CANADA

EXPERIMENTAL ELECTRIC SMELTING OF MANGANESE ORES

PART I

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R. A. CAMPBELL, G. E. VIENS & R. R. ROGERS
MINERAL DRESSING AND PROCESS METALLURGY DIVISION

REPRINTED FROM CANADIAN INSTITUTE OF MINING AND METALLURGY BULLETIN VOL. 49, 1956, pp. 274-280.

DEPARTMENT OF MINES AND TECHNICAL SURVEYS, OTTAWA

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Experimental Electric Smelting of Manganese Ores*

At the Department of Mines and Technical Surveys, Ottawa

By R. A. CAMPBELL†, *G. E. VIENS*† *and R. R. ROGERS*§

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ABSTRACT

The electric smelting of five low-grade Canadian manganese ores has been investigated at the Mines Branch, Department of Mines and Technical Surveys, Ottawa. Ferromanganese, silicomanganese, and spiegeleisen were produced by special smelting processes from these ores since the latter were too low grade to be treated by conventional smelting methods. In one case the results were considered to be sufficiently promising to justify the construction of a pilot plant, by the Company concerned, for the further development of the process.

* * *

Introduction

MANGANESE is the most important of the non-ferrous elements used in steel making, and large quantities of it also are required in the production of non-ferrous alloys. At the present time, North America is largely dependent on foreign countries such as Turkey, India, Africa, and Brazil for its supply of manganese ore. This situation is highly undesirable because it might be difficult to obtain adequate supplies of the ore in an emergency, and because the manganese ores in Canada and the United States are not being utilized.

Unfortunately, the ores available in Canada and the United States are low-grade and thus cannot be treated successfully by standard processes. Accordingly, it is necessary to develop new, economically sound processes for their treatment. The manganese used by the steel industry is mainly in the form of ferromanganese, silicomanganese, and spiegeleisen, and accordingly it is quite possible that the production of these ferro-alloys by smelting the low-grade ores or their concentrates may prove to be the most satisfactory solution to this problem.

While not neglecting other approaches to the problem, the Mines Branch, Department of Mines and Technical Surveys, Ottawa, has investigated the electric smelting of low-grade manganese ores or concentrates from the following locations in Canada:

I.—Woodstock, New Brunswick
II.—Brigus Bay, Newfoundland
III.—Madoc, Ontario
IV.—Steep Rock, Ontario
V.—Knob Lake, Quebec

The purpose of the present paper is to summarize this work. The analyses of the ores investigated are given in Table I.

A continuously-operating, 3-phase 250 k.v.a. arc smelting furnace and a batch-type single phase 60 k.v.a. arc smelting furnace are available at the Mines Branch for this type of work. Although there have been cases in which the smelting of the ore has been investigated in the large furnace without any preliminary work in the small furnace, the following procedure is preferred:

(1) Determine the most satisfactory pre-treatment. In some cases beneficiation is advisable and in others the ore must be agglomerated before it can be used as a furnace feed. Calcination frequently has proved to be beneficial, particularly when the ore contains considerable quantities of carbonate, or combined water. The pre-treatment experiments are performed in co-operation with the Mineral Dressing Section.

(2) Perform a number of smelting experiments in the small furnace to determine the feasibility of the operation from a chemical standpoint, and to obtain some preliminary qualitative information regarding the conditions which are likely to give the most satisfactory results. These small-scale experiments have the advantage of being quickly performed and inexpensive.

(3) Providing that the results obtained with the 60 k.v.a. furnace were promising, perform a continuous experiment with the 250 k.v.a. furnace of sufficient length (usually at least a week) to obtain quantitative data on the process. These data are useful in determining whether the process is sufficiently promising to justify the erection of an expensive pilot plant. Much valuable information regarding the details of the process and preliminary cost figures are obtained.

The facilities for electric smelting research at the Mines Branch, and the various types of experimental work which have been done since the 250 k.v.a. furnace was installed in 1953, will be described in considerable detail in another paper which will be published shortly.

PART I

Silicomanganese and Ferromanganese from Woodstock Ore (N.B.)

