzed and found to be similar in composition. The

average chemistry was 18.10 percent manganese, 37.67 percent iron. The three samples were blended to form a single composite for these tests.

2. Two separate ACCAR simulation tests were performed. The first using coarse lump ore with charcoal as the reducing agent. The second test employed pelletized ore and natural gas.

3. The lump/charcoal test did not yield the results as expected due to an insufficient amount of sized lump and unexpected early burn out of the charcoal used.

4. The pellet/natural gas test results were more favorable with most of the iron oxide being converted to metallic iron. There is a lack of confirming data to quantify the amount of iron oxide conversion to metallic iron. Qualitative data suggests that most iron oxide was converted and that metallization (with respect to iron) is in excess of 72 percent. The product carbon level was determined to be 0.3 percent.

5. Total manganese was determined to be 19.38 percent in the reduced pellet product.

6. X-ray diffraction for ACCAR Simulation Test 80-10 shows manganese in two forms: $Mn_2SiO_4$ (tephroite) as the minor to major element; MnO as the minor element and approximately one-half as much as $Mn_2SiO_4$.

7. X-ray diffraction for ACCAR Simulation Test 80-10 shows the major element in the product sample to be metallic iron with no iron oxide in the form of wustite detected. Metallic iron is estimated to be five times as much as $Mn_2SiO_4$.

8. The results of Phases I and II of this preliminary study indicates gaseous iron ore reduction of the Sinai material can be achieved. There appears to be no unusual characteristics exhibited by this material that would prevent ACCAR processing on a commercial scale with either gas or a solid reductant. To further confirm this fact it is recommended that an in-depth study be initiated to fully characterize the ore, determine the strengths and weaknesses of pellet versus lump processing, investigate various reduction processing temperatures and to provide data necessary for the sizing and warranting of commercial equipment.

## CHARACTERISTICS OF THE SINAI ORE

Allis-Chalmers received three separate bags of the Sinai ore on March 28, 1980. Each bag contained approximately 25 kilograms of material. The bags were identified as samples 1, 2 and 3.

## 1. Sieve Analyses

Upon receipt of these materials a screen analysis was performed. The results are shown in Table I.

TABLE I

SIEVE ANALYSES OF AS RECEIVED SHIPMENTS

| Sieve Size | | Percent Passing | | |
|---|---|---|---|---|
| ASTM Microns | mm | Sample 1 | Sample 2 | Sample 3 |
| 106,000 | 106 | 100 | 100 | 100 |
| 75,000 | 75 | 100 | 100 | 81 |
| 53,000 | 53 | 100 | 100 | 75 |
| 26,500 | 26.5 | 100 | 100 | 62 |
| 13,200 | 13.2 | 100 | 100 | 41 |
| 6,700 | 6.7 | 100 | 94 | 19 |
| 3,350 | 3.4 | 70 | 75 | 10 |
| 1,700 | 1.7 | 47 | 57 | 7 |
| 600 | 28 mesh | 26 | 37 | 4 |
| 150 | 100 mesh | 13 | 18 | 2 |
| 75 | 200 mesh | 8 | 11 | 1 |
| 45 | 325 mesh | 7 | 9 | 1 |

## 2. Chemical Analyses

A sample from each sample bag was analyzed for total iron, manganese and LOI. These results are shown in Table II.

TABLE II

CHEMICAL ANALYSES OF AS RECEIVED SHIPMENTS

| | Weight Percent | | |
|---|---|---|---|
| Sample | Total Iron | Manganese | LOI |
| 1 | 38.80 | 17.40 | 5.91 |
| 2 | 39.12 | 16.80 | 6.52 |
| 3 | 34.42 | 20.10 | 7.93 |
| Average | 37.67 | 18.10 | 6.78 |

# REDUCTION TEST(S)

## 1. Objective

The objective of the reduction test(s) was to produce 15 kilograms of +90 percent metallized (with respect to iron) product with a carbon content of less than 0.5 percent.

## 2. ACCAR Simulation Test 80-09

The chemical analyses performed on the three bag samples did not show a wide variance of quality and, therefore, were combined into a single composite totaling 72 kilograms.

All coarse fractions were crushed to minus 25 mm. An ACCAR simulation test charge, consisting of the 25 mm x 6 mm sized material, was synthesized from the composite. This charge totaled 19.3 kilograms.

Charcoal was selected as the reductant on the basis of its clean nature (no sulfur to transfer to the sponge iron), its reactivity as a reductant and to serve as a void filler since the 19.3 kilogram of lump charge was small compared to conventional deep bed ACCAR practice. Enough charcoal would be used to fill the available ACCAR simulator volume to its normal operating level.

The operating parameters used for ACCAR Simulation Test 80-09 are shown in Table III.

TABLE III

OPERATING PARAMETERS

ACCAR SIMULATION TEST 80-09

| | |
|---|---|
| Ore Feed Charge (kg) | 19.3 |
| Size Fraction (mm) | 25 x 6 |
| Bulk Density (kg/m$^3$) | 1650 |
| Charcoal Charge (kg) | 4.5 (2.3 kg added at 105 minutes into test) |
| Size Fraction (mm) | 25 x 6 |
| Bulk Density (kg/m$^3$) | 272 |
| Reduction Time (hrs.) | 3 |
| Processing Temperature (°C) | 1000 |
| Reactor Rotation (rpm) | 0.5 |

ACCAR Simulation Test 80-09 did not achieve the level of success that was expected. A high level of iron oxide reduction was not reached. An early burn out of the charcoal was experienced which left the ACCAR simulator void of reductant and the necessary driving potential to complete reduction. The test was aborted at the end of 150 minutes because of difficulty in controlling the reactor temperatures and the obvious lack of reduction seen in the samples taken during the test.

Chemical analyses were performed on the time samples and are tabulated in Table IV.

TABLE IV

CHEMICAL ANALYSES

ACCAR SIMULATION TEST 80-09

| Sample (Minute) | Weight Percent Total Iron | Weight Percent Metallic Iron |
|---|---|---|
| 10 | 33.42 | < .08 |
| 30 | 47.72 | < .08 |
| 50 | 37.12 | < .08 |
| 70 | 38.57 | 8.68 |
| 90 | 34.23 | 5.78 |
| 120 | 57.04 | 7.23 |
| 130 | 38.24 | 4.18 |
| 140 | 41.14 | 14.14 |

The lack of success on this first ACCAR test should not be construed as implying a difficulty associated with the reduction processing of the Sinai lump material. The insufficient quantities of sized lump ore influenced the selection of parameters under which this test was

performed and contributed to the less than satisfactory results achieved. Also, the lack of success cannot be contributed to a solid fuel being a poor reductant.

3. Balling and Induration

A Kaiser/Allis-Chalmers decision was made to pelletize the balance of the Sinai ore for a second reduction test using natural gas as the reductant. The remaining ore stock amounted to 52.7 kilograms of minus 6 mm material which was treated as follows:

a. All material was oven dried.

b. All minus 150 mesh material was screened from the remaining stock.

c. The coarse fraction was crushed to minus 6 mesh then pulverized to 75 percent minus 325 mesh.

d. A blend was made of the minus 150 mesh and 325 mesh fractions.

e. A screen analysis was performed on this new blend of pellet feed and is tabulated in Table V below.

f. A Blaine measurement was taken on the above pellet feed and found to be 7,600 $cm^2/grm$.

TABLE V

PELLET FEED SIZE FRACTION

| Sieve Size ASTM Microns | Mesh | Percent Passing |
|---|---|---|
| 300 | 48 | 100 |
| 75 | 200 | 98 |
| 45 | 325 | 86 |
| 26 | 500 | 72 |

4. Muffel Furnace Test

A small batch of pellet feed was balled with 0.5 percent of bentonite and placed in a muffel furnace and heated to 1260°C. During the heat up, pellets were withdrawn from the furnace at 982°C, 1065°C and 1260°C. Compression strength measurements were taken and microscopic analyses made to assist in the selection of a firing temperature for the balance of the pelletized feed. A tabulation of compression strengths vs. induration temperature is presented in Table VI.

TABLE VI

COMPRESSION STRENGTHS VS. INDURATION TEMPERATURE

| Induration Temperature °C | Compression Strength kilograms |
|---|---|
| 982 | 40 |
| 1065 | 80 |
| 1260 | 47 |

## 5. Microscopic Analysis of Oxide Pellets

During the muffel furnace induration test, samples were withdrawn from the furnace at temperatures of 982°C, 1065°C and 1260°C. These samples were mounted and polished for microscopic examination. Photomicrographs were prepared and are illustrated in the following figures.

Figures 1 and 2 show the 982°C oxide pellet structure at 50x and 200x magnifications respectively. The pellets have partially sintered.

It appears that complex mineral components have formed a matrix. Large gangue grains (gray) and large metal ore grains (white) retain their individual integrity. The irregular shaped black areas are pores.

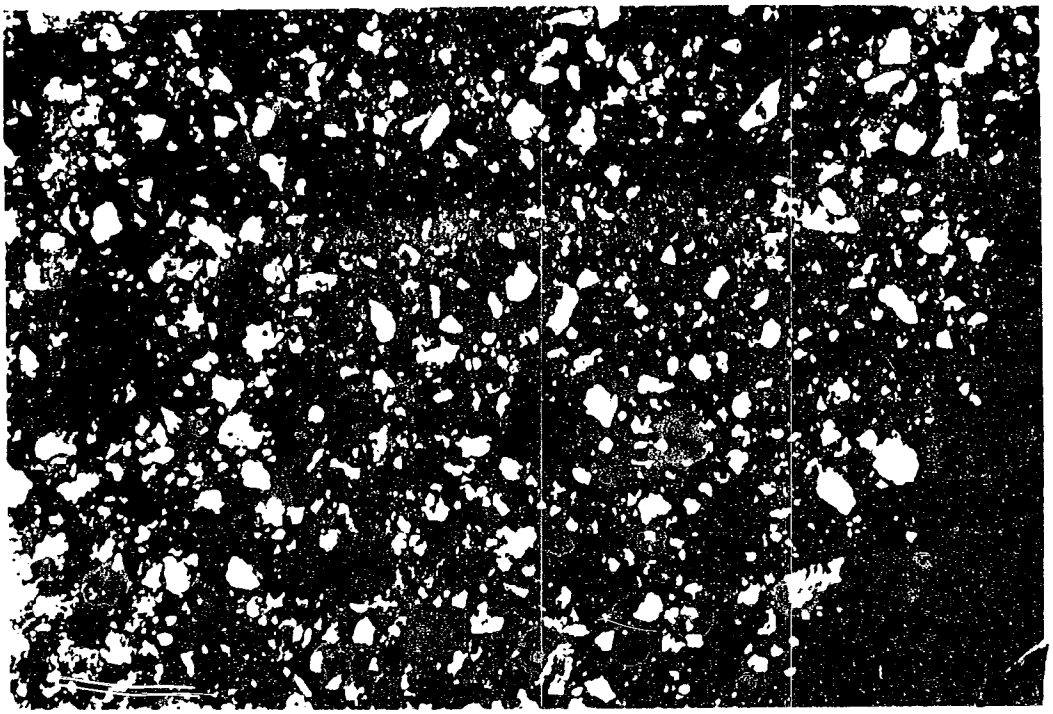

Figure 1. Photomicrograph of Oxide Pellet
982°C, 50X

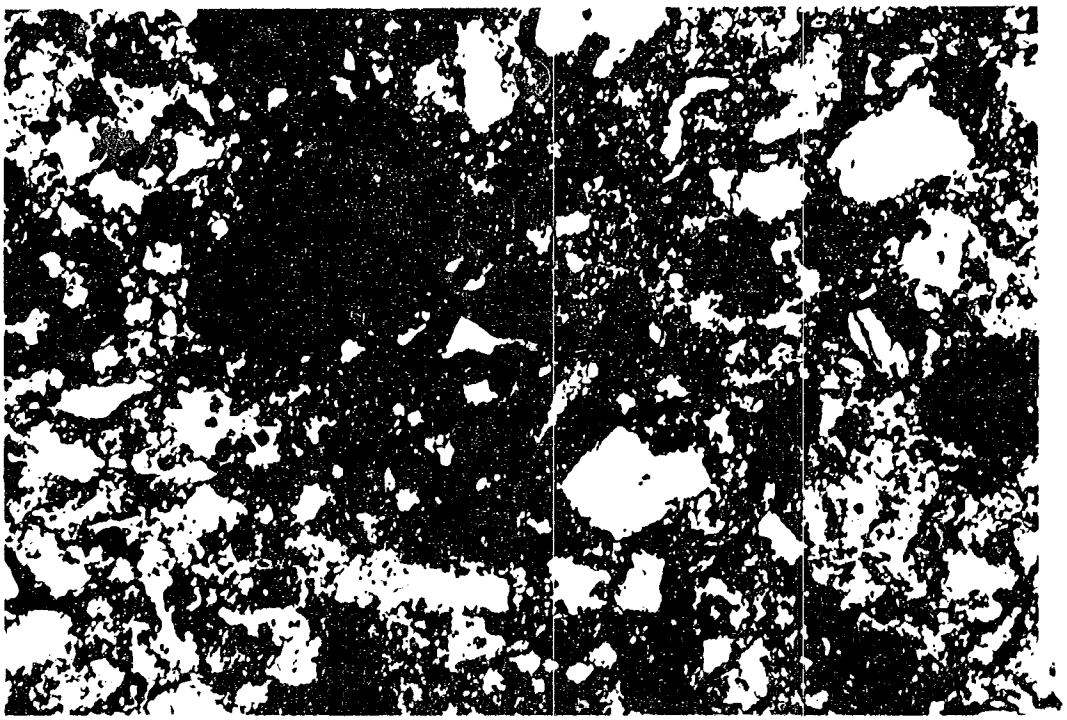

Figure 2. Photomicrograph of Oxide Pellet
982°C, 200X

Figures 3 and 4 show a pellet structure at 1065°C with magnifications of 50x and 400x respectively. Large grains are now rounded and slightly dissolved. Dissolution of various components can be observed. Pores (black) show coalescence.

Figures 5 and 6 are oxide pellet structures at 1260°C. Slags have been formed and surround the brighter metal mineral phase. Pores are closed and round.

As a result of the above analyses a decision was made to pelletize the balance of the prepared feed stock at a temperature of 1037°C, using 0.5 percent bentonite. The balling data are presented in Table VII.

TABLE VII

SINAI ORE

BALLING DATA

| | |
|---|---|
| Green Ball Bulk Density ($kg/m^3$) | 1562 |
| Green Ball Moisture (%) | 12.5 |
| Wet Compressive Strength (kg) | 1.97 |
| Dry Compressive Strength (kg) | 7.9 |
| 45.7 Centimeter Drops | +20 |
| Total Green Balls (kg) | 43.4 |

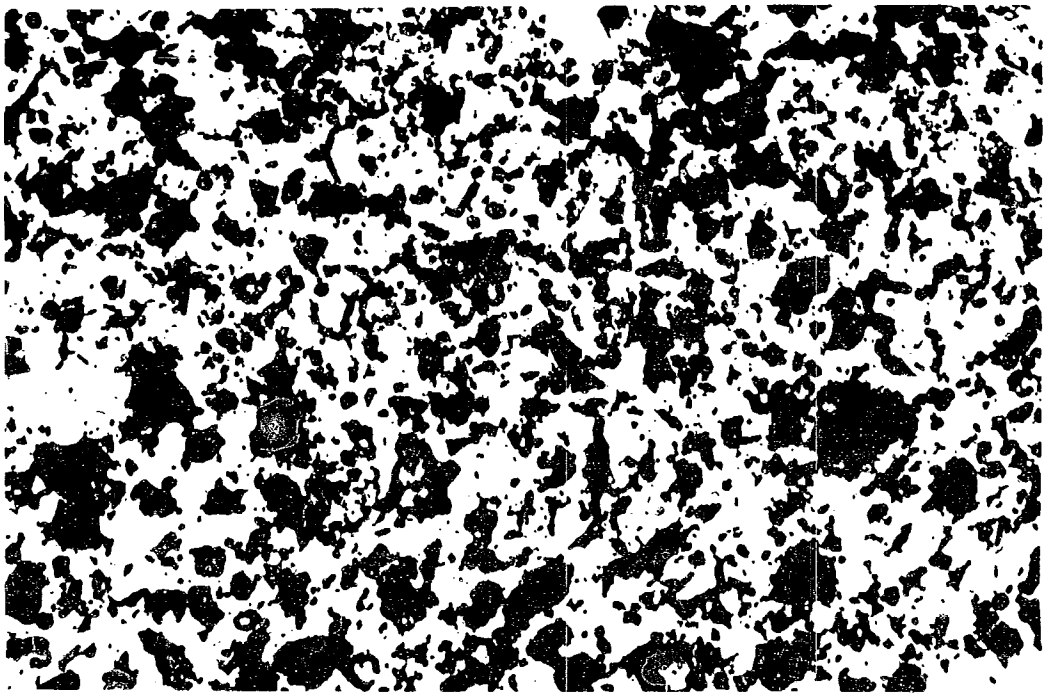

Figure 3. Photomicrograph of Oxide Pellet
1065°C, 50X

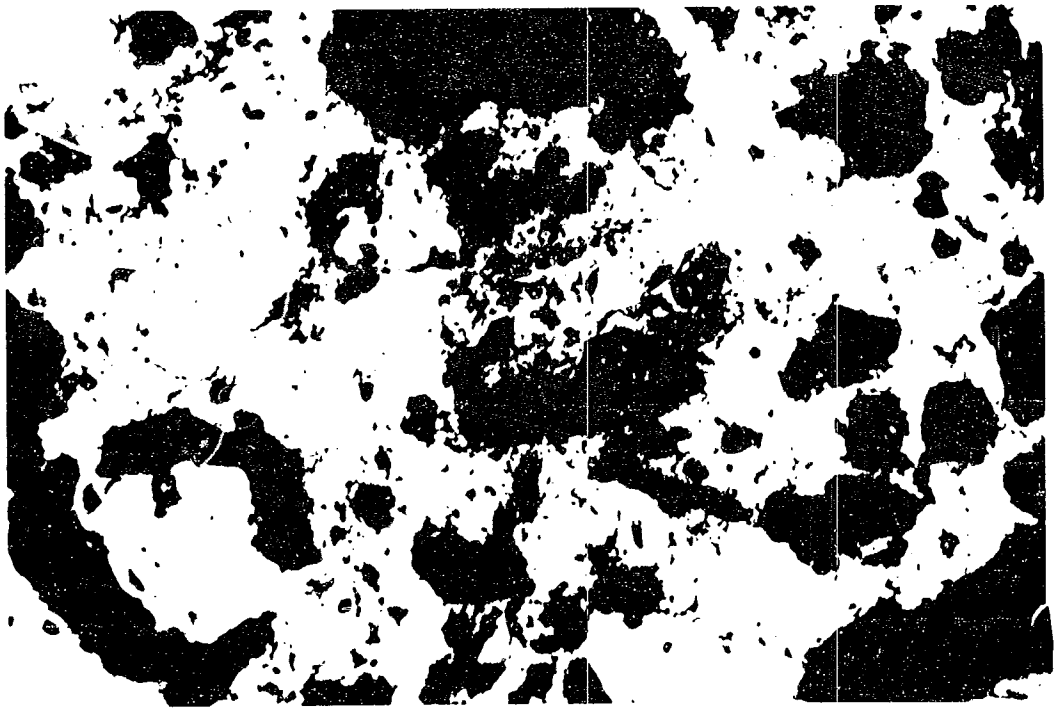

Figure 4. Photomicrograph of Oxide Pellet
1065°C, 400X

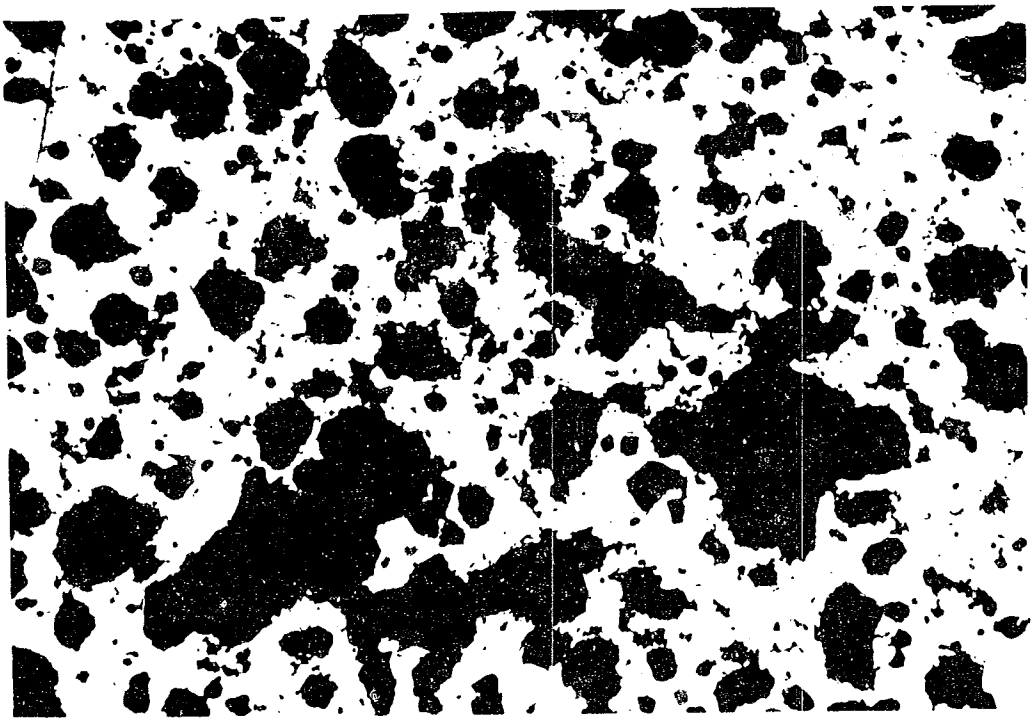

Figure 5. Photomicrograph of Oxide Pellet
1260°C, 50X

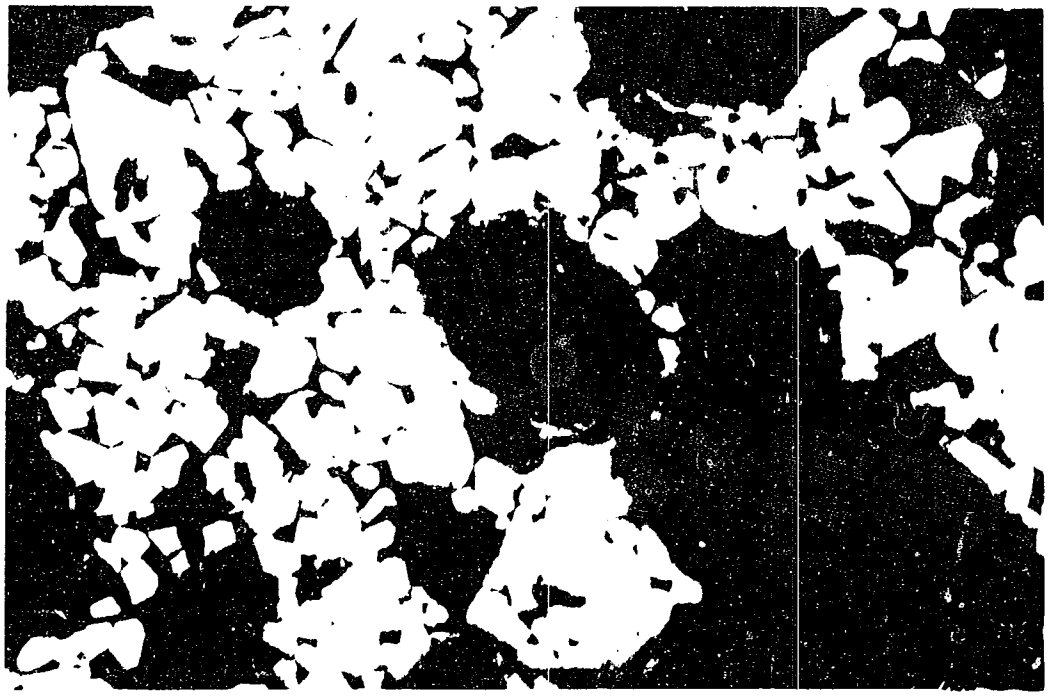

Figure 6. Photomicrograph of Oxide Pellet
1260°C, 400X

The balls were fired in an oxidizing pot grate at a temperature of 1037°C. The results of this firing are tabulated in Table VIII.

TABLE VIII

FIRED PELLETS PHYSICAL PROPERTIES

| | |
|---|---|
| Apparent Density ($g/cm^3$) | 3.19 |
| Matrix Density ($g/cm^3$) | 4.51 |
| Open Porosity (%) | 29.30 |
| Pellet Strength (kg) | 120 |
| Bulk Density ($kg/m^3$) | 1866 |
| Total Fired Pellets (kg) | 38 |

## 6. ACCAR Simulation Test 80-10

The above fired pellets were blended with 7 kilograms of +6 mm lump material from ACCAR Simulation Test 80-09 and served as the charge for the second reduction test.

Natural gas was selected as the reductant and a conventional time-temperature ACCAR simulation test was planned. The operating parameters used for this test are tabulated in Table IX.

TABLE IX

OPERATING PARAMETERS

ACCAR SIMULATION TEST 80-10

| | |
|---|---|
| Feed Charge (kg) | 45 |
| Size Fraction (mm) | 12 x 6 |
| Bulk Density (kg/m$^3$) | 1900 |
| Reduction Time (hrs.) | 3 |
| Processing Temperature (°C) | 1000 |
| Reactor Rotation (rpm) | 0.5 |

This test was conducted in the ACCAR simulator for a period of 3 hours at a temperature of 1000°C. The feed charge consisted of 11 mm x 6 mm sized pellets.

The results of this test appear to be excellent although there is some question as to the quantitative values of metallic iron that have been reported. The information evaluated thus far suggest a product metallization (with respect to iron) in excess of 72 percent.

An alternate laboratory has been contacted and asked to confirm a metallic iron determination on the 180 minute test sample. This has been done as a result of apparent discrepancies which

evolved during the Phase I evaluation. The results of this second analysis will be forwarded to Kaiser under a separate cover at a later date.

During any ACCAR simulation test it is customary to sample the charge on a regular basis to develop a time history of reduction.

Chemical analyses were performed on these samples. The results are presented in Table X.

TABLE X

CHEMICAL ANALYSES

ACCAR SIMULATION TEST 80-10

| Sample (Minute) | Weight Percent | | |
|---|---|---|---|
| | Total Iron | Metallic Iron | Metallization |
| 20 | 45.33 | 0.08 | ---- |
| 40 | 46.12 | 1.58 | 3.4 |
| 60 | 47.14 | 7.41 | 15.7 |
| 80 | 47.86 | 11.83 | 24.7 |
| 100 | 48.65 | 16.08 | 33.1 |
| 120 | 49.67 | 22.39 | 45.1 |
| 140 | 50.22 | 28.62 | 57.0 |
| 160 | 51.41 | 35.40 | 68.9 |
| 180 | 51.88 | 35.87 | 69.1 |
| Product | 52.27 | 37.85 | 72.41 |

The final product was also analyzed for manganese (19.38 percent) and carbon (0.3 percent).

In addition to the above chemical analyses, physical measurements were made on the reduced product. These values are presented in Table XI.

TABLE XI

PHYSICAL PROPERTIES OF REDUCED PELLETS

| | |
|---|---|
| Apparent Density ($g/cm^3$) | 2.60 |
| Matrix Density ($g/cm^3$) | 5.34 |
| Open Porosity (%) | 48.70 |
| Bulk Density ($kg/m^3$) | 1650 |
| Compression Strength (kg) | 32 |
| Total Reduced Product (kg) (Includes lump ore also) | 38 |

Because of the Phase I discrepancies between the metallic iron chemistry and the apparent quality of the reduced material, an X-ray diffraction analysis of the product sample referred to in Table X was done. The results are as follows:

Met Fe: Major element, approximately five times as much present as $Mn_2SiO_4$.

$Mn_2SiO_4$: Minor to major element, mineral tephroite.

MnO: Minor element, approximately one-half as much as $Mn_2SiO_4$.

$SiO_2$: None

FeO: None

C: Trace.

According to this analysis, most of the iron oxide was converted to metallic iron during ACCAR processing.

## 7. Microscopic Analysis of Reduced Pellets

In addition to the chemical and X-ray analysis, photomicrographs were taken of a reduced pellet's cross section to explore the hypothesis that there may be interactions occurring during the wet chemical analyses or during reduction processing which masks the degree of iron oxide conversion to metallic iron.

Figures 7 and 8 are photomicrographs of reduced product. Numerous scattered white grains are metallic iron. In the center of several large iron grains (Figure 8) are some unreduced iron oxides. The gray matrix surrounding the iron grains is probably the manganese rich mineral compounds. The dark spots are pores.

## DISPOSITION OF REDUCED PRODUCT

Thirty-eight kilograms of reduced product resulted from ACCAR Simulation Test 80-10. Approximately half of this material has been shipped to Kaiser Engineers, Oakland, ATTN: R. B. Greenwalt. The remainder of the material will be stored at Allis-Chalmers Process Research and Test Center for the next 6 months awaiting final disposition.

David W. Rierson
Manager, ACCAR Process Engineer
CEMENT, MINING & METALS SYSTEMS DIVISION

Shaochi Huang
Senior Metallurgist
CEMENT, MINING & METALS SYSTEMS DIVISION

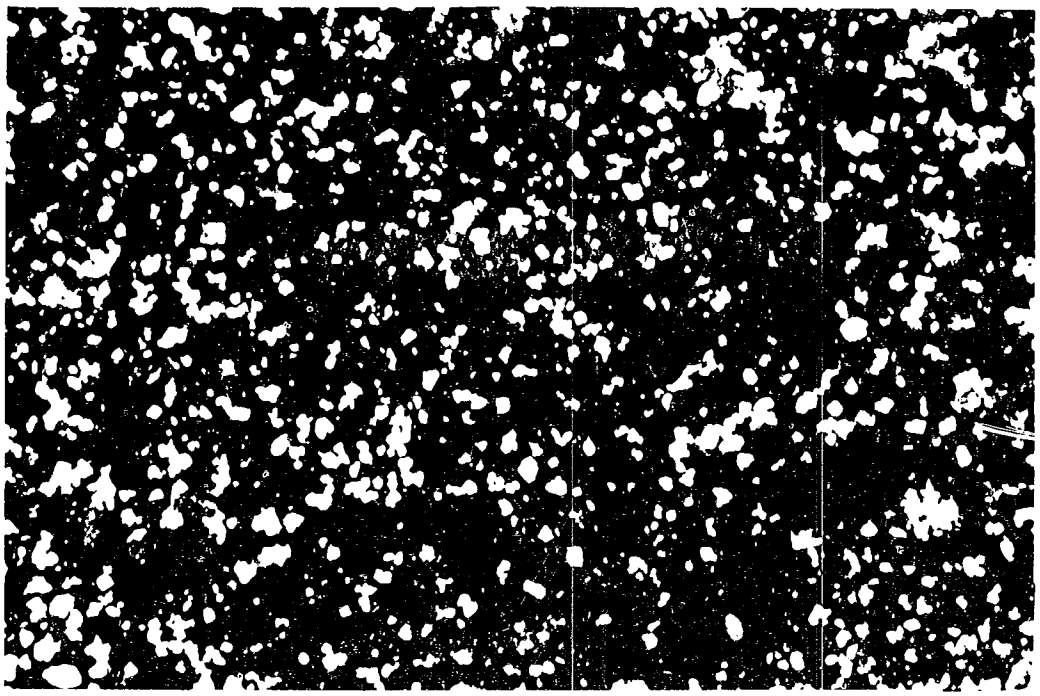

Figure 7. Photomicrograph of Reduced Pellet
100X

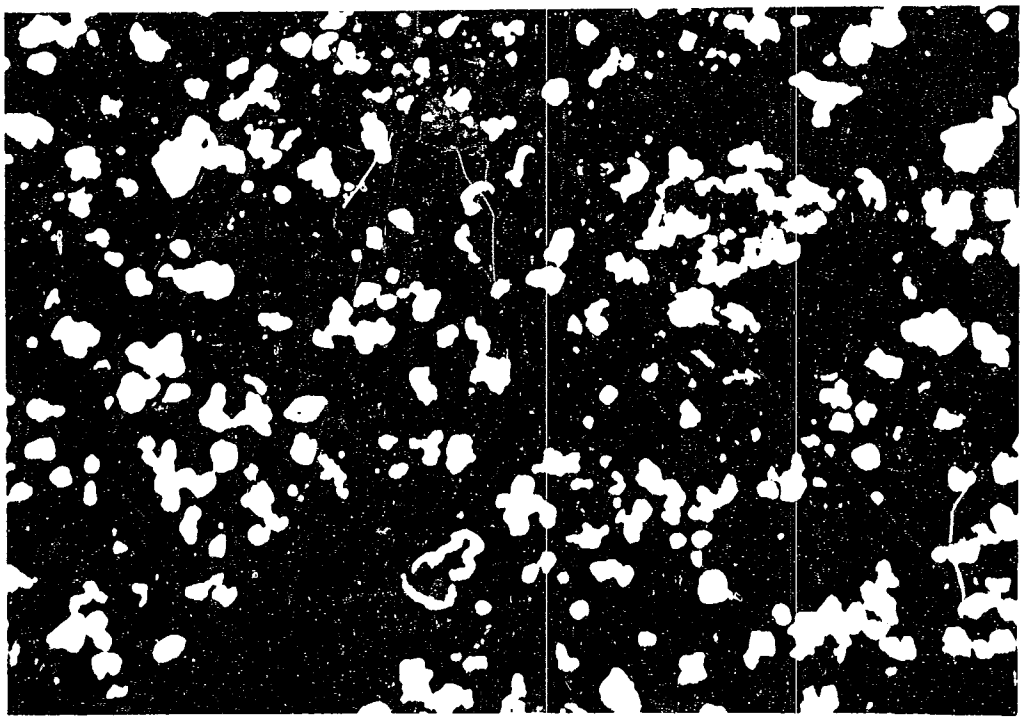

Figure 8. Photomicrograph of Reduced Pellet
200X

# APPENDIX

OVER 80 YEARS OF SERVICE

# LERCH BROTHERS INCORPORATED

## GENERAL ANALYTICAL CHEMISTS

MINNESOTA LABORATORIES
HIBBING
HIBBING Special
HIBBING Water

CONSULTING SERVICE — MINNESOTA, WISCONSIN AND CANADA

GENERAL OFFICES — CORNER N. 4th AVE. W and GRANT STREET
MAIL ADDRESS — P.O. BOX 8 — PHONE (218) 262-3456

HIBBING, MINNESOTA 55746

WISCONSIN LABORATORIES
ALLOUEZ Superior
CANADIAN SERVICE
c/o IRON ORE CO. OF CANADA
LABRADOR CITY, NFLD
SCHEFFERVILLE, QUEBEC
SEPT ILES, QUEBEC

June 20, 1980

Dr. S. Huang
Allis-Chalmers Corp.
Mining Systems
P.O. Box 512 (DB)
Milwaukee, WI 53201

Dear Dr. Huang:

The following are the results of the semi-quantitative scan performed on X-Ray on your sample labelled "product of 80-048A series".

