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ELECTRIC SMELTING OF NICKELIFEROUS MAGNETITE IN THE  
60-KVA ELECTRIC ARC-FURNACE TO PRODUCE LOW-GRADE  
FERRONICKEL FOR CAREY CANADIAN MINES LTD.,  
EAST BROUGHTON, QUEBEC

by

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Extraction Metallurgy Division

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G.V. Sirianni\*

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SUMMARY

Ferronickel containing 1.28, 2.42, 4.91, 7.02 and 24.4% nickel was produced by smelting a concentrate containing 0.98% nickel and 64.3% iron, in the 60-kVA electric-arc furnace. After the reduction was complete the metal contained 1.28% nickel, 3.82% carbon, 0.52% chromium and the balance mainly iron. The silicon, sulphur, and phosphorus contents of the metal were low. As the reduction became more selective, the nickel content of the metal increased, the amounts of the other constituents in the metal decreased, and the loss of iron to the slag increased. The loss of nickel to the slag was low (less than 5%) when the metal contained up to 7.02% nickel, but was considerably higher (about 20%) when the metal contained 24.4% nickel.

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## INTRODUCTION

Carey Canadian Mines Ltd., East Broughton, Quebec, can produce, as a by-product from their asbestos operation, a nickeliferous magnetite concentrate containing about 65% iron and 1% nickel. A representative of the company, Mr. R. Laroche, approached the Pyrometallurgy Section requesting information concerning the possible use of this material. It was suggested that a possible route to recover nearly all of the nickel and a substantial portion of the iron would be to produce low-grade ferronickel by electric smelting. Subsequent to this discussion the company determined that a market for ferronickel, containing 2 to 5% nickel, could be readily obtained. In the meantime, the Pyrometallurgy Section was requested to perform a small-scale smelting investigation in the 60-kVA arc furnace to determine the feasibility of producing metal containing up to 25% nickel.

On December 13, 1967, about 400 lb of concentrate, which was 75% minus 325-mesh, was received for this work.

## EXPERIMENTAL WORK

(1) Raw Materials

The raw materials used in this work were the nickeliferous magnetite concentrate, limestone, silica sand and coke.

The concentrate was dried at 110°C before a head sample was obtained by riffing. The chemical analysis of the concentrate is given in Table 1.

The coke and limestone had already been analysed for other work and their analyses are given in Tables 2 and 3. The sand was not analysed but it was known to be of high purity.

TABLE 1 .

Chemical Analysis of Concentrate

| Constituent                    | %       |
|--------------------------------|---------|
| Total Fe                       | 64.3    |
| Fe <sup>++</sup>               | 9.46    |
| Fe <sup>+++</sup>              | 54.9    |
| Ni                             | 0.98    |
| Cr                             | 0.24    |
| MgO                            | 3.70    |
| SiO <sub>2</sub>               | 3.09    |
| Al <sub>2</sub> O <sub>3</sub> | 0.19    |
| CaO                            | < 0.02  |
| S                              | 0.01    |
| P                              | < 0.002 |

TABLE 2

Chemical Analysis of Coke

| Constituent %                  | "As received" | Dry basis |
|--------------------------------|---------------|-----------|
| Moisture                       | 1.68          | 0         |
| Ash *                          | 20.71         | 21.06     |
| Volatile                       | 3.42          | 3.48      |
| Fixed Carbon                   | 74.19         | 75.46     |
| *Ash Composition               |               |           |
| SiO <sub>2</sub>               | 63.74         |           |
| Al <sub>2</sub> O <sub>3</sub> | 32.60         |           |
| Fe <sub>2</sub> O <sub>3</sub> | 3.30          |           |
| CaO                            | 2.24          |           |
| MgO                            | 1.31          |           |

TABLE 3

Chemical Analysis of Limestone

| Constituent %                  |       |
|--------------------------------|-------|
| CaO                            | 54.2  |
| SiO <sub>2</sub>               | 0.88  |
| Al <sub>2</sub> O <sub>3</sub> | 0.63  |
| MgO                            | 0.52  |
| Fe                             | 0.36  |
| S                              | 0.10  |
| P                              | 0.01  |
| LOI                            | 43.16 |

(2) Equipment and Procedure

The furnace used for smelting was a single-phase, two-electrode 60-kVA arc furnace. The electrodes were graphite rods 1 1/2 inches in diameter and the furnace shell was circular, 18 inches in diameter, 13 inches deep and lined with about 3 inches of refractory.