In this investigation, the objective was the production of silicomanganese and medium-carbon ferromanganese from low-grade ore from Woodstock, N.B., by electric smelting. Since the ore did not have a sufficiently high manganese : iron ratio for the direct production of ferromanganese (4 : 1), a three stage process was used for its treatment. In the first stage of this process, sufficient iron was removed from the slag by means of a carbonaceous reducing agent to give a manganese : iron ratio of at least 4 : 1. In the second stage, part of this high-grade slag was treated with a carbonaceous reducing agent to produce silicomanganese. In the third stage, slag from the first stage was smelted to produce medium-carbon ferromanganese, silicomanganese from the second stage being used as the reducing agent.

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Table 1.– Analysis of Manganese Ores Used in Smelting Experiments (%)

Constituent	Woodstock, (N.B.) A	Woodstock, (N.B.) B *	Brigus Bay (Nfld.)	Madoc (Ont.)*	Steep Rock (Ont.) *	Knob Lake (Que.) *
Mn	9.7	12.30	22.14	2.16	3.68	13.6
Fe	11.9	29.50	4.9	41.9	32.3	53.6
CaO	1.7	7.27	1.2	24.4	--	N.D.
MgO	7.2	2.60	1.8	11.4	--	N.D.
SiO_2	38.2	20.80	23.2	1.63	39.7	3.2
Al_2O_3	12.2	11.20	13.8	--	--	1.2
S	0.35	--	0.18	--	--	-
P	0.27	0.98	0.06	--	--	0.2
Mn:Fe Ratio	1:1.2	1:2.4	4.5:1	1:19.4	1:8.8	1:3.9

* Calcined ore

N.D. None detected

Preliminary experiments, performed in the batch-type 60 k.v.a. smelting furnace, showed that the desired chemical reactions actually can take place. In view of these favourable results it was decided to investigate the process in the 250 k.v.a. furnace in order to obtain quantitative information which would be of service in evaluating the process, and would be of assistance in designing a pilot plant.

60 k.v.a. Furnace Experiments

The ore (ore *A* in Table I) was prepared for the first smelting experiment by calcining a mixture of ore and lime at about 1,100°C. The lime was added to increase the base : acid ratio. The calcined material then was smelted using a basic lining, an arc-resistance type of heating, and coke as the reducing agent. The resulting slag contained 10.6 per cent manganese and 3.8 per cent iron (manganese : iron ratio of 2.8 : 1).

In a second experiment, the third stage of the process was simulated by smelting this comparatively high grade slag with silicon as the reducing agent. The base : acid ratio of the slag had been increased by the addition of more lime prior to the smelting. The analyses of the metal and slag produced are shown in Table II. The high silicon content of the metal was due to the excess of silicon reducing agent which was used in making up the charge.

Table II.—Analyses of Metal and Slag from the Third Stage of Smelting Woodstock Ore in the 60 k.v.a. Furnace

Constituent	Per Cent In Metal	Per Cent In Slag
Mn	42	4
Fe	34	0.2
Si	17	
C	0.15	

These results were considered to be excellent in view of the fact that the experiments were batch-type and were operated on a very small scale. It was believed that much better results would be obtained when using the comparatively large 250 k.v.a. continuous smelting furnace.

250 k.v.a. Furnace Experiments

Ore *B* (Table I) was used in the smelting experiments in the 250 k.v.a. furnace. It will be noted that this ore contained considerably more iron and phosphorus than did ore *A*, which was used in the experiments with the 60 k.v.a. furnace.

Calcination

Ore *B* was calcined in an oil-fired rotary kiln at 1,000-1,100°C. prior to smelting. The weight loss during the calcination was about 8 per cent.

Smelting: First Stage

In this stage about 30 tons of calcined ore was smelted with coke as reducing agent, and with lime added to increase the base : acid ratio of the resulting slag. Graphite electrodes and a basic furnace lining were used, and the furnace was covered with a firebrick roof. The heating was accomplished mainly by arc resistance.

