

UNITED STATES  
DEPARTMENT OF THE INTERIOR  
HAROLD L. ICKES, SECRETARY

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BUREAU OF MINES  
R. R. SAYERS, DIRECTOR  
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REPORT OF INVESTIGATIONS

MANGANESE INVESTIGATIONS - METALLURGICAL DIVISION

8. PYROMETALLURGICAL STUDIES OF MANGANESE ORES

SINTERING OR NODULIZING OF FERROGRADE MANGANESE MILL  
PRODUCTS AND FINE ORES FOR SMELTING PURPOSES



BY

VIRGIL MILLER, F. B. PETERMANN, J. A. PIKE, AND R. G. PETERSON



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#### PYROMETALLURGICAL STUDIES OF MANGANESE ORES

##### 8. Sintering or Nodulizing of Ferrograde Manganese Mill Products and Fine Ores for Smelting Purposes <sup>1/</sup>

By Virgil Miller,<sup>2/</sup> F. B. Petermann,<sup>3/</sup> J. A. Pike,<sup>4/</sup>  
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#### FOREWORD

Ferrograde manganese ore or its equivalent is essential to the manufacture of every ton of steel produced; although it is well-known that there are large deposits of low-grade ore in the United States, the production of substantial amounts of ferrograde material from domestic sources presents a problem that becomes more and more critical as the stock-piled ore is depleted through inability to procure adequate supplies from foreign sources. Consequently, a program of laboratory and pilot-plant investigations designed to solve the problem of obtaining a domestic supply of manganese has been undertaken by the Metallurgical Division, Bureau of Mines.

This paper is one of a new series that will include reports of results obtained in the various investigations conducted under the manganese program. The scope of the program and the organization that was set up to direct and supervise the work were discussed in the foreword of the first paper of this series, Report of Investigations 3606, Manganese Investigations.

1. Concentration of Manganese Ores from the Drum Mountain District, Utah, by S. R. Zimmerley, J. D. Vincent, and C. R. Schack. Other reports will be published as the work progresses.

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<sup>1/</sup> The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Report of Investigations 3625."

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## INTRODUCTION

As virtually no published data are available on the sintering of fine, minus-100-mesh, ferrograde manganese ores, it is most opportune to present data on the amenability of various fine ores and mill products to the sintering process. These data cover the sintering or nodulizing of finely crushed, high-grade pyrolusite and rhodochrosite ores, sintering of manganese carbonate flotation concentrate, sintering or nodulizing the calcine from the deleading of a manganese oxide flotation concentrate, and sintering the calcines made in a Herreshoff furnace from the treatment of manganese sulfate products.

If finely sized products are to be smelted in the present electric or blast ferromanganese furnaces, they must be sintered or nodulized. The only specification as to the size of the sintered or nodulized product is that it must pass a 6-inch screen and not contain over 12-1/2 percent minus 20-mesh material. The minimum-maximum size has not been established. Undoubtedly this optimum size will be set by the ferromanganese industry when ample quantities of manganese oxide sinters have been smelted.

## ACKNOWLEDGMENTS

These studies on the sintering or nodulizing of fine ferrograde manganese ores and mill products were instigated by R. G. Knickerbocker, formerly in charge of the Pyrometallurgical Unit of the Bureau of Mines, Salt Lake City, Utah. The authors wish to thank the various contributors of ores and mill products for their cooperation.

## LABORATORY SINTERING APPARATUS

The laboratory apparatus used in this study of sintering comprised an 8-inch circular iron pipe, fitted with a removable, 3/8-inch, cast-iron perforated grate, and six sections of 3-inch pipe, 3, 5, 8, 16, 24, and 36 inches long, for convenience in treating material at any desired depth of bedded charge up to 36 inches. The 7-1/2-inch section of 8-inch pipe was connected below the grate or windbox by a 1-1/2-inch pipe to a 1-1/2 inch pyrex air-jet exhauster. This glass exhauster was connected to the 1-1/2-inch iron pipe by a short section of rubber steam hose. To protect the rubber hose from overheating, a 5-foot section of the 1-1/2-inch iron connecting pipe was water-jacketed with a pipe 3 inches in diameter.