Spec. Lab #29117

| | |
|---|---|
| Met Fe: | Major element, approximately five times as much present as $Mn_2SiO_4$. |
| $Mn_2SiO_4$: | Minor to major element, mineral tephroite. |
| MnO: | Minor element, approximately one-half as much as $Mn_2SiO_4$. |
| $SiO_2$: | None |
| FeO: | None |
| C: | Trace |

Sincerely,

Donald H. J. Schnortz, Jr.
Chief Chemist

# PRELIMINARY DIRECT REDUCTION STUDIES

FOR

KAISER ENGINEERS

OAKLAND, CALIFORNIA

ON

SINAI MANGANESE

APRIL, 1980

SUBMITTED BY

ALLIS-CHALMERS CORPORATION

CEMENT, MINING & METALS SYSTEMS DIVISION

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## INTRODUCTION

At the request of Richard B. Greenwalt, Project Manager, Kaiser Engineers, Cement, Mining and Metals Systems Division was to perform preliminary chemical analyses and tube furnace reduction studies on various samples of Sinai manganese ore.

The purpose of this investigation was to perform gaseous reduction on an ore sample which contained approximately 20 percent manganese, 40 percent iron, and achieve 90 percent metallization with less than 0.5 percent carbon in the reduced product.

The investigation consisted of a single tube furnace reduction test and numerous chemical analyses on ore samples submitted by Kaiser Engineers. Account Number 01-3537-72537 was assigned to this study for control purposes and all charges accured were billed against Kaiser Purchase Order 80012-002.

## SUMMARY AND CONCLUSIONS

1. Thirteen ore samples were analyzed for manganese and total iron.

2. One sample (M-1) was found acceptable for further testing. This sample had a weight percent chemistry of 34.57 percent manganese, 23.84 percent total iron.

3. A single tube furnace reduction test was performed on ore sample M-1. Qualitative results indicate that most of the oxygen was removed from the iron oxide resulting in a highly metallized product.

4. Difficulty was experienced in the quantative determination of metallic iron by the mercuric chloride method, in the tube furnace product. X-ray diffraction was used for the qualitative identification of the compounds and elements in the reduced product.

5. By x-ray diffraction it is estimated that all iron oxide in the tube furnace product was converted to metallic iron.

6. By x-ray diffraction it is estimated that all manganese in the reduced product was in the form of MnO.

7. On the basis of this preliminary test it appears that there are no unusual characteristics which would prevent iron ore reduction from occurring, using ACCAR technology and processing at approximately 1000°C.

PRELIMINARY ANALYSES OF SINAI MANGANESE ORE

Allis-Chalmers received three manganese ore samples (A, B, C) from Kaiser Engineers in November, 1979.

In January, 1980, chemical analyses were made; the results are as follows:

| Sample | Weight Percent | |
|---|---|---|
| | Mn | Fe |
| A | 57.25 | 0.31 |
| B | 58.45 | 0.08 |
| C | 51.96 | 0.52 |

All three samples are judged to be of high grade manganese ore with low iron content.

Mineralogical samples of A, B and C were also prepared and examined. Photomicrographs on all samples showed massive grains. No attempt was made to identify the minerals.

Samples A, B and C were found unsuitable for further testing due to their low iron content.

A second shipment of samples was received in late January, 1980. These samples were classified as high (H) (5 pieces), Medium (M) (3 pieces) and low (L) (4 pieces) grade. Ten (10) fine ground samples were prepared from the above three grades of lump ore for chemical analyses. The results are as follows.

| Sample | Weight Percent | |
|---|---|---|
| | Mn | Fe |
| H-1 | 59.05 | 0.13 |
| H-2 | 57.28 | 0.06 |
| H-3 | 58.69 | 0.04 |
| M-1 | 34.57 | 23.84 |
| M-2 | 59.72 | 0.33 |
| M-3 | 57.41 | 1.92 |
| L-1 | 58.56 | 0.86 |
| L-2 | 52.69 | 1.53 |
| L-3 | 57.96 | 0.23 |
| L-4 | 51.04 | 0.44 |

All samples contained high manganese. Sample M-1 had a high iron content (23.84% Fe). An interesting feature of sample M-1 was that the fines of this ore showed ferromagnetism while other samples were non-magnetic. Also, the color of the fines of M-1 was slightly brown compared with other samples which were grayish black.

The sample M-1 was selected for a reduction tube furnace test.

## REDUCTION TEST

The reduction test of sample M-1 was performed in a 2.9 inch diameter electric heated tube furnace. Conditions of the tests were as follows:

| | |
|---|---|
| Sample Weight | 264.9 grams |
| Reduction temperature | 1000°C |
| Reducing Gas | 25% $H_2$, 25% CO, 50% $N_2$ |
| Gas Flow rate | 10 l/min. total |
| Reduction Time | 3 hrs. |

The sample was heated in the tube furnace in nitrogen to a temperature of 1000°C. Then the reducing gas was introduced into the tube furnace. The sample was reduced at 1000°C for three hours and then nitrogen cooled.

## RESULTS

### Chemistry

| | Lump Ore | Reduced Product |
|---|---|---|
| Total Iron (%) | 23.84 | 30.64 |
| Metallic Iron (%) | | 30.64 (estimated with the aid of x-rays diffraction) |
| Manganese (%) | 35.57 | 52.29 |
| MnO (%) | | 67.45 (calculated) |
| $SiO_2$ (%) | | 1.65 |
| C (%) | | 0.30 |
| Mn/Fe | 1.45 | 1.71 |

The reduced product was strongly magnetic. The microstructure showed a large amount of metallic iron. However, the result of a wet chemical analysis (mercuric chloride method) by Lerch Brothers Laboratory, Hibbing, Minnesota, did not indicate any metallic iron. An x-rays diffraction analysis was made to identify the compounds in the reduced product. The diffraction pattern revealed two compounds in the sample. They were metallic iron and MnO. The greenish appearance (which suggests MnO) of the reduced product supported this x-ray diffraction conclusion. It was speculated that the presence of MnO in the sample may have interfered with the chemical reaction during the wet analysis for metallic iron.

## ORE AND PRODUCT PHYSICAL PROPERTIES

| | Lump Ore (M-1) | Reduced Product |
|---|---|---|
| Apparent density ($g/cm^3$) | 4.14 | 2.90 |
| Matrix density ($g/cm^3$) | 4.26 | 5.51 |
| Open porosity (%) | 2.8 | 47.4 |
| Weight loss after reduction (%) | | 25.1 |

## ORE AND PRODUCT MICROSTRUCTURES

The microstructure of a sample of manganese ore is shown in Figure 1. The diagonal large grain at the center of the photomicrograph exhibits lenticular structure. It is probably a high manganese mineral. At the upper left and lower right corner, the white grains are possibly iron rich minerals. The work of identification of these minerals was not performed.

Figure 2 shows the structure of reduced manganese ore. The numerous white grains are metallic iron. The discontinuous grey network in the iron matrix is nonferrous material. The black spots are porosities.

Shaochi Huang

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CEMENT, MINING & METALS SYSTEMS DIVISION

FIGURE 1. MANGANESE ORE 200 X

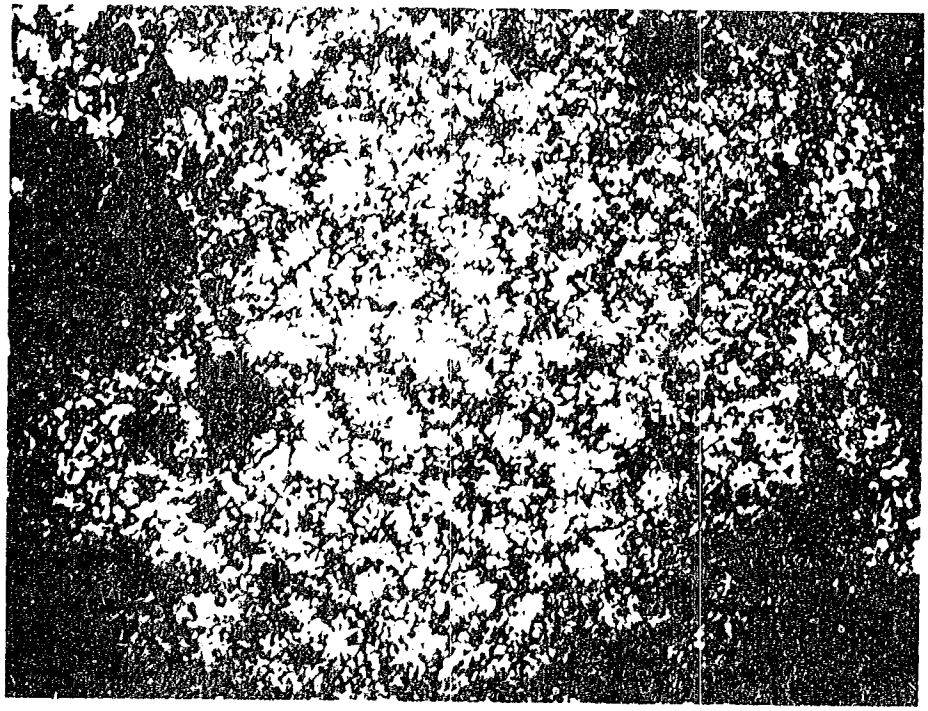

FIGURE 2. REDUCED MANGANESE ORE 200X

## ORE RESERVE DATA

The output from rehabilitating the existing 13.2MVA SAEF at Abu Zeneima is highly influenced by the Mn grade and the Mn/Fe ratio of the proven and projected ore reserves. Separate analyses have been prepared for three cases of ore reserves and metallurgical balances computed. The cases are as follows:

- o Case I Proven ore reserves except the ore fines stockpile at Abu Zeneima having a cumulative Mn/Fe ratio of 1.03.
- o Case II Proven and possible reserves having a cumulative Mn/Fe ratio of not less than 2.0.
- o Case III Proven and possible reserves having a cumulative Mn/Fe ratio of not less than 3.0.

The annual 13.2-MVA SAEF output and ore requirements were then computed for each of the ore reserve cases using the cumulative Mn and Fe grades which are listed as follows:

| Case | Mn/Fe | % Mn | % Fe | Reserves tonnes |
|---|---|---|---|---|
| I | 1.03 | 27.40 | 26.71 | 913,843 |
| II | 2.0 | 33.0 | 16.5 | 1,500,000 |
| III | 3.0 | 39.0 | 13.0 | 650,000 |

From the above data, annual production and ore consumption figures were computed for the rehabilitated 13.2-MVA furnace at Abu Zeneima, as summarized below:

| Case | Ore Mn/Fe | Production - t/y FeMn | Production - t/y Pig Iron | Mn Ore Req'd t/y |
|---|---|---|---|---|
| I | 1.03 | 14,045 | 14,268 | 62,218 |
| II | 2.0 | 17,197 | 7,682 | 66,268 |
| III | 3.0 | 19,824 | 4,570 | 61,239 |

Based on these ore consumptions, the life of the proven and possible ore reserves is as follows:

| Case | Total Reserves tonnes | Ore Req'd t/y | Ore Reserves years |
|---|---|---|---|
| I | 913,843 | 62,218 | 14.7 |
| II | 1,500,000 | 66,268 | 22.6 |
| III | 650,00 | 61,239 | 10.6 |

These tables show that the Mn/Fe ratio in the ore reserve has a highly significant effect on FeMn production and ore reserve life. In fact, at the 3.0 Mn/Fe ratio the projected 1985 FeMn requirement of 20,000 t/y can nearly be produced by the rehabilitated 13.2-MVA smelter furnace.

TABLE 6-29

SUMMARY - OPERATING ALTERNATIVES

ORE RESERVE DATA

| Description | FeMn t/y | Pig iron t/y | SiMn t/y | Semi-Steel t/y | Total Mn Ore t/y | Reduced ore t/y | Coke t/y | Electric Power GW/y | Natural Gas $Mm^3/y$ | Electrode Carbon t/y |
|---|---|---|---|---|---|---|---|---|---|---|
| SAEF - 13.. MVA/1.0Mw Rehabilitated Unit | | | | | | | | | | |
| Mn Ore 1.03 Mn/Fe | 14645 | 14,[illegible] | - | - | [illegible] | - | 18032 | 82.3 | - | 565 |
| Mn Ore [illegible] Mn/Fe | [illegible] | [illegible] | - | - | [illegible] | - | 17742 | 82.3 | - | 545 |
| Mn Ore 3.[illegible] Mn/Fe | 10834 | 8870 | - | - | 61239 | - | 17735 | 82.3 | - | 564 |

SINAI MANGANESE COMPANY

SUMMARY - OPERATING ALTERNATIVES

ORE RESERVE DATA

TABLE 6-30

SAEF

MN ORE - 1.03 MN/FE

PIG IRON + FEMN

ORE RESERVE DATA

METALLURGICAL DATA

| | Pig Iron | High C FeMn |
|---|---|---|
| Operating Load - kWh | 10,000 | 10,000 |
| Operating Time - % | 94 | 94 |
| Avg. Load - kW | 9,400 | 9,400 |
| kWh/kg Metal | 2.29 | 3.53 |
| kWh/t Metal | 2,290 | 3,530 |
| % Mn | 4.0 | 75.0 |
| % Fe | 90.0 | 16.0 |
| % Si | 1.0 | 1.5 |
| % C | 4.0 | 6.5 |
| Electrode Paste - kg/t | 15 | 25 |

TABLE 6-31
SAEF

Mn Ore - 1.03 MN/FE

PIG IRON + FEMN

ORE RESERVE DATA

CAMPAIGN PROGRAM

| | |
|---|---|
| 1000 kg Mn ore 1.05 Mn/Fe | 262 kg pig iron + 570 kg high Mn slag |
| 800 kg high Mn slag<br>200 kg Mn ore 1.05 Mn/Fe | 362 kg FeMn +<br>744 kg low Mn slag |

HOURLY PRODUCTION

| | | |
|---|---|---|
| Pig iron | 9400/1200 + 1090 | = 4.10 t/h |
| High Mn slag | 4.10 x 570/262 | = 8.92 t/h |
| FeMn | 9400/2500 + 1030 | = 2.66 t/h |

ANNUAL PRODUCTION - Pig Iron 145d/4.8 mo FeMn 220d/7.2 mo

| | | |
|---|---|---|
| Pig iron | 145 x 24 x 4.10 | = 14,268 t/y |
| High Mn slag | 145 x 24 x 8.92 | = 31,042 t/y |
| FeMn | 220 x 24 x 2.66 | = 14,045 t/y |
| Slag req'd | 14,045 x 800/362 | = 31,039 t/y |
| Ore req'd | 14,268 x 1000/262 = 54,458<br>14,045 x 200/362 = 7,760 | 62,218 t/y |
| Coke req'd | 14,268 x 210/262 = 11,436<br>14,045 x 170/362 = 6,596 | 18,032 t/y |
| Low Mn slag | 14,045 x 744/362 | = 28,866 t/y |

TABLE 6-32

SAEF

MN ORE - 1.03 MN/FE

PIG IRON + FEMN

ORE RESERVE DATA

SUMMARY - RAW MATERIAL REQUIREMENTS

| Pig Iron | kg/ Batch | kg/t Iron | t/d | t/y 145 d 4.8 mo |
|---|---|---|---|---|
| Mn ore 1.03 Mn/Fe | 1,000 | 3,817 | 376 | 54,458 |
| Coke | 210 | 802 | 79 | 11,436 |
| Quartzite | 130 | 496 | 49 | 7,077 |
| Total | 1,340 | 5,115 | 504 | 72,971 |
| Pig iron | 262 | 1,000 | 98 | 14,268 |
| High Mn slag | 570 | 2,176 | 214 | 31,042 |

| FeMn | kg/ Batch | kg/t FeMn | t/d | t/y 220 d 7.2 mo |
|---|---|---|---|---|
| High Mn slag | 800 | 2,210 | 141 | 31,039 |
| Mn ore 1.03 Mn/Fe | 200 | 552 | 35 | 7,760 |
| Coke | 170 | 470 | 30 | 6,596 |
| Dolomite | 500 | 1,381 | 88 | 19,396 |
| Total | 1,670 | 4,613 | 294 | 64,791 |
| FeMn | 362 | 1,000 | 64 | 14,045 |
| Low Mn slag | 744 | 2,055 | 131 | 28,866 |
| Total ore req'd | | | | 62,218 |

TABLE 6-33
SAEF - MANGANESE ORE 1.03 MN/FE - PIG IRON + FEMN
ORE RESERVE DATA

| Material | Wt/Chge kg | $MnO_2$ %/kg | Mn %/kg | MnO %/kg | Mn %/kg | $Fe_2O_3$ %/kg | Fe %/kg | FeO %/kg | Fe %/kg | $SiO_2$ % | kg | $Al_2O_3$ % | kg | CaO % | kg | MgO % | kg | BaO % | kg | P % | kg | S % | kg | C % | kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mn ore 1.03 Mn/Fe | 1,000 | 27.40 | 274 | | | | 26.71 | 267 | | 4.0 | 40 | 1.0 | 10 | 3.0 | 30 | 1.0 | 10 | | | | | | | | |
| Coke | 210 | | | | | 2.0 | 4 | | 3 | 5.0 | 11 | 3.0 | 6 | | | | | | | | | | | 75.0 | 158 |
| Quartzite | 130 | | | | | | | | | 99.0 | 129 | 1.0 | 2 | | | | | | | | | | | | |
| TOTALS | 1,340 | | 274 | | | | | | 270 | | 180 | | 17 | | 30 | | 10 | | | | | | | | 158 |

PIG IRON PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| Mn | 10 | 11 | 4.0 |
| Fe | 236 | 248 | 90.0 |
| Si | 3 | 3 | 1.0 |
| P | - | - | - |
| S | - | | - |
| C | 10 | 11 | 4.0 |
| Other | 3 | 3 | 1.0 |
| TOTAL | 262 | 276 | 100.0 |

SLAG PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| $SiO_2$ | 168 | 174 | 29.0 |
| $Al_2O_3$ | 16 | 17 | 2.8 |
| CaO | 29 | 30 | 5.0 |
| MgO | 10 | 10 | 1.7 |
| MnO | 323 | 340 | 56.8 |
| FeO | 27 | 28 | 4.7 |
| BaO/Other | - | - | - |
| TOTAL | 570 | 599 | 100.0 |

MATERIAL BALANCES

| | kg Product/kg Feed | | Unit Recovery |
|---|---|---|---|
| Mn | 260/274 | = | 0.950 |
| Fe | 257/270 | = | 0.952 |
| Si0 | 171/180 | = | 0.952 |
| $Al_2O_3$ | 16/17 | = | 0.941 |
| CaO | 29/30 | = | 0.967 |
| MgO | 10/10 | = | 1.000 |

CARBON

| Reactions | kg |
|---|---|
| $MnO_2/MnO$ | 59.8 |
| MnO/Mn | 2.4 |
| $Fe_2O_3/FeO$ | 28.9 |
| FeO/Fe | 53.1 |
| $SiO_2/Si$ | 2.6 |
| C in Metal | 11.0 |
| TOTAL | 157.8 |

157.8/.75 = 210.4 Use 210 kg/t

PROCESS RATIOS

| | | |
|---|---|---|
| Slag/t (570/262)1000 | = | 2176 kg |
| Slag Ratio CaO + MgO + MnO/$SiO_2$ | = | 1.93 |
| Coke/t (210/262)1000 | = | 802 |
| Coke to Mix % (210/1340)100 | = | 15.7 |
| $SiO_2$/t (130/262)1000 | = | 496 |
| $SiO_2$ to Mix % (130/1340)100 | = | 9.7 |
| Dolomite/t | = | - |
| Dolomite to Mix % | = | - |
| Mn/Fe Slag | = | 11.9 |

TABLE 6-34
SAEF - MANGANESE ORE 1.03 MN/FE - PIG IRON + FEMN
ORE RESERVE DATA

| Material | Wt/Chge kg | $MnO_2$ %/kg | Mn %/kg | MnO %/kg | Mn %/kg | $Fe_2O_3$ %/kg | Fe %/kg | FeO %/kg | Fe %/kg | $SiO_2$ % | kg | $Al_2O_3$ % | kg | CaO % | kg | MgO % | kg | BaO % | kg | P % | kg | S % | kg | C % | kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| High Mn slag | 800 | | | 56.8 | 454 | | | 4.7 | 38 | 29.0 | 232 | 2.8 | 22 | 5.0 | 40 | 1.7 | 14 | | | | | | | | |
| Mn ore 1.03 Mn/Fe | 200 | 27.40 | 55 | | 352 | | 26.71 | | 29 | 4.0 | 8 | 1.0 | 2 | 3.0 | 6 | 1.0 | 2 | | | | | | | | |
| Coke | 170 | | | | | 2.0 | 53 | | | 5.0 | 9 | 3.0 | 5 | | | | | | | | | | | 75.0 | 128 |
| Dolomite | 500 | | | | | 3 | 2 | | | 2.0 | 10 | | | 30.2 | 151 | 21.0 | 105 | | | | | | | | |
| TOTALS | 1,670 | | 55 | | 352 | | 55 | | 29 | | 259 | | 29 | | 197 | | 121 | | | | | | | | 128 |

FEMN PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| Mn | 271 | 285 | 75.0 |
| Fe | 58 | 61 | 16.0 |
| Si | 5 | 5 | 1.5 |
| P | | - | - |
| S | - | | - |
| C | 24 | 25 | 6.5 |
| Other | 4 | - | 1.0 |
| TOTAL | 362 | 380 | 100.0 |

SLAG PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| $SiO_2$ | 236 | 248 | 31.9 |
| $Al_2O_3$ | 28 | 29 | 3.7 |
| CaO | 187 | 197 | 25.2 |
| MgO | 115 | 121 | 15.5 |
| MnO | 149 | 157 | 20.1 |
| FeO | 29 | 30 | 3.6 |
| BaO/Other | - | - | - |
| TOTAL | 744 | 782 | 100.0 |

MATERIAL BALANCES

| | kg Product/kg Feed | | Unit Recovery |
|---|---|---|---|
| Mn | 386/407 | = | 0.949 |
| Fe | 81/84 | = | 0.959 |
| $SiO_2$ | 247/259 | = | 0.953 |
| $Al_2O_3$ | 28/29 | = | 0.966 |
| CaO | 187/197 | = | 0.949 |
| MgO | 115/121 | = | 0.950 |

CARBON

| Reactions | kg |
|---|---|
| $MnO_2/MnO$ | 12.0 |
| MnO/Mn | 62.2 |
| $Fe_2O_3/FeO$ | 5.9 |
| FeO/Fe | 13.1 |
| $SiO_2/Si$ | 4.3 |
| C in Metal | 25.0 |
| TOTAL | 122.5 |

122.5/.75 = 163.3 Use 170 kg/t

PROCESS RATIOS

| | |
|---|---|
| Slag/t (744/362)1000 | = 2055 kg |
| Slag Ratio CaO + MgO + MnO/$SiO_2$ | = 2.11 |
| Coke/t (170/362)1000 | = 470 kg |
| Coke to Mix % (170/1670)100 | = 10.2 |
| $SiO_2$/t | = - |
| $SiO_2$ to Mix % | = - |
| Dolimite/t (500/362)1000 | = 1381 kg |
| Dolomite to Mix % (500/1670)100 | = 29.9 |
| Mn/Fe Slag | = 5.12 |

TABLE 6-35

SAEF

MN ORE - 2.0 MN/FE

PIG IRON + FEMN

ORE RESERVE DATA

METALLURGICAL DATA

| | Pig Iron | High C FeMn |
|---|---|---|
| Operating Load - kWh | 10,000 | 10,000 |
| Operating Time - % | 94 | 94 |
| Avg. Load - kW | 9,400 | 9,400 |
| kWh/kg Metal | 3.23 | 3.35 |
| kWh/t Metal | 3,230 | 3,350 |
| | | |
| % Mn | 4.0 | 75.0 |
| % Fe | 90.0 | 16.0 |
| % Si | 1.0 | 1.5 |
| % C | 4.0 | 6.5 |
| Electrode Paste - kg/t | 15 | 25 |

TABLE 6-36

SAEF

MN ORE - 2.0 MN/FE

PIG IRON + FEMN

ORE RESERVE DATA

CAMPAIGN PROGRAM

| | |
|---|---|
| 1000 kg Mn ore 2.0 Mn/Fe | 165 kg pig iron + 669 kg high Mn slag |
| 600 kg high Mn slag 400 kg Mn ore 2.0 Mn/Fe | 349 kg FeMn + 587 kg low Mn slag |

HOURLY PRODUCTION

| | | | |
|---|---|---|---|
| Pig iron | 9400/1200 + 2030 | = | 2.91 t/h |
| High Mn slag | 2.91 x 669/165 | = | 11.80 t/h |
| FeMn | 9400/2500 + 850 | = | 2.81 t/h |

ANNUAL PRODUCTION - Pig Iron 110d/3.6 mo FeMn 255d/8.4 mo

| | | | |
|---|---|---|---|
| Pig iron | 110 x 24 x 2.91 | = | 7682 t/y |
| High Mn slag | 110 x 24 x 11.80 | = | 31152 t/y |
| FeMn | 255 x 24 x 2.81 | = | 17197 t/y |
| Slag req'd | 17197 x 600/349 | = | 29565 t/y |
| Ore req'd | 7682 x 1000/165 = 46558<br>17197 x 400/349 = 19710 | | 66268 t/y |
| Coke req'd | 7682 x 180/165 = 8380<br>17197 x 190/349 = 9362 | | 17742 t/y |
| Low Mn slag | 17197 x 587/349 | = | 28924 t/y |

TABLE 6-37
SAEF

MN ORE - 2.0 MN/FE

PIG IRON + FEMN

ORE RESERVE DATA

SUMMARY - RAW MATERIAL REQUIREMENTS

| Pig Iron | kg/ Batch | kg/t Iron | t/d | t/y 110 d 3.6 mo |
|---|---|---|---|---|
| Mn ore 2.0 Mn/Fe | 1,000 | 6,061 | 423 | 46,563 |
| Coke | 180 | 1,091 | 76 | 8,381 |
| Quartzite | 150 | 909 | 63 | 6,983 |
| Total | 1,330 | 8,061 | 562 | 61,927 |
| Pig Iron | 165 | 1,000 | 70 | 7,682 |
| High Mn slag | 669 | 4,055 | 283 | 31,152 |

| FeMn | kg/ Batch | kg/t FeMn | t/d | t/y 255 d 8.4 mo |
|---|---|---|---|---|
| High Mn slag | 600 | 1,719 | 116 | 29,562 |
| Mn ore 2.0 | 400 | 1,146 | 77 | 19,708 |
| Coke | 190 | 544 | 37 | 9,355 |
| Dolomite | 300 | 860 | 58 | 14,790 |
| Total | 1,490 | 4,269 | 288 | 73,415 |
| FeMn | 349 | 1,000 | 67 | 17,197 |
| Low Mn slag | 587 | 1,682 | 113 | 28,926 |
| Total ore req'd | - | - | - | 66,268 |

TABLE 6-37
SAEF

MN ORE - 2.0 MN/FE

PIG IRON + FEMN

ORE RESERVE DATA

SUMMARY - RAW MATERIAL REQUIREMENTS

| Pig Iron | kg/ Batch | kg/t Iron | t/d | t/y 110 d 3.6 mo |
|---|---|---|---|---|
| Mn ore 2.0 Mn/Fe | 1,000 | 6,061 | 423 | 46,563 |
| Coke | 180 | 1,091 | 76 | 8,381 |
| Quartzite | 150 | 909 | 63 | 6,983 |
| Total | 1,330 | 8,061 | 562 | 61,927 |
| Pig Iron | 165 | 1,000 | 70 | 7,682 |
| High Mn slag | 669 | 4,055 | 283 | 31,152 |

| FeMn | kg/ Batch | kg/t FeMn | t/d | t/y 255 d 8.4 mo |
|---|---|---|---|---|
| High Mn slag | 600 | 1,719 | 116 | 29,562 |
| Mn ore 2.0 | 400 | 1,146 | 77 | 19,708 |
| Coke | 190 | 544 | 37 | 9,355 |
| Dolomite | 300 | 860 | 58 | 14,790 |
| Total | 1,490 | 4,269 | 288 | 73,415 |
| FeMn | 349 | 1,000 | 67 | 17,197 |
| Low Mn slag | 587 | 1,682 | 113 | 28,926 |
| Total ore req'd | - | - | - | 66,268 |

TABLE 6-38

SAEF - MANGANESE ORE 2.0 MN/FE - PIG IRON + FEMN
ORE RESERVE DATA

| Material | Wt/Chge kg | $MnO_2$ %/kg | Mn %/kg | MnO %/kg | Mn %/kg | $Fe_2O_3$ %/kg | Fe %/kg | FeO %/kg | Fe %/kg | $SiO_2$ % | $SiO_2$ kg | $Al_2O_3$ % | $Al_2O_3$ kg | CaO % | CaO kg | MgO % | MgO kg | BaO % | BaO kg | P % | P kg | S % | S kg | C % | C kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mn ore 2.0 Mn/Fe | 1,000 | | 33.0<br>330 | | | | 16.5<br>165 | | | 5.0 | 50 | 1.0 | 10 | 4.0 | 40 | 1.0 | 10 | | | | | | | | |
| Coke | 180 | | | | | 2.0<br>4 | 3 | | | 5.0 | 9 | 3.0 | 5 | | | | | | | | | | | 75.0 | 135 |
| Quartzite | 150 | | — | | | | — | | | 99.0 | 149 | 1.0 | 1 | | — | | — | | | | | | | | — |
| TOTALS | 1,330 | | 330 | | | | 168 | | | | 208 | | 16 | | 40 | | 10 | | | | | | | | 135 |

PIG IRON PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| Mn | 7 | 7 | 4.0 |
| Fe | 147 | 155 | 90.0 |
| Si | 2 | 2 | 1.0 |
| P | - | - | - |
| S | - | - | - |
| C | 7 | 7 | 4.0 |
| Other | 2 | 2 | 1.0 |
| TOTAL | 165 | 173 | 100.0 |

SLAG PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| $SiO_2$ | 194 | 204 | 29.0 |
| $Al_2O_3$ | 15 | 16 | 2.3 |
| CaO | 38 | 40 | 5.7 |
| MgO | 10 | 10 | 1.4 |
| MnO | 396 | 417 | 56.2 |
| FeO | 16 | 17 | 2.4 |
| BaO/Other | - | - | - |
| TOTAL | 669 | 704 | 100.0 |

MATERIAL BALANCES

| | kg Product/kg Feed | | Unit Recovery |
|---|---|---|---|
| Mn | 314/330 | = | 0.951 |
| Fe | 159/168 | = | 0.949 |
| $SiO_2$ | 198/208 | = | 0.953 |
| $Al_2O_3$ | 15/16 | = | 0.938 |
| CaO | 38/40 | = | 0.950 |
| MgO | 10/10 | = | 1.000 |

CARBON

| Reactions | kg |
|---|---|
| $MnO_2/MnO$ | 72.0 |
| MnO/Mn | 1.5 |
| $Fe_2O_3/FeO$ | 18.0 |
| FeO/Fe | 33.2 |
| $SiO_2/Si$ | 1.7 |
| C in Metal | 7.0 |
| TOTAL | 133.4 |

133.4/.75 = 177.9 Use 180 kg/t

PROCESS RATIOS

| | |
|---|---|
| Slag/t (669/165)1000 | = 4055 kg |
| Slag Ratio $CaO + MgO + MnO/SiO_2$ | = 2.01 |
| Coke/t (180/165)1000 | = 1091 kg |
| Coke to Mix % (180/1330)100 | = 13.5 |
| $SiO_2$/t (150/165)1000 | = 909 kg |
| $SiO_2$ to Mix % (150/1330)100 | = 11.3 |
| Dolimite/t | - |
| Dolomite to Mix % | - |
| Mn/Fe Slag | = 24.7 |