During the first few days, the furnace had not reached thermal equilibrium and the operations were somewhat erratic, resulting in rather wide fluctuations in the slag and metal compositions. However, during the latter part of the operation much more stable conditions and much more uniform results were obtained.

The data obtained during this first stage are summarized in Tables III and IX. It will be noted that the overall results are given in the first column of Table III and that the results obtained after the furnace conditions had become stabilized are given in the second column. Although the information given in both columns is of considerable importance, it is obvious that much greater weight should be given to that in the second column.

The results presented in tabular form in Table III and graphically in Figure 1 show that the main objective, *i.e.*, the production of a slag with a manganese : iron ratio of 4 : 1 or higher was achieved. Particularly during the last part of the experiment, the manganese content of the slag remained in the range of 20—24 per cent and the manganese : iron ratio was well above 4 : 1 almost constantly. During this part of the experiment, the manganese in the metal usually remained well below 1 per cent, indicating comparatively little loss.

The slag and metal analyses reported for the first stage (and also for the second and third stages) are weighted average values calculated from the analyses of the individual taps. At the end of the first stage, all of the slag produced was crushed to −3/8-inch, magnetically cleaned, mixed, sampled, and analyzed. The results obtained in this way agreed very closely with the calculated data shown in Table III.

Table III.—Results of First Stage Smelting of Woodstock, N.B. Ore in 250 KVA Furnace.

	Overall		Period 2 (Best results)		
Total ore fed (lb.)	61,111		31,910		
Total slag produced (lb.)	36,300		20,949		
Total metal produced (lb.)	17,621		8,598		
Duration (hours)	228		122		
Average power input (KWH/H)	188		181		
Slag analysis (per cent)			Min.	Av.	Max.
Mn	21.5		20.3	22.0	23.9
Fe	5.4		2.4	5.4	9.6
P	0.44		0.15	0.48	0.95
Mn:Fe Ratio	4.0		2.5	4.1	6.5
Basicity* of slag	1.4		1.4		
Metal analysis (per cent)			Min.	Av.	Max.
Mn	5.2		0.26	0.90	4.2
P	2.1		1.4	1.9	2.7
C	2.1		1.2	1.7	2.2
Percentage recoveries	In Slag	In Metal	In Slag		In Metal
Mn	89	10	99		1.6
P	26	60	31		50

$$\text{Basicity} = \text{mol ratio } \frac{CaO+MgO+MnO}{SiO_2}$$

Smelting: Second Stage

In this stage of the operation, silicomanganese was made from part of the slag produced during the first stage, coke being used as the reducing agent and lime being added to maintain the base : acid ratio at about 1.5 : 1. During this stage the furnace was lined with carbon. The data obtained are summarized in Tables IV and IX.

Since the amount of material smelted was much less than that in the first stage, the total length of time required was much less. For this reason, the furnace did not reach thermal equilibrium and the operating conditions never became stabilized. Doubtless, if data could have been obtained after a steady condition had been reached, they would have been superior to those actually obtained.

All of the silicomanganese produced was crushed to −3/8-inch, sampled, and analyzed, and the results thus obtained agreed closely with the calculated data presented in Table IV.

Smelting: Third Stage

In this stage, some of the remaining slag from the first stage was smelted to produce medium-carbon ferromanganese, silicomanganese produced in the second stage being used as the reducing agent, and sufficient lime being added to increase the base : acid ratio to 2.3 : 1. A basic furnace lining was used. The