In the first smelting experiment, the furnace was lined with carbon paste because the object was to produce high-carbon nickel-bearing pig iron; excess of coke was used as reductant. In all other experiments, where a selective reduction was performed, the furnace shell was lined with a refractory high in magnesia. Before each smelting experiment the furnace refractory was preheated for about one hour. The carbon-lined furnace was

preheated by arcing on coke, which was removed prior to smelting. The magnesia-lined furnace was preheated with a gas burner.

In order to minimize dusting of the fine concentrate during smelting, the material was agglomerated by balling in a small rotating tire. Water plus 1/2 percent bentonite were used as binders, and the green balls, which were all about minus 1/2 inch in diameter, were dried at 110°C prior to smelting.

In each experiment, 20 lb of balled concentrate were melted. About 8 lb of the balled concentrate plus the required flux were first placed on the bottom of the preheated furnace, and smelting was begun by arcing between the electrodes. After a molten pool had formed, the electrodes were spread apart and arced to the bath, and the remainder of the charge was added as required. Upon completion of the smelting, the roof and electrodes were lifted and the contents of the furnace were discharged into a cast iron slag pot. After cooling, the metal and slag were separated. The metal button was drilled to obtain a sample for chemical analyses, and the slag was crushed to about 6 mesh before a sample was obtained from it by riffing.

### (3) Smelting

A series of experiments were performed in which the amount of coke per 20 lb of concentrate was decreased from 6.6 to 2.0 lb. The 6.6 lb of coke was sufficient to reduce all the nickel and iron oxides in the concentrate and supply enough carbon to produce a high-carbon nickel-bearing pig iron. The other amounts of coke used were sufficient to reduce all the nickel oxide and varying amounts of the iron oxide in the concentrate. The selective reductions were performed to increase the nickel content of the metal produced.

Previous experience in smelting other materials had indicated that when the magnesia (MgO) content of the slag was high (about 25%) much ash was produced, which was mainly magnesia. Also, small explosions occurred in the furnace, which ejected molten slag. Therefore in these experiments limestone and sand were added to dilute the MgO content of the slag. The charge compositions used in smelting are given in Table 4.

## RESULTS

The weights of the metals produced and their chemical analyses, are given in Table 5, and those of the slags are given in Table 6. The recovery of nickel in the metal and slag phases is shown in Table 7.

The results in Table 5 show clearly that the highest yield of metal was obtained when the nickel content of the metal was lowest, and that, as the yield of metal decreased, the nickel content of the metal increased. The reason for this is that when the reduction of the nickel and iron oxides is essentially complete, the metal will contain nearly all of the nickel and iron, in approximately the same ratio as in the concentrate. Because nickel oxide is more easily reduced than iron oxide, as the amount of reductant is decreased, nearly all of the nickel oxide will still be reduced but less iron oxide will be reduced. Therefore the nickel/iron ratio in the metal will increase.

TABLE 4

Materials Used in Smelting

| Experiment<br>No. | Charge (lb) |      |           |      |
|-------------------|-------------|------|-----------|------|
|                   | Conc        | Coke | Limestone | Sand |
| 67-5-10           | 20          | 6.6  | 7.34      | 2.3  |
| 67-5-18           | 20          | 4.5  | 7.74      | 2.5  |
| 67-5-11           | 20          | 3.3  | 4.34      | 0.8  |
| 67-5-17           | 20          | 2.7  | 7.34      | 2.3  |
| 67-5-12           | 20          | 2.0  | 4.34      | 0.8  |

TABLE 5

Weight of Metal and Chemical Analyses

| Experiment<br>No. | Weight<br>(lb) | Analyses (%) |        |        |        |       |         |
|-------------------|----------------|--------------|--------|--------|--------|-------|---------|
|                   |                | Ni           | C      | Cr     | Si     | S     | P       |
| 67-5-10           | 11.85          | 1.28         | 3.82   | 0.52   |        | 0.04  |         |
| 67-5-18           | 7.2            | 2.42         | < 0.02 | 0.01   | < 0.02 | 0.046 |         |
| 67-5-11           | 2.54           | 4.91         | 0.24   | < 0.02 |        | 0.02  | < 0.005 |
| 67-5-17           | 1.82           | 7.02         | 0.02   |        | < 0.05 | 0.03  | 0.001   |
| 67-5-12           | 0.26           | 24.4         | < 0.01 | < 0.02 |        | 0.009 | < 0.005 |