TABLE 6-39
SAEF - MANGANESE ORE 2.0 MN/FE - PIG IRON / FEMN
ORE RESERVE DATA

| Material | Wt/Chge kg | $MnO_2$ %/kg | Mn %/kg | MnO %/kg | Mn %/kg | $Fe_2O_3$ %/kg | Fe %/kg | FeO %/kg | Fe %/kg | $SiO_2$ % | kg | $Al_2O_3$ % | kg | CaO % | kg | MgO % | kg | BaO % | kg | P % | kg | S % | kg | C % | kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| High Mn slag | 600 | | | 56.2 | | | | 2.4 | | 29.0 | 174 | 2.3 | 14 | 5.7 | 34 | 1.4 | 8 | | | | | | | | |
| | | | | 337 | 261 | | | 14 | 11 | | | | | | | | | | | | | | | | |
| Mn ore 2.0 Mn/Fe | 400 | 33.0 | | | | | 16.5 | | | 5.0 | 20 | 1.0 | 4 | 4.0 | 16 | 1.0 | 4 | | | | | | | | |
| | | 132 | | | | | 66 | | | | | | | | | | | | | | | | | | |
| Coke | 100 | | | | | 2.0 | | | | 5.0 | 10 | 3.0 | 6 | | | | | | | | | | | 75.0 | 143 |
| | | | | | | 4 | 3 | | | | | | | | | | | | | | | | | | |
| Dolomite | 300 | | | | | | | | | 2.0 | 6 | | | 30.2 | 91 | 21.0 | 63 | | | | | | | | |
| TOTALS | 1,490 | 132 | | 261 | | 69 | | 11 | | | 210 | | 24 | | 141 | | 75 | | | | | | | | 143 |

FEMN PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| Mn | 261 | 275 | 75.0 |
| Fe | 56 | 59 | 16.0 |
| Si | 5 | 5 | 1.5 |
| P | - | - | - |
| S | | - | - |
| C | 23 | 24 | 6.5 |
| Other | 4 | 4 | 1.0 |
| TOTAL | 349 | 367 | 100.0 |

SLAG PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| $SiO_2$ | 189 | 199 | 32.2 |
| $Al_2O_3$ | 23 | 24 | 3.9 |
| CaO | 134 | 141 | 22.8 |
| MgO | 71 | 75 | 12.1 |
| MnO | 144 | 152 | 24.6 |
| FeO | 26 | 27 | 4.4 |
| BaO/Other | - | - | - |
| TOTAL | 587 | 618 | 100.0 |

MATERIAL BALANCES

| | kg Product/kg Feed | | Unit Recovery |
|---|---|---|---|
| Mn | 373/393 | = | 0.948 |
| Fe | 76/80 | = | 0.953 |
| $SiO_2$ | 200/210 | = | 0.950 |
| $Al_2O_3$ | 23/24 | = | 0.958 |
| CaO | 134/141 | = | 0.950 |
| MgO | 71/75 | = | 0.947 |

CARBON

| Reactions | kg |
|---|---|
| $MnO_2/MnO$ | 28.8 |
| MnO/Mn | 60.0 |
| $Fe_2O_3/FeO$ | 7.4 |
| FeO/Fe | 12.6 |
| $SiO_2/Si$ | 4.3 |
| C in Metal | 24.0 |
| TOTAL | 137.1 |

137.1/.75 = 182.8 Use 190 kg/t

PROCESS RATIOS

| | | |
|---|---|---|
| Slag/t (587/349)1000 | = | 1682 |
| Slag Ratio $CaO + MgO + MnO/SiO_2$ | = | 1.97 |
| Coke/t (190/349)1000 | = | 544 |
| Coke to Mix % (190/1490)100 | = | 12.8 |
| $SiO_2$/t | = | - |
| $SiO_2$ to Mix % | = | - |
| Dolimite/t (300/349)1000 | = | 860 |
| Dolomite to Mix % (300/1490)100 | = | 20.1 |
| Mn/Fe Slag | = | 5.5 |

TABLE 6-40

SAEF

MN ORE - 3.0 MN/FE

PIG IRON + FEMN

ORE RESERVE DATA

METALLURGICAL DATA

| | Pig Iron | High C FeMn |
|---|---|---|
| Operating Load - kWh | 10,000 | 10,000 |
| Operating Time - % | 94 | 94 |
| Avg. Load - kW | 9,400 | 9,400 |
| kWh/kg Metal | 4.19 | 3.19 |
| kWh/t Metal | 4,190 | 3,190 |
| | | |
| % Mn | 4.0 | 75.0 |
| % Fe | 90.0 | 16.0 |
| % Si | 1.0 | 1.5 |
| % C | 4.0 | 6.5 |
| Electrode Paste - kg/t | 15 | 25 |

TABLE 6-41

SAEF

MN ORE - 3.0 MN/FE

PIG IRON + FEMN

ORE RESERVE DATA

CAMPAIGN PROGRAM

| | |
|---|---|
| 1000 kg Mn ore 3.0 Mn/Fe | 129 kg pig iron + 771 kg high Mn slag |
| 500 kg high Mn slag<br>500 kg Mn ore 3.0 Mn/Fe | 384 kg FeMn +<br>524 kg low Mn slag |

HOURLY PRODUCTION

| | | | |
|---|---|---|---|
| Pig iron | 9400/1200 + 2990 | = | 2.24 t/h |
| High Mn slag | 2.24 x 771/129 | = | 13.41 t/h |
| FeMn | 9400/2500 + 690 | = | 2.95 t/h |

ANNUAL PRODUCTION - Pig iron 85d/2.8 mos FeMn 280d/9.2 mos

| | | | |
|---|---|---|---|
| Pig iron | 85 x 24 x 2.24 | = | 4,570 t/y |
| High Mn slag | 85 x 24 x 13.41 | = | 27,356 t/y |
| FeMn | 280 x 24 x 2.95 | = | 19,824 t/y |
| Slag req'd | 19,824 x 500/384 | = | 25,813 t/y |
| Ore req'd | 4,570 x 1000/129 = 35,426<br>19,824 x 500/384 = 25,813 | | 61,239 t/y |
| Coke req'd | 4,570 x 180/129 = 6,377<br>19,824 x 220/384 = 11,358 | | 17,735 t/y |
| Low Mn slag | 19,824 x 524/384 | = | 27,052 t/y |

TABLE 6-42

SAEF

MN ORE - 3.0 MN/FE

PIG IRON + FEMN

ORE RESERVE DATA

SUMMARY - RAW MATERIAL REQUIREMENTS

| Pig Iron | kg/ Batch | kg/t Iron | t/d | t/y 85 d 2.8 mos |
|---|---|---|---|---|
| Mn ore 3.0 Mn/Fe | 1,000 | 7,752 | 417 | 35,426 |
| Coke | 180 | 1,395 | 75 | 6,377 |
| Quartzite | 200 | 1,550 | 83 | 7,085 |
| Total | 1,380 | 10,697 | 575 | 48,888 |
| Pig iron | 129 | 1,000 | 54 | 4,570 |
| High Mn slag | 771 | 5,977 | 322 | 27,356 |

| FeMn | kg/ Batch | kg/t FeMn | t/d | t/y 280 d 9.2 mos |
|---|---|---|---|---|
| High Mn slag | 500 | 1,302 | 92 | 25,811 |
| Mn ore 3.0 Mn/Fe | 500 | 1,302 | 92 | 25,811 |
| Coke | 220 | 573 | 41 | 11,358 |
| Dolomite | 250 | 651 | 46 | 12,906 |
| Total | 1,470 | 3,828 | 271 | 75,886 |
| FeMn | 384 | 1,000 | 71 | 19,824 |
| Low Mn slag | 524 | 1,365 | 97 | 27,052 |
| Total ore req'd | - | - | - | 61,239 |

TABLE 6-43
SAEF - MANGANESE ORE 3.0 MN/FE - PIG IRON + FEMN
ORE RESERVE DATA

| Material | Wt/Chge kg | $MnO_2$ %/kg | Mn %/kg | MnO %/kg | Mn %/kg | $Fe_2O_3$ %/kg | Fe %/kg | FeO %/kg | Fe %/kg | $SiO_2$ % | kg | $Al_2O_3$ % | kg | CaO % | kg | MgO % | kg | BaO % | kg | P % | kg | S % | kg | C % | kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mn ore 3.0 Mn/Fe | 1,000 | | 39.0 | | | | 13.0 | | | 4.0 | 40 | 1.0 | 10 | 3.0 | 30 | 1.0 | 10 | | | | | | | | |
| | | | 390 | | | | 130 | | | | | | | | | | | | | | | | | | |
| Coke | 180 | | | | | 2.0 | | | | 5.0 | 9 | 3.0 | 5 | | | | | | | | | | | 75.0 | 135 |
| | | | | | | 4 | 3 | | | | | | | | | | | | | | | | | | |
| Quartzite | 200 | | | | | | | | | 99.0 | 198 | 1.0 | 2 | | | | | | | | | | | | |
| TOTALS | 1,380 | | 390 | | | | 133 | | | | 247 | | 17 | | 30 | | 10 | | | | | | | | 135 |

PIG IRON PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| Mn | 5 | 5 | 4.0 |
| Fe | 116 | 122 | 90.0 |
| Si | 2 | 2 | 1.0 |
| P | - | - | - |
| S | - | - | - |
| C | 5 | 5 | 4.0 |
| Other | 1 | 1 | 1.0 |
| | 129 | 135 | 100.0 |

SLAG PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| $SiO_2$ | 231 | 243 | 30.0 |
| $Al_2O_3$ | 16 | 17 | 2.1 |
| CaO | 29 | 30 | 3.7 |
| MgO | 10 | 10 | 1.2 |
| MnO | 472 | 497 | 61.3 |
| FeO | 13 | 14 | 1.7 |
| BaO/Other | - | - | - |
| | 771 | 811 | 100.0 |

MATERIAL BALANCES

| | | | |
|---|---|---|---|
| Mn | 371/390 | = | 0.950 |
| Fe | 126/133 | = | 0.948 |
| $SiO_2$ | 235/247 | = | 0.953 |
| $Al_2O_3$ | 16/17 | = | 0.941 |
| CaO | 29/30 | = | 0.967 |
| MgO | 10/10 | = | 1.000 |

C

| | |
|---|---|
| $MnO_2$/MnO | 85.1 |
| MnO/Mn | 1.1 |
| $Fe_2O_3$/FeO | 14.3 |
| FeO/Fe | 26.1 |
| $SiO_2$/Si | 1.7 |
| C in Metal | 5.0 |
| | 133.3 |

133.3/.75 = 177.7 Use 180 kg/t

PROCESS RATIOS

| | | | |
|---|---|---|---|
| Slag/t | (771/129)1000 | = | 5977 kg |
| Slag Ratio | CaO + MgO + MnO/$SiO_2$ | = | 1.91 |
| Coke/t | (180/129)1000 | = | 1395 kg |
| Coke to Mix % | (180/1380)100 | = | 13.0 |
| $SiO_2$/t | (200/129)1000 | = | 1550 kg |
| $SiO_2$ to Mix % | (200/1380)100 | = | 14.5 |
| Dolomite/t | | | - |
| Dolomite to Mix % | | | - |
| Mn/Fe Slag | | | 36.2 |

TABLE 6-44
SAEF - MANGANESE ORE 3.0 MN/FE - PIG IRON + FEMN
ORE RESERVE DATA

| Material | Wt/Chge kg | $MnO_2$ %/kg | Mn %/kg | MnO %/kg | Mn %/kg | $Fe_2O_3$ %/kg | Fe %/kg | FeO %/kg | Fe %/kg | $SiO_2$ % | kg | $Al_2O_3$ % | kg | CaO % | kg | MgO % | kg | BaO % | kg | P % | kg | S % | kg | C % | kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| High Mn slag | 500 | | | 61.3 | | | | 1.7 | | 30.0 | 150 | 2.1 | 11 | 3.7 | 19 | 1.2 | 6 | | | | | | | | |
| | | | | 307 | 237 | | | 9 | 7 | | | | | | | | | | | | | | | | |
| Mn ore 3.0 Mn/Fe | 500 | | 39.0 | | | | 13.0 | | | 4.0 | 20 | 1.0 | 5 | 3.0 | 15 | 1.0 | 5 | | | | | | | | |
| | | | 195 | | | | 65 | | | | | | | | | | | | | | | | | | |
| Coke | 220 | | | | | 2.0 | | | | 5.0 | 11 | 3.0 | 7 | | | | | | | | | | | 75.0 | 165 |
| | | | | | | 4 | 3 | | | | | | | | | | | | | | | | | | |
| Dolomite | 250 | | | | | | | | | 2.0 | 5 | | | 30.2 | 76 | 21.0 | 53 | | | | | | | | |
| TOTALS | 1,470 | | 195 | | 237 | | 68 | | 7 | | 186 | | 23 | | 110 | | 64 | | | | | | | | 165 |

FEMN PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| Mn | 287 | 302 | 75.0 |
| Fe | 62 | 65 | 16.0 |
| Si | 6 | 6 | 1.5 |
| P | - | - | - |
| S | - | - | - |
| C | 25 | 26 | 6.5 |
| Other | 4 | 4 | 1.0 |
| | 384 | 403 | 100.0 |

SLAG PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| $SiO_2$ | 164 | 173 | 31.4 |
| $Al_2O_3$ | 22 | 23 | 4.2 |
| CaO | 105 | 110 | 19.9 |
| MgO | 61 | 64 | 11.6 |
| MnO | 160 | 168 | 30.5 |
| FeO | 12 | 13 | 2.4 |
| BaO/Other | - | - | - |
| | 524 | 551 | 100.0 |

MATERIAL BALANCES

| | | | |
|---|---|---|---|
| Mn | 411/432 | = | 0.951 |
| Fe | 71/75 | = | 0.951 |
| $SiO_2$ | 177/186 | = | 0.951 |
| $Al_2O_3$ | 22/23 | = | 0.957 |
| CaO | 105/110 | = | 0.955 |
| MgO | 61/64 | = | 0.953 |

C

| | |
|---|---|
| $MnO_2/MnO$ | 42.[illegible] |
| MnO/Mn | 65.9 |
| $Fe_2O_3/FeO$ | 7.3 |
| FeO/Fe | 13.9 |
| $SiO_2/Si$ | 5.1 |
| C in Metal | 26.0 |
| | 160.7 |

160.7/.75 = 214.3 Use 220 kg/t

PROCESS RATIOS

| | | | |
|---|---|---|---|
| Slag/t | (524/384)1000 | = | 1365 kg |
| Slag Ratio | CaO + MgO + MnO/$SiO_2$ | = | 2.06 |
| Coke/t | (220/384)1000 | = | 573 kg |
| Coke to Mix % | (220/1470)100 | = | 15.0 |
| $SiO_2$/t | | | - |
| $SiO_2$ to Mix % | | | - |
| Dolomite/t | (250/384)1000 | = | 651 kg |
| Dolomite to Mix % | (250/1470)100 | = | 17.0 |
| Mn/Fe Slag | | | 13.3 |

## Mn GRADE AND Mn/Fe RATIO

### Duplex Smelting

Without large reserves of direct shipping ore (48% Mn), exploitation of the Om Bogma area ores requires some method of reducing the iron content of the ore. Without iron elimination, the project is limited to production of a ferruginous manganese ore for which there is a limited demand or a high iron furnace product (spiegeleisen) for which there is little, if any, market.

Therefore, a two-stage furnace process, duplex smelting, has been selected as the most favorable method of treating Om Bogma area ore. The method of duplex smelting is one in which iron is removed in the primary stage furnace operation and FeMn is produced in the secondary stage furnace operation.

The model economic plan for treating the present ore reserves is to rehabilitate the existing 13.2-MVA submerged arc electric furnace (SAEF) at Abu Zeneima. Accordingly, KECI/ACB has carefully studied the alternative methods of rehabilitation and the effects of variations in the quality of ore reserves on project economics.

Metallurgical balances and summary tables were computed for a range of Mn/Fe ratios and are included in the Appendix for reference purposes.

TABLE 6-45

SUMMARY - OPERATING ALTERNATIVES

SAEF SMELTING - PIG IRON + FeMn

| Description | FeMn t/y | Pig Iron t/y | SiMn t/y | Semi-Steel t/y | Total Mn Ore t/y | Reduced Ore t/y | Coke t/y | Electric Power TW/y | Natural Gas Mm3/y | Electrode Carbon t/y |
|---|---|---|---|---|---|---|---|---|---|---|
| SAEF - 13.2 MVA/10MW Rehabilitated Unit | | | | | | | | | | |
| Mn Ore 0.0 Mn/Fe | 11578 | 23044 | - | - | 68367 | - | 20667 | 82.3 | - | 535 |
| Mn Ore 1.0 Mn/Fe | 12953 | 14173 | - | - | 66449 | - | 17193 | 82.3 | - | 538 |
| Mn Ore 2.0 Mn/Fe | 16[illegible] | 77[illegible] | - | - | 62186 | - | 17161 | 82.3 | - | 525 |
| Mn Ore 3.0 Mn/Fe | 18883 | 42[illegible] | - | - | 62586 | - | 16844 | 82.3 | - | 535 |
| Mn Ore 4.0 Mn/Fe | 21594 | 2333 | - | - | 64304 | - | 17784 | 82.3 | - | 584 |
| Mn Ore 5.0 Mn/Fe | 27156 | - | - | - | 70400 | - | 20654 | 82.3 | - | 679 |

SINAI MANGANESE 80012

SUMMARY - OPERATING ALTERNATIVES

SAEF SMELTING - PIG IRON + FeMn

TABLE 6-46

SUMMARY - OPERATING ALTERNATIVES

SAFF SMELTING - TWO UNITS - HI IRON + FeMn

| Description | FeMn t/y | Pig Iron t/y | SiMn t/y | Semi-Steel t/y | Total Mn Ore t/y | Reduced Ore t/y | Coke t/y | Electric Power GW/y | Natural Gas Nm3/y | Electrode Carbon t/y |
|---|---|---|---|---|---|---|---|---|---|---|
| SAFF - 2 x 13.5MVA/1.5MW | | | | | | | | | | |
| Mn Ore 2.0 Mn/Fe | [illegible] | [illegible] | - | - | [illegible] | - | 41,014 | 164.[illegible] | - | 1,070 |
| Mn Ore 1.0 Mn/Fe | [illegible] | [illegible] | - | - | [illegible] | - | 4[illegible] | 164.[illegible] | - | 1072 |
| Mn Ore 2.0 Mn/Fe | [illegible] | [illegible] | - | - | [illegible] | - | [illegible] | 164.[illegible] | - | [illegible] |
| Mn Ore 3.0 Mn/Fe | [illegible] | [illegible] | - | - | [illegible] | - | [illegible] | 164.[illegible] | - | [illegible] |
| Mn Ore 4.0 Mn/Fe | [illegible] | [illegible] | - | - | [illegible] | - | [illegible] | 164.[illegible] | - | 1168 |
| Mn Ore 5.0 Mn/Fe | [illegible] | - | - | - | [illegible] | - | [illegible] | 164.[illegible] | - | 1305 |

FINAL MANGANESE 80012

SUMMARY - OPERATING ALTERNATIVES

SAFF SMELTING - TWO UNITS - HI IRON + FeMn

TABLE 6-47

SAEF

MN ORE - 0.6 MN/FE

PIG IRON + FEMN

METALLURGICAL DATA

| | PIG IRON | HIGH C FEMN |
|---|---|---|
| Operating Load - kW | 10,000 | 10,000 |
| Operating Time - % | 94 | 94 |
| Avg. Load - kW | 9,400 | 9,400 |
| kWh/kg Metal | 1.81 | 3.51 |
| kWh/t Metal | 1,810 | 3,510 |
| % Mn | 4.0 | 75.0 |
| % Fe | 90.0 | 16.0 |
| % Si | 1.0 | 1.5 |
| % C | 4.0 | 6.5 |
| Electrode Paste - kg/t | 15 | 25 |

TABLE 6-48
SAEF

MN ORE - 0.6 MN/FE

PIG IRON + FEMN

CAMPAIGN PROGRAM

| | |
|---|---|
| 1000 kg Mn ore - 0.6 Mn/Fe | 353 kg pig iron +<br>429 kg high Mn slag |
| 900 kg high Mn slag<br>100 kg Mn ore 0.6 Mn/Fe | 375 kg FeMn +<br>752 kg low Mn slag |

HOURLY PRODUCTION

| | | | |
|---|---|---|---|
| Pig iron | 9400/1200 + 610 | = | 5.19 t/h |
| High Mn slag | 5.19 x 429/353 | = | 6.31 t/h |
| FeMn | 9400/2500 + 1010 | = | 2.68 t/h |

ANNUAL PRODUCTION - Pig iron 185d/y 6.1 mos FeMn 180d/y 5.9 mos

| | | | |
|---|---|---|---|
| Pig iron | 185d x 24h x 5.19 | = | 23,044 t/y |
| High Mn slag | 185d x 24h x 6.31 | = | 28,016 t/y |
| FeMn | 180d x 24h x 2.68 | = | 11,578 t/y |
| Slag req'd | 11,578 x 900/375 | = | 27,786 t/y |
| Ore req'd | 23,044 x 1000/353 = 65,280<br>11,578 x 100/375 = 3,087 | | 68,367 t/y |
| Coke req'd | 23,044 x 240/353 = 15,667<br>11,578 x 160/375 = 4,940 | | 20,607 t/y |
| Low Mn slag | 11,578 x 752/375 | = | 23,218 t/y |

TABLE 6-49

SAEF

MN ORE 0.6 MN/FE

PIG IRON + FEMN

SUMMARY - RAW MATERIAL REQUIREMENTS

| Pig Iron | kg/ batch | kg/t Iron | t/d | t/y 185 d 6.1 mos |
|---|---|---|---|---|
| Mn ore 0.6 Mn/Fe | 1,000 | 2,833 | 353 | 65,280 |
| Coke | 240 | 680 | 85 | 15,667 |
| Quartzite | 50 | 142 | 18 | 3,280 |
| TOTAL | 1,290 | 3,655 | 456 | 84,227 |
| Pig iron | 353 | 1,000 | 125 | 23,[illegible] |
| High Mn slag | 429 | 1,215 | 151 | 28,016 |

| FeMn | kg/ batch | kg/t FeMn | t/d | t/y 180 d 5.9 mos |
|---|---|---|---|---|
| High Mn slag | 900 | 2,400 | 154 | 27,786 |
| Manganese ore 0.6 Mn/Fe | 100 | 267 | 17 | 3,087 |
| Coke | 160 | 427 | 27 | 4,940 |
| Dolomite | 500 | 1,333 | 86 | 15,433 |
| TOTAL | 1,660 | 4,427 | 284 | 51,246 |
| FeMn | 375 | 1,000 | 64 | 11,578 |
| Low Mn slag | 752 | 2,005 | 129 | 23,218 |
| Total Mn ore req'd | - | - | - | 68,367 |

TABLE 6-50
SAEF SMELTING - MN ORE 0.6 MN/FE - PIG IRON + FEMN

| Material | Wt. per Charge kg | $MnO_2$ %/kg | Mn %/kg | MnO %/kg | Mn %/kg | $Fe_2O_3$ %/kg | Fe %/kg | FeO %/kg | Fe %/kg | $SiO_2$ % | kg | $Al_2O_3$ % | kg | CaO % | kg | MgO % | kg | BaO % | kg | P % | kg | S % | kg | C % | kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Low Grade Ore | 1,000 | 32.76 | | 0.97 | | 51.47 | | | | 5.80 | 58 | 2.38 | 24 | 0.78 | 8 | 0.10 | 1 | 0.11 | 1 | 0.10 | 1 | 0.10 | 1 | 0.02 | - |
| | | 328 | 207 | 10 | 8 | 515 | 361 | | | | | | | | | | | | | | | | | | |
| Coke | 240 | | | | | 2.00 | | | | 5.00 | 12 | 3.00 | 7 | | | | | | | | | 1.00 | 2 | 75.00 | 180 |
| | | | | | | 5 | 3 | | | | | | | | | | | | | | | | | | |
| Quartzite | 50 | | | | | | | | | 99.00 | 49 | 1.00 | 1 | | | | | | | | | | | | |
| TOTALS | 1,290 | | 207 | | 8 | | 364 | | | | 119 | | 32 | | 8 | | 1 | | 1 | | 1 | | 3 | | 180 |

PIG IRON PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| Fe | 318 | 335 | 90.0 |
| Si | 4 | 4 | 1.0 |
| P | 1 | 1 | 0.3 |
| Mn | 14 | 15 | 4.0 |
| S | - | - | 0.03 |
| C | 14 | 15 | 4.0 |
| Other | 2 | 2 | 0.67 |
| | 353 | 372 | 100.00 |

SLAG PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| $SiO_2$ | 105 | 110 | 24.4 |
| $Al_2O_3$ | 30 | 32 | 7.1 |
| CaO | 8 | 8 | 1.8 |
| MgO | 1 | 1 | 0.2 |
| MnO | 245 | 258 | 57.2 |
| FeO | 35 | 37 | 8.2 |
| BaO/Other | 5 | 5 | 1.1 |
| | 429 | 451 | 100.0 |

MATERIAL BALANCES

| | kg Products | kg Feed | Unit Recovery |
|---|---|---|---|
| Fe | 345 | 364 | 0.948 |
| Mn | 204 | 215 | 0.949 |
| $SiO_2$ | 114 | 119 | 0.958 |
| $Al_2O_3$ | 30 | 32 | 0.938 |
| CaO | 8 | 8 | 1.000 |
| MgO | 1 | 1 | 1.000 |

Carbon

| | |
|---|---|
| $Fe_2O_3$/FeO | 39.0 |
| FeO/Fe | 71.8 |
| MnO/Mn | 3.3 |
| $MnO_2$/MnO | 45.2 |
| $SiO_2$/Si | 3.4 |
| $P_2O_5$/P | 1.0 |
| C in Pig Iron | 15.0 |
| | 178.7 |

178.7 .75 = 238 kg Coke  Use 240

PROCESS RATIOS

Slag/t
(429/353)1000 = 1215 kg

Slag Ratio
$\frac{CaO + MnO + MgO}{SiO_2}$ = 2.07

Coke/t
(240/353)1000 = 680 kg

Coke to Mix %
(240/1290)100 = 18.6

$SiO_2$/t (50/353) 1000 = 142

$SiO_2$ to Mix %
(50/1290) 100 = 3.9

Mn/Fe Slag
= 7.0

TABLE 6-51
SAEF SMELTING - MN ORE 0.6 MN/FE - PIG IRON + FEMN PRODUCTION

| Material | Weight per Charge kg | $MnO_2$ %/kg | Mn %/kg | MnO %/kg | Mn %/kg | $Fe_2O_3$ %/kg | Fe %/kg | FeO %/kg | Fe %/kg | $SiO_2$ % | kg | $Al_2O_3$ % | kg | CaO % | kg | MgO % | kg | BaO % | kg | P % | kg | S % | kg | C % | kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| High Mn slag | 900 | | | 57.2 | | | | 8.2 | | 24.4 | 220 | 7.1 | 64 | 1.8 | 16 | 0.2 | 2 | 1.1 | 10 | | | | | | |
| | | | | 515 | 399 | | | 74 | 57 | | | | | | | | | | | | | | | | |
| Low grade ore | 100 | 32.76 | | 0.97 | | 51.47 | | | | 5.80 | 6 | 2.38 | 2 | 0.78 | 1 | 0.10 | - | 0.99 | 1 | 0.10 | - | 0.09 | - | | |
| | | 33 | 21 | | 1 | 51 | 36 | | | | | | | | | | | | | | | | | | |
| Coke | 160 | | | | | 2.00 | | | | 5.00 | 8 | 3.00 | 5 | | | | | | | | | | | 75.00 | 120 |
| Dolomite | 500 | | | | | 3 | | | | 2.00 | 10 | | | 30.20 | 151 | 21.00 | 105 | | | | | | | | |
| | | | — | | — | | 2 | | — | | | | — | | | | | | — | | | | | | — |
| TOTALS | 1,660 | | 21 | | 400 | | 38 | | 57 | | 244 | | 71 | | 168 | | 107 | | 11 | | | | | | 120 |

FEMN PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| Mn | 280 | 295 | 75.0 |
| Fe | 60 | 63 | 16.0 |
| C | 25 | 26 | 6.5 |
| Si | 6 | 6 | 1.5 |
| P | - | - | - |
| S | - | - | - |
| Other | 4 | 4 | 1.0 |
| | 375 | 394 | 100.0 |

SLAG PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| $SiO_2$ | 219 | 231 | 29.1 |
| $Al_2O_3$ | 67 | 71 | 9.0 |
| CaO | 160 | 168 | 21.2 |
| MgO | 102 | 107 | 13.5 |
| MnO | 155 | 163 | 20.6 |
| FeO | 39 | 41 | 5.2 |
| BaO/Other | 10 | 11 | 1.4 |
| | 752 | 792 | 100.0 |

MATERIAL BALANCES

| | kg Product/kg Feed | Unit Recovery |
|---|---|---|
| Fe | 90/95 | 0.947 |
| Mn | 400/421 | 0.950 |
| $SiO_2$ | 232/244 | 0.951 |
| $Al_2O_3$ | 67/71 | 0.944 |
| CaO | 160/168 | 0.952 |
| MgO | 102/107 | 0.953 |

Carbon

| | |
|---|---|
| $Fe_2O_3/FeO$ | 4.1 |
| FeO/Fe | 13.5 |
| $MnO_2/MnO$ | 4.5 |
| MnO/Mn | 64.4 |
| $SiO_2/Si$ | 5.1 |
| C in FeMn | 26.0 |
| | 117.7 |

117.7/.75 = 157 Coke  Use 160

PRODUCT RATIOS

Slag/t (752/375)1000 = 2005 kg

Slag Ratio $\frac{CaO+MgO+MnO+BaO}{SiO_2}$ = 2.10

Coke/t (160/375)1000 = 427 kg

Coke to Mix % (160/1660)100 = 9.6

Dol/t (500/375)1000 = 1333 kg

Dol to Mix % (500/1660)100 = 30.1

TABLE 6-52

SAEF

MN ORE - 1.0 MN/FE

PIG IRON + FEMN

METALLURGICAL DATA

| | Pig Iron | High C FeMn |
|---|---|---|
| Operating Load - kW | 10,000 | 10,000 |
| Operating Time - % | 94 | 94 |
| Avg. Load - kW | 9,400 | 9,400 |
| kWh/kg Metal | 2.47 | 3.66 |
| kWh/t Metal | 2,470 | 3,660 |
| | | |
| % Mn | 4.0 | 75.0 |
| % Fe | 90.0 | 16.0 |
| % Si | 1.0 | 1.5 |
| % C | 4.0 | 6.5 |
| Electrode Paste - kg/t | 15 | 25 |

TABLE 6-53

SAEF

MN ORE - 1.0 MN/FE

PIG IRON + FEMN

CAMPAIGN PROGRAM

| | |
|---|---|
| 1000 kg 1.0 Mn/Fe ore | 237 kg pig iron + 592 kg high Mn slag |
| 850 kg high Mn slag | 311 kg FeMn |
| 150 kg 1.0 Mn/Fe ore | 719 kg low Mn slag |

HOURLY PRODUCTION

| | | | |
|---|---|---|---|
| Pig iron | 9400/1200 + 1270 | = | 3.81 t/h |
| High Mn slag | 3.81 x 592 /237 | = | 9.51 t/h |
| FeMn | 9400/2500 + 1160 | = | 2.57 t/h |

ANNUAL PRODUCTION - Pig iron 155d/5.1 mos FeMn 210d/6.9 mos

| | | | |
|---|---|---|---|
| Pig iron | 155 x 24 x 3.81 | = | 14,173 t/y |
| High Mn slag | 155 x 24 x 9.51 | = | 35,377 t/y |
| FeMn | 210 x 24 x 2.57 | = | 12,953 t/y |
| Slag req'd | 12,953 x 850/311 | = | 35,402 t/y |
| Ore req'd | 14,173 x 1000/237 = 59,802<br>12,953 x 150/311 = 6,247 | | 66,049 t/y |
| Coke req'd | 14,173 x 190/237 = 11,362<br>12,953 x 140/311 = 5,831 | | 17,193 t/y |
| Low Mn slag | 12,953 x 719/311 | = | 29,946 t/y |

TABLE 6-54
SAEF

MN ORE - 1.0 MN/FE

PIG IRON + FEMN

SUMMARY - RAW MATERIAL REQUIREMENTS

| Pig Iron | kg/ batch | kg/t Iron | t/d | t/y 155 d 5.1 mos |
|---|---|---|---|---|
| Manganese ore 1.0 Mn/Fe | 1,000 | 4,219 | 384 | 59,509 |
| Coke | 190 | 802 | 73 | 11,312 |
| Quartzite | 70 | 295 | 27 | 4,161 |
| TOTAL | 1,260 | 5,316 | 484 | 74,982 |
| Pig iron | 237 | 1,000 | 91 | 14,105 |
| High Mn slag | 592 | 2,493 | 227 | 35,234 |

| FeMn | kg/ batch | kg/t FeMn | t/d | t/y 210 d 6.9 mos |
|---|---|---|---|---|
| High Mn slag | 850 | 2,733 | 169 | 35,402 |
| Manganese ore 1.0 Mn/Fe | 150 | 482 | 30 | 6,247 |
| Coke | 140 | 450 | 28 | 5,831 |
| Dolomite | 300 | 965 | 60 | 12,500 |
| TOTAL | 1,440 | 4,630 | 287 | 59,980 |
| FeMn | 311 | 1,000 | 62 | 12,953 |
| Low Mn slag | 719 | 2,312 | 143 | 29,946 |
| Total Mn ore req'd | - | - | - | 66,049 |