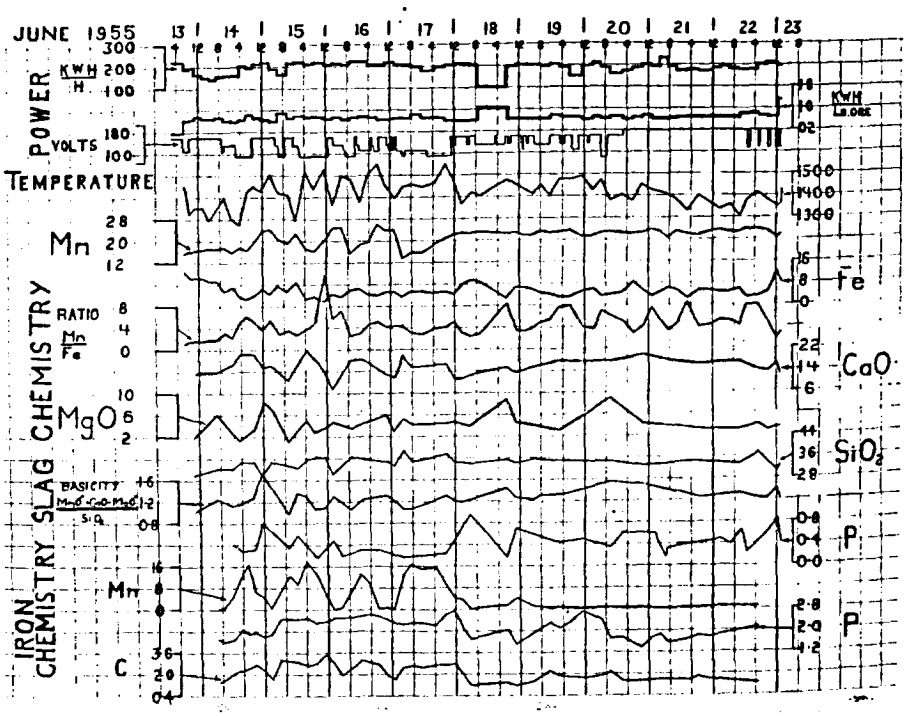

Figure 1.—Chart of analytical results and other variables covering the first stage of smelting.

Table IV.—Results of Second Stage Smelting of Woodstock, N.B. Ore in the 250 KVA Furnace.

Total slag fed (lb.)	14,200		
Total silicomanganese produced (lb.)	3,057		
Total slag produced (lb.)	9,937		
Duration (hours)	87		
Average power input (KWH/H)	225		
Metal analysis (per cent)	Min.	Av.	Max.
Si	8.7	17.8	26.9
Mn	37.8	52.3	61.5
Fe	15.6	20.7	32.2
P	1.1	1.6	2.1
C	0.08	1.1	1.9
Ratio Mn:Fe		2.5:1	
Slag analysis (per cent)	Min.	Av.	Max.
Mn	1.2	4.3	10.5
Fe	0.19	0.94	4.48
Basicity of slag		1.5	
Percentage recoveries	In Metal		In Slag
Mn	51		14
Fe	85		11
P	79		--

Table V.—Results of Third Stage Smelting of Woodstock, N.B. Ore in the 250 KVA Furnace

Total slag fed (lb.)	6,700		
Total ferromanganese produced (lb.)	2,531		
Total slag produced (lb.)	11,167		
Duration (hours)	56		
Average power input (KWH/H)	158		
Metal analysis (per cent)	Min.	Av.	Max.
Mn	52.9	57.1	58.8
Fe	33.4	35.6	36.2
Si	2.9	4.7	5.7
P	2.10	2.11	2.30
C	1.52	1.81	2.37
Mn:Fe Ratio	1.5	1.6	1.6
Slag Analysis (per cent)	Min.	Av.	Max.
Mn	2.20	5.90	9.75
Fe	0.39	2.09	4.23
P	0.010	0.035	0.075
Basicity of slag	2.3		

data obtained are summarized in Tables V and IX.

Since this stage required even less time than the second stage, it was not possible for the furnace to reach thermal equilibrium and for steady conditions to be attained. Here again, if it had been possible to operate the furnace after proper operating conditions had been obtained, the results would have been considerably better than those reported in Table V.

It should be mentioned that part of the difficulty in maintaining stable conditions in stages two and three was due to unforeseen difficulties which arose in handling the molten products. In many cases it was necessary to tap metal and slag together and separate them by hand after cooling. It is anticipated that difficulties of this nature will be reduced to a minimum in the future due to equipment alterations which recently have been completed.