TABLE 6

Weight of Slag and Chemical Analyses

| Experiment<br>No. | Weight<br>(lb) | Analyses (%) |       |      |      |                  |                                |
|-------------------|----------------|--------------|-------|------|------|------------------|--------------------------------|
|                   |                | Tot Fe       | Ni    | CaO  | MgO  | SiO <sub>2</sub> | Al <sub>2</sub> O <sub>3</sub> |
| 67-5-10           | 6.8            | 5.70         | 0.05  | 47.6 | 6.28 | 35.2             | 5.29                           |
| 67-5-18           | 12.4           | 35.9         | 0.065 | 23.0 | 7.89 | 18.1             | 2.66                           |
| 67-5-11           | 14.9           | 45.3         | 0.03  | 18.5 | 5.59 | 11.2             | 2.34                           |
| 67-5-17           | 16.5           | 45.9         | 0.05  | 16.3 | 9.54 | 14.1             | 1.26                           |
| 67-5-12           | 17.6           | 55.6         | 0.22  | 10.3 | 5.97 | 8.12             | 1.17                           |

TABLE 7

Recovery of Nickel

| Experiment<br>No. | Nickel (lb) |         | Recovery (%) Nickel |         |       |
|-------------------|-------------|---------|---------------------|---------|-------|
|                   | In Metal    | In Slag | In Metal            | In Slag | Total |
| 65-5-10           | 0.152       | 0.0034  | 77.6                | 1.73    | 79.3  |
| 67-5-18           | 0.174       | 0.0081  | 88.8                | 4.13    | 92.9  |
| 67-5-11           | 0.125       | 0.0045  | 63.8                | 2.3     | 66.1  |
| 67-5-17           | 0.128       | 0.0083  | 65.3                | 4.2     | 69.5  |
| 67-5-12           | 0.0634      | 0.039   | 32.3                | 19.9    | 52.2  |

The results in Table 5, 6 and 7 show that the loss of nickel to the slag was fairly low in all experiments except Experiment 67-5-12 where the metal contained 24.4% nickel. However, the total nickel accounted for in these experiments varied from 92.3 to 52.2%. One reason for this wide variation is the small scale of the experiments. In trying to find the nickel unaccounted for, the furnace linings from some experiments were removed, crushed and sampled. It was found that, on the average, about 12% of the nickel charged per experiment was accounted for in this way. Probably during smelting some molten ore had soaked into the lining. On a continuous pilot-plant scale, the loss of nickel in this way would eventually cease because the hearth would be protected by a molten pool of metal, and the walls by unsmelted charge.

The relationships between the nickel, chromium, and carbon contents of the metal, and the amount of reductant used are shown in Figure 1. It can be seen that, as the amount of coke is increased, the nickel content of the metal decreases due to the dilution of the nickel with iron. Also, when the reduction of the concentrate nears completion, the carbon and chromium contents increase.

The results in Figure 2 show that elements such as carbon and chromium in the metal decrease considerably for a small increase in the grade of ferronickel produced, however, the loss of iron to the slag also increases.

#### DISCUSSION

It can be seen from Figure 2 that the loss of iron to the slag was high when the grade of ferronickel (2 to 5% Ni) desired by the company was produced. The reason for this is that the utilization of iron from the concentrate is related to the iron/nickel ratio desired in the metal, e.g. if ferronickel with about 5% nickel is required, the iron/nickel ratio in the metal is about 19/1. Therefore, the iron from the concentrate that can be utilized is about 19 times the nickel content in the concentrate. Because the iron and nickel contents are 64.3% and 0.98% respectively, it is obvious that much iron has to be left in the slag if ferronickel containing 5% nickel is produced.

One way of utilizing more iron would be to increase the nickel content of the concentrate. During the course of this investigation, Mr. Larochele stated that a fairly pure nickel sulphide concentrate would be produced in addition to the nickeliferous magnetite. Therefore it was suggested to the company that the nickel sulphide should be roasted to remove the sulphur and the roasted material should be added to the nickeliferous magnetite. The quantity of roasted material expected would be sufficient to double the nickel content of the nickeliferous magnetite.

The losses of iron to the slag were calculated on a theoretical basis when smelting the nickeliferous magnetite with and without the added roasted concentrate and these curves are shown in Figure 3. It can be seen that when ferronickel containing 5% nickel is produced from material containing 2% nickel, the loss of iron to the slag will be much lower than when the same grade of ferronickel is produced from material containing 0.98% Ni.