TABLE 6-55
SAEF - MN ORE 1.0 MN/FE - PIG IRON + FEMN

| Material | Wt/Chge kg | $MnO_2$ %/kg | Mn %/kg | MnO %/kg | Mn %/kg | $Fe_2O_3$ %/kg | Fe %/kg | FeO %/kg | Fe %/kg | $SiO_2$ % | kg | $Al_2O_3$ % | kg | CaO % | kg | MgO % | kg | BaO % | kg | P % | kg | S % | kg | C % | kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mn Ore - 1.0 Mn/Fe | 1,000 | 38.0 | 24.0 | | | 34.3 | 24.0 | | | 10.0 | 100 | 5.0 | 50 | 4.0 | 40 | 3.0 | 30 | | | | | | | | |
| | | 380 | 240 | | | 343 | 240 | | | | | | | | | | | | | | | | | | |
| Coke | 190 | | | | | 2.0 | | | | 5.0 | 10 | 3.0 | 6 | | | | | | | | | | | 75.0 | 143 |
| | | | | | | 4 | 3 | | | | | | | | | | | | | | | | | | |
| Quartzite | 70 | | | | | | | | | 99.0 | 69 | 1.0 | 1 | | | | | | | | | | | | |
| TOTALS | 1,260 | | 240 | | | | 243 | | | | 179 | | 57 | | 40 | | 30 | | | | | | | | 143 |

PIG IRON PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| Fe | 213 | 224 | 90.0 |
| Si | 2 | 2 | 1.0 |
| P | - | - | - |
| Mn | 10 | 10 | 4.0 |
| S | - | - | - |
| C | 10 | 10 | 4.0 |
| Other | 2 | 2 | 1.0 |
| | 237 | 248 | 100.0 |

SLAG PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| $SiO_2$ | 166 | 175 | 28.1 |
| $Al_2O_3$ | 54 | 57 | 9.1 |
| CaO | 38 | 40 | 6.4 |
| MgO | 29 | 30 | 4.8 |
| MnO | 282 | 297 | 47.7 |
| FeO | 23 | 24 | 3.9 |
| BaO/Other | - | - | - |
| | 592 | 623 | 100.0 |

MATERIAL BALANCES

| | kg Product/kg Feed | | Unit Recovery |
|---|---|---|---|
| Fe | 231/243 | = | 0.950 |
| Mn | 228/240 | = | 0.952 |
| $SiO_2$ | 170/179 | = | 0.951 |
| $Al_2O_3$ | 54/57 | = | 0.947 |
| CaO | 38/40 | = | 0.950 |
| MgO | 29/30 | = | 0.967 |

C

| | |
|---|---|
| $MnO_2/MnO$ | 50.2 |
| $MnO_2/Mn$ | 4.4 |
| $Fe_2O_3/FeO$ | 2.0 |
| $Fe_2O_3/Fe$ | 72.0 |
| $SiO_2/Si$ | 1.7 |
| C in Metal | 10.0 |
| | 140.3 |

140.3/.75 = 187.1 Use 190

PRODUCT RATIOS

| | | |
|---|---|---|
| Slag/t (592/237)1000 | = | 2493 kg |
| Slag Ratio CaO + MgO + MnO/$SiO_2$ | = | 1.94 |
| Coke/t (190/237)1000 | = | 802 kg |
| Coke to Mix % (190/1260)100 | = | 15.1 |
| $SiO_2$/t (70/237)1000 | = | 295 kg |
| $SiO_2$ to Mix % (70/1260)100 | = | 5.6 |
| Mn/Fe Slag | | 12.2 |

TABLE 6-56
SAEF - MN ORE 1.0 MN/FE - PIG IRON + FEMN

| Material | Wt/Chge kg | $MnO_2$ %/kg | Mn %/kg | MnO %/kg | Mn %/kg | $Fe_2O_3$ %/kg | Fe %/kg | FeO %/kg | Fe %/kg | $SiO_2$ % | kg | $Al_2O_3$ % | kg | CaO % | kg | MgO % | kg | BaO % | kg | P % | kg | S % | kg | C % | kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| High Mn slag | 850 | | | 47.7 | | | | 3.9 | | 28.1 | 239 | 9.1 | 77 | 6.4 | 54 | 4.8 | 41 | | | | | | | | |
| | | | | 405 | 314 | | | 33 | 26 | | | | | | | | | | | | | | | | |
| Mn ore 1.0 Mn/Fe | 150 | 38.0 | 24.0 | | | 34.3 | 24.0 | | | 10.0 | 15 | 5.0 | 8 | 4.0 | 6 | 3.0 | 5 | | | | | | | | |
| | | | 36 | | | | 36 | | | | | | | | | | | | | | | | | | |
| Coke | 140 | | | | | 2.0 | | | | 5.0 | 7 | 3.0 | 4 | | | | | | | | | | | 75.0 | 105 |
| | | | | | | 3 | 2 | | | | | | | | | | | | | | | | | | |
| Dolomite | 300 | | | | | | | | | 2.0 | 6 | | | 30.2 | 91 | 21.0 | 63 | | | | | | | | |
| TOTALS | 1,440 | | 36 | | 314 | | 38 | | 26 | | 267 | | 89 | | 151 | | 109 | | | | | | | | 105 |

FEMN PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| Mn | 232 | 245 | 75.0 |
| Fe | 50 | 53 | 16.0 |
| C | 20 | 21 | 6.5 |
| Si | 5 | 5 | 1.5 |
| P | - | - | - |
| S | - | - | - |
| Other | 4 | 4 | 1.0 |
| | 311 | 328 | 100.0 |

SLAG PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| $SiO_2$ | 244 | 257 | 33.9 |
| $Al_2O_3$ | 86 | 90 | 11.9 |
| CaO | 143 | 151 | 19.9 |
| MgO | 104 | 109 | 14.4 |
| MnO | 129 | 136 | 18.0 |
| FeO | 13 | 14 | 1.9 |
| BaO/Other | - | - | - |
| | 719 | 757 | 100.0 |

MATERIAL BALANCES

| | kg Product/kg Feed | | Unit Recovery |
|---|---|---|---|
| Mn | 332/350 | = | 0.948 |
| Fe | 60/64 | = | 0.939 |
| $SiO_2$ | 255/267 | = | 0.954 |
| $Al_2O_3$ | 86/89 | = | 0.966 |
| CaO | 143/151 | = | 0.947 |
| MgO | 104/109 | = | 0.954 |

| C | |
|---|---|
| $MnO_2/MnO$ | 7.9 |
| MnO/Mn | 53.5 |
| $Fe_2O_3/FeO$ | 4.1 |
| FeO/Fe | 11.4 |
| $SiO_2/Si$ | 4.3 |
| C in Metal | 21.0 |
| | 102.2 |

102.2/.75 = 136.3 Use 140 kg/t

PRODUCT RATIOS

| | | |
|---|---|---|
| Slag/t (719/311)1000 | = | 2312 kg |
| Slag Ratio $CaO + MgO + MnO/SiO_2$ | = | 1.71 |
| Coke/t (140/311)1000 | = | 450 kg |
| Coke to Mix % (140/1440)100 | = | 9.7 |
| Dolomite/t (300/311)1000 | = | 965 kg |
| Dolomite to Mix % (300/1440)100 | = | 20.8 |
| Mn/Fe Slag | = | 9.9 |

TABLE 6-57

SAEF

MN ORE - 2.0 MN/FE

PIG IRON + FEMN

METALLURGICAL DATA

| | Pig Iron | High C FeMn |
|---|---|---|
| Operating Load - kW | 10,000 | 10,000 |
| Operating Time - % | 94 | 94 |
| Avg. Load - kW | 9,400 | 9,400 |
| kWh/kg Metal | 3.37 | 3.40 |
| kWh/t Metal | 3,370 | 3,400 |
| | | |
| % Mn | 4.0 | 75.0 |
| % Fe | 90.0 | 16.0 |
| % Si | 1.0 | 1.5 |
| % C | 4.0 | 6.5 |
| Electrode Paste - kg/t | 15 | 25 |

TABLE 6-58
SAEF

MN ORE - 2.0 MN/FE

PIG IRON + FEMN

CAMPAIGN PROGRAM

| | |
|---|---|
| 1000 kg Mn ore - 2.0 Mn/Fe | 160 kg pig iron + 695 kg high Mn slag |
| 700 kg high Mn slag<br>300 kg Mn ore - 2.0 Mn/Fe | 352 kg FeMn<br>645 kg low Mn slag |

HOURLY PRODUCTION

| | | | |
|---|---|---|---|
| Pig iron | 9400/1200 + 2170 | = | 2.79 t/h |
| High Mn slag | 2.79 x 695/160 | = | 12.11 t/h |
| FeMn | 9400/2500 + 920 | = | 2.75 t/h |

ANNUAL PRODUCTION - Pig iron 115d/3.8 mos FeMn 250d/8.2 mos

| | | | |
|---|---|---|---|
| Pig iron | 115 x 24 x 2.79 | = | 7,700 t/y |
| High Mn slag | 115 x 24 x 12.11 | = | 33,424 t/y |
| FeMn | 250 x 24 x 2.75 | = | 16,500 t/y |
| Slag req'd | 16,500 x 700/352 | = | 32,813 t/y |
| Ore req'd | 7,700 x 1000/160 = 48,125<br>16,500 x 300/352 = 14,063 | | 62,188 t/y |
| Coke req'd | 7,700 x 180/160 = 8,663<br>16,500 x 180/352 = 8,438 | | 17,101 t/y |
| Low Mn slag | 16,500 x 645/352 | = | 30,234 t/y |

TABLE 6-59
SAEF

MN ORE - 2.0 MN/FE

PIG IRON + FEMN

SUMMARY - RAW MATERIAL REQUIREMENTS

| Pig Iron | kg/ Batch | kg/t Iron | t/d | t/y 115 d 3.8 mos |
|---|---|---|---|---|
| Mn ore 2.0 Mn/Fe | 1,000 | 6,250 | 419 | 48,125 |
| Coke | 180 | 1,125 | 75 | 8,663 |
| Quartzite | 100 | 625 | 42 | 4,813 |
| TOTAL | 1,280 | 8,000 | 536 | 61,601 |
| Pig iron | 160 | 1,000 | 67 | 7,700 |
| High Mn slag | 695 | 4,344 | 291 | 33,424 |

| FeMn | kg/ Batch | kg/t FeMn | t/d | t/y 250 d 8.2 mos |
|---|---|---|---|---|
| High Mn slag | 700 | 1,989 | 131 | 32,813 |
| Manganese ore 2.0 Mn/Fe | 300 | 852 | 56 | 14,063 |
| Coke | 180 | 511 | 34 | 8,438 |
| Dolomite | 300 | 852 | 56 | 14,058 |
| TOTAL | 1,480 | 4,204 | 277 | 69,372 |
| FeMn | 352 | 1,000 | 66 | 16,500 |
| Low Mn slag | 645 | 1,832 | 121 | 30,234 |
| Total Mn ore req'd | - | - | - | 62,188 |

TABLE 6-60
SAEF - MN ORE - 2.0 MN/FE - PIG IRON + FEMN

| Materials | Wt/Chge kg | $MnO_2$ %/kg | Mn %/kg | MnO %/kg | Mn %/kg | $Fe_2O_3$ %/kg | Fe %/kg | FeO %/kg | Fe %/kg | $SiO_2$ % | kg | $Al_2O_3$ % | kg | CaO % | kg | MgO % | kg | BaO % | kg | P % | kg | S % | kg | C % | kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mn Ore - 2.0 Mn/Fe | 1,000 | | 32.0 | | | | 16.0 | | | 9.0 | 90 | 4.0 | 40 | 4.0 | 40 | 3.0 | 30 | | | | | | | | |
| | | | 320 | | | | 160 | | | | | | | | | | | | | | | | | | |
| Coke | 180 | | | | | 2.0 | | | | 5.0 | 9 | 3.0 | 5 | | | | | | | | | | | 75.0 | 135 |
| | | | | | | 4 | 3 | | | | | | | | | | | | | | | | | | |
| Quartzite | 100 | | | | | | | | | 99.0 | 99 | 1.0 | 1 | | | | | | | | | | | | |
| TOTAL | 1,280 | | 320 | | | | 163 | | | | 198 | | 46 | | 40 | | 30 | | | | | | | | 135 |

PIG IRON PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| Fe | 142 | 150 | 90.0 |
| Si | 2 | 2 | 1.0 |
| P | - | - | - |
| Mn | 7 | 7 | 4.0 |
| S | - | - | - |
| C | 7 | 7 | 4.0 |
| Other | 3 | 2 | 1.0 |
| | 160 | 168 | 100.0 |

SLAG PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| $SiO_2$ | 184 | 194 | 26.5 |
| $Al_2O_3$ | 44 | 46 | 6.3 |
| CaO | 38 | 40 | 5.5 |
| MgO | 29 | 30 | 4.1 |
| MnO | 384 | 404 | 55.3 |
| FeO | 16 | 17 | 2.3 |
| BaO/Other | - | - | - |
| | 695 | 731 | 100.0 |

MATERIAL BALANCES

| | | | |
|---|---|---|---|
| Fe | 154/163 | = | 0.945 |
| Mn | 304/320 | = | 0.952 |
| $SiO_2$ | 188/198 | = | 0.950 |
| $Al_2O_3$ | 44/46 | = | 0.957 |
| CaO | 38/40 | = | 0.950 |
| MgO | 29/30 | = | 0.967 |

C

| | |
|---|---|
| $MnO_2/MnO$ | 69.8 |
| MnO/Mn | 1.5 |
| $Fe_2O_3/FeO$ | 17.5 |
| FeO/Fe | 32.1 |
| $SiO_2/Si$ | 1.7 |
| C in Metal | 7.0 |
| | 129.6 |

129.6/.75 = 172.8 Use 180 kg/t

PRODUCT RATIOS

| | | | |
|---|---|---|---|
| Slag/t | (695/160)1000 | = | 4344 kg |
| Slag Ratio | CaO + MgO + MnO/$SiO_2$ | = | 2.22 |
| Coke/t | (180/160)1000 | = | 1125 kg |
| Coke to Mix % | (180/1280)100 | = | 14.1 |
| $SiO_2$/t | (100/160)1000 | = | 625 kg |
| $SiO_2$ to Mix % | (100/1280)100 | = | 7.8 |
| Mn/Fe Slag | | | 23.9 |

TABLE 6-61
SAEF - MN ORE 2.0 MN/FE — PIG IRON + FEMN

| Material | Wt/Chge kg | $MnO_2$ %/kg | Mn %/kg | MnO %/kg | Mn %/kg | $Fe_2O_3$ %/kg | Fe %/kg | FeO %/kg | Fe %/kg | $SiO_2$ % | kg | $Al_2O_3$ % | kg | CaO % | kg | MgO % | kg | BaO % | kg | P % | kg | S % | kg | C % | kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| High Mn Slag | 700 | | | 55.3 | 42.8 | | | 2.3 | 1.8 | 26.5 | 186 | 6.3 | 44 | 5.5 | 39 | 4.1 | 29 | | | | | | | | |
| | | | | | 300 | | | | 13 | | | | | | | | | | | | | | | | |
| Mn Ore - 2.0 Mn/Fe | 300 | | 32.0 | | | | 16.0 | | | 9.0 | 27 | 4.0 | 12 | 4.0 | 12 | 3.0 | 9 | | | | | | | | |
| | | | 96 | | | | 48 | | | | | | | | | | | | | | | | | | |
| Coke | 180 | | | | | 2.0 | | | | 5.0 | 9 | 3.0 | 5 | | | | | | | | | | | 75.0 | 135 |
| | | | | | | 4 | 3 | | | | | | | | | | | | | | | | | | |
| Dolomite | 300 | | | | | | | | | 2.0 | 6 | | | 30.2 | 91 | 21.0 | 63 | | | | | | | | |
| TOTAL | 1,480 | | 96 | | 300 | | 51 | | 13 | | 228 | | 61 | | 142 | | 101 | | | | | | | | 135 |

FEMN PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| Mn | 263 | 277 | 75.0 |
| Fe | 56 | 59 | 16.0 |
| C | 23 | 24 | 6.5 |
| Si | 6 | 6 | 1.5 |
| P | - | - | - |
| S | - | - | - |
| Other | 4 | 4 | 1.0 |
| | 352 | 370 | 100.0 |

SLAG PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| $SiO_2$ | 204 | 215 | 31.6 |
| $Al_2O_3$ | 58 | 61 | 9.0 |
| CaO | 135 | 142 | 20.9 |
| MgO | 96 | 101 | 14.9 |
| MnO | 146 | 154 | 22.7 |
| FeO | 6 | 6 | 0.9 |
| BaO/Other | - | - | - |
| | 645 | 679 | 100.0 |

MATERIAL BALANCES

| | | | |
|---|---|---|---|
| Mn | 376/396 | = | 0.950 |
| Fe | 61/64 | = | 0.948 |
| $SiO_2$ | 217/228 | = | 0.951 |
| $Al_2O_3$ | 58/61 | = | 0.951 |
| CaO | 135/142 | = | 0.951 |
| MgO | 96/101 | = | 0.951 |

C

| | |
|---|---|
| $MnO_2/MnO$ | 20.9 |
| MnO/Mn | 60.4 |
| $Fe_2O_3/FeO$ | 5.5 |
| FeO/Fe | 12.6 |
| $SiO_2/Si$ | 5.1 |
| C in Metal | 24.0 |
| | 128.5 |

128.5/.75 = 171.3 Use 180 kg/t

PRODUCT RATIOS

| | | | |
|---|---|---|---|
| Slag/t | (645/352)1000 | = | 1832 kg |
| Slag Ratio | $CaO + MgO + MnO/SiO_2$ | = | 2.02 |
| Coke/t | (180/352)1000 | = | 511 kg |
| Coke to Mix % | (180/1480)100 | = | 12.2 |
| Dol/t | (300/352)1000 | = | 852 kg |
| Dol to Mix % | (300/1480)100 | = | 20.3 |
| Mn/Fe Slag | | | 24.2 |

TABLE 6-62

SAEF

MN ORE - 3.0 MN/FE

PIG IRON - FEMN

METALLURGICAL DATA

| | Pig Iron | High C FeMn |
|---|---|---|
| Operating Load - kW | 10,000 | 10,000 |
| Operating Time - % | 94 | 94 |
| Avg. Load - kW | 9,400 | 9,400 |
| kWh/kg Metal | 4.56 | 3.34 |
| kWh/t Metal | 4,560 | 3,340 |
| % Mn | 4.0 | 75.0 |
| % Fe | 90.0 | 16.0 |
| % Si | 1.0 | 1.5 |
| % C | 4.0 | 6.5 |
| Electrode Paste - kg/t | 15 | 25 |

TABLE 6-63
SAEF

MN ORE - 3.0 MN/FE

PIG IRON + FEMN

CAMPAIGN PROGRAM

| | |
|---|---|
| 1000 kg Mn ore - 3.0 Mn/Fe | 118 kg pig iron + 793 kg high Mn slag |
| 500 kg high Mn slag<br>500 kg Mn ore - 3.0 Mn/Fe | 350 kg FeMn +<br>588 kg low Mn slag |

HOURLY PRODUCTION

| | | | |
|---|---|---|---|
| Pig iron | 9400/1200 + 3360 | = | 2.06 t/h |
| High Mn slag | 2.06 x 793/118 | = | 13.85 t/h |
| FeMn | 9400/2500 + 840 | = | 2.81 t/h |

ANNUAL PRODUCTION - Pig iron 85d/y 2.8 mos FeMn 280d/y 9.2 mos

| | | | |
|---|---|---|---|
| Pig iron | 85 x 24 x 2.06 | = | 4,202 t/y |
| High Mn slag | 85 x 24 x 13.85 | = | 28,254 t/y |
| FeMn | 280 x 24 x 2.81 | = | 18,883 t/y |
| Slag req'd | 18,883 x 500/350 | = | 26,976 t/y |
| Ore req'd | 4,202 x 1000/118 = 35,610<br>18,883 x 500/350 = 26,976 | | 62,586 t/y |
| Coke req'd | 4,202 x 170/118 = 6,054<br>18,883 x 200/350 = 10,790 | | 16,844 t/y |
| Low Mn slag | 18,883 x 588/350 | = | 31,723 t/y |

TABLE 6-64
SAEF

MN ORE - 3.0 MN/FE

PIG IRON + FEMN

SUMMARY - RAW MATERIAL REQUIREMENTS

| Pig Iron | kg/ Batch | kg/t Iron | t/d | t/y 85 d 2.8 mos |
|---|---|---|---|---|
| Mn ore 3.0 Mn/Fe | 1,000 | 8,474 | 419 | 35,610 |
| Coke | 170 | 1,441 | 71 | 6,054 |
| Quartzite | 150 | 1,271 | 63 | 5,341 |
| TOTAL | 1,320 | 11,186 | 553 | 47,005 |
| Pig iron | 118 | 1,000 | 49 | 4,202 |
| High Mn slag | 793 | 6,720 | 332 | 28,254 |

| FeMn | kg/ Batch | kg/t FeMn | t/d | t/y 280 d 9.2 mos |
|---|---|---|---|---|
| High Mn slag | 500 | 1,429 | 96 | 26,976 |
| Mn ore 3.0 Mn/Fe | 500 | 1,429 | 96 | 26,976 |
| Coke | 200 | 571 | 39 | 10,790 |
| Dolomite | 250 | 714 | 48 | 13,482 |
| TOTAL | 1,450 | 4,143 | 279 | 78,224 |
| FeMn | 350 | 1,000 | 67 | 18,883 |
| Low Mn slag | 588 | 1,680 | 113 | 31,723 |
| Total Mn ore req'd | - | - | - | 62,586 |

TABLE 6-65
SAEF - MN ORE 3.0 MN/FE - PIG IRON + FEMN

| Materials | Wt/Chge kg | $MnO_2$ %/kg | Mn %/kg | MnO %/kg | Mn %/kg | $Fe_2O_3$ %/kg | Fe %/kg | FeO %/kg | Fe %/kg | $SiO_2$ % | kg | $Al_2O_3$ % | kg | CaO % | kg | MgO % | kg | BaO % | kg | P % | kg | S % | kg | C % | kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mn Ore - 3.0 Mn/Fe | 1,000 | 56.9 | 36.0 | | | 17.1 | 12.0 | | | 9.0 | 90 | 4.0 | 40 | 4.0 | 40 | 3.0 | 30 | | | | | | | | |
| | | | 360 | | | | 120 | | | | | | | | | | | | | | | | | | |
| Coke | 170 | | | | | 5.0 | | | | 5.0 | 9 | 3.0 | 5 | | | | | | | | | | | 75.0 | 128 |
| | | | | | | 3 | 2 | | | | | | | | | | | | | | | | | | |
| Quartzite | 150 | | | | | | | | | 99.0 | 149 | 1.0 | 2 | | | | | | | | | | | | |
| TOTAL | 1,320 | | 360 | | | | 122 | | | | 248 | | 47 | | 40 | | 30 | | | | | | | | 128 |

PIG IRON PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| Fe | 106 | 112 | 90.0 |
| Si | 1 | 1 | 1.0 |
| P | - | - | - |
| Mn | 5 | 5 | 4.0 |
| S | - | - | - |
| C | 5 | 5 | 4.0 |
| Other | 1 | 1 | 1.0 |
| | 118 | 124 | 100.0 |

SLAG PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| $SiO_2$ | 234 | 246 | 29.5 |
| $Al_2O_3$ | 45 | 47 | 5.6 |
| CaO | 38 | 40 | 4.8 |
| MgO | 29 | 30 | 3.6 |
| MnO | 435 | 458 | 54.9 |
| FeO | 12 | 13 | 1.6 |
| BaO/Other | - | - | - |
| | 793 | 834 | 100.0 |

MATERIAL BALANCES

| | kg Product/kg Feed | | Unit Recovery |
|---|---|---|---|
| Fe | 115/122 | = | 0.943 |
| Mn | 342/360 | = | 0.950 |
| $SiO_2$ | 236/248 | = | 0.952 |
| $Al_2O_3$ | 45/47 | = | 0.957 |
| CaO | 38/40 | = | 0.950 |
| MgO | 29/30 | = | 0.967 |

C

| | |
|---|---|
| $MnO_2/MnO$ | 77.4 |
| $MnO_2/Mn$ | 2.2 |
| $Fe_2O_3/FeO$ | 1.1 |
| $Fe_2O_3/Fe$ | 36.0 |
| $SiO_2/Si$ | 0.9 |
| C in Metal | 5.0 |
| | 122.6 |

122.6/0.75 = 163.5 Use 170 kg/t

PRODUCT RATIOS

| | | | |
|---|---|---|---|
| Slag/t | (793/118)1000 | = | 6720 kg |
| Slag Ratio | $CaO + MgO + MnO/SiO_2$ | = | 1.93 |
| Coke/t | (170/118)1000 | = | 1441 kg |
| Coke to Mix % | (170/1320)100 | = | 12.9 |
| $SiO_2$/t | (150/118)1000 | = | 1271 kg |
| $SiO_2$ to Mix % | (150/1320)100 | = | 11.4 |
| Mn/Fe Slag | | | 36.1 |

TABLE 6-66

SAEF - MN ORE 3.0 MN/FE - HIG IRON + FEMN

| Material | Wt/Chge kg | $MnO_2$ %/kg | Mn %/kg | MnO %/kg | Mn %/kg | $Fe_2O_3$ %/kg | Fe %/kg | FeO %/kg | Fe %/kg | $SiO_2$ % | kg | $Al_2O_3$ % | kg | CaO % | kg | MgO % | kg | BaO % | kg | P % | kg | S % | kg | C % | kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| High Mn Slag | 500 | | | 54.9 | 42.5<br>213 | | | 1.6 | 1.2<br>6 | 29.5 | 148 | 5.6 | 28 | 4.8 | 24 | 3.6 | 18 | | | | | | | | |
| Mn Ore - 3.0 Mn/Fe | 500 | 56.9<br>285 | 36.0<br>180 | | | 17.1<br>86 | 12.0<br>60 | | | 9.0 | 45 | 4.0 | 20 | 4.0 | 20 | 3.0 | 15 | | | | | | | | |
| Coke | 200 | | | | | 2.0<br>4 | 3 | | | 5.0 | 10 | 3.0 | 6 | | | | | | | | | | | 75.0 | 150 |
| Dolomite | 250 | | | | | | | | | 2.0 | 5 | | | 30.2 | 76 | 21.6 | 53 | | | | | | | | |
| TOTAL | 1,450 | | 180 | | 213 | | 63 | | 6 | | 208 | | 54 | | 120 | | 86 | | | | | | | | 150 |

FEMN PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| Mn | 261 | 275 | 75.0 |
| Fe | 56 | 59 | 16.0 |
| C | 23 | 24 | 6.5 |
| Si | 6 | 6 | 1.5 |
| P | - | - | - |
| S | - | - | - |
| Other | 4 | 4 | 1.0 |
| | 350 | 368 | 100.0 |

SLAG PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| $SiO_2$ | 185 | 195 | 28.4 |
| $Al_2O_3$ | 51 | 54 | 7.7 |
| CaO | 114 | 120 | 23.5 |
| MgO | 82 | 86 | 16.8 |
| MnO | 144 | 152 | 21.8 |
| FeO | 12 | 13 | 1.8 |
| BaO/Other | - | - | - |
| | 588 | 620 | 100.0 |

MATERIAL BALANCES

| | | | |
|---|---|---|---|
| Mn | 373/393 | = | 0.948 |
| Fe | 65/69 | = | 0.947 |
| $SiO_2$ | 198/208 | = | 0.951 |
| $Al_2O_3$ | 51/54 | = | 0.944 |
| CaO | 114/120 | = | 0.950 |
| MgO | 82/86 | = | 0.954 |
| C | | | |
| $MnO_2$/MnO | 39.3 | | |
| MnO/Mn | 60.0 | | |
| $Fe_2O_3$/FeO | 6.8 | | |
| FeO/Fe | 12.6 | | |
| $SiO_2$/Si | 5.1 | | |
| C in Metal | 24.0 | | |
| | 147.8 | | |
| 147.8/.75 = 197.1 | (Use 200) | | |

PRODUCT RATIOS

| | | | |
|---|---|---|---|
| Slag/t | (588/350)1000 | = | 1680 kg |
| Slag Ratio | CaO + MgO + MnO/$SiO_2$ | = | 1.98 |
| Coke/t | (200/350)1000 | = | 571 |
| Coke to Mix % | (200/1450)100 | = | 13.8 |
| Dol/t | (250/350)1000 | = | 714 |
| Dol to Mix % | (250/1450)100 | = | 17.2 |
| Mn/Fe Slag | | | 12.0 |

TABLE 6-67
SAEF

MN ORE - 4.0 MN/FE

PIG IRON + FEMN

METALLURGICAL DATA

| | Pig Iron | High C FeMn |
|---|---|---|
| Operating Load - kWh | 10,000 | 10,000 |
| Operating Time - % | 94 | 94 |
| Avg. Load - kW | 9,400 | 9,400 |
| kWh/kg Metal | 5.79 | 3.19 |
| kWh/t Metal | 5,790 | 3,190 |
| % Mn | 4.0 | 75.0 |
| % Fe | 90.0 | 16.0 |
| % Si | 1.0 | 1.5 |
| % C | 4.0 | 6.5 |
| Electrode Paste - kg/t | 15 | 25 |

TABLE 6-68

SAEF

MN ORE - 4.0 Mn/Fe

PIG IRON + FEMN

CAMPAIGN PROGRAM

| | |
|---|---|
| 1000 kg Mn ore 4.0 Mn/Fe | 91 kg pig iron + 835 kg high Mn slag |
| 350 kg high Mn slag<br>650 kg Mn ore 4.0 Mn/Fe | 363 kg FeMn<br>501 kg low Mn slag |

HOURLY PRODUCTION

| | | |
|---|---|---|
| Pig iron | 9400/1200 + 4590 | = 1.62 t/h |
| High Mn slag | 1.62 x 835/91 | = 14.86 t/h |
| FeMn | 9400/2500 + 690 | = 2.95 t/h |

ANNUAL PRODUCTION - Pig iron 60d/2.0 mo FeMn 305d/10 mos.

| | | |
|---|---|---|
| Pig iron | 60 x 24 x 1.62 | = 2,333 t/y |
| High Mn slag | 60 x 24 x 14.86 | = 21,398 t/y |
| FeMn | 305 x 24 x 2.95 | = 21,594 t/y |
| Slag req'd | 21,594 x 350/363 | = 20,821 t/y |
| Ore req'd | 2,333 x 1000/91 = 25,637<br>21,594 x 650/363 = 38,667 | 64,304 t/y |
| Coke req'd | 2,333 x 160/91 = 4,102<br>21,594 x 230/363 = 13,682 | 17,784 t/y |
| Low Mn slag | 21,594 x 501/363 | = 29,803 t/y |

TABLE 6-69
SAEF

MN ORE - 4.0 MN/FE

PIG IRON + FEMN

SUMMARY - RAW MATERIAL REQUIREMENTS

| Pig Iron | kg/ Batch | kg/t Iron | t/d | t/y 60 d 2.0 mos. |
|---|---|---|---|---|
| Mn ore 4.0 Mn/Fe | 1,000 | 10,989 | 427 | 25,635 |
| Coke | 160 | 1,758 | 68 | 4,101 |
| Quartzite | 160 | 1,758 | 68 | 4,101 |
| Total | 1,320 | 14,505 | 563 | 33,837 |
| Pig Iron | 91 | 1,000 | 39 | 2,333 |
| High Mn slag | 835 | 9,176 | 357 | 21,406 |

| FeMn | kg/ Batch | kg/t FeMn | t/d | t/y 305 d 10.0 mo. |
|---|---|---|---|---|
| High Mn slag | 350 | 964 | 68 | 20,817 |
| Mn ore 4.0 Mn/Fe | 650 | 1,791 | 127 | 38,675 |
| Coke | 230 | 634 | 45 | 13,691 |
| Dolomite | 150 | 413 | 29 | 8,918 |
| Total | 1,380 | 3,802 | 269 | 82,101 |
| FeMn | 363 | 1,000 | 71 | 21,594 |
| Low Mn slag | 501 | 1,380 | 98 | 29,800 |
| Total ore req'd | | | | 64,304 |

TABLE 6-70
SAEF - MANGANESE ORE 4.0 MN/FE - PIG IRON - FEMN

| Material | Wt/Charge kg | $MnO_2$ % | $MnO_2$ kg | MnO % | MnO kg | Mn % | Mn kg | $Fe_2O_3$ % | $Fe_2O_3$ kg | Fe % | Fe kg | FeO % | FeO kg | Fe % | Fe kg | $SiO_2$ % | $SiO_2$ kg | $Al_2O_3$ % | $Al_2O_3$ kg | CaO % | CaO kg | MgO % | MgO kg | BaO % | BaO kg | P % | P kg | S % | S kg | C % | C kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mn ore 4.0 Mn/Fe | 1,000 | 61.5 | 39.0 | | | | | 12.0 | | 9.0 | | | | | | 9.0 | 90 | 4.0 | 40 | 4.0 | 40 | 3.0 | 30 | | | | | | | | |
| | | 61.5 | 390 | | | | | 120 | | 90 | | | | | | | | | | | | | | | | | | | | | |
| Coke | 160 | | | | | | | 2.0 | | | | | | | | 5.0 | 8 | 3.0 | 5 | | | | | | | | | | | 75.0 | 120 |
| | | | | | | | | 3 | | 2 | | | | | | | | | | | | | | | | | | | | | |
| Quartzite | 160 | | | | | | | | | | | | | | | 99.0 | 158 | 1.0 | 2 | | | | | | | | | | | | |
| TOTALS | 1,320 | | 390 | | | | | | | 90 | | | | | | | 256 | | 47 | | 40 | | 30 | | | | | | | | 120 |