An attempt was made to produce high-carbon ferromanganese from part of the slag resulting from the first stage of smelting. However, the operation was too short for the conditions to become stabilized. The results, though promising, were not sufficiently reliable to permit an accurate evaluation of the process.

While the smelting operations were in progress, analytical results and other variables of interest were plotted on large wall-charts. These graphs, by permitting the ready detection of trends in the operations, aided materially in conducting the experiments, and served as useful records for future reference. One of these wall-charts, produced during the first stage of smelting, is shown in Figure 1 as an example.

Discussion

Most of the commercial grades of medium-carbon ferromanganese require a manganese content of 80 to 85 per cent, and a maximum of 0.20 or 0.25 per cent of phosphorus. The ferromanganese produced in these experiments did not meet these specifications, the manganese content being too low and the phosphorus content too high. However, the results obtained indicated fairly clearly the sources of the difficulties and the methods for overcoming them.

The desired manganese : iron ratio of 4 : 1 or higher was obtained in the slag produced in the first stage of smelting. However, the ratio was only 2.5 : 1 in the silicomanganese produced in the second stage. Two factors appear to have been mainly responsible for this decrease. The first factor was that the slag from the first stage contained fine globules of metallic iron which had not had sufficient time to settle out during the smelting operation. These globules were not considered in the analysis of the iron content of the slag. Hence, the total iron content of the slag was higher, and the manganese : iron ratio was actually lower, than is indicated by the analyses shown in Table III. This can be remedied, in a large-scale plant, by running the slag into a holding furnace where the metallic iron globules will have an opportunity to settle out, also by producing slag having a ratio much greater than 4 : 1 in the first stage smelting. Toward the end of the first-stage smelting, it was shown that a much higher ratio actually can be obtained.

The second factor in causing an undesirably low manganese : iron ratio in the silicomanganese was the loss of manganese by volatilization during the second-stage smelting, as shown by the occasional change in colour of the furnace gases; also by the fact that the dust collected from the superstructure above the furnace at the end of the experiments contained about 10 per cent of manganese. It is anticipated that this loss due to volatilization would have been considerably less after the furnace had reached thermal equilibrium and operating conditions had ceased to fluctuate.

Whereas the manganese : iron ratio in the silicomanganese was undesirably low (2.5 : 1), it was lower still (1.6 : 1) in the final ferromanganese. This was to be expected, because the raw materials were silicomanganese of low manganese : iron ratio and slag from the first stage of smelting which contained globules of metallic iron. In addition, there was a further loss of manganese by volatilization, which loss would have been considerably less after the operating conditions had ceased to fluctuate.

The phosphorus content of the ore was comparatively high. In addition, some phosphorus entered the furn-

ace as a constituent of the coke. Although much of this phosphorus was removed with the iron produced in the first stage of smelting, the amount remaining in the slag was much higher than desirable, since most of it entered the final ferromanganese. No doubt a considerable proportion of the phosphorus in the slag was contained in the fine globules of metallic iron. This would be eliminated by the use of a holding furnace, as already explained.

Two other modifications in the process, in order to permit the use of ores having a high phosphorus content, have been envisaged. In the first modification an excess of iron would be added in the first stage of smelting to absorb and remove more phosphorus.

In the second modification, silicomanganese, instead of coke, would be used as the reducing agent in the first stage. The iron originally in the silicomanganese, and the iron produced by the reduction of the iron oxide in the slag by the silicon and manganese, would carry down the phosphorus with them. Since manganese oxide is produced when the iron oxide is reduced by the manganese, the ratios of manganese : iron and manganese : phosphorus in the slag would be materially increased. In addition, there would be no additional phosphorus pick-up from the coke.

An experiment in the 60 k.v.a. furnace demonstrated that the phosphorus content may be lowered by the latter method. In this experiment, a mixture of iron, silicomanganese, and ore was smelted and a slag was produced containing 30.2 per cent manganese, 5.4 per cent iron, and 0.11 per cent phosphorus. The improvement obtained is shown clearly in Table VI. The data on coke reduction, which are included in the Table for comparison, were obtained from an experiment in the 250 k.v.a. furnace.