## CONCLUSIONS

These experiments have demonstrated that ferronickel, with nickel contents ranging from 1.28 to 24.4%, can be produced from this material by smelting it in the 60-kVA electric-arc furnace with coke as reductant. The amount of reductant used affects the composition of the metal obtained and the recovery of nickel and iron from the concentrate. When the reduction was essentially complete, i.e. when sufficient reductant was present to reduce all the nickel and iron, the metal contained 1.28% nickel, 3.82% carbon and 0.52% chromium and the losses of nickel and iron to the slag were very small. As the reduction became more selective, i.e. as less reductant was supplied in the charge, the nickel content of the metal increased and the chromium and carbon contents decreased. Also, although the losses of iron to the slag increased rapidly under these conditions, the losses of nickel to the slag were low (less than 5%) except when the nickel content of the metal was 24.4%.

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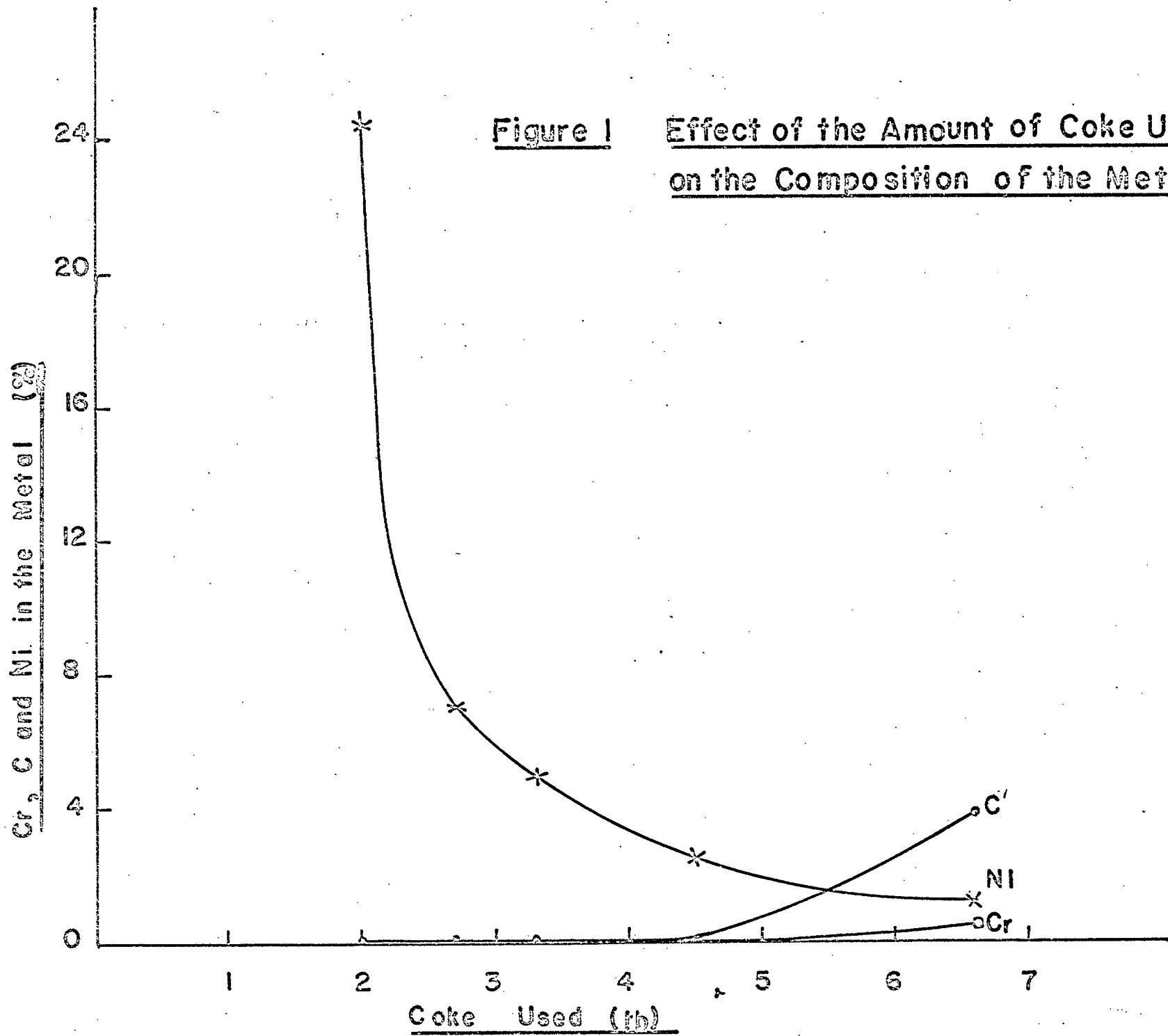