PIG IRON PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| Mn | 4 | 4 | 4 |
| Fe | 81 | 85 | 90 |
| Si | 1 | 1 | 1 |
| P | - | - | - |
| S | - | - | - |
| C | 4 | 4 | 4 |
| Other | 1 | 1 | 1 |
| | 91 | 95 | 100.0 |

SLAG PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| $SiO_2$ | 241 | 254 | 28.9 |
| $Al_2O_3$ | 45 | 47 | 5.4 |
| CaO | 38 | 40 | 4.6 |
| MgO | 29 | 30 | 3.4 |
| MnO | 473 | 498 | 56.7 |
| FeO | 9 | 9 | 1.0 |
| BaO Other | - | - | - |
| | 835 | 878 | 100.0 |

MATERIAL BALANCES

| | kg Product/kg Feed | | Unit Recovery |
|---|---|---|---|
| Mn | 370/390 | = | 0.949 |
| Fe | 88/92 | = | 0.957 |
| $SiO_2$ | 243/256 | = | 0.949 |
| $Al_2O_3$ | 45/47 | = | 0.957 |
| CaO | 38/40 | = | 0.950 |
| MgO | 29/30 | = | 0.967 |

| | |
|---|---|
| $MnO_2$/MnO | 85.1 |
| MnO/Mn | 0.9 |
| $Fe_2O_3$/FeO | 9.9 |
| FeO/Fe | 18.2 |
| $SiO_2$/Si | 0.9 |
| C in Metal | 4.6 |
| | 119.0 |

119.0% = 187.7 Use 160 kg

PROCESS RATIOS

| | | |
|---|---|---|
| Slag/t (835/91)1000 | = | 9176 kg |
| Slag Ratio CaO + MgO + MnO/$SiO_2$ | = | 2.01 |
| Coke/t (160/91) 1000 | = | 1758 kg |
| Coke to Mix % (160/1320)100 | = | 12.1 |
| $SiO_2$/t (160/91)1000 | = | 1758 kg |
| $SiO_2$ to Mix % (160/1320)100 | = | 12.1 |
| Dolomite/t | | - |
| Dolomite to Mix % | | - |
| Mn/Fe Slag | = | 52.3 |

TABLE 6-71
SAEF - MANGANESE ORE 4.0 MN/FE - PIG IRON + FEMN

| Material | Wt Charge kg | $MnO_2$ % | $MnO_2$ kg | Mn % | Mn kg | MnO % | MnO kg | Mn % | Mn kg | $Fe_2O_3$ % | $Fe_2O_3$ kg | Fe % | Fe kg | FeO % | FeO kg | Fe % | Fe kg | $SiO_2$ % | $SiO_2$ kg | $Al_2O_3$ % | $Al_2O_3$ kg | CaO % | CaO kg | MgO % | MgO kg | BaO % | BaO kg | P % | P kg | S % | S kg | C % | C kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| High Mn slag | 350 | | | [illegible] | 104 | | 153 | | | | | | | 1.0 | 4 | | 3 | [illegible] | 101 | [illegible] | 10 | [illegible] | 16 | 3.4 | 12 | | | | | | | | |
| Mn ore 4.0 Mn Fe | 650 | [illegible] | 401 | 30.0 | 294 | | | | | 10.0 | 82 | 9.0 | 60 | | | | | 9.0 | 59 | 4.0 | 26 | 4.0 | 26 | 3.0 | 20 | | | | | | | | |
| Coke | 230 | | | | | | | | | [illegible] | [illegible] | | 3 | | | | | [illegible] | 12 | [illegible] | [illegible] | | | | | | | | | | | 75.0 | 173 |
| Dolomite | 150 | | | | | | | | | | | | | | | | | 3.0 | 3 | | | 30.0 | 45 | 21.0 | 32 | | | | | | | | |
| TOTALS | 1,380 | | 294 | | 153 | | 60 | | | | | | 3 | | | | | | 175 | | 62 | | 87 | | 64 | | | | | | | | 173 |

FEMN PRODUCT

| | kg | Initial kg | Initial % |
|---|---|---|---|
| Mn | 277 | 285 | [illegible] |
| Fe | [illegible] | 61 | 10.0 |
| Si | [illegible] | [illegible] | 1.5 |
| P | - | - | - |
| S | - | - | - |
| C | 24 | 25 | [illegible] |
| Other | 4 | 4 | 1.0 |
| | [illegible] | 451 | 100.0 |

SLAG PRODUCT

| | kg | Initial kg | Initial % |
|---|---|---|---|
| $SiO_2$ | 184 | 192 | 30.1 |
| $Al_2O_3$ | 60 | 62 | 9.9 |
| CaO | 83 | 87 | 13.6 |
| MgO | 71 | 74 | 12.1 |
| MnO | 140 | 145 | 23.8 |
| FeO | 6 | 6 | 1.0 |
| BaO Other | - | - | - |
| | 601 | 621 | 100.0 |

MATERIAL BALANCES

| | | | |
|---|---|---|---|
| Mn | 386 401 | = | 0.048 |
| Fe | 62 [illegible] | | 0.054 |
| $SiO_2$ | 1[illegible] 175 | = | 0.054 |
| $Al_2O_3$ | 60 62 | = | 0.042 |
| CaO | 83 87 | = | 0.054 |
| MgO | 71 74 | = | 0.053 |

| | |
|---|---|
| $MnO_2$ Mn | [illegible] |
| Mn Mn | [illegible] |
| $Fe_2O_3$ Fe | [illegible] |
| FeO Fe | 13.1 |
| $SiO_2$ Si | [illegible] |
| Tin Metal | 25.0 |
| | [illegible] |
| [illegible] | Use 230 kg |

PROCESS RATIOS

| | | |
|---|---|---|
| Slag/t (601/363)1000 | = | 1380 kg |
| Slag Ratio CaO + MgO + MnO $SiO_2$ | | 1.09 |
| Coke/t (230/363)1000 | = | 634 kg |
| Coke to Mix % (230/1380)100 | = | 16.7 |
| $SiO_2$/t | | - |
| $SiO_2$ to Mix % | | |
| Dolomite/t (150/363)1000 | = | 413 kg |
| Dolomite to Mix % (150/1380)100 | = | 10.9 |
| Mn/Fe Slag | | 29.[illegible] |

TABLE 6-72
SAEF

Mn ORE 5.0 Mn/Fe

FeMn

METALLURGICAL DATA

| | High C FeMn |
|---|---|
| Operating Load - KWH | 10,000 |
| Operating Time - % | 94 |
| Avg. Load - KW | 9,400 |
| KWH/Kg Metal | 3.03 |
| KWH/t Metal | 3,030 |
| % Mn | 75.0 |
| % Fe | 16.0 |
| % Si | 1.5 |
| % C | 6.5 |
| Electrode Paste - Kg/t | 25 |

TABLE 6-73

SAEF

MN ORE - 5.0 MN/FE

FEMN

CAMPAIGN PROGRAM

| | |
|---|---|
| 1000 kg Mn ore 5.0 Mn/Fe | 355 kg FeMn + 377 kg high Mn slag |

HOURLY PRODUCTION

| | | | |
|---|---|---|---|
| High Mn slag | 3.10 x 377/355 | = | 3.29 t/h |
| FeMn | 9400/2500 + 530 | = | 3.10 t/h |

ANNUAL PRODUCTION

| | | | |
|---|---|---|---|
| High Mn slag | 3.29 x 365 x 24 | = | 28,860 t/y |
| FeMn | 3.10 x 365 x 24 | = | 27,156 t/y |
| Ore req'd | 27,156 x 1000/355 | = | 76,496 t/y |
| Coke req'd | 27,156 x 270/355 | = | 20,654 t/y |

TABLE 6-74
SAEF - MANGANESE ORE 5.0 MN/FE - FEMN

| Material | Wt/Chge kg | $MnO_2$ %/kg | Mn %/kg | MnO %/kg | Mn %/kg | $Fe_2O_3$ %/kg | Fe %/kg | FeO %/kg | Fe %/kg | $SiO_2$ % | kg | $Al_2O_3$ % | kg | CaO % | kg | MgO % | kg | BaO % | kg | P % | kg | S % | kg | C % | kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mn Ore 5.0 Mn/Fe | 1,000 | | 40.0 | | | | 8.0 | | | 9.0 | 90 | 4.0 | 40 | 4.0 | 40 | 3.0 | 30 | | | | | | | | |
| | | | 400 | | | | 80 | | | | | | | | | | | | | | | | | | |
| Coke | 270 | | | | | 2.0 | | | | 5.0 | 14 | 3.0 | 8 | | | | | | | | | | | 75.0 | 203 |
| | | | | | | 5 | 4 | | | | | | | | | | | | | | | | | | |
| Quartzite | | | | | | | | | | 99.0 | | 1.0 | | | | | | | | | | | | | |
| TOTALS | 1,270 | | 400 | | | | 84 | | | | 104 | | 48 | | 40 | | 30 | | | | | | | | 203 |

FEMN PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| Mn | 266 | 280 | 75.0 |
| Fe | 57 | 60 | 16.0 |
| Si | 5 | 5 | 1.5 |
| P | - | - | - |
| S | - | - | - |
| C | 23 | 24 | 6.5 |
| Other | 4 | 4 | 1.0 |
| | 355 | 373 | 100.0 |

SLAG PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| $SiO_2$ | 88 | 93 | 23.4 |
| $Al_2O_3$ | 46 | 48 | 12.1 |
| CaO | 38 | 40 | 10.1 |
| MgO | 29 | 30 | 7.6 |
| MnO | 147 | 155 | 39.0 |
| FeO | 29 | 31 | 7.8 |
| BaO/Other | - | - | - |
| | 377 | 397 | 100.0 |

MATERIAL BALANCES

| | | | |
|---|---|---|---|
| Mn | 380/400 | = | 0.950 |
| Fe | 80/84 | = | 0.947 |
| $SiO_2$ | 99/104 | = | 0.952 |
| $Al_2O_3$ | 46/48 | = | 0.958 |
| CaO | 38/40 | = | 0.950 |
| MgO | 29/30 | = | 0.967 |

| C | |
|---|---|
| $MnO_2/MnO$ | 26.2 |
| $MnO_2/Mn$ | 2.2 |
| $Fe_2O_3/FeO$ | 2.5 |
| $Fe_2O_3/Fe$ | 19.3 |
| $SiO_2/Si$ | 4.3 |
| C in Metal | 24.0 |
| | 198.5 |

198.5/.75 = 264.7 (Use 270 kg/t)

PROCESS RATIOS

| | | | |
|---|---|---|---|
| Slag/t | (377/355)1000 | = | 1062 kg |
| Slag Ratio | CaO + MgO + MnO/$SiO_2$ | = | 2.35 |
| Coke/t | (270/355)1000 | = | 761 kg |
| Coke to Mix % | (270/1270)100 | = | 21.3 |
| $SiO_2$/t | | | - |
| $SiO_2$ to Mix % | | | - |
| Dolomite/t | | | - |
| Dolomite to Mix % | | | - |
| Mn/Fe Slag | | | 5.1 |

## PREHEAT KILN

In the review of original process technology and testing data, evidence was developed by Elkem showing an increase in the output of the submerged arc furnace with preheating and partial reduction of the ferruginous manganese ore and hot charging of the preheated ore to the furnace. In addition the 1960 Birlefco proposal was based on solid carbon reduction of the iron-bearing manganese ore to sponge iron and MnO with subsequent melting of the reduced product in an open arc furnace to produce pig iron for marketing and a high manganese slag for FeMn production in the submerged arc electric furnace. The ore preparation procedures of Elkem and Birlefco were developed to increase the capacity of the SAEF and to improve its efficiency.

As means of enhancing the duplex smelter process, a further investigation was conducted by KECI/ACB to determine the effect of preheating and preproduction on high iron-bearing manganese ore. Ore samples were obtained at the Abu Zeneima in March, 1980, and forwarded to Allis-Chalmers (A-C) Research Laboratories.

Initial tube test results conducted on an iron-bearing hand sample were favorable with metallization of the iron and reduction of the manganese to MnO.

Metallurgical balances and summary tables indicating anticipated increases in production are included in the Appendix for reference purposes.

TABLE 6-76

SUMMARY - OPERATING ALTERNATIVES

PREHEAT KILN + SAEF - PIG IRON + FeMn

| Description | FeMn t/y | Pig Iron t/y | SiMn t/y | Semi-Steel t/y | Total Mn Ore t/y | Reduced Ore t/y | Coke t/y | Electric Power GW/y | Natural Gas Mm3/y | Electrode Carbon t/y |
|---|---|---|---|---|---|---|---|---|---|---|
| P.H. + SAEF - 13.[illegible] MVA/10M. Rehabilitated Furnace | | | | | | | | | | |
| Mn Ore [illegible] Mn/Fe | [illegible] | [illegible] | - | - | [illegible] | - | [illegible] | 82.3 | - | 705 |
| Mn Ore 1.[illegible] Mn/Fe | [illegible] | 1578 | - | - | 73325 | - | 19081 | 82.3 | - | 595 |
| Mn Ore [illegible] Mn/Fe | [illegible] | [illegible] | - | - | [illegible] | - | [illegible] | 82.3 | - | 586 |
| Mn Ore 3.[illegible] Mn/Fe | [illegible] | [illegible] | - | - | [illegible] | - | [illegible] | 82.3 | - | 59[illegible] |

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SUMMARY - OPERATING ALTERNATIVES

PREHEAT KILN + SAEF - PIG IRON + FeMn

TABLE 6-76

PH + SAEF

MN ORE - 0.6 MN/FE

PIG IRON + FEMN

METALLURGICAL DATA

| | Pig Iron | High C FeMn |
|---|---|---|
| Operating Load - kW | 10,000 | 10,000 |
| Operating Time - % | 94 | 94 |
| Avg. Load - kW | 9,400 | 9,400 |
| kWh/kg Metal | 1.63 | 3.16 |
| kWh/t Metal | 1,630 | 3,160 |
| % Mn | 4.0 | 75.0 |
| % Fe | 90.0 | 16.0 |
| % Si | 1.0 | 1.5 |
| % C | 4.0 | 6.5 |
| Electrode Paste - kg/t | 15 | 25 |

TABLE 6-77

SAEF + Preheat Kiln

Mn Ore - 0.6 Mn/Fe

Pig Iron + FeMn

CAMPAIGN PROGRAM

| | |
|---|---|
| 1000 kg Mn ore - 0.6 Mn/Fe | 353 kg pig iron + 429 kg high Mn slag |
| 900 kg high Mn slag<br>100 kg Mn ore - 0.6 Mn/Fe | 375 kg FeMn<br>752 kg low Mn slag |

HOURLY PRODUCTION

| | | | |
|---|---|---|---|
| Pig iron | 9400/(1200 + 610).90 | = | 5.77 t/h |
| High Mn slag | 5.77 x 429/353 | = | 7.01 t/h |
| FeMn | 9400/(2500 + 1010).90 | = | 2.97 t/h |

ANNUAL PRODUCTION - Pig Iron 185d/6.1 mo FeMn 180d/5.9 mo

| | | | |
|---|---|---|---|
| Pig iron | 5.77 x 185 x 24 | = | 25,619 t/y |
| High Mn slag | 7.01 x 185 x 24 | = | 31,124 |
| FeMn | 2.97 x 180 x 24 | = | 12,830 |
| Slag Req'd | 12,830 x 900/375 | = | 30,792 |
| Ore Req'd | 25,619 x 1000/353 = 72,575<br>12,830 x 100/375 = 3,421 | | 75,996 |
| Coke Req'd | 25,619 x 240/353 = 17,418<br>12,830 x 160/375 = 5,474 | | 22,892 |
| Low Mn slag | 12,830 x 752/375 | = | 25,728 |

TABLE 6-78
PH + SAEF

MN ORE 0.6 MN/FE

PIG IRON + FE/MN

SUMMARY - RAW MATERIAL REQUIREMENTS

| Pig Iron | kg/ batch | kg/t Iron | t/d | t/y 185 d 6.1 mo |
|---|---|---|---|---|
| Mn ore 0.6 Mn/Fe | 1,000 | 2,833 | 392 | 72,575 |
| Coke | 240 | 680 | 94 | 17,418 |
| Quartzite | 50 | 142 | 20 | 3,638 |
| TOTAL | 1,290 | 3,655 | 506 | 93,631 |
| Pig iron | 353 | 1,000 | 138 | 25,619 |
| High Mn slag | 429 | 1,215 | 168 | 31,124 |

| FeMn | kg/ batch | kg/t FeMn | t/d | t/y 180 d 5.9 mo |
|---|---|---|---|---|
| High Mn slag | 900 | 2,400 | 171 | 30,792 |
| Manganese ore 0.6 Mn/Fe | 100 | 267 | 19 | 3,421 |
| Coke | 160 | 427 | 30 | 5,474 |
| dolomite | 500 | 1,333 | 95 | 17,103 |
| TOTAL | 1,660 | 4,427 | 315 | 56,790 |
| FeMn | 375 | 1,000 | 71 | 12,830 |
| Low Mn slag | 752 | 2,005 | 143 | 25,728 |
| Total Mn ore req'd | - | - | - | 75,996 |

TABLE 6-79
PH + SAEF

MN ORE - 1.0 MN/FE

PIG IRON + FEMN

METALLURGICAL DATA

| | Pig Iron | High C FeMn |
|---|---|---|
| Operating Load - kW | 10,000 | 10,000 |
| Operating Time - % | 94 | 94 |
| Avg. Load - kW | 9,400 | 9,400 |
| kWh/kg Metal | 2.22 | 3.30 |
| kWh/t Metal | 2,220 | 3,300 |
| % Mn | 4.0 | 75.0 |
| % Fe | 90.0 | 16.0 |
| % Si | 1.0 | 1.5 |
| % C | 4.0 | 6.5 |
| Electrode Paste - kg/t | 15 | 25 |

TABLE 6-80

PH + SAEF

MN ORE - 1.0 MN/FE

PIG IRON + FEMN

CAMPAIGN PROGRAM

| | |
|---|---|
| 1000 kg Mn ore - 1.0 Mn/Fe | 237 kg pig iron<br>592 kg high Mn slag |
| 850 kg high Mn slag<br>150 kg 1.0 Mn/Fe ore | 311 FeMn<br>719 low Mn slag |

HOURLY PRODUCTION

| | | | |
|---|---|---|---|
| Pig iron | 9400/(1200 + 1270).90 | = | 4.23 t/h |
| High Mn slag | 4.23 x 592/237 | = | 10.57 t/h |
| FeMn | 9400/(2500 + 1160).90 | = | 2.85 t/h |

ANNUAL PRODUCTION - Pig Iron 155d/5.1 mo FeMn 210d/6.9 mo

| | | | |
|---|---|---|---|
| Pig iron | 155 x 24 x 4.23 | = | 15,736 t/y |
| High Mn slag | 155 x 24 x 10.57 | = | 39,320 t/y |
| FeMn | 210 x 24 x 2.85 | = | 14,364 t/y |
| Slag Req'd | 14,364 x 850/311 | = | 39,258 t/y |
| Ore Req'd | 15,736 x 1000/237 = 66,397<br>14,364 x 150/311 = 6,928 | | 73,325 t/y |
| Coke Req'd | 15,736 x 190/237 = 12,615<br>14,364 x 140/311 = 6,466 | | 19,081 t/y |
| Low Mn slag | 14,364 x 719/311 | = | 33,208 t/y |

TABLE 6-81

PH + SAEF

MN ORE 1.0 MN/FE

PIG IRON + FEMN

SUMMARY - RAW MATERIAL REQUIREMENTS

| Pig Iron | | kg/ batch | kg/t Iron | t/d | t/y 155 d 5.1 mo |
|---|---|---|---|---|---|
| Mn ore 1.0 Mn/Fe | | 1,000 | 4,219 | 428 | 66,397 |
| Coke | | 190 | 802 | 81 | 12,615 |
| Quartzite | | 70 | 295 | 30 | 4,642 |
| | TOTAL | 1,260 | 5,316 | 539 | 83,654 |
| Pig Iron | | 237 | 1,000 | 102 | 15,736 |
| High Mn slag | | 592 | 2,498 | 254 | 39,320 |

| FeMn | | kg/ batch | kg/t FeMn | t/d | t/y 210 d 6.9 mo |
|---|---|---|---|---|---|
| High Mn slag | | 850 | 2,733 | 187 | 39,258 |
| Mn ore 1.0 Mn/Fe | | 150 | 482 | 33 | 6,928 |
| Coke | | 140 | 450 | 31 | 6,466 |
| Dolomite | | 300 | 965 | 66 | 13,861 |
| | TOTAL | 1,440 | 4,630 | 317 | 66,513 |
| FeMn | | 311 | 1,000 | 68 | 14,364 |
| Low Mn slag | | 719 | 2,312 | 158 | 33,208 |
| Total Mn ore req'd | | - | - | - | 73,325 |

TABLE 6-82

PH + SAEF

MN ORE - 2.0 MN/FE

PRIMARY PIG IRON & SECONDARY FEMN

METALLURGICAL DATA

| | Pig Iron | High C FeMn |
|---|---|---|
| Operating Load - kW | 10,000 | 10,000 |
| Operating Time - % | 94 | 94 |
| Avg. Load - kW | 9,400 | 9,400 |
| kWh/kg Metal | 3.03 | 3.08 |
| kWh/t Metal | 3,030 | 3,080 |
| % Mn | 4.0 | 75.0 |
| % Fe | 90.0 | 16.0 |
| % Si | 1.0 | 1.5 |
| % C | 4.0 | 6.5 |
| Electrode Paste - kg/t | 15 | 25 |

TABLE 6-83

SAEF + Preheat Kiln

Mn Ore - 2.0 Mn/Fe

Primary Pig Iron + Secondary FeMn

CAMPAIGN PROGRAM

| | |
|---|---|
| 1000 kg Mn ore - 2.0 Mn/Fe | 160 kg pig iron + 695 kg high Mn slag |
| 700 kg high Mn slag<br>300 kg Mn ore 2.0 Mn/Fe | 352 kg FeMn +<br>645 kg low Mn slag |

HOURLY PRODUCTION

| | | | |
|---|---|---|---|
| Pig iron | 9400/(1200 + 2170).90 | = | 3.10 t/h |
| High Mn slag | 3.10 x 695/160 | = | 13.47 t/h |
| FeMn | 9400/(2500 + 920).90 | = | 3.05 t/h |

ANNUAL PRODUCTION - Pig Iron 115d/3.8 mo FeMn 250d/8.2 mo

| | | | |
|---|---|---|---|
| Pig iron | 115 x 24 x 3.10 | = | 8,556 t/y |
| High Mn slag | 115 x 24 x 13.47 | = | 37,177 t/y |
| FeMn | 250 x 24 x 3.05 | = | 18,300 t/y |
| Slag Req'd | 18,300 x 700/352 | = | 36,392 t/y |
| Ore Req'd | 8,556 x 1000/160<br>18,300 x 300/352 | = 53,475<br>= 15,597 | 69,072 t/y |
| Coke Req'd | 8,556 x 180/160<br>18,300 x 180/352 | = 9,626<br>= 9,358 | 18,984 t/y |
| Low Mn slag | 18,300 x 645/352 | = | 33,533 t/y |

TABLE 6-84

PH + SAFF

MN ORE 2.0 MN/FE

PIG IRON + FEMN

SUMMARY - RAW MATERIAL REQUIREMENTS

| Pig Iron | | kg/ batch | kg/t Iron | t/d | t/y 115 d 3.8 mo |
|---|---|---|---|---|---|
| Mn ore 2.0 Mn/Fe | | 1,000 | 6,250 | 465 | 53,475 |
| Coke | | 180 | 1,125 | 84 | 9,626 |
| Quartzite | | 100 | 625 | 46 | 5,348 |
| | TOTAL | 1,280 | 8,000 | 595 | 68,449 |
| Pig Iron | | 160 | 1,000 | 74 | 8,556 |
| High Mn slag | | 695 | 4,344 | 323 | 37,177 |

| FeMn | | kg/ batch | kg/t FeMn | t/d | t/y 250 d 8.2 mo |
|---|---|---|---|---|---|
| High Mn slag | | 700 | 1,989 | 146 | 36,392 |
| Mn ore 2.0 Mn/Fe | | 300 | 852 | 62 | 15,597 |
| Coke | | 180 | 511 | 37 | 9,358 |
| Dolomite | | 300 | 852 | 62 | 15,597 |
| | TOTAL | 1,480 | 4,204 | 307 | 76,944 |
| FeMn | | 352 | 1,000 | 73 | 18,300 |
| Low Mn slag | | 645 | 1,832 | 134 | 33,533 |
| Total Mn ore req'd | | - | - | - | 69,072 |

TABLE 6-85
PH + SAEF

MN ORE - 3.0 MN/FE

PIG IRON + FeMn

METALLURGICAL DATA

| | Pig Iron | High C FeMn |
|---|---|---|
| Operating Load - kW | 10,000 | 10,000 |
| Operating Time - % | 94 | 94 |
| Avg. Load - kW | 9,400 | 9,400 |
| kWh/kg Metal | 4.10 | 3.01 |
| kWh/t Metal | 4,100 | 3,010 |
| % Mn | 4.0 | 75.0 |
| % Fe | 90.0 | 16.0 |
| % Si | 1.0 | 1.5 |
| % C | 4.0 | 6.5 |
| Electrode Paste - kg/t | 15 | 25 |

TABLE 6-86
PH + SAEF

MN ORE - 3.0 MN/FE

PIG IRON + FEMN

CAMPAIGN PROGRAM

| | |
|---|---|
| 1000 kg Mn ore - 3.0 Mn/Fe | 118 kg pig iron + 793 kg high Mn slag |
| 500 kg high Mn slag<br>500 kg ore 3.0 Mn/Fe | 350 kg FeMn<br>588 kg low Mn slag |

HOURLY PRODUCTION

| | | | |
|---|---|---|---|
| Pig iron | 9400/(1200 + 3360).90 | = | 2.29 t/h |
| High Mn slag | 2.29 x 793/118 | = | 15.39 t/h |
| FeMn | 9400/(2500 + 840).90 | = | 3.13 t/h |

ANNUAL PRODUCTION - Pig Iron 85d/2.8 mo FeMn 280d/9.2 mo

| | | | |
|---|---|---|---|
| Pig iron | 85 x 24 x 2.29 | = | 4,672 t/y |
| High Mn slag | 85 x 24 x 15.39 | = | 31,396 t/y |
| FeMn | 280 x 24 x 3.13 | = | 21,034 t/y |
| Slag Req'd | 21,034 x 500/350 | = | 30,048 t/y |
| Ore Req'd | 4672 x 1000/118 = 39,593<br>21034 x 500/350 = 30,048 | | 69,642 t/y |
| Coke Req'd | 4672 x 170/118 = 6,731<br>21034 x 200/350 = 12,019 | | 18,750 t/y |
| Low Mn slag | 21034 x 588/350 | = | 35,337 t/y |

TABLE 6-87

PH + SAFF

MANGANESE ORE 3.0 MN/FE

PIG IRON + FEMN

SUMMARY - RAW MATERIAL REQUIREMENTS

| Pig Iron | | kg/ batch | kg/t Iron | t/d | t/y 35 d 2.8 mo |
|---|---|---|---|---|---|
| Mn Ore 3.0 Mn/Fe | | 1,000 | 8,474 | 466 | 39,593 |
| Coke | | 170 | 1,441 | 79 | 6,731 |
| Quartzite | | 150 | 1,271 | 70 | 5,938 |
| | TOTAL | 1,320 | 11,186 | 615 | 52,262 |
| Pig Iron | | 118 | 1,000 | 55 | 4,672 |
| High Mn slag | | 793 | 6,720 | 369 | 31,396 |

| FeMn | | kg/ batch | kg/t FeMn | t/d | t/y 280 d 9.2 mo |
|---|---|---|---|---|---|
| High Mn slag | | 500 | 1,429 | 107 | 30,048 |
| Mn Ore 3.0 Mn/Fe | | 500 | 1,429 | 107 | 30,048 |
| Coke | | 200 | 571 | 43 | 12,019 |
| Dolomite | | 250 | 714 | 54 | 15,018 |
| | TOTAL | 1,450 | 4,143 | 311 | 87,133 |
| FeMn | | 350 | 1,000 | 75 | 21,034 |
| Low Mn slag | | 588 | 1,680 | 126 | 35,337 |
| Total Mn ore req'd | | - | - | | 69,642 |

# REDUCTION AND MELTING

With an ample supply of local natural gas available in the Abu Zeneima area, it is important to investigate ore processing methods which use the local energy to the fullest extent. Birlefco had proposed iron elimination by ore reduction with solid carbon and melting of the metallic iron product to obtain pig iron and high Mn slag in an open-arc furnace.

In this investigation KECI/ACB considered a system for natural gas reduction in a rotary kiln to produce a low-carbon sponge iron from the ferruginous manganese ore. In the following step the gas-reduced ore is melted in a conventional open arc steelmaking furnace to obtain low-carbon semi-steel and a high Mn slag for submerged arc furnace smelting.

The major advantages of this system are the following:

- An approximate 50% reduction in imported coke consumption by using natural gas for reduction.
- Full allocation of the rehabilitated smelter furnace to ferroalloy production.

With the 13.2-MVA smelter furnace fully available for FeMn production by using the gas reduction system, the following annual quantities of ore and products result:

| | Production - t/y | | Ore Req'd |
|---|---|---|---|
| Mn/Fe Ratio | FeMn | Semi-Steel | t/y |
| 0.6 | 25,492 | 34,305 | 117,442 |
| 1.0 | 23,915 | 18,631 | 103,765 |
| 2.0 | 25,054 | 7,302 | 77,000 |
| 3.0 | 25,842 | 3,970 | 71,305 |

Metallurgical balances and summary tables are included in the Appendix for reference purposes.