The scale of these experiments in the 250 k.v.a. furnace, although considerably larger than that of the batch-type experiments in the 60 k.v.a. furnace, was quite small compared to that in a commercial plant. It is anticipated that, in commercial operations, the furnaces would be at thermal equilibrium, less severe fluctuations would occur in the slag and metal compositions, handling losses would be much less, and power and electrode consumptions would be much lower than in these present experiments.

TABLE VI.—COMPARISON OF COKE AND SILICOMANGANESE REDUCTION

RATIO	IN ORE	IN SLAG	
		Coke Reduction	Silicomanganese Reduction
Mn : Fe	1 : 2.4	4 : 1	6 : 1
Mn : P	12 : 1	45 : 1	275 : 1

Table VII.—Results of Smelting of Brigus Bay Ore (Nfld)

	Overall		Best Period of Operation
Total ore fed (lb.)	16,840		9,260
Total silicomanganese produced (lb)	4,177		2,550
Total slag produced (lb)	8,751		5,460
Duration (hours)	108		59
Average power input (KWH/H)	185		179
Silicomanganese analysis (per cent)			
Si	14.7		14.4
Mn	64.4		64.4
Fe	17.2		17.3
C	1.98		1.98
P	0.20		
Mn:Fe Ratio	3.7		3.7
Slag analysis (per cent)			
Mn	2.80		2.92
Fe	0.53		0.55
Basicity of slag	1.3		
Percentage recoveries	In Metal	In Slag	
Mn	71	6	
Fe	82	5	
S	1	87	
P	68	11	

PART II

SILICOMANGANESE FROM BRIGUS BAY ORE (Nfld.)

The objective in this campaign was the production of silicomanganese from a low-grade siliceous manganese-oxide ore from Brigus Bay, Newfoundland, by a process which we call 'cold dry-top smelting'.* The main feature of this process is the use of a porous low-density furnace charge which is obtained by supplying part or all of the carbon requirement in the form of wood waste materials such as chips, sawdust, shavings, etc. The deep bed of charge maintained in the furnace prevents losses of heat and volatile metals from the top of the furnace, and yet is porous enough to permit the escape of the furnace gases. The charge descends in the furnace at a rate largely governed by its bulk density.

EXPERIMENTAL WORK

The composition of the ore used in this campaign is given in Table I. It will be noted that the manganese and iron contents of this ore were about the same as those of the enriched slag produced in the first stage of smelting the Woodstock ore.

During this operation the furnace lining was of carbon, and graphite electrodes were used. Limestone was added to the charge to adjust the base : acid ratio of the resulting slag. It was possible to operate the furnace without a roof, which facilitated the feeding of the bulky charge and permitted easy observation of the progress of the smelting.

The results obtained in this campaign are summarized in Tables VII and IX.

DISCUSSION

The results of this campaign showed that the cold dry-top method of smelting may be used successfully for the direct production of silicomanganese from this ore. One of the most popular grades of silicomanganese has the following composition:

*Cold dry-top smelting is considered to take place when the molten bath is completely covered with a layer of porous solid charge, and when this layer is deep enough so that it approaches room temperature on top.

Manganese	65–75	per cent
Silicon	17–20	" "
Carbon	1.5 (max)	" "

Near the end of the campaign the silicomanganese produced met these specifications except that it contained only 62.3 per cent manganese. It is believed that, if the manganese : iron ratio in the ore had been slightly higher, the silicon content of the metal produced could have been maintained in the range of 17-20 per cent without depressing the manganese content below the specified 65 per cent. It is possible that the 65 per cent figure could have been reached in a commercial-size furnace operating with maximum efficiency.

Near the end of the operation, when the silicon content reached 18 per cent, the carbon content of the product was depressed to values below the specified maximum of 1.5 per cent.

A short period (8 hours) of particularly good furnace operation occurred near the end of the campaign, when a mixture of wet, stringy bark and fine anthracite coal was substituted for the mixture of chips and sawdust. Since this coincided with the time when the furnace had reached thermal equilibrium and when the optimum proportions of ore, reductant, and limestone had been fairly well established, it was impossible to decide whether or not the improved operation was due to the use of the bark-anthracite combination. The limited supply of ore did not permit a more thorough investigation of this interesting point.