Figure 1 Effect of the Amount of Coke Used  
on the Composition of the Metal

Figure 2

Grade of Ferronickel Vs. C and Cr  
in the Metal and Iron Loss to the Slag

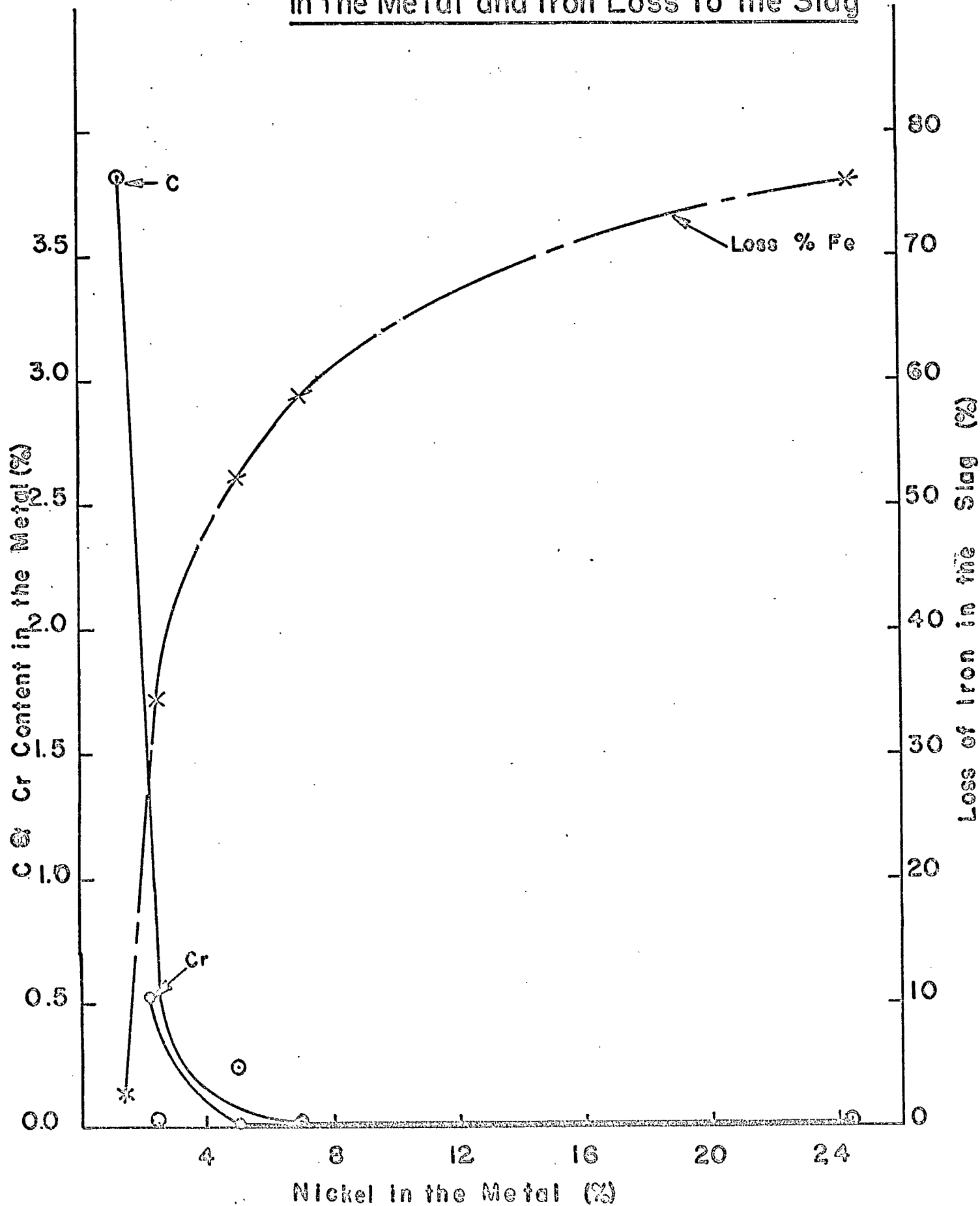


Figure 3 Theoretical Loss of Iron in the Slag