TABLE 6-88

SUMMARY - OPERATING ALTERNATIVES

REDUCED ORE

| Description | FeMn t/y | Pig Iron t/y | SiMn t/y | Semi-Steel t/y | Total Mn Ore t/y | Reduced Ore t/y | Coke t/y | Electric Power GW/y | Natural Gas Mm3/y | Electrode Carbon t/y |
|---|---|---|---|---|---|---|---|---|---|---|
| DR + OAEF + OAEF (SiMn Production) | | | | | | | | | | |
| Mn Ore .0 Mn/Fe | [illegible] | - | 3477 | 3435 | 117440 | 79539 | 11004 | 142.5 | 28.80 | 862 |
| Mn Ore 1.0 Mn/Fe | [illegible] | - | 2434 | 1831 | 103365 | 79779 | 10777 | 132.4 | 22.24 | 716 |
| Mn Ore 2.0 Mn/Fe | [illegible] | - | 3474 | 7302 | 77[illegible] | 39470 | 12247 | 114.9 | 12.90 | 669 |
| Mn Ore 3.0 Mn/Fe | [illegible] | - | 4.24 | [illegible] | 71305 | 28079 | 14187 | 105.6 | 9.35 | 669 |
| DR + OAEF + OAEF (No SiMn Production) | | | | | | | | | | |
| Mn Ore 0.0 Mn/Fe | 25442 | - | - | 3435 | 117419 | 79539 | 11004 | 142.5 | 28.80 | 877 |
| Mn Ore 1.0 Mn/Fe | 23415 | - | - | 1831 | 104924 | 79779 | 11354 | 132.4 | 22.24 | 728 |
| Mn Ore 2.0 Mn/Fe | 25254 | - | - | 7302 | 78304 | 39470 | 12775 | 114.9 | 12.90 | 677 |
| Mn Ore 3.0 Mn/Fe | 25642 | - | - | 3477 | 74533 | 28079 | 15033 | 105.6 | 9.35 | 674 |

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SUMMARY- OPERATING ALTERNATIVES

REDUCED ORE

TABLE 6-89

DR + OAEF + SAEF

MN ORE - 0.6 MN/FE

SEMI-STEEL + FEMN + SIMN

Metallurgical Data

| | OAEF Semi-Steel | SAEF FeMn | SAEF SiMn |
|---|---|---|---|
| Operating Load - kWh | 10,000 | 10,000 | 10,000 |
| Operating Time - % | 69 | 94 | 94 |
| Avg. Load - kW | 6,870 | 9,400 | 9,400 |
| kWh/kg Metal | 1.23 | 3.23 | 5.14 |
| kWh/t Metal | 1,229 | 3,230 | 5,140 |
| % Mn | 0.44 | 75.0 | 65.0 |
| % Fe | 98.24 | 16.0 | 17.0 |
| % Si | - | 1.5 | 16.0 |
| % C | 0.04 | 6.5 | 2.0 |
| Electrode Paste - kg/t | 7 | 25 | 35 |

TABLE 6-90

DR + OAEF + SAEF

MN ORE - 0.6 MN/FE

SEMI-STEEL + FEMN + SIMN

CAMPAIGN PROGRAM

| | |
|---|---|
| 1000 kg Mn ore 0.6 Mn/Fe | 714.6 kg reduced ore |
| 1000 kg reduced ore | 431.3 kg semi-steel + 542.7 kg high Mn slag |
| 900 kg high Mn slag<br>100 kg Mn ore 0.6 Mn/Fe<br>900 kg low Mn slag<br>100 kg Mn ore 0.6 Mn/Fe | 417 kg FeMn +<br>605 kg low Mn slag<br>259 kg SiMn +<br>588 kg slag |

HOURLY PRODUCTION

| | | |
|---|---|---|
| Semi-steel | 34,305 t/y/8,760 x .70 | = 5.59 t/h |
| High Mn slag | 5.59 x 542.7/431.3 | = 7.03 t/h |
| Low Mn slag | 2.91 x 605/417 | = 4.22 t/h |
| FeMn | 9400/(2500 + 730) | = 2.91 t/h |
| SiMn | 9400/(4000 + 1140) | = 1.83 t/h |

ANNUAL PRODUCTION - FeMn 286d/19.4 mo SiMn 79d/2.6 mo

| | | | |
|---|---|---|---|
| High Mn slag | 20,000 t/y FeMn x 900/417 | | = 43,165 t/y |
| Semi-steel | 43,165 x 431.3/542.7 | | = 34,305 t/y |
| FeMn | 20,000/2.91 x 24 | | = 286 d/y |
| | 2.91 x 286 x 24 | | = 20,000 t/y |
| SiMn | 1.83 x 79 x 24 | | = 3,470 t/y |
| Low Mn slag req'd | 3,470 x 900/259 | | = 12,058 t/y |
| Reduced ore req'd | 34,305 x 1000/431.3 | | = 79,539 t/y |
| Ore req'd | 79,539 x 1000/714.6 | = 111,306 | |
| | 20,000 x 100/417 | = 4,796 | |
| | 3,470 x 100/259 | = 1,340 | |
| | | | 117,442 t/y |
| Coke req'd | 20,000 x 180/417 | = 8,633 | |
| | 3,470 x 140/259 | = 1,876 | |
| | | | 10,509 t/y |
| Final slag | 20,000 x 605/417 | = 29,017 | |
| | | - 12,058 | |
| | 3,470 x 588/259 | = 7,878 | |
| | | | 24,837 t/y |

TABLE 6-91

DR + OAEF + SAEF

MN ORE - 0.6 MN/FE

SEMI-STEEL + FEMN + SIMN

SUMMARY - RAW MATERIAL REQUIREMENTS

| | kg/batch | kg/t semi-steel | t/d | t/y 365 d 12 mo |
|---|---|---|---|---|
| Mn ore - 0.6 Mn/Fe | - | - | 305 | 111,306 |
| Reduced ore | 1,000 | 2,320 | 218 | 79,539 |
| Quartzite | 30 | 70 | 7 | 2,399 |
| Coke | - | - | - | - |
| TOTAL | 1,030 | 2,390 | 225 | 81,938 |
| Semi-steel | 431 | 1,000 | 94 | 34,305 |
| High Mn slag | 543 | 1,260 | 119 | 43,165 |

| | kg/batch | kg/t FeMn | t/d | t/y 286 d 9.4 mo |
|---|---|---|---|---|
| High Mn slag | 900 | 2,158 | 151 | 43,165 |
| Mn ore 0.6 Mn/Fe | 100 | 240 | 17 | 4,796 |
| Dolomite | 300 | 719 | 50 | 14,361 |
| Coke | 180 | 432 | 30 | 8,633 |
| TOTAL | 1,480 | 3,549 | 248 | 70,955 |
| FeMn | 417 | 1,000 | 70 | 20,000 |
| Low Mn slag | 605 | 1,451 | 101 | 29,017 |

| | kg/batch | kg/t SiMn | t/d | t/y 79 d 2.6 mo |
|---|---|---|---|---|
| Low Mn slag | 900 | 3,475 | 153 | 12,058 |
| Mn ore 0.6 Mn/Fe | 100 | 386 | 17 | 1,340 |
| Coke | 140 | 541 | 24 | 1,876 |
| Quartzite | - | - | - | - |
| TOTAL | 1,140 | 4,402 | 194 | 15,274 |
| SiMn | 259 | 1,000 | 44 | 3,470 |
| Low Mn slag | 588 | 2,270 | 100 | 7,878 |
| Total slag | - | - | - | 24,837 |
| Total Mn ore required | - | - | - | 117,442 |

FeMn produced if operated for 365 days = 25,492 t/y

TABLE 6-92
DR + OAEF + SAEF - MN ORE 0.6 MN/FE
SEMI-STEEL + FEMN + SIMN

| Material | Wt. per Charge kg | $MnO_2$ %/kg | Mn %/kg | MnO %/kg | Mn %/kg | FeO %/kg | Fe %/kg | Fe % | Fe kg | $SiO_2$ % | $SiO_2$ kg | $Al_2O_3$ % | $Al_2O_3$ kg | CaO % | CaO kg | MgO % | MgO kg | BaO % | BaO kg | P % | P kg | S % | S kg | C % | C kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Direct Reduced Ore | 1,000 | | | 36.83 | 28.49 | 4.31 | | 44.55 | 446 | 7.71 | 77 | 3.16 | 32 | 1.04 | 10 | 0.13 | 1 | 1.32 | 13 | 0.137 | 1.4 | 0.01 | 0.1 | 0.30 | 3 |
| - 0.6 Mn/Fe | | | | 368 | 285 | 43 | 34 | | | | | | | | | | | | | | | | | | |
| Quartzite | 30 | | | | | | | | | 99.00 | 30 | 1.00 | - | | | | | | | | | | | | |
| Coke | - | | | | | | | | | | | | | | | | | | | | | | | | |
| TOTALS | 1,030 | | | 368 | 285 | 43 | 34 | | 446 | | 107 | | 32 | | 10 | | 1 | | 13 | | 1.4 | | 0.1 | | 3 |

## Semi-Steel Produced

| | kg | Initial kg | % |
|---|---|---|---|
| Mn | 1.9 | 2.0 | 0.44 |
| Fe | 423.7 | 446.0 | 98.24 |
| C | 0.2 | 0.2 | 0.04 |
| Si | - | - | |
| P | 1.2 | 1.3 | 0.29 |
| S | - | - | |
| Other | 4.3 | 4.5 | 0.99 |
| TOTALS | 431.3 | 454.0 | 100.00 |

## Slag Produced

| | kg | Initial kg | % |
|---|---|---|---|
| $SiO_2$ | 101.6 | 107.0 | 18.74 |
| $Al_2O_3$ | 30.4 | 32.0 | 5.60 |
| CaO | 9.5 | 10.0 | 1.75 |
| MgO | 1.0 | 1.0 | 0.18 |
| BaO | 12.3 | 13.0 | 2.28 |
| MnO | 347.0 | 365.3 | 63.92 |
| FeO | 40.9 | 43.0 | 7.53 |
| TOTALS | 542.7 | 571.3 | 100.00 |

## Material Balances

| | kg Product/kg Feed | Unit Recovery |
|---|---|---|
| Fe | 456/480 = | 0.949 |
| Mn | 271/285 = | 0.949 |
| $SiO_2$ | 102/107 = | 0.953 |
| $Al_2O_3$ | 30/32 = | 0.950 |
| CaO | 9.5/10 = | 0.950 |
| MgO | 1/1 = | 1.000 |
| BaO | 12/13 = | 0.923 |

| C | |
|---|---|
| MnO/Mn | 0.4 |
| FeO/Fe | - |
| $P_2O_5$/P | 1.3 |
| C in Metal | 0.2 |
| | 1.9/3.0 = 0.633 |

## Product Ratios

| | |
|---|---|
| Slag/t (542.7/431.3)1000 | = 1258 kg |
| Slag Ratio CaO + MgO + BaO + MnO/$SiO_2$ | = 3.05 |
| Coke/t | - |
| Coke to Mix % | - |
| $SiO_2$ to Mix % (30/1030)100 | = 2.9 |
| $SiO_2$/t (30/431.3)1000 | = 70 kg |
| Mn/Fe Slag (269/32) | = 8.45 |

TABLE 6-93
DR + OAEF + SAEF - MN ORE 0.6 MN/FE
SEMI-STEEL + FEMN + SIMN

| Material | Wt/Chge kg | $MnO_2$ %/kg | Mn %/kg | MnO %/kg | Mn %/kg | $Fe_2O_3$ %/kg | Fe %/kg | FeO %/kg | Fe %/kg | $SiO_2$ % | kg | $Al_2O_3$ % | kg | CaO % | kg | MgO % | kg | BaO % | kg | P % | kg | S % | kg | C % | kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| High Mn Slag | 900 | | | 63.92 | | | | 7.53 | | 18.74 | 169 | 5.60 | 50 | 1.75 | 16 | 0.18 | 2 | 2.28 | 21 | | | | | | |
| | | | | 575 | 44[illegible] | | | 68 | 53 | | | | | | | | | | | | | | | | |
| Mn Ore 0.6 Mn/Fe | 100 | 32.76 | 20.71 | 0.97 | 0.75 | 51.52 | 36.03 | | | 5.80 | 6 | 2.38 | 2 | 0.78 | 1 | 0.10 | | 0.99 | 1 | .103 | | .09 | | | |
| | | 33 | 21 | | 1 | 52 | 36 | | | | | | | | | | | | | | | | | | |
| Dolomite | 300 | | | | | | | | | 2.0 | 6 | | | 30.2 | 91 | 21.0 | 63 | | | | | | | | |
| Coke | 180 | | | | | 2.00 | | | | 5.00 | 9 | 3.00 | 5 | | | | | | | | | | | 75.00 | 135 |
| | | | | | | 4 | 3 | | | | | | | | | | | | | | | | | | |
| TOTAL | 1,480 | | 21 | | 447 | | 39 | | 53 | | 190 | | 57 | | 108 | | 65 | | 22 | | | | | | 135 |

FEMN PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| Mn | 312 | 328 | 75.0 |
| Fe | 67 | 70 | 16.0 |
| C | 27 | 28 | 6.5 |
| Si | 7 | 7 | 1.5 |
| P | - | - | - |
| S | - | - | - |
| Other | 4 | 4 | 1.0 |
| | 417 | 437 | 100.0 |

SLAG PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| $SiO_2$ | 166 | 175 | 27.5 |
| $Al_2O_3$ | 54 | 57 | 9.0 |
| CaO | 103 | 108 | 17.0 |
| MgO | 62 | 65 | 10.2 |
| BaO | 21 | 22 | 3.4 |
| MnO | 172 | 181 | 28.5 |
| FeO | 27 | 28 | 4.4 |
| | 605 | 636 | 100.0 |

MATERIAL BALANCES

| | | | |
|---|---|---|---|
| Mn | 445/468 | = | 0.951 |
| Fe | 88/92 | = | 0.956 |
| $SiO_2$ | 181/190 | = | 0.953 |
| $Al_2O_3$ | 54/57 | = | 0.947 |
| CaO | 103/108 | = | 0.954 |
| MgO | 62/65 | = | 0.954 |
| BaO | 21/22 | = | 0.954 |

C

| | |
|---|---|
| $MnO_2/MnO$ | 4.6 |
| MnO/Mn | 71.6 |
| $Fe_2O_3/FeO$ | 4.2 |
| FeO/Fe | 15.0 |
| $SiO_2/Si$ | 6.0 |
| C in Metal | 28.0 |
| | 129.4 |

129.4/.75 = 172.5 (Use 180 kg/t)

PRODUCT RATIOS

Slag/t
(605/417)1000 = 1451 kg

Slag Ratio
$\frac{CaO + MgO + BaO + MnO}{SiO_2}$ = 2.15

Coke/t
(180/417)1000 = 432 kg

Coke to Mix %
(180/1480)100 = 12.2

Dol/t
(300/417)1000 = 719 kg

Dol to Mix %
(300/1480)100 = 20.3

Mn/Fe Slag = 6.3

TABLE 6-94
SINAI MANGANESE - 80012
DK + OAEF + SAEF - MN ORE 0.6 MN/FE - SEMI-STEEL + MN + SIMN

| Material | Wt/Chge kg | $MnO_2$ %/kg | Mn %/kg | MnO %/kg | Mn %/kg | $Fe_2O_3$ %/kg | Fe %/kg | FeO %/kg | Fe %/kg | $SiO_2$ % | kg | $Al_2O_3$ % | kg | CaO % | kg | MgO % | kg | BaO % | kg | P % | kg | S % | kg | C % | kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Low Mn Slag | 900 | | | 28.5 | | | | 4.4 | | 27.5 | 248 | 9.0 | 81 | 17.0 | 153 | 10.2 | 92 | 3.4 | 31 | | | | | | |
| | | | | 257 | 199 | | | 40 | 31 | | | | | | | | | | | | | | | | |
| Mn Ore 0.6 Mn/Fe | 100 | 32.76 | | 0.97 | | 51.47 | | | | 5.8 | 6 | 2.38 | 2 | 0.78 | 1 | 0.10 | - | 0.99 | 1 | 0.10 | - | 0.09 | - | | |
| | | 33 | 21 | 1 | 1 | 51 | 36 | | | | | | | | | | | | | | | | | | |
| Coke | 140 | | | | | 2.0 | | | | 5.0 | 7 | 3.0 | 4 | | | | | | | | | | | 75.0 | 105 |
| | | | | | | 3 | 2 | | | | | | | | | | | | | | | | | | |
| Quartzite | - | | | | | | | | | 99.0 | - | 1.0 | - | | | | | | | | | | | | |
| TOTALS | 1,140 | | 21 | | 200 | | 38 | | 31 | | 261 | | 87 | | 154 | | 92 | | 32 | | | | | | 105 |

SIMN PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| Mn | 168 | 177 | 65.0 |
| Fe | 44 | 46 | 17.0 |
| C | 5 | 5 | 2.0 |
| Si | 42 | 44 | 16.0 |
| P | - | - | - |
| S | - | - | - |
| Other | - | - | - |
| | 259 | 272 | 100.0 |

SLAG PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| $SiO_2$ | 159 | 167 | 27.0 |
| $Al_2O_3$ | 83 | 87 | 14.0 |
| CaO | 146 | 154 | 24.9 |
| MgO | 87 | 92 | 14.9 |
| BaO | 30 | 32 | 5.2 |
| MnO | 54 | 57 | 9.2 |
| FeO | 29 | 30 | 4.8 |
| | 588 | 619 | 100.0 |

MATERIAL BALANCES

| | | | |
|---|---|---|---|
| Mn | 210/221 | = | 0.949 |
| Fe | 67/69 | = | 0.971 |
| $SiO_2$ | 249/261 | = | 0.953 |
| $Al_2O_3$ | 83/87 | = | 0.954 |
| CaO | 146/154 | = | 0.948 |
| MgO | 87/92 | = | 0.945 |

| | |
|---|---|
| C | |
| $MnO_2/MnO$ | 4.6 |
| MnO/Mn | 38.6 |
| $Fe_2O_3/FeO$ | 4.1 |
| FeO/Fe | 9.9 |
| $SiO_2/Si$ | 37.7 |
| C in Metal | 5.0 |
| | 99.9 |

99.9 / .75 = 133.2 (Use 140 kg/t)

PRODUCT RATIOS

| | | |
|---|---|---|
| Slag/t | (588/259)1000 | = 2270 kg |
| Slag Ratio | $\frac{CaO + MgO + BaO + MnO}{SiO_2}$ | = 2.17 |
| Coke/t | (140/259)1000 | = 541 kg |
| Coke to mix % | | |
| $SiO_2$/t | | = - |
| $SiO_2$ to Mix % | | = - |
| Mn/Fe Slag | | 1.9 |

TABLE 6-95

DR + OAEF + SAEF

Mn ORE 1.0 Mn/Fe

Semi-Steel + FeMn + SiMn

METALLURGICAL DATA

| | OAEF Semi-Steel | SAEF FeMn | SAEF SiMn |
|---|---|---|---|
| Operating Load - KWH | 10,000 | 10,000 | 10,000 |
| Operating Time - % | 57 | 94 | 94 |
| Avg. Load - KW | 5,700 | 9,400 | 9,400 |
| KWH/Kg Metal | 1.87 | 3.44 | 5.57 |
| KwH/t Metal | 1,874 | 3,440 | 5,570 |
| % Mn | 0.44 | 75.0 | 65.0 |
| % Fe | 98.24 | 16.0 | 17.0 |
| % Si | - | 1.5 | 16.0 |
| % C | 0.04 | 6.5 | 2.0 |
| Electrode Paste - Kg/t | 7 | 25 | 35 |

TABLE 6-96
DR + OAEF + SAEF

Mn ORE 1.0 Mn/Fe

SEMI-STEEL + FeMn + SiMn

## CAMPAIGN PROGRAM

| | |
|---|---|
| 1000 kg Mn ore 1.0 Mn/Fe | 736 kg reduced ore |
| 1000 kg reduced ore | 279 kg semi-steel + 711 kg high Mn slag |
| 800 kg high Mn slag<br>200 kg Mn ore 1.0 Mn/Fe | 337 kg FeMn +<br>631 kg low Mn slag |
| 900 kg low Mn slag<br>100 kg Mn ore 1.0 Mn/Fe | 209 kg SiMn +<br>653 kg slag |

## HOURLY PRODUCTION

| | | | |
|---|---|---|---|
| Semi-steel | 18,631/8,760 x .70 | = | 3.04 t/h |
| High Mn slag | 3.04 x 711/279 | = | 7.75 t/h |
| FeMn | 9,400/(2,500 + 940) | = | 2.73 t/h |
| Low Mn slag | 2.73 x 631/337 | = | 5.12 t/h |
| SiMn | 9,400/(4,000 + 1,570) | = | 1.69 t/h |

## ANNUAL PRODUCTION - FeMn 305d/10.0 mo SiMn 60d/2.0 mo

| | | | | | |
|---|---|---|---|---|---|
| High Mn slag | 20,000 t/y x 800/337 | | | = | 47,478 t/y |
| Semi-steel | 47,478 x 279/711 | | | = | 18,631 t/y |
| FeMn | 20,000/2.73 x 24 | | | = | 305 d/y |
| | 2.73 x 305 x 24 | | | = | 20,000 t/y |
| SiMn | 1.69 x 60 x 24 | | | = | 2,434 t/y |
| Low Mn slag | 2,434 x 900/209 | | | = | 10,481 t/y |
| Reduced ore req'd. | 18,631 x 1,000/279 | | | = | 66,778 t/y |
| | 66,778 x 1,000/736 | = | 90,731 | | |
| | 20,000 x 200/337 | = | 11,869 | | |
| | 2,434 x 100/209 | = | 1,165 | | |
| | | | | | 103,765 t/y |
| Coke req'd. | 20,000 x 160/337 | = | 9,496 | | |
| | 2,434 x 110/209 | = | 1,281 | | |
| | | | | | 10,777 t/y |
| Final slag | 20,000 x 631/337 | = | 37,448 | | |
| | | - | 10,481 | | |
| | 2,434 x 653/209 | = | 7,605 | | |
| | | | | | 34,572 t/y |

TABLE 6-97
DR + OAEF + SAEF

MN ORE - 1.0 MN/FE

SEMI-STEEL + FEMN + SIMN

SUMMARY - RAW MATERIAL REQUIREMENTS

| | kg/batch | kg/t semi-steel | t/d | t/y 365 d 12 mo |
|---|---|---|---|---|
| Mn ore - 1.0 Mn/Fe | - | - | 236 | 90,731 |
| Reduced ore | 1,000 | 3,584 | 183 | 66,778 |
| Quartzite | 50 | 179 | 9 | 3,337 |
| Coke | - | - | - | - |
| TOTAL | 1,050 | 3,763 | 192 | 70,115 |
| Semi-steel | 279 | 1,000 | 51 | 18,631 |
| High Mn slag | 711 | 2,548 | 130 | 47,478 |

| | kg/batch | kg/t FeMn | t/d | t/y 305 d 10.0 mo |
|---|---|---|---|---|
| High Mn slag | 800 | 2,374 | 156 | 47,478 |
| Mn ore - 1.0 Mn/Fe | 200 | 593 | 39 | 11,869 |
| Dolomite | 200 | 593 | 39 | 11,869 |
| Coke | 160 | 475 | 31 | 9,496 |
| TOTAL | 1,360 | 4,035 | 265 | 80,712 |
| FeMn | 337 | 1,000 | 66 | 20,000 |
| Low Mn slag | 631 | 1,872 | 123 | 37,448 |

| | kg/batch | kg/t SiMn | t/d | t/y 60 d 2.0 mo |
|---|---|---|---|---|
| Low Mn slag | 900 | 4,306 | 175 | 10,481 |
| Mn ore - 1.0 Mn/Fe | 100 | 479 | 19 | 1,165 |
| Coke | 110 | 526 | 21 | 1,281 |
| Quartzite | - | - | - | - |
| TOTAL | 1,110 | 5,311 | 215 | 12,927 |
| SiMn | 209 | 1,000 | 41 | 2,434 |
| Low Mn slag | 653 | 3,124 | 127 | 7,605 |
| Final slag | - | - | - | 34,572 |
| Total Mn ore req'd | - | - | - | 103,765 |

FeMn produced if operated for 365 days = 23,915 t/y

TABLE 6-98
DR + OAEF + SAEF - MN ORE 1.0 MN/FE - SEMI-STEEL + FEMN + SIMN

| Material | Wt/Chge kg | $MnO_2$ %/kg | Mn %/kg | MnO %/kg | Mn %/kg | $Fe_2O_3$ %/kg | Fe %/kg | FeO %/kg | Fe %/kg | $SiO_2$ % | kg | $Al_2O_3$ % | kg | CaO % | kg | MgO % | kg | BaO % | kg | P % | kg | S % | kg | C % | kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reduced Ore 1.0 Mn/Fe | 1,000 | | | | 31.0 | | 28.8 | | 2.2 | 12.9 | 129 | 5.2 | 52 | 5.2 | 52 | 3.9 | 39 | | | | | | | | |
| | | | | | 310 | | 288 | | 22 | | | | | | | | | | | | | | | | |
| Quartzite | 50 | | | | — | | — | | — | 99.0 | 50 | 1.0 | — | | — | | — | | | | | | | | |
| TOTAL | 1,050 | | | | 310 | | 288 | | 22 | | 179 | | 52 | | 52 | | 39 | | | | | | | | |

SEMI-STEEL PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| Mn | 1 | 1 | 0.34 |
| Fe | 274 | 288 | 98.24 |
| C | - | - | 0.04 |
| Si | - | - | - |
| P | - | - | - |
| S | - | - | - |
| Other | 4 | 4 | 1.28 |
| | 279 | 293 | 100.00 |

SLAG PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| $SiO_2$ | 170 | 179 | 23.9 |
| $Al_2O_3$ | 49 | 52 | 6.9 |
| CaO | 49 | 52 | 6.9 |
| MgO | 37 | 39 | 5.2 |
| MnO | 379 | 399 | 53.4 |
| FeO | 27 | 28 | 3.7 |
| BaO/Other | - | - | - |
| | 711 | 749 | 100.0 |

MATERIAL BALANCES

| | | | |
|---|---|---|---|
| Mn | 295/310 | = | 0.952 |
| Fe | 295/310 | = | 0.952 |
| $SiO_2$ | 170/179 | = | 0.950 |
| $Al_2O_3$ | 49/52 | = | 0.942 |
| CaO | 49/52 | = | 0.942 |
| MgO | 37/39 | = | 0.949 |

PRODUCT RATIOS

| | | | |
|---|---|---|---|
| Slag/t | (711/279)1000 | = | 2548 kg |
| Slag Ratio | CaO + MgO + MnO/$SiO_2$ | = | 2.52 |
| Coke/t | | | - |
| Coke to Mix % | | | - |
| $SiO_2$/t | (50/279)1000 | = | 179 kg |
| $SiO_2$ to Mix % | (50/1050)100 | = | 4.8 |
| Mn/Fe Slag | (294/21) | = | 14.0 |

TABLE 6-99
DR + OAEF + SAEF - MN ORE 1.0 MN/FE - SEMI-STEEL + FEMN + SIMN

| Material | Wt/Chge kg | $MnO_2$ %/kg | Mn %/kg | MnO %/kg | Mn %/kg | $Fe_2O_3$ %/kg | Fe %/kg | FeO %/kg | Fe %/kg | $SiO_2$ % | $SiO_2$ kg | $Al_2O_3$ % | $Al_2O_3$ kg | CaO % | CaO kg | MgO % | MgO kg | BaO % | BaO kg | P % | P kg | S % | S kg | C % | C kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| High Mn slag | 800 | | | 53.4 | | | | 3.7 | | 23.9 | 191 | 6.9 | 55 | 6.9 | 55 | 5.2 | 42 | | | | | | | | |
| | | | | 427 | 331 | | | 36 | 23 | | | | | | | | | | | | | | | | |
| Mn Ore 1.0 Mn/Fe | 200 | | 24.0 | | | | 24.0 | | | 10.0 | 20 | 5.0 | 10 | 4.0 | 8 | 3.0 | 6 | | | | | | | | |
| | | | 48 | | | | 48 | | | | | | | | | | | | | | | | | | |
| Coke | 160 | | | | | 2.0 | | | | 5.0 | 8 | 3.0 | 5 | | | | | | | | | | | 75.0 | 120 |
| | | | | | | 3 | 2 | | | | | | | | | | | | | | | | | | |
| Dolomite | 200 | | | | | | | | | 2.0 | 4 | | | 30.2 | 60 | 21.0 | 42 | | | | | | | | |
| TOTAL | 1,360 | | 48 | | 331 | | 50 | | 23 | | 223 | | 70 | | 123 | | 90 | | | | | | | | 120 |

FEMN PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| Mn | 252 | 265 | 75.0 |
| Fe | 54 | 57 | 16.0 |
| C | 22 | 23 | 6.5 |
| Si | 5 | 5 | 1.5 |
| P | - | - | - |
| S | - | - | - |
| Other | 4 | 4 | 1.0 |
| | 337 | 354 | 100.0 |

SLAG PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| $SiO_2$ | 201 | 212 | 32.0 |
| $Al_2O_3$ | 67 | 70 | 10.5 |
| CaO | 117 | 123 | 18.5 |
| MgO | 86 | 90 | 13.6 |
| MnO | 140 | 147 | 22.2 |
| FeO | 20 | 21 | 3.2 |
| BaO/Other | - | - | - |
| | 631 | 663 | 100.0 |

MATERIAL BALANCES

| | | | |
|---|---|---|---|
| Mn | 360/379 | = | 0.951 |
| Fe | 70/73 | = | 0.953 |
| $SiO_2$ | 216/227 | = | 0.950 |
| $Al_2O_3$ | 67/70 | = | 0.957 |
| CaO | 175/184 | = | 0.951 |
| MgO | 125/132 | = | 0.947 |

C

| | |
|---|---|
| $MnO_2$/MnO | 10.5 |
| MnO/Mn | 57.8 |
| $Fe_2O_3$/FeO | 5.4 |
| FeO/Fe | 12.2 |
| $SiO_2$/Si | 4.3 |
| C in Metal | 23.0 |
| | 113.2 |

113.2/.75 = 150.9 (Use 160)

PRODUCT RATIOS

| | | |
|---|---|---|
| Slag/t (631/337)1000 | = | 1872 kg |
| Slag Ratio CaO + MgO + MnO/$SiO_2$ | = | 1.85 |
| Coke/t (160/337)1000 | = | 475 kg |
| Coke to Mix % (160/1360)100 | = | 11.8 |
| Dol/t (200/337)1000 | = | 594 kg |
| Dol to Mix % (200/1360)100 | = | 14.7 |
| Mn/Fe Slag | = | 7.0 |

TABLE 6-100
MANGANESE ORE 1.0 MN/FE - SEMI-STEEL + FEMN + SIMN

| Material | Wt/Chge kg | $MnO_2$ %/kg | Mn %/kg | MnO %/kg | Mn %/kg | $Fe_2O_3$ %/kg | Fe %/kg | FeO %/kg | Fe %/kg | $SiO_2$ % | kg | $Al_2O_3$ % | kg | CaO % | kg | MgO % | kg | BaO % | kg | P % | kg | S % | kg | C % | kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Low Mn Slag | 900 | | | 22.2 | | | | 3.2 | | 32.0 | 288 | 10.5 | 95 | 18.5 | 167 | 13.6 | 122 | | | | | | | | |
| | | | | 200 | 155 | | | 29 | 22 | | | | | | | | | | | | | | | | |
| Mn Ore 1.0 Mn/Fe | 100 | | 24.0 | | | | 24.0 | | | 10.0 | 10 | 5.0 | 5 | 4.0 | 4 | 3.0 | 3 | | | | | | | | |
| | | | 24 | | | | 24 | | | | | | | | | | | | | | | | | | |
| Coke | 110 | | | | | 2.0 | | | | 5.0 | 5 | 3.0 | 3 | | | | | | | | | | | 75.0 | 83 |
| | | | | | | 2 | 2 | | | | | | | | | | | | | | | | | | |
| TOTALS | 1,110 | | 24 | | 155 | | 26 | | 22 | | 303 | | 104 | | 171 | | 125 | | | | | | | | 83 |

SIMN PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| Mn | 136 | 143 | 65.0 |
| Fe | 36 | 38 | 17.0 |
| Si | 33 | 35 | 16.0 |
| P | - | - | - |
| S | - | - | - |
| C | 4 | 4 | 2.0 |
| Other | - | - | - |
| | 209 | 220 | 100.0 |

SLAG PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| $SiO_2$ | 217 | 228 | 33.2 |
| $Al_2O_3$ | 99 | 104 | 15.1 |
| CaO | 162 | 171 | 24.9 |
| MgO | 119 | 125 | 18.2 |
| MnO | 44 | 46 | 6.7 |
| FeO | 12 | 13 | 1.9 |
| BaO/Other | - | - | |
| | 653 | 687 | 100.0 |

MATERIAL BALANCES

| | | | |
|---|---|---|---|
| Mn | 170/179 | = | 0.950 |
| Fe | 45/48 | = | 0.944 |
| $SiO_2$ | 288/303 | = | 0.949 |
| $Al_2O_3$ | 99/104 | = | 0.952 |
| CaO | 162/171 | = | 0.947 |
| MgO | 119/125 | = | 0.952 |

C

| | |
|---|---|
| $MnO_2/MnO$ | 5.2 |
| MnO/Mn | 31.2 |
| $Fe_2O_3/FeO$ | 2.8 |
| FeO/Fe | 8.1 |
| $SiO_2/Si$ | 30.0 |
| C in Metal | 4.0 |
| | 81.3 |

81.3/.75 = 108.4 (Use 110)

PROCESS RATIOS

| | |
|---|---|
| Slag/t (653/209)1000 | = 3,124 kg |
| Slag Ratio $CaO + MgO + MnO/SiO_2$ | = 1.79 |
| Coke/t (110/209)1000 | = 526 kg |
| Coke to Mix % (110/1110)100 | = 9.9 |
| $SiO_2$/t | = - |
| $SiO_2$ to Mix % | = - |
| Dolomite/t | - |
| Dolomite to Mix % | - |
| Mn/Fe Slag | = 3.7 |

TABLE 6-101
DR + OAEF + SAEF

Mn ORE 2.0 Mn/Fe

Semi-Steel + FeMn + SiMn

METALLURGICAL DATA

| | OAEF Semi-Steel | SAEF FeMn | SAEF SiMn |
|---|---|---|---|
| Operating Load - KWh | 10,000 | 10,000 | 10,000 |
| Operating Time - % | 37 | 94 | 94 |
| Avg. Load - KW | 3,720 | 9,400 | 9,400 |
| KWH/Kg Metal | 3.12 | 3.29 | 4.94 |
| KWH/t Metal | 3,120 | 3,290 | 4,940 |
| % Mn | 0.44 | 75.0 | 65.0 |
| % Fe | 98.24 | 16.0 | 17.0 |
| % Si | - | 1.5 | 16.0 |
| % C | 0.04 | 6.5 | 2.0 |
| Electrode Paste - Kg/t | 7 | 25 | 35 |

TABLE 6-102

DR + OAEF + SAEF

MN ORE - 2.0 MN/FE

SEMI-STEEL + FEMN + SIMN

## CAMPAIGN PROGRAM

| | |
|---|---|
| 1000 kg Mn ore 2.0 Mn/Fe | 737 kg reduced ore |
| 1000 kg reduced ore 2.0 Mn/Fe | 185 kg semi-steel + 933 kg high Mn slag |
| 650 kg high Mn slag<br>350 kg Mn ore 2.0 Mn/Fe | 353 kg FeMn +<br>523 kg final slag |

## HOURLY PRODUCTION

| | | |
|---|---|---|
| Semi-steel | 7,302 t/y/8760 x .70 | = 1.19 t/h |
| High Mn slag | 1.19 x 933/185 | = 6.00 t/h |
| FeMn | 9400/(2500 + 790) | = 2.86 t/h |
| Low Mn slag | 2.86 x 558/353 | = 4.52 t/h |
| SiMn | 9400/(4000 + 940) | = 1.90 t/h |