As in all other experimental work with the 250 k.v.a. furnace, the figures for power and electrode consumption doubtless were considerably higher than they would be in a large-scale commercial operation.

PART III

Spiegeleisen from Madoc Ore (Ont.)

The ore from Madoc, Ontario, was essentially siderite containing about 1.4 per cent of manganese. Its analysis is given in Table I. It was anticipated that pig iron and spiegeleisen could be produced from this ore by the following process:

(1) Calcine the ore to decompose the carbonate and remove any combined water that might be present.

(2) Smelt the calcined ore to remove a large proportion of the iron as pig iron, and produce a slag having a manganese : iron ratio of 1 : 3, or possibly even 1 : 2.

(3) Re-smelt the slag produced in (2), with an added amount of lime, to produce spiegeleisen.

Experimental Work

A small-scale experiment in the batch-type 60 k.v.a. furnace was performed to determine the feasibility of producing pig iron and enriched slag from the calcined ore. The calcination, performed at about 950°C. in an oil-fired rotary kiln, resulted in a loss of 34 per cent in the weight. This loss was approximately equivalent to the percentage of CO_2 in the original ore.

In the smelting operation, a basic furnace-lining and arc-resistance heating were employed. Coke was used as the reductant. Since the ore contained very little silica, quartz was added to adjust the base : acid ratio. The slag produced contained 4.3 per cent manganese and 9.1 per cent iron. The metal contained 3 per cent manganese.

Discussion

The manganese : iron ratio was increased from 1: 19 to 1 : 2.1 in this smelting operation. In view of the experience gained in the smelting of the Woodstock ore, there seemed to be little doubt that this enriched slag could be re-smelted to produce spiegeleisen. Accordingly, it was decided to discontinue the work with the 60 k.v.a. furnace and perform the complete process, (2) and (3) above, on a larger scale in the 250 k.v.a. furnace at a later date.

PART IV

Spiegeleisen from Steep Rock 'Wall Paint' Ore (Ont.)

The ore from Steep Rock, Ontario, known as 'Wall Paint', is essentially a low-grade iron ore containing about 3 per cent of manganese. It was anticipated that pig iron and spiegeleisen could be produced from this material by a process similar to that used in the case of the siderite ore from Madoc.

The results obtained in preliminary experiments in the 60 k.v.a. furnace were sufficiently encouraging to justify experimentation in the 250 k.v.a. furnace. As this article is being written, this larger-scale work is in progress. It is hoped that it will be possible to report the results obtained in a later article.

PART V

Spiegeleisen from Knob Lake Ore (Que.)

The ore from Knob Lake, Quebec, was a manganiferous iron ore containing about 13 per cent manganese. The analysis of the material after calcination is shown in Table I. Since the manganese : iron ratio in this material was 1 : 3.9, it was hoped that a standard spiegeleisen containing 16-19 per cent manganese, 6.5 per cent maximum carbon, and 3 per cent maximum silicon could be produced in a single smelting operation. This investigation is still in progress and it is possible to report only the results of two preliminary experiments in the present article.

Experimental Work

Two small-scale batch-type experiments were performed in the 60 k.v.a. furnace. In each case, coke was used as the reducing agent. Since the ore contained only small amounts of slag-forming constituents, both lime and silica were added to the charges. A higher base : acid ratio was used in the first experiment than in the second one.

The results of these experiments are shown in Table VIII.

Table VIII.—Analyses of Spiegeleisen Produced from Knob Lake Ore (%)

Constituent	Expt. No. 1	Expt. No. 2
Fe	80.3	80.5
Mn	12.0	9.2
Si	5.3	6.2
C	3.2	2.7
P	0.2	0.3
S	0.007	0.016

The slag from the second experiment contained 6.8 per cent manganese and 4.2 per cent iron.