## ANNUAL PRODUCTION - FeMn 291d/9.6 mo SiMn 74d/2.4 mo

| | | | |
|---|---|---|---|
| High Mn slag | 20,000 t/y FeMn x 650/353 | | = 36,827 t/y |
| Semi-steel | 36,827 x 185/933 | | = 7,302 t/y |
| FeMn | 20,000/2.86 x 24 | | = 291 d/y |
| | 2.86 x 291 x 24 | | = 20,000 t/y |
| SiMn | 1.90 x 74 x 24 | | = 3,374 t/y |
| Low Mn slag req'd | 3,374 x 700/280 | | = 8,436 t/y |
| Reduced ore req'd | 7,302 x 1000/185 | | = 39,470 t/y |
| Ore req'd | 39,470 x 1000/737 | = 53,555 | |
| | 20,000 x 350/353 | = 19,830 | |
| | 3,374 x 300/280 | = 3,615 | |
| | | | 77,000 t/y |
| Coke req'd | 20,000 x 180/353 | = 10,198 | |
| | 3,374 x 170/280 | = 2,049 | |
| | | | 12,247 t/y |
| Total slag | 20,000 x 558/353 | = 31,615 | |
| | | - 8,436 | |
| | 3,374 x 523/280 | = 6,302 | |
| | | | 29,481 t/y |

TABLE 6-103

DR + OAEF + SAEF

MN ORE - 2.0 MN/FE

SEMI-STEEL + FEMN + SIMN

SUMMARY - RAW MATERIAL REQUIREMENTS

| | kg/batch | kg/t semi-steel | t/d | t/y 365 d 12 mo |
|---|---|---|---|---|
| Mn Ore - 2.0 Mn/Fe | - | - | (147) | (53,555) |
| Reduced ore | 1,000 | 5,405 | 108 | 39,470 |
| Quartzite | 150 | 811 | 16 | 5,921 |
| Coke | - | | | |
| TOTAL | 1,150 | 6,216 | 124 | 45,391 |
| Semi-steel | 185 | 1,000 | 20 | 7,302 |
| High Mn slag | 933 | 5,043 | 101 | 36,827 |

| | kg/batch | kg/t FeMn | t/d | t/y 291 d 9.6 mo |
|---|---|---|---|---|
| High Mn slag | 650 | 1,841 | 127 | 36,827 |
| Mn ore 2.0 Mn/Fe | 350 | 992 | 68 | 19,830 |
| Dolomite | 150 | 425 | 29 | 8,489 |
| Coke | 180 | 510 | 35 | 10,198 |
| TOTAL | 1,330 | 3,768 | 259 | 75,344 |
| FeMn | 353 | 1,000 | 69 | 20,000 |
| Low Mn slag | 558 | 1,581 | 109 | 31,614 |

| | kg/batch | kg/t SiMn | t/d | t/y 74 d 2.4 mo |
|---|---|---|---|---|
| Low Mn slag | 700 | 2,500 | 114 | 8,436 |
| Mn ore 2.0 Mn/Fe | 300 | 1,071 | 49 | 3,615 |
| Coke | 170 | 607 | 28 | 2,049 |
| Quartzite | - | - | - | - |
| TOTAL | 1,170 | 4,178 | 191 | 14,100 |
| SiMn | 280 | 1,000 | 46 | 3,374 |
| Low Mn slag | 523 | 2,868 | 85 | 6,302 |
| Total slag | - | - | - | 29,481 |
| Total Mn ore req'd | - | - | - | 77,000 |

FeMn produced if operated for 365 days = 25,054 t/y

TABLE 6-104
DR + OAEF + SAEF - MANGANESE ORE 2.0 MN/FE - SEMI-STEEL + FEMN + SIMN

| Material | Wt/Chge kg | $MnO_2$ %/kg | Mn %/kg | MnO %/kg | Mn %/kg | $Fe_2O_3$ %/kg | Fe %/kg | FeO %/kg | Fe %/kg | $SiO_2$ % | kg | $Al_2O_3$ % | kg | CaO % | kg | MgO % | kg | BaO % | kg | P % | kg | S % | kg | C % | kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reduced Ore 2.0 Mn/Fe | 1,000 | | | | 43.1 | | | | 20.6 | 11.6 | 116 | 5.2 | 52 | 5.2 | 52 | 3.9 | 39 | | | | | | | | |
| | | | | | 431 | | | | 206 | | | | | | | | | | | | | | | | |
| Quartzite | 150 | | | | | | | | | 99.0 | 149 | 1.0 | 1 | | | | | | | | | | | | |
| TOTALS | 1,150 | | | | 431 | | | | 206 | | 265 | | 53 | | 52 | | 39 | | | | | | | | |

SEMI-STEEL PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| Mn | 1 | 1 | 0.44 |
| Fe | 182 | 192 | 98.24 |
| Si | - | - | - |
| P | - | - | - |
| S | - | - | - |
| C | - | - | 0.04 |
| Other | 2 | 2 | 1.28 |
| | 185 | 195 | 100.00 |

SLAG PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| $SiO_2$ | 252 | 265 | 26.9 |
| $Al_2O_3$ | 50 | 53 | 5.4 |
| CaO | 49 | 52 | 5.3 |
| MgO | 37 | 39 | 4.0 |
| MnO | 528 | 556 | 56.6 |
| FeO | 17 | 18 | 1.8 |
| BaO/Other | - | - | - |
| | 933 | 983 | 100.0 |

MATERIAL BALANCES

| | | | |
|---|---|---|---|
| Mn | 410/431 | = | 0.951 |
| Fe | 195/206 | = | 0.948 |
| $SiO_2$ | 252/265 | = | 0.951 |
| $Al_2O_3$ | 50/53 | = | 0.943 |
| CaO | 49/52 | = | 0.942 |
| MgO | 37/39 | = | 0.949 |

PROCESS RATIOS

| | | |
|---|---|---|
| Slag/t (933/185)1000 | = | 5043 kg |
| Slag Ratio $CaO + MgO + MnO/SiO_2$ | = | 2.20 |
| Coke/t | | - |
| Coke to Mix % | | - |
| $SiO_2$/t (150/185)1000 | = | 811 kg |
| $SiO_2$ to Mix % (150/1150)100 | = | 13.0 |
| Dolomite/t | | - |
| Dolomite to Mix % | | - |
| Mn/Fe Slag | | 30.9 |

TABLE 6-105
DR + OAEF + SAEF - MANGANESE ORE 2.0 MN/FE - SEMI-STEEL + FEMN + SIMN

| Material | Wt/Chge kg | $MnO_2$ %/kg | Mn %/kg | MnO %/kg | Mn %/kg | $Fe_2O_3$ %/kg | Fe %/kg | FeO %/kg | Fe %/kg | $SiO_2$ % | kg | $Al_2O_3$ % | kg | CaO % | kg | MgO % | kg | BaO % | kg | P % | kg | S % | kg | C % | kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| High Mn Slag | 650 | | | 56.6 | | | | 1.8 | | 26.9 | 175 | 5.4 | 35 | 5.3 | 34 | 4.0 | 26 | | | | | | | | |
| | | | | 368 | 285 | | | 12 | 9 | | | | | | | | | | | | | | | | |
| Mn Ore 2.0 Mn/Fe | 350 | | 32.0 | | | | 16.0 | | | 9.0 | 32 | 4.0 | 14 | 4.0 | 14 | 3.0 | 11 | | | | | | | | |
| | | | 112 | | | | 56 | | | | | | | | | | | | | | | | | | |
| Coke | 180 | | | | | 2.0 | | | | 5.0 | 9 | 3.0 | 5 | | | | | | | | | | | 75.0 | 135 |
| | | | | | | 4 | 3 | | | | | | | | | | | | | | | | | | |
| Dolomite | 150 | | | | | | | | | 2.0 | 3 | | | 30.2 | 45 | 21.0 | 32 | | | | | | | | |
| TOTALS | 1,330 | | 112 | | 285 | | 59 | | 9 | | 219 | | 54 | | 93 | | 69 | | | | | | | | 135 |

FEMN PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| Mn | 264 | 278 | 75.0 |
| Fe | 56 | 59 | 16.0 |
| Si | 6 | 6 | 1.5 |
| P | - | - | - |
| S | - | - | - |
| C | 23 | 24 | 6.5 |
| Other | 4 | 4 | 1.0 |
| | 353 | 371 | 100.0 |

SLAG PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| $SiO_2$ | 196 | 206 | 35.0 |
| $Al_2O_3$ | 51 | 54 | 9.2 |
| CaO | 88 | 93 | 15.8 |
| MgO | 66 | 69 | 11.7 |
| MnO | 146 | 154 | 26.2 |
| FeO | 11 | 12 | 2.1 |
| BaO/Other | - | - | - |
| | 558 | 588 | 100.0 |

MATERIAL BALANCES

| | | | |
|---|---|---|---|
| Mn | 377/397 | = | 0.950 |
| Fe | 65/68 | = | 0.949 |
| $SiO_2$ | 209/219 | = | 0.954 |
| $Al_2O_3$ | 51/54 | = | 0.944 |
| CaO | 88/93 | = | 0.946 |
| MgO | 66/69 | = | 0.956 |

C

| | |
|---|---|
| $MnO_2$/MnO | 24.4 |
| MnO/Mn | 60.7 |
| $Fe_2O_3$/FeO | 6.3 |
| FeO/Fe | 12.6 |
| $SiO_2$/Si | 5.1 |
| C in Metal | 24.0 |
| | 133.1 |

133.1/.75 = 177.5 (Use 180)

PROCESS RATIOS

| | | | |
|---|---|---|---|
| Slag/t | (558/353)1000 | = | 1581 kg |
| Slag Ratio | CaO + MgO + MnO/$SiO_2$ | = | 1.62 |
| Coke/t | (180/353)1000 | = | 510 kg |
| Coke to Mix % | (180/1330)100 | = | 13.5 |
| $SiO_2$/t | | | - |
| $SiO_2$ to Mix % | | | - |
| Dolomite/t | (150/353)1000 | = | 425 kg |
| Dolomite to Mix % | (130/1330)100 | = | 9.8 |
| Mn/Fe slag | | | 13.2 |

TABLE 6-106
DR + OAEF + SAEF - MANGANESE ORE 2.0 MN/FE - SEMI-STEEL + FEMN + SIMN

| Material | Wt/Chge kg | $MnO_2$ %/kg | Mn %/kg | MnO %/kg | Mn %/kg | $Fe_2O_3$ %/kg | Fe %/kg | FeO %/kg | Fe %/kg | $SiO_2$ % | kg | $Al_2O_3$ % | kg | CaO % | kg | MgO % | kg | BaO % | kg | P % | kg | S % | kg | C % | kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Low Mn Slag | 700 | | | 26.2 | | | | 2.1 | | 35.0 | 245 | 9.2 | 64 | 15.8 | 111 | 11.7 | 82 | | | | | | | | |
| | | | | 183 | 142 | | | 15 | 11 | | | | | | | | | | | | | | | | |
| Mn Ore 2.0 Mn/Fe | 300 | | 32.0 | | | | 16.0 | | | 9.0 | 27 | 4.0 | 12 | 4.0 | 12 | 3.0 | 9 | | | | | | | | |
| | | | 96 | | | | 48 | | | | | | | | | | | | | | | | | | |
| Coke | 170 | | | | | 2.0 | | | | 5.0 | 9 | 3.0 | 5 | | | | | | | | | | | 75.0 | 128 |
| | | | | | | 3 | 2 | | | | | | | | | | | | | | | | | | |
| TOTALS | 1,170 | | 96 | | 142 | | 50 | | 11 | | 281 | | 81 | | 123 | | 91 | | | | | | | | 128 |

SIMN PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| Mn | 181 | 190 | 65.0 |
| Fe | 48 | 50 | 17.0 |
| Si | 45 | 47 | 16.0 |
| P | - | - | - |
| S | - | - | - |
| C | 6 | 6 | 2.0 |
| Other | - | - | - |
| | 280 | 293 | 100.0 |

SLAG PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| $SiO_2$ | 171 | 180 | 32.7 |
| $Al_2O_3$ | 77 | 81 | 14.7 |
| CaO | 117 | 123 | 22.3 |
| MgO | 86 | 91 | 16.5 |
| MnO | 59 | 62 | 11.3 |
| FeO | 13 | 14 | 2.5 |
| BaO/Other | - | - | - |
| | 523 | 551 | 100.0 |

MATERIAL BALANCES

| | | | |
|---|---|---|---|
| Mn | 227/238 | = | 0.954 |
| Fe | 58/61 | = | 0.953 |
| Si | 267/281 | = | 0.952 |
| $Al_2O_3$ | 77/81 | = | 0.951 |
| CaO | 117/123 | = | 0.951 |
| MgO | 86/91 | = | 0.945 |

C

| | |
|---|---|
| $MnO_2/MnO$ | 20.9 |
| MnO/Mn | 41.5 |
| $Fe_2O_3/FeO$ | 5.4 |
| FeO/Fe | 10.7 |
| $SiO_2/Si$ | 40.3 |
| C in Metal | 6.0 |
| | 124.8 |
| 124.8/.75 = 166.- | (Use 170) |

PROCESS RATIOS

| | |
|---|---|
| Slag/t (523/280)1000 | = 1868 kg |
| Slag Ratio CaO + MgO + MnO/$SiO_2$ | = 1.78 |
| Coke/t (170/280)1000 | = 607 kg |
| Coke to Mix % (170/1170)100 | = 14.5 |
| $SiO_2$/t | - |
| $SiO_2$ to Mix % | - |
| Dolomite/t | - |
| Dolomite to Mix % | - |
| Mn/Fe Slag | 4.5 |

TABLE 6-107

DR + CAEF + SAEF

Mn ORE 3.0 Mn/Fe

Semi-Steel + FeMn + SiMn

METALLURGICAL DATA

| | OAEF Semi-steel | SAEF FeMn | SAEF SiMn |
|---|---|---|---|
| Operating Load - KWh | 10,000 | 10,000 | 10,000 |
| Operating Time - % | 27 | 94 | 94 |
| Avg. Load - KW | 2,660 | 9,400 | 9,400 |
| KWh/Kg Metal | 4.09 | 3.19 | 4.66 |
| KWh/t Metal | 4,090 | 3,190 | 4,660 |
| % Mn | 0.44 | 75.0 | 65.0 |
| % Fe | 98.24 | 16.0 | 17.0 |
| % Si | - | 1.5 | 16.0 |
| % C | 0.04 | 6.5 | 2.0 |
| Electrode Paste - Kg/t | 7 | 25 | 35 |

TABLE 6-108
DR + OAEF + SAEF

Mn Ore 3.0 Mn/Fe

Semi-Steel + FeMn + SiMn

CAMPAIGN PROGRAM

| | |
|---|---|
| 1000 kg Mn ore 3.0 Mn/Fe | 748 kg reduced ore |
| 1000 kg reduced ore 3.0 Mn/Fe | 137 kg semi-steel +<br>956 kg high Mn slag |
| 500 kg high Mn slag<br>500 kg Mn ore 3.0 Mn/Fe | 361 kg FeMn +<br>498 kg low Mn slag |
| 600 kg low Mn slag<br>400 kg Mn ore 3.0 Mn/Fe | 331 kg SiMn +<br>438 kg final slag |

HOURLY PRODUCTION

| | | | |
|---|---|---|---|
| Semi-steel | 3970 t/y/8760 x .70 | = | 0.65 t/h |
| High Mn slag | 0.65 x 956/137 | = | 4.52 t/h |
| FeMn | 9400/(2500 + 690) | = | 2.95 t/h |
| Low Mn slag | 2.95 x 498/361 | = | 4.06 t/h |
| SiMn | 9400/(4000 + 660) | = | 2.02 t/h |

ANNUAL PRODUCTION - FeMn 282d/9.3 mo SiMn 83d/2.7 mo

| | | | |
|---|---|---|---|
| High Mn slag | 20,000 t/y FeMn x 500/361 | = | 27,701 t/y |
| Semi-steel | 27,701 x 137/956 | = | 3,970 t/y |
| FeMn | 20,000/2.95 x 24 | = | 282 d |
| | 2.95 x 282 x 24 | = | 20,000 t/y |
| SiMn | 2.02 x 83 x 24 | = | 4,024 t/y |
| Low Mn slag req'd | 4,024 x 600/331 | = | 7,294 t/y |
| Reduced ore req'd | 3,970 x 1000/137 | = | 28,978 t/y |
| Ore req'd | 28,978 x 1000/748 = 38,741 | | |
| | 20,000 x 500/361 = 27,701 | | |
| | 4,024 x 400/331 = 4,863 | | |
| | | | 71,305 t/y |
| Coke req'd | 20,000 x 210/361 = 11,634 | | |
| | 4,024 x 210/ 331 = 2,553 | | |
| | | | 14,187 t/y |
| Total slag | 20,000 x 498/361 = 27,590 | | |
| | - 7,294 | | |
| | 4,024 x 438/331 = 5,325 | | |
| | | | 25,621 t/y |

TABLE 6-109

DR + OAEF + SAEF

Mn Ore - 3.0 Mn/Fe

Semi-Steel + FeMn + SiMn

SUMMARY - RAW MATERIAL REQUIREMENTS

| | kg/batch | kg/t semi-steel | t/d | t/y 365 d 12 mo |
|---|---|---|---|---|
| Mn ore 3.0 Mn/Fe | - | - | 106 | 38,741 |
| Reduced ore | 1,000 | 7,299 | 79 | 28,978 |
| Quartzite | 150 | 1,095 | 12 | 4,364 |
| Coke | - | - | - | - |
| TOTAL | 1,150 | 8,394 | 91 | 33,342 |
| Semi-steel | 137 | 1,000 | 11 | 3,970 |
| High Mn slag | 956 | 6,985 | 76 | 27,701 |

| | kg/batch | kg/t FeMn | t/d | t/y 282 d 9.3 mo |
|---|---|---|---|---|
| High Mn slag | 500 | 1,385 | 98 | 27,701 |
| Mn ore 3.0 Mn/Fe | 500 | 1,385 | 98 | 27,701 |
| Dolomite | 100 | 277 | 20 | 5,540 |
| Coke | 210 | 582 | 41 | 11,634 |
| TOTAL | 1,310 | 3,629 | 257 | 72,576 |
| FeMn | 361 | 1,000 | 71 | 20,000 |
| Low Mn slag | 498 | 1,380 | 98 | 27,590 |

| | kg/batch | kg/t SiMn | t/d | t/y 83 d 2.7 mo |
|---|---|---|---|---|
| Low Mn slag | 600 | 1,813 | 88 | 7,294 |
| Mn ore 3.0 Mn/Fe | 400 | 1,209 | 58 | 4,863 |
| Coke | 210 | 634 | 31 | 2,553 |
| Quartzite | - | - | - | - |
| TOTAL | 1,210 | 3,656 | 177 | 14,710 |
| SiMn | 331 | 1,000 | 48 | 4,024 |
| Low Mn slag | 438 | 1,323 | 64 | 5,325 |
| Total slag | - | - | - | 25,621 |
| Total Mn ore req'd | - | - | - | 71,305 |

FeMn produced if operated for 365 days = 25,842 t/y

TOTAL 6-110

DR + OAEF + SAEF - MANGANESE ORE 3.0 MN/FE - SEMI-STEEL + FEMN + SIMN

| Material | Wt/Chge kg | $MnO_2$ %/kg | Mn %/kg | MnO %/kg | Mn %/kg | $Fe_2O_3$ %/kg | Fe %/kg | FeO %/kg | Fe %/kg | $SiO_2$ % | kg | $Al_2O_3$ % | kg | CaO % | kg | MgO % | kg | BaO % | kg | P % | kg | S % | kg | C % | kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reduced Ore 3.0 Mn/Fe | 1,000 | | | | 45.7 | | | | 15.2 | 11.4 | 114 | 5.1 | 51 | 5.1 | 51 | 3.8 | 38 | | | | | | | | |
| | | | | | 457 | | | | 152 | | | | | | | | | | | | | | | | |
| Quartzite | 150 | | | | | | | | | 99.0 | 149 | 1.0 | 1 | | | | | | | | | | | | |
| TOTALS | 1,150 | | | | 457 | | | | 152 | | 263 | | 52 | | 51 | | 38 | | | | | | | | |

SEMI-STEEL PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| Mn | 1 | 1 | 0.44 |
| Fe | 134 | 141 | 98.24 |
| Si | - | - | - |
| P | - | - | - |
| S | - | - | - |
| C | - | - | 0.04 |
| Other | 2 | 2 | 1.28 |
| | 137 | 144 | 100.00 |

SLAG PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| $SiO_2$ | 250 | 263 | 26.1 |
| $Al_2O_3$ | 49 | 52 | 5.2 |
| CaO | 48 | 51 | 5.1 |
| MgO | 36 | 38 | 3.8 |
| MnO | 560 | 589 | 58.4 |
| FeO | 13 | 14 | 1.4 |
| BaO/Other | - | - | - |
| | 956 | 1,007 | 100.0 |

MATERIAL BALANCES

| | kg Product/kg Feed | | Unit Recovery |
|---|---|---|---|
| Mn | 435/457 | = | 0.951 |
| Fe | 144/152 | = | 0.948 |
| $SiO_2$ | 250/263 | = | 0.951 |
| $Al_2O_3$ | 49/52 | = | 0.942 |
| CaO | 48/51 | = | 0.941 |
| MgO | 36/38 | = | 0.947 |

PROCESS RATIOS

| | | |
|---|---|---|
| Slag/t (956/137)1000 | = | 6978 kg |
| Slag Ratio $CaO + MgO + MnO/SiO_2$ | = | 2.32 |
| Coke/t | | - |
| Coke to Mix % | | - |
| $SiO_2$/t (150/137)1000 | = | 1095 kg |
| $SiO_2$ to Mix % (150/1150)1000 | = | 13.0 |
| Dolomite/t | | - |
| Dolomite to Mix % | | - |
| Mn/Fe Slag | | 42.9 |

TABLE 6-111
DR + OAEF + SAEF - MANGANESE ORE 3.0 MN/FE - SEMI-STEEL + FEMN + SIMN

| Material | Wt/Chge kg | $MnO_2$ %/kg | Mn %/kg | MnO %/kg | Mn %/kg | $Fe_2O_3$ %/kg | Fe %/kg | FeO %/kg | Fe %/kg | $SiO_2$ % | kg | $Al_2O_3$ % | kg | CaO % | kg | MgO % | kg | BaO % | kg | P % | kg | S % | kg | C % | kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| High Mn slag | 500 | | | 58.4 | 292 | | | 1.4 | 7 | 26.1 | 131 | 5.2 | 26 | 5.2 | 26 | 3.8 | 19 | | | | | | | | |
| Mn ore 3.0 Mn/Fe | 500 | 36.0 | 180 | | | | 12.0 | 60 | | 9.0 | 45 | 4.0 | 20 | 4.0 | 20 | 3.0 | 15 | | | | | | | | |
| Coke | 210 | | | | | 2.0 | 4 | | | 5.0 | 11 | 3.0 | 6 | | | | | | | | | | | 75.0 | 158 |
| Dolomite | 100 | | | | | | | | | 2.0 | 2 | | | 30.2 | 33 | 21.0 | 21 | | | | | | | | |
| TOTAL | 1,310 | | 180 | | 226 | | 63 | | 5 | | 189 | | 52 | | 79 | | 55 | | | | | | | | 158 |

FEMN PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| Mn | 270 | 284 | 75.0 |
| Fe | 58 | 61 | 16.0 |
| Si | 6 | 6 | 1.5 |
| P | - | - | - |
| S | - | - | - |
| C | 23 | 24 | 6.5 |
| Other | 4 | 4 | 1.0 |
| | 361 | 379 | 100.0 |

SLAG PRODUCT

| | kg | Initial kg | Initial % |
|---|---|---|---|
| $SiO_2$ | 167 | 176 | 33.5 |
| $Al_2O_3$ | 49 | 52 | 9.9 |
| CaO | 72 | 76 | 14.5 |
| MgO | 52 | 55 | 10.5 |
| MnO | 149 | 157 | 29.9 |
| FeO | 9 | 9 | 1.7 |
| BaO/Other | - | - | - |
| | 498 | 525 | 100.0 |

MATERIAL BALANCES

| | | | |
|---|---|---|---|
| Mn | 385/406 | = | 0.948 |
| Fe | 60/63 | = | 0.950 |
| $SiO_2$ | 180/189 | = | 0.952 |
| $Al_2O_3$ | 49/52 | = | 0.942 |
| CaO | 72/76 | = | 0.947 |
| MgO | 52/55 | = | 0.945 |
| C | | | |
| $MnO_2/MnO$ | 39.5 | | |
| MnO/Mn | 62.0 | | |
| $Fe_2O_3/FeO$ | 0.8 | | |
| FeO/Fe | 17.1 | | |
| $SiO_2/Si$ | 5.1 | | |
| C in Metal | 24.0 | | |
| | 150.3 | | |
| 150.3/.75 = 200.4 | (Use 210) | | |

PROCESS RATIOS

| | | | |
|---|---|---|---|
| Slag/t | (498/361)1000 | = | 1380 kg |
| Slag Ratio | CaO + MgO + MnO/$SiO_2$ | = | 1.68 |
| Coke/t | (210/361)1000 | = | 582 kg |
| Coke to Mix % | (210/1310)100 | = | 16.0 |
| $SiO_2$/t | | | - |
| $SiO_2$ to Mix % | | | - |
| Dolomite/t | (100/361)1000 | = | 277 kg |
| Dolomite to Mix % | (100/1310)100 | = | 7.6 |
| Mn/Fe Slag | | | 16.5 |

TABLE 6-112
DR + OAEF + SAEF - MANGANESE ORE 3.0 MN/FE - SEMI-STEEL + FEMN + SIMN

| Material | Wt/Chge kg | $MnO_2$ %/kg | Mn %/kg | MnO %/kg | Mn %/kg | $Fe_2O_3$ %/kg | Fe %/kg | FeO %/kg | Fe %/kg | $SiO_2$ % | kg | $Al_2O_3$ % | kg | CaO % | kg | MgO % | kg | BaO % | kg | P % | kg | S % | kg | C % | kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Low Mn Slag | 600 | | | 29.9 | | | | 1.7 | | 33.5 | 201 | 9.9 | 59 | 14.5 | 87 | 10.5 | 63 | | | | | | | | |
| | | | | 179 | 139 | | | 10 | 8 | | | | | | | | | | | | | | | | |
| Mn Ore 3.0 Mn/Fe | 400 | | 36.0 | | | | 12.0 | | | 9.0 | 36 | 4.0 | 16 | 4.0 | 16 | 3.0 | 12 | | | | | | | | |
| | | | 144 | | | | 48 | | | | | | | | | | | | | | | | | | |
| Coke | 210 | | | | | 2.0 | | | | 5.0 | 11 | 3.0 | 6 | | | | | | | | | | | 75.0 | 158 |
| | | | | | | 4 | | | | | | | | | | | | | | | | | | | |
| | | | | | | | 3 | | | | | | | | | | | | | | | | | | |
| TOTALS | 1,210 | | 144 | | 139 | | 51 | | 8 | | 248 | | 81 | | 103 | | 75 | | | | | | | | 158 |

SIMN PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| Mn | 215 | 226 | 65.0 |
| Fe | 56 | 59 | 17.0 |
| Si | 53 | 56 | 16.0 |
| P | - | - | - |
| S | - | - | - |
| C | 7 | 7 | 2.0 |
| Other | - | - | - |
| | 331 | 348 | 100.0 |

SLAG PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| $SiO_2$ | 122 | 128 | 27.8 |
| $Al_2O_3$ | 77 | 81 | 17.6 |
| CaO | 98 | 103 | 22.3 |
| MgO | 71 | 75 | 16.3 |
| MnO | 70 | 74 | 16.0 |
| FeO | - | - | - |
| BaO/Other | - | - | - |
| | 438 | 461 | 100.0 |

MATERIAL BALANCES

| | | | |
|---|---|---|---|
| Mn | 269/283 | = | 0.951 |
| Fe | 56/59 | = | 0.949 |
| $SiO_2$ | 236/248 | = | 0.950 |
| $Al_2O_3$ | 77/81 | = | 0.951 |
| CaO | 98/103 | = | 0.952 |
| MgO | 71/75 | = | 0.947 |

C

| | |
|---|---|
| $MnO_2$/MnO | 31.4 |
| MnO/Mn | 49.3 |
| $Fe_2O_3$/FeO | 5.5 |
| FeO/Fe | 12.6 |
| $SiO_2$/Si | 48.0 |
| C in Metal | 7.0 |
| | 153.8 |

153.8/.75 = 205.1 (Use 210)

PROCESS RATIO.

| | |
|---|---|
| Slag/t (438/331)1000 | = 1323 kg |
| Slag Ratio CaO + MgO + MnO/$SiO_2$ | 2.22 |
| Coke/t (210/331)1000 | = 634 kg |
| Coke to Mix % (210/1210)100 | = 17.4 |
| $SiO_2$/t | - |
| $SiO_2$ to Mix % | - |
| Dolomite/t | - |
| Dolomite to Mix % | - |
| Mn/Fe Slag | - |

## SPIEGELEISEN

Metallurgical balances and summary tables were prepared to illustrate the type and quantity of ferroalloys (spiegeleisen) produced by directly treating low grade ferruginous manganese ores in the smelter furnace without the initial stage of iron removal.

The low manganese contents of the spiegeleisen obtained by direct smelting did not meet the minimum standards of 70% Mn for a marketable FeMn, therefore, spiegeleisen production was not pursued.

TABLE 6-113

SUMMARY - OPERATING ALTERNATIVES

SPIEGELEISEN

| Description | FeMn t/y | Pig Iron t/y | SiMn t/y | Semi-Steel t/y | Total Mn Ore t/y | Reduced Ore t/y | Coke t/y | Electric Power GW/y | Natural Gas Mm3/y | Electrode Carbon t/y | Spiegeleisen t/y |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mn Ore - 0.6 Mn/Fe | - | - | - | - | 62150 | - | 19267 | 82.3 | - | 220 | 31448 |
| Mn Ore - 1.0 Mn/Fe | - | - | - | - | 75978 | - | 19754 | 82.3 | - | 216 | 30923 |

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SUMMARY - OPERATING ALTERNATIVES

SPIEGELEISEN

TABLE 6-114

SAEF

MN ORE - 0.6 MN/FE

SPIEGELEISEN

| METALLURGICAL DATA | SPIEGELEISEN |
|---|---|
| Operating Load - kW | 1,000 |
| Operating Time - % | 94 |
| Avg. Load - kW | 9,400 |
| kWh/kg Metal | 2.62 |
| kWh/t Metal | 2,620 |
| | |
| % Mn | 28.4 |
| % Fe | 65.0 |
| % Si | 0.9 |
| % C | 5.7 |
| Electrode Paste - kg/t | 7 |

TABLE 6 -115

SAEF

MN ORE - 0.6 MN/FE

SPIEGELEISEN

CAMPAIGN PROGRAM

| | |
|---|---|
| 1000 kg Mn ore 0.6 Mn/Fe | 506 kg Spiegeleisen<br>227 kg low Mn slag |

HOURLY PRODUCTION

| | | | |
|---|---|---|---|
| Spiegeleisen | 9400/(2500 + 120) | = | 3.59 t/h |
| Low Mn slag | 3.59 x 227/506 | = | 1.61 t/h |

ANNUAL PRODUCTION

| | | | |
|---|---|---|---|
| Spiegeleisen | 3.59 x 365 x 24 | = | 31,448 t/y |
| Low Mn slag | 1.61 x 365 x 24 | = | 14,100 t/y |
| Ore req'd | 31,448 x 1000/506 | = | 62,150 t/y |
| Coke req'd | 31,448 x 310/506 | = | 19,267 t/y |

TABLE 6-116
SAEF
MN ORE - 0.6 MN/FE
SPIEGELEISEN

SUMMARY - RAW MATERIAL REQUIREMENTS

| | kg/ batch | kg/t Spiegeleisen | t/d | t/y 365 d 12 mo |
|---|---|---|---|---|
| Mn Ore - 0.6 Mn/Fe | 1,000 | 1,976 | 170 | 62,150 |
| Coke | 310 | 613 | 53 | 19,267 |
| Dolomite | 50 | 99 | 9 | 3,113 |
| TOTAL | 1,360 | 2,688 | 232 | 84,530 |
| Spiegeleisen | 506 | 1,000 | 86 | 31,448 |
| Low Mn Slag | 227 | 449 | 39 | 14,100 |

TABLE 6-117
SAEF - MANGANESE ORE 0.6 MN/FE - SPIEGELEISEN

| Material | Wt/Chge kg | $MnO_2$ %/kg | Mn %/kg | MnO %/kg | Mn %/kg | $Fe_2O_3$ %/kg | Fe %/kg | FeO %/kg | Fe %/kg | $SiO_2$ % | kg | $Al_2O_3$ % | kg | CaO % | kg | MgO % | kg | BaO % | kg | P % | kg | S % | kg | C % | kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mn Ore 0.6 Mn/Fe | 1,000 | 32.76 | | 0.97 | | 51.47 | | | | 5.80 | 58 | 2.38 | 24 | 0.78 | 8 | 0.10 | 1 | 0.11 | 1 | 0.10 | 1 | 0.10 | 1 | 0.02 | - |
| | | 328 | 207 | 10 | 8 | 515 | 360 | | | | | | | | | | | | | | | | | | |
| Coke | 310 | | | | | 2.0 | | | | 5.0 | 16 | 3.0 | 9 | | | | | | | | | | | 75.0 | 233 |
| | | | | | | 6 | 4 | | | | | | | | | | | | | | | | | | |
| Dolomite | 50 | | | | | | | | | 2.0 | 1 | | | 30.2 | 15 | 21.0 | 11 | | | | | | | | |
| TOTALS | 1,360 | | 207 | | 8 | | 364 | | | | 75 | | 33 | | 23 | | 12 | | 1 | | 1 | | 1 | | 233 |

SPIEGELEISEN PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| Mn | 143 | 151 | 28.4 |
| Fe | 329 | 346 | 65.0 |
| Si | 5 | 5 | 0.9 |
| P | - | - | - |
| S | - | - | - |
| C | 29 | 30 | 5.7 |
| Other | - | - | - |
| | 506 | 532 | 100.0 |

SLAG PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| $SiO_2$ | 61 | 64 | 26.8 |
| $Al_2O_3$ | 31 | 33 | 13.8 |
| CaO | 22 | 23 | 9.6 |
| MgO | 11 | 12 | 5.0 |
| MnO | 79 | 83 | 34.8 |
| FeO | 22 | 23 | 9.6 |
| BaO/Other | 1 | 1 | 0.4 |
| | 227 | 239 | 100.0 |

MATERIAL BALANCES

| | | | |
|---|---|---|---|
| Mn | 204/215 | = | 0.950 |
| Fe | 346/364 | = | 0.951 |
| $SiO_2$ | 72/75 | = | 0.956 |
| $Al_2O_3$ | 31/33 | = | 0.939 |
| CaO | 22/23 | = | 0.957 |
| MgO | 11/12 | = | 0.917 |
| C | | | |
| $MnO_2/MnO$ | 45.2 | | |
| MnO/Mn | 32.9 | | |
| $Fe_2O_3/FeO$ | 39.0 | | |
| FeO/Fe | 74.1 | | |
| $SiO_2/Si$ | 4.3 | | |
| C in Metal | 30.0 | | |
| | 225.5 | | |

225.5/.75 = 300.7 (Use 310 kg/t)

PROCESS RATIOS

| | | | |
|---|---|---|---|
| Slag/t (227/506)1000 | = | 449 kg |
| Slag Ratio $CaO + MgO + MnO/SiO_2$ | = | 1.76 |
| Coke/t (310/506)1000 | = | 613 kg |
| Coke to Mix % (310/1360)100 | = | 22.8 |
| $SiO_2$/t | | - |
| $SiO_2$ to Mix % | | - |
| Dolomite/t (50/506)1000 | = | 99 kg |
| Dolomite to Mix % (50/1360)100 | = | 3.7 |
| Mn/Fe Slag | | 3.6 |

TABLE 6-118
SAEF
MN ORE - 1.0 MN/FE
SPIEGELEISEN

METALLURGICAL DATA

| | Spiegeleisen |
|---|---|
| Operating Load - kW | 10,000 |
| Operating Time - % | 94 |
| Avg. Load - kW | 9,400 |
| kWh/kg Metal | 2.66 |
| kWh/t Metal | 2,660 |
| | |
| % Mn | 39.3 |
| % Fe | 54.2 |
| % Si | 0.9 |
| % C | 5.6 |
| Electrode Paste - kg/t | 7 |

TABLE 6-119

SAEF

MN ORE 1.0 MN/FE

SPIEGELEISEN

CAMPAIGN PROGRAM

1000 kg Mn ore 0.6 Mn/Fe — 407 kg Spiegeleisen + 323 kg low Mn slag

HOURLY PRODUCTION

| | | | |
|---|---|---|---|
| Spiegeleisen | 9400/(2500 + 160) | = | 3.53 t/h |
| Low Mn slag | 3.53 x 323/407 | = | 2.80 t/h |

ANNUAL PRODUCTION

| | | | |
|---|---|---|---|
| Spiegeleisen | 3.53 x 365 x 24 | = | 30,923 t/y |
| Low Mn slag | 2.80 x 365 x 24 | = | 24,528 t/y |
| Ore req'd | 30,923 x 1000/407 | = | 75,978 t/y |
| Coke req'd | 30,923 x 260/407 | = | 19,754 t/y |

TABLE 6-120
SAEF
MN ORE 1.0 MN/FE
SPIEGELEISEN

SUMMARY - RAW MATERIAL REQUIREMENTS

| Pig Iron | kg/ batch | kg/t Iron | t/d | t/y 365 d 12 mo |
|---|---|---|---|---|
| Manganese ore 1.0 Mn/Fe | 1,000 | 2,457 | 208 | 75,978 |
| Coke | 260 | 639 | 54 | 19,754 |
| Quartzite | - | - | - | - |
| TOTAL | 1,260 | 3,096 | 262 | 95,732 |
| Spiegeleisen | 407 | 1,000 | 85 | 30,923 |
| Low Mn slag | 323 | 794 | 67 | 24,528 |

TABLE 6-121
SAEF - MANGANESE ORE 1.0 MN/FE - SPIEGELEISEN

| Material | Wt/Chge kg | $MnO_2$ %/kg | Mn %/kg | MnO %/kg | Mn %/kg | $Fe_2O_3$ %/kg | Fe %/kg | FeO %/kg | Fe %/kg | $SiO_2$ % | kg | $Al_2O_3$ % | kg | CaO % | kg | MgO % | kg | BaO % | kg | P % | kg | S % | kg | C % | kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mn Ore 1.0 Mn/Fe | 1,000 | | 24.0 | | | | 24.0 | | | 10.0 | 100 | 5.0 | 50 | 4.0 | 40 | 3.0 | 30 | | | | | | | | |
| | | | 240 | | | | 240 | | | | | | | | | | | | | | | | | | |
| Coke | 260 | | | | | 2.0 | | | | 5.0 | 13 | 3.0 | 8 | | | | | | | | | | | 75.0 | 195 |
| | | | | | | 5 | 4 | | | | | | | | | | | | | | | | | | |
| | 1,260 | | 240 | | | | 244 | | | | 113 | | 58 | | 40 | | 30 | | | | | | | | 195 |

SPIEGELEISEN PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| Mn | 160 | 168 | 39.3 |
| Fe | 220 | 232 | 54.2 |
| Si | 4 | 4 | 0.9 |
| P | - | - | - |
| S | - | - | - |
| C | 23 | 24 | 5.6 |
| Other | - | - | - |
| | 407 | 428 | 100.0 |

SLAG PRODUCED

| | kg | Initial kg | Initial % |
|---|---|---|---|
| $SiO_2$ | 99 | 104 | 30.5 |
| $Al_2O_3$ | 55 | 58 | 17.1 |
| CaO | 38 | 40 | 11.8 |
| MgO | 29 | 30 | 8.8 |
| MnO | 88 | 93 | 27.4 |
| FeO | 14 | 15 | 4.4 |
| BaO/Other | - | - | - |
| | 323 | 340 | 100.0 |

MATERIAL BALANCES

| | | | |
|---|---|---|---|
| Mn | 228/240 | = | 0.951 |
| Fe | 231/244 | = | 0.946 |
| $SiO_2$ | 108/113 | = | 0.952 |
| $Al_2O_3$ | 55/58 | = | 0.948 |
| CaO | 38/40 | = | 0.950 |
| MgO | 29/30 | = | 0.967 |

C

| | |
|---|---|
| $MnO_2/MnO$ | 15.7 |
| $MnO_2/Mn$ | 73.3 |
| $Fe_2O_3/FeO$ | 1.3 |
| $Fe_2O_3/Fe$ | 74.3 |
| $SiO_2/Si$ | 3.4 |
| C in Metal | 24.0 |
| | 192.0 |

192/.75 = 256 (Use 260 kg/t)

PROCESS RATIOS

| | | | |
|---|---|---|---|
| Slag/t | (323/407)1000 | = | 794 kg |
| Slag Ratio | CaO + MgO + MnO/$SiO_2$ | = | 1.60 |
| Coke/t | (260/407)1000 | = | 639 kg |
| Coke to Mix % | (260/1260)100 | = | 20.6 |
| $SiO_2$/t | | | - |
| $SiO_2$ to Mix % | | | - |
| Dolomite/t | | | - |
| Dolomite to Mix % | | | - |
| Mn/Fe Slag | | | 6.3 |

## IMPORTED AND HIGH GRADE ORE

In order to demonstrate potential alternates for interim operation, metallurgical balances and summary tables were prepared for processing imported and domestic high grade ores.

With a balanced production schedule using the slag produced from the ferromanganese smelting to produce silicomanganese, approximately 20,000 tonnes/year of ferromanganese can be produced.

TABLE 6-122

SUMMARY - OPERATING ALTERNATIVES

IMPORTED AND HIGH GRADE ORE

| Description | FeMn t/y | Pig Iron t/y | SiMn t/y | Semi-Steel t/y | Total Mn Ore t/y | Reduced Ore t/y | Coke t/y | Electric Power GW/y | Natural Gas Mm3/y | Electrode Carbon t/y |
|---|---|---|---|---|---|---|---|---|---|---|
| Imported Ore - 50% Mn | 19090 | - | 6835 | - | 42899 | - | 17428 | 82.3 | - | 716 |
| High Grade Ore - 51.5% Mn | 18008 | - | 7020 | - | 42889 | - | 16495 | 80.9 | - | 696 |

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[redacted] - OPERATING ALTERNATIVES

IMPORTED AND HIGH GRADE ORE

TABLE 6-123

SAEF

HIGH/LOW GRADE ORE

Primary FeMn + Secondary SiMn

METALLURGICAL DATA

| | High C FeMn | SiMn |
|---|---|---|
| Operating Load - kW | 9,000 | 11,000 |
| Operating Time - % | 94 | 94 |
| Avg. Load - kW | 8,460 | 10,340 |
| kWh/kg Alloy | 2.42 | 5.24 |
| kWh/t Alloy | 2,424 | 5,290 |
| % Mn in Metal | 75.0 | 65.0 |
| % Fe in Metal | 16.0 | 17.0 |
| % Si in Metal | 1.5 | 16.0 |
| % C in Metal | 6.5 | 2.0 |
| Electrode Paste - kg/t | 15 | 30 |

TABLE 6-124
SAEF

HIGH/LOW GRADE ORE

FEMN + SIMN

CAMPAIGN PROGRAM

| | |
|---|---|
| 900 kg high grade ore<br>100 kg low grade ore | 431 kg FeMn +<br>507 kg high Mn slag |
| 950 kg high Mn slag<br>50 kg low grade ore | 317 kg SiMn +<br>861 kg low Mn slag |

HOURLY PRODUCTION

| | | | |
|---|---|---|---|
| FeMn | 8,460/2,424 | = | 3.49 t/h |
| High Mn slag | 507/431 x 3.49 | = | 4.11 t/h |
| SiMn | 10,340/5,290 | = | 1.95 t/h |

ANNUAL OPERATION - FeMn 215 d/7.1 mos SiMn 150 d/5.9 mos

| | | | |
|---|---|---|---|
| FeMn | 215 d x 24 h x 3.49 | = | 18,008 t/y |
| High Mn slag | 215 d x 24 h x 4.11 | = | 21,208 |
| SiMn | 150 d x 24 h x 1.95 | = | 7,020 |
| Slag req'd | 7,020 x 950/317 | = | 21,038 |

Ore req'd:

| | | | |
|---|---|---|---|
| High grade | 28,008 x 900/431 = 37,604 | | |
| Low grade | 18,008 x 100/431 = 4,178 | | |
| | 7,020 x 50/317 = 1,107 | | |
| | | | 42,889 |
| Coke req'd | 18,008 x 310/431 = 12,952 | | |
| | 7,020 x 160/317 = 3,543 | | |
| | | | 16,495 |
| Low Mn slag | 7,020 x 861/317 | = | 19,067 |

TABLE 6-125

SAEF

HIGH/LOW GRADE ORE

FEMN + SIMN

SUMMARY - RAW MATERIAL REQUIREMENTS

| FeMn | kg/ Batch | kg/t FeMn | t/d | t/y 215 d 7.1 mos |
|---|---|---|---|---|
| High grade ore - 51.5% Mn | 900 | 2,088 | 174.9 | 37,604 |
| Low grade ore - 21.5% Mn | 100 | 232 | 19.4 | 4,178 |
| Coke | 310 | 719 | 60.2 | 12,952 |
| Quartzite | 120 | 278 | 23.3 | 5,014 |
| Dolomite | 240 | 557 | 46.6 | 10,028 |
| TOTAL | 1,670 | 3,874 | 324.4 | 69,776 |
| FeMn | 431 | 1,000 | 83.8 | 18,008 |
| High Mn slag | 507 | 1,176 | 98.6 | 21,208 |

| SiMn | kg/ Batch | kg/t SiMn | t/d | t/y 150 d 4.9 mos |
|---|---|---|---|---|
| High Mn slag | 950 | 2,997 | 140.3 | 21,038 |
| Low grade ore - 21.5% Mn | 50 | 158 | 7.4 | 1,107 |
| Coke | 160 | 505 | 23.6 | 3,543 |
| Quartzite | 150 | 473 | 22.1 | 3,322 |
| Dolomite | 400 | 1,262 | 59.0 | 8,858 |
| | 1,710 | 5,395 | 252.4 | 37,868 |
| SiMn | 317 | 1,000 | 46.8 | 7,020 |
| Low Mn slag | 861 | 2,716 | 127.1 | 19,067 |

TABLE 6-126
SAEF - HIGH/LOW GRADE ORE - PRIMARY FEMN + SECONDARY SIMN - FEMN PRODUCTION

| Material | Wt/Chge | $MnO_2$ %/kg | Mn %/kg | MnO %/kg | Mn %/kg | $Fe_2O_3$ %/kg | Fe %/kg | $SiO_2$ % | kg | $Al_2O_3$ % | kg | CaO % | kg | MgO % | kg | BaO % | kg | P % | kg | S % | kg | C % | kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Low Grade Ore | 100 | 32.76 | 20.71 | 0.97 | 0.75 | 51.52 | 36.03 | 5.80 | 6 | 2.38 | 2 | 0.78 | 1 | 0.10 | - | 0.99 | 1 | 0.103 | - | 0.09 | - | | |
| | | 33 | 21 | 1 | 1 | 52 | 36 | | | | | | | | | | | | | | | | |
| High Grade Ore | 900 | 67.77 | 42.84 | 11.18 | 8.66 | 9.79 | 6.85 | 1.16 | 10 | 0.90 | 8 | 1.45 | 13 | 0.35 | 3 | 1.38 | 12 | 0.081 | 1 | 0.09 | 1 | | |
| | | 610 | 386 | 101 | 78 | 88 | 62 | | | | | | | | | | | | | | | | |
| Coke | 310 | | | | | 2.0 | 1.4 | 5.0 | 16 | 3.0 | 9 | | | | | | | | | 1.0 | 3 | 75.0 | 233 |
| | | | | | | 6 | 4 | | | | | | | | | | | | | | | | |
| Quartzite | 120 | | | | | | | 99.0 | 119 | 1.0 | 1 | | | | | | | | | | | | |
| Dolomite | 240 | — | — | — | — | — | — | 2.0 | 5 | | — | 30.2 | 72 | 21.0 | 50 | | — | | — | | — | | — |
| TOTAL | 1,670 | 643 | 407 | 102 | 79 | 140 | 98 | | 156 | | 20 | | 86 | | 53 | | 13 | | 1 | | 4 | | 233 |

**FEMN PRODUCED**

| | Actual | Initial kg | Initial % |
|---|---|---|---|
| Mn | 323 | 340 | 75.0 |
| Fe | 69 | 73 | 16.0 |
| C | 28 | 30 | 6.5 |
| Si | 7 | 7 | 1.5 |
| P | 1 | 1 | 0.2 |
| S | - | | - |
| Other | 3 | 3 | 0.8 |
| | 431 | 454 | 100.0 |

**SLAG PRODUCED**

| | Actual | Initial kg | Initial % |
|---|---|---|---|
| $SiO_2$ | 134 | 141 | 26.5 |
| $Al_2O_3$ | 19 | 20 | 3.8 |
| CaO | 82 | 86 | 16.1 |
| MgO | 50 | 53 | 9.9 |
| MnO | 179 | 188 | 35.3 |
| FeO | 30 | 32 | 6.0 |
| BaO/Other | 13 | 13 | 2.4 |
| | 507 | 533 | 100.0 |

**MATERIAL BALANCES**

| | | | |
|---|---|---|---|
| Fe | 92/98 | = | 0.942 |
| Mn | 462/486 | = | 0.950 |
| $SiO_2$ | 149/156 | = | 0.955 |
| $Al_2O_3$ | 19/20 | = | 0.950 |
| CaO | 82/86 | = | 0.953 |
| MgO | 50/53 | = | 0.943 |
| C | | | |
| $MnO_2/MnO$ | 14.5 | | |
| $MnO_2/Mn$ | 148.4 | | |
| $Fe_2O_3/FeO$ | 2.7 | | |
| $Fe_2O_3/Fe$ | 23.5 | | |
| $SiO_2/Si$ | 6.0 | | |
| $P_2O_5/P$ | 1.0 | | |
| C in Metal | 30.0 | | |
| | 226.1 | | |

226.1/.75 = 301.5 (Use 310 kg)

**PRODUCT RATIOS**

| | | | |
|---|---|---|---|
| Slag/t | (507/431)1000 | = | 1176 kg |
| Slag Ratio | $\frac{CaO+MgO+MnO+BaO}{SiO_2}$ | = | 2.38 |
| Coke/t | (310/431)1000 | = | 719 kg |
| Coke to Mix % | (310/1670)100 | = | 18.6 |
| $SiO_2$/t | (120/431)1000 | = | 278 kg |
| $SiO_2$ to Mix % | (120/1670)100 | = | 7.2 |
| Dolomite/t | (240/431)1000 | = | 557 kg |
| Dol. to Mix % | (240/1670/100 | = | 14.4 |
| Mn/Fe Slag | | | 5.94 |

TABLE 6-127
SAEF - HIGH/LOW GRADE ORE - PRIMARY FEMN + SECONDARY SIMN - SIMN PRODUCTION

| Material | Wt/Chge | $MnO_2$ %/kg | Mn %/kg | MnO %/kg | Mn %/kg | $Fe_2O_3$ %/kg | Fe %/kg | FeO %/kg | Fe %/kg | $SiO_2$ % | kg | $Al_2O_3$ % | kg | CaO % | kg | MgO % | kg | BaO % | kg | P % | kg | S % | kg | C % | kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| High Mn Slag | 950 | | | 35.3 | 27.3 | | | 6.0 | 4.7 | 26.5 | 252 | 3.8 | 36 | 16.1 | 153 | 9.9 | 94 | 2.4 | 23 | - | - | | | | |
| | | | | 335 | 260 | | | 57 | 45 | | | | | | | | | | | | | | | | |
| Low Grade Ore | 50 | 32.76 | 20.71 | 0.97 | 0.75 | 51.52 | 36.03 | | | 5.8 | 3 | 2.38 | 1 | 0.78 | | 0.10 | - | 0.99 | 1 | 0.103 | - | 0.09 | - | | |
| | | 16 | 10 | 1 | 1 | 26 | 18 | | | | | | | | | | | | | | | | | | |
| Coke | 160 | | | | | 2.0 | | | | 5.0 | 8 | 3.0 | 5 | | | | | | | | | 1.0 | 2 | 75.0 | 120 |
| | | | | | | 3 | 2 | | | | | | | | | | | | | | | | | | |
| Quartzite | 150 | | | | | | | | | 99.0 | 149 | 1.0 | 1 | | | | | | | | | | | | |
| Dolomite | 400 | — | — | — | — | — | — | — | — | 2.0 | 8 | | — | 30.2 | 121 | 21.0 | 84 | | — | | | | — | | — |
| TOTAL | 1,710 | 16 | 10 | 336 | 261 | 29 | 20 | 57 | 45 | | 420 | | 43 | | 274 | | 178 | | 24 | | | | 2 | | 120 |

SIMN PRODUCED

| | Actual kg | Initial kg | Initial % |
|---|---|---|---|
| Mn | 206 | 217 | 65.0 |
| Fe | 54 | 57 | 17.0 |
| C | 7 | 7 | 2.0 |
| Si | 50 | 53 | 16.0 |
| P | - | - | - |
| S | - | - | - |
| Other | - | - | - |
| | 317 | 334 | 100.0 |

SLAG PRODUCED

| | Actual kg | Initial kg | Initial % |
|---|---|---|---|
| $SiO_2$ | 291 | 306 | 33.8 |
| $Al_2O_3$ | 41 | 43 | 4.7 |
| CaO | 260 | 274 | 30.3 |
| MgO | 169 | 178 | 19.7 |
| MnO | 67 | 70 | 7.7 |
| FeO | 10 | 10 | 1.1 |
| BaO/Other | 23 | 24 | 2.7 |
| | 861 | 905 | 100.0 |

MATERIAL BALANCES

| | | | |
|---|---|---|---|
| Fe | 62/65 | = | 0.954 |
| Mn | 258/271 | = | 0.952 |
| $SiO_2$ | 398/420 | = | 0.948 |
| $Al_2O_3$ | 41/43 | = | 0.954 |
| CaO | 260/274 | = | 0.949 |
| MgO | 169/178 | = | 0.949 |
| C | | | |
| $MnO_2/MnO$ | 2.3 | | |
| MnO/Mn | 47.3 | | |
| $Fe_2O_3/FeO$ | 2.1 | | |
| FeO/Fe | 12.2 | | |
| $SiO_2/Si$ | 45.4 | | |
| C in Metal | 7.0 | | |
| | 116.3 | | |

116.3/.75 = 155 (Use 160 kg)

PRODUCT RATIOS

| | | |
|---|---|---|
| Slag/t | (861/317)1000 | = 2716 kg |
| Slag Ratio | $\frac{CaO+MgO+BaO+MnO}{SiO_2}$ | = 2.05 |
| Coke/t | (160/317)1000 | = 505 kg |
| Coke to Mix % | (160/1710)100 | = 9.4 |
| $SiO_2$/t | (150/317)1000 | = 473 kg |
| $SiO_2$ to Mix % | (150/1710)100 | = 8.8 |
| Dolomite/t | (400/317)1000 | = 1262 kg |
| Dol to Mix % | (400/1710)100 | = 23.4 |
| Mn/Fe in Slag | | 6.67 |

TABLE 6-128
SAEF SMELTING
IMPORTED ORE

METALLURGICAL DATA

| | High C FeMn | SiMn |
|---|---|---|
| Operating Load - kW | 10,000 | 10,000 |
| Operating Time - % | 94 | 94 |
| Avg. Load - kW | 9,400 | 9,400 |
| kWh/kg Alloy | 2.42 | 5.29 |
| kWh/t Alloy | 2,424 | 5,290 |
| % Mn in Metal | 75.0 | 65.0 |
| % Fe in Metal | 16.0 | 17.0 |
| % Si in Metal | 1.5 | 16.0 |
| % C in Metal | 6.5 | 2.0 |
| Electrode Paste - kg/t | 15 | 30 |

TABLE 6-129

SAEF

IMPORTED ORE

FEMN + SiMn

CAMPAIGN PROGRAM

| | |
|---|---|
| 1000 kg imported ore | 445 kg FeMn + 420 kg high Mn slag |
| 1000 kg high Mn slag | 397 kg SiMn + 817 kg low Mn slag |

HOURLY PRODUCTION

| | | | |
|---|---|---|---|
| FeMn | 9400/2424 | = | 3.88 t/h |
| High Mn slag | 420/445 x 3.88 | = | 3.66 t/h |
| SiMn | 9400/5290 | = | 1.78 t/h |

ANNUAL OPERATION - FeMn 205 d/6.7 mos. SiMn 160d/5.3 mos.

| | | | |
|---|---|---|---|
| FeMn | 205d x 24h x 3.88 | = | 19,090 t/y |
| High Mn slag | 205d x 24h x 3.66 | = | 18,007 |
| SiMn | 160d x 24h x 1.78 | = | 6,835 |
| Slag req'd | 6835 x 1000/397 | = | 17,217 |
| Ore req'd | 19,090 x 1000/445 | = | 42,899 |
| Low Mn slag | 6835 x 817/397 | = | 14,066 |
| Coke req'd | 19,090 x 330/445 = 14,157<br>6,835 x 190/397 = 3,271 | | 17,428 |

TABLE 6-130

SAEF

IMPORTED ORE

FEMN + SIMN

SUMMARY - RAW MATERIAL REQUIREMENTS

| FeMn | kg/ Batch | kg/t FeMn | t/d | t/y 205 d 6.7 mos |
|---|---|---|---|---|
| Imported ore - 50% Mn | 1,000 | 2,247 | 209 | 42,899 |
| Coke | 330 | 742 | 69 | 14,157 |
| Limestone | 110 | 247 | 23 | 4,719 |
| Dolomite | 20 | 45 | 4 | 858 |
| Quartzite | 70 | 157 | 15 | 3,003 |
| Scrap | 55 | 124 | 12 | 2,359 |
| Total | 1,585 | 3,562 | 332 | 67,995 |
| FeMn | 445 | 1,000 | 93 | 19,090 |
| High Mn slag | 420 | 944 | 88 | 18,007 |

| SiMn | kg/ Batch | kg/t SiMn | t/d | t/y 160 d 5.3 mos |
|---|---|---|---|---|
| High Mn slag | 1,000 | 2,519 | 108 | 17,217 |
| Coke | 190 | 479 | 20 | 3,271 |
| Limestone | 300 | 756 | 32 | 5,165 |
| Dolomite | 50 | 126 | 5 | 861 |
| Quartzite | 140 | 353 | 15 | 2,413 |
| Scrap | 70 | 176 | 8 | 1,203 |
| Total | 1,750 | 4,409 | 188 | 30,130 |
| SiMn | 397 | 1,000 | 43 | 6,835 |
| Low Mn slag | 817 | 2,058 | 88 | 14,066 |

TABLE 6-131
SAEF SMELTING; IMPORTED ORE FEMN PRODUCTION

| Material | Wt. per Chge. kg | $MnO_2$ %/kg | Mn %/kg | MnO %/kg | Mn %/kg | $Fe_2O_3$ %/kg | Fe %/kg | FeO %/kg | Fe %/kg | $SiO_2$ % | kg | $Al_2O_3$ % | kg | CaO % | kg | MgO % | kg | BaO % | kg | P % | kg | S % | kg | C % | kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| High Grade Ore | 1,000 | 79.09 | 50.0 | | | 2.86 | 2.00 | | | 2.70 | 27 | 6.00 | 60 | - | | - | | - | | 0.01 | - | - | | - | |
| | | 791 | 500 | | | 29 | 20 | | | | | | | | | | | | | | | | | | |
| Coke | 330 | | | | | 2.00 | | | | 5.00 | 17 | 3.00 | 10 | | | | | | | | | | | 75.00 | 248 |
| | | | | | | 7 | 5 | | | | | | | | | | | | | | | | | | |
| Limestone | 110 | | | | | | | | | 1.80 | 2 | | | 55.00 | 61 | | | | | | | | | | |
| Dolomite | 20 | | | | | | | | | 2.00 | - | | | 30.20 | 6 | 21.00 | 4 | | | | | | | | |
| Quartzite | 70 | | | | | | | | | 99.00 | 69 | 1.00 | 1 | | | | | | | | | | | | |
| Scrap | 55 | | | | | | 55 | | | | | | | | | | | | | | | | | | |
| TOTALS | 1,585 | | 500 | | | | 80 | | | | 115 | | 71 | | 67 | | 4 | | | | | | | | 248 |

**FEMN PRODUCED**

| | kg | Balance kg | Balance % |
|---|---|---|---|
| Mn | 333 | 350 | 75.00 |
| Fe | 71 | 75 | 16.00 |
| C | 29 | 30 | 6.50 |
| Si | 7 | 7 | 1.50 |
| P | - | - | - |
| S | - | - | - |
| Other | 5 | 5 | 1.00 |
| | 445 | 467 | 100.00 |

**SLAG PRODUCED**

| | kg | Balance kg | Balance % |
|---|---|---|---|
| $SiO_2$ | 95 | 100 | 22.6 |
| $Al_2O_3$ | 67 | 71 | 16.1 |
| CaO | 64 | 67 | 15.1 |
| MgO | 4 | 4 | 1.0 |
| MnO | 184 | 194 | 43.9 |
| FeO | 6 | 6 | 1.3 |
| Other | - | - | - |
| | 420 | 442 | 100.00 |

**MATERIAL BALANCES**

| | kg Product/kg Feed | Unit Recovery |
|---|---|---|
| Fe | 76/80 | 0.946 |
| Mn | 476/500 | 0.951 |
| $SiO_2$ | 110/115 | 0.957 |
| $Al_2O_3$ | 67/71 | 0.944 |
| CaO | 64/67 | 0.955 |
| MgO | 4/4 | 1.000 |

Carbon

| | |
|---|---|
| $Fe_2O_3$/Fe | 24.0 |
| $Fe_2O_3$/FeO | 0.7 |
| $MnO_2$/Mn | 152.7 |
| $MnO_2$/MnO | 32.7 |
| $SiO_2$/Si | 6.0 |
| C in FeMn | 30.0 |
| TOTAL C | 246.1 |

246.1/0.75 = 328.1 kg
(Use 330)

**PROCESS RATIOS**

| | | | |
|---|---|---|---|
| Slag/t FeMn | (420/445)1000 | = | 944 kg |
| Slag Ratio | $\frac{CaO + MgO + MnO}{SiO_2}$ | = | 2.42 |
| Coke/t | (330/445)1000 | = | 742 kg |
| Coke to Mix % | (330/1585)100 | = | 20.8 |
| LS + Dol/t | (130/445)1000 | = | 292 kg |
| LS + Dol % | (130/1585)100 | = | 8.2 |
| Quartzite/t | (70/445)1000 | = | 157 kg |
| Quartzite to Mix % | (70/1585)100 | = | 4.4 |
| Mn/Fe Ratio in Slag | | = | 30.5 |

TABLE 6-132
SAEF SMELTING; SILICO-MANGANESE PRODUCTION FROM MEDIUM GRADE SLAG, IMPORTED ORE

| Material | Wt. per Chge. kg | $MnO_2$ %/kg | Mn %/kg | MnO % | Mn %/kg | $Fe_2O_3$ % | Fe %/kg | FeO %/kg | Fe %/kg | $SiO_2$ % | kg | $Al_2O_3$ % | kg | CaO % | kg | MgO % | kg | Other % | kg | P % | kg | S % | kg | C % | kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| High Mn Slag | 1,000 | | | 43.9 | | | | 1.30 | | 22.6 | 226 | 16.1 | 161 | 15.1 | 151 | 1.0 | 10 | - | - | - | | - | | - | |
| | | | | 439 | 340 | | | 13 | 10 | | | | | | | | | | | | | | | | |
| Coke | 190 | | | | | 2.00 | | | | 5.0 | 10 | 3.0 | 6 | | | | | | | | | | | 75.00 | 143 |
| | | | | | | 4 | 3 | | | | | | | | | | | | | | | | | | |
| Limestone | 300 | | | | | | | | | 1.8 | 5 | | | 55.0 | 165 | | | | | | | | | | |
| Dolomite | 50 | | | | | | | | | 2.0 | 1 | | | 30.2 | 15 | 21.0 | 11 | | | | | | | | |
| Quartzite | 140 | | | | | | | | | 99.0 | 139 | 1.0 | 1 | | | | | | | | | | | | |
| Scrap | 70 | | | | | | | | 70 | | | | | | | | | | | | | | | | |
| TOTALS | 1,750 | | | | 340 | | 3 | | 80 | | 381 | | 168 | | 331 | | 21 | | - | | | | | | 143 |

SIMN PRODUCED

| | kg | Balance kg | Balance % |
|---|---|---|---|
| Mn | 258 | 272 | 65.00 |
| Fe | 67 | 71 | 17.00 |
| C | 8 | 8 | 2.00 |
| Si | 64 | 67 | 16.00 |
| P | - | - | - |
| S | - | - | - |
| Other | - | - | - |
| | 397 | 418 | 100.00 |

SLAG PRODUCED

| | kg | Balance kg | Balance % |
|---|---|---|---|
| $SiO_2$ | 225 | 237 | 27.6 |
| $Al_2O_3$ | 160 | 168 | 19.5 |
| CaO | 314 | 331 | 38.5 |
| MgO | 20 | 21 | 2.4 |
| MnO | 84 | 88 | 10.2 |
| FeO | 14 | 15 | 1.8 |
| Other | - | - | - |
| | 817 | 860 | 100.00 |

MATERIAL BALANCES

| | kg Product/Feed | Unit Recovery |
|---|---|---|
| Fe | 78/83 | 0.940 |
| Mn | 323/340 | 0.950 |
| $SiO_2$ | 362/381 | 0.950 |
| $Al_2O_3$ | 160/168 | 0.952 |
| CaO | 314/331 | 0.949 |
| MgO | 20/21 | 0.952 |

| Carbon | |
|---|---|
| $Fe_2O_3$/FeO | 0.3 |
| FeO/Fe | 15.2 |
| MnO/Mn | 59.3 |
| $SiO_2$Si | 57.4 |
| C in SiMn | 8.0 |
| | 140.2 |

140.2/0.75 = 186.9 kg Coke
Use 190

PROCESS RATIOS

| | | | |
|---|---|---|---|
| Slag/t SiMn | (817/397)1000 | = | 2058 kg |
| Slag Ratio | $\frac{CaO + MgO + MnO}{SiO_2}$ | = | 1.94 |
| Coke/t | (190/397)1000 | = | 479 kg |
| Coke to Mix % | (190/1750)100 | = | 10.9 |
| LS + Dol/t | (350/397)1000 | = | 882 kg |
| LS + Dol % | (350/1750)100 | = | 20.0 |
| Quartzite/t | (140/397)1000 | | 353 kg |
| Quartzite to Mix % | (140/1750)100 | = | 8.0 |