Discussion

Although spiegeleisen having the desired manganese content of 16 per cent was not obtained in either of these experiments, the results obtained indicated the probable sources of the difficulties and pointed to methods of overcoming them. Some manganese was lost by vaporization in the first experiment and a considerable amount of manganese was left in the slag in the second experiment. The spiegeleisen produced in the second experiment (lower base : acid ratio) had a lower manganese content and a higher content

of silicon, phosphorus, and sulphur than the metal produced in the first experiment.

It is planned to perform further experiments with ore from Knob Lake, paying particular attention to the maintenance of an optimum base : acid ratio in the slag and to methods of reducing the manganese loss due to volatilization. It is hoped that spiegeleisen having a manganese content of at least 16 per cent can eventually be produced in a single-stage operation.

SUMMARY

(1) Experiments at the Mines Branch, Dept. of Mines and Technical Surveys, Ottawa, have shown that a number of Canadian manganese ores, which are too low in grade to be treated by conventional methods, can be treated by electric smelting to produce ferromanganese, silicomanganese, or spiegeleisen.

(2) Very large laboratory-scale experiments on a low-grade manganese ore from Woodstock, N.B., have shown that the production of ferromanganese and pig iron from this ore by a three-stage smelting process is feasible, and the results obtained have been sufficiently promising to warrant the construction of a pilot plant for the further development of the process.

(3) A very large laboratory-scale experiment on a low-grade ore from Brigus Bay, Newfoundland, has shown that silicomanganese can be produced from this material in a single-stage smelting process.

(4) Smaller-scale experiments on a low-grade siderite-type ore from Madoc, Ontario, and on a low-grade iron ore (known as 'Wall Paint') from Steep Rock, Ontario, indicated that spiegeleisen and pig iron could be produced from each of these materials by a two-stage process. In both cases, the results were considered to be sufficiently promising to warrant further experimental work on a larger scale.

Table IX.—Materials Used and Energy Consumed per Ton of Useful Product in 250 KVA Furnace Experiments.

Material	Woodstock, N.B., Ore			Brigus Bay Nfld. Ore
	Useful Product			
	Enriched Slag, (First Stage)	Silico-manganese (Second Stage)	Ferro-manganese (Third Stage)	Silico-manganese (15% Si)
Ore (lb.)	3046			7263
Enriched Slag (lb.)		9290	5294	
Lime (lb.)	114	604	3600	
Limestone (lb.)				2905
Coke (lb.)	361	1635		
Wood waste (lb.)				10816
Silicomanganese (18% Si) (lb.)			2415	
Electrodes (lb.)	45	277	180	192
Energy (KWH)	2110	12820	6980	8267

(5) Preliminary small-scale experiments on a manganiferous iron ore from Knob Lake, Quebec, indicated the possibility of producing a standard grade of spiegeleisen from this ore by a single-stage smelting process.

The results of these experiments clearly show the value of electric smelting for the treatment of low-grade manganese ores. If the manganese : iron ratio in the ore is suitable, silicomanganese or spiegeleisen may be produced by a single-stage smelting operation. If this ratio is particularly low it may be preferable to use a two-stage or three-stage smelting operation.

In Table IX, a summary is given of the materials used and the power consumed in producing one ton of useful product in each stage of the smelting of the Woodstock ore, and in the smelting of the Brigus Bay ore.

While a great deal has been accomplished in the researches reported in this article, much still remains to be done. It is planned to experiment with manganese ores from other parts of the country and an attempt will be made to solve the problems which will arise in each particular case. In addition, it is planned to continue the investigation of problems such as the effects of manganese : iron ratio and base : acid ratio, methods of treating high-phosphorus ores, methods of reducing manganese volatilization, and the use of wood waste as a reductant.

The excellent co-operation of the companies which have submitted their problems for investigation has been particularly noteworthy and the authors wish to take this opportunity to express their appreciation. A number of these companies have contributed the services of specialists from their own staffs. The advice of these men, including H. V. Glunz, L. J. Lichty, R. T. C. Rasmussen, and M. J. Udy, has contributed materially to the success of the various smelting campaigns.