A manometer was installed for rough control of the volume of air employed for sintering. For closer control a No. 250-B, 75-pound metric meter, having a capacity of 3,000 cubic feet an hour, was connected to a tightly fitting, sintering-hearth cover. To insure that all the air had been metered and that no dilution of the effluent gases occurred, an iron band 4-3/8 inches in length by 8-15/16 inches in diameter was welded to the windbox section of the sintering hearth, and the 5/32-inch space left between the removable section of the sintering hearth and iron band was packed tightly with asbestos cord.

## CHEMICAL ANALYSES OF PRODUCTS TREATED

There are many conflicting opinions among metallurgists as to the grade of manganese that can be nodulized or sintered. Some still believe that considerable silica must be present to form low-melting-point silicates, which act as binding material. This belief will be discussed later in this report.

TABLE 1. - Chemical analyses of sintered or nodulized ores and mill products, percent

Material .....	Mn	Fe	CaO	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Pb	S
Pyrolusite ore .....	51.4	0.4	0.8	2.7	1.4	-	-
Rhodochrosite ore .....	35.5	4.8	5.3	1.6	2.5	-	-
Manganese carbonate flotation concentrate .....	37.4	1.7	1.2	6.0	.8	-	-
Mixed oxide and carbonate ores.....	45.6	3.4	1.5	6.7	3.2	-	-
Calcine from deleading manganese oxide flotation concentrate.....	50.8	-	-	10.7		0.04	
Calcine from deleading manganese oxide flotation concentrate.....	51.6	-	-	11.4		.32	
Calcined manganese sulfate	64.8	.8	.1	0.7	1.0		2.22

## PRELIMINARY SINTERING EXPERIMENTS

When the Bureau of Mines began its extensive program on the beneficiation of manganese ores, several ideas were conceived as to the grade and physical nature of the products. One was that in no event would they be amenable to electric- or blast-furnace treatment for the production of ferromanganese.

At that time there seemed to be a possibility of having centrally located sintering or nodulizing plants for the various products made by ore-dressing or hydrometallurgical methods. In the beneficiation of these ores by the Ore-Dressing Section it seemed very likely that some jig, table, and flotation products would be made. Naturally the relative percentage of each was not known.

When this investigation to determine the feasibility of sintering relatively high grade manganese products of ferrograde was begun manganese ores were obtained because no mill products were available. The ores were crushed to different degrees of fineness for the various sintering tests so that they would compare more closely with mill products in size.

In the first series of tests (shown in table 2) all charges were blended carefully as to size of particles and placed on the sintering hearth in such a manner that the bedded charge was progressively finer from bottom to top. Petroleum coke was used as fuel for sintering.

Although the data do not include complete analysis of the sieve sizes of the sintered product, tests 2, 3, 5, and 6 satisfied specifications for sizes of nodulized or sintered ferrograde manganese products.

The conditioning of the minus-100-mesh material to form pellets and thus be less resistant to the passage of air through the charge was tried, using various materials (not exceeding 5 percent) such as road oil (80 percent asphalt), manganese sulfate, sodium carbonate, cement (as used in concrete), iron pyrite, and sodium sulfate. No definite benefits were derived from these additions, although owing to the cheapness of sodium sulfate and its fluxing action the possible use of this reagent was kept in mind.

In table 3, tests 1 to 4 inclusive, the entire raw-ore feed was minus-100-mesh. For these tests the percentage of return sinter and the depth of bed were varied.

In test 5 the coke was cut from 5.8 to 4.2 percent. This percentage of fuel was too low to produce a sinter containing 12 percent or less minus 20-mesh material.

In test 6 no return sinter was used. The final sinter contained an excessive quantity of minus-20-mesh material. The preparation of the feed for tests of this series differed from that for the series shown in table 2. The quantity of water added was increased 57 percent; the water was added to the minus-100-mesh raw ore and thoroughly mixed, then the return sinter was added and worked into the wet fines by thoroughly hand pugging. The coke was added later. The prepared charge was then bedded on the sintering hearth without regard to layering of sizes. Excellent sinters were produced from tests 1, 2, 3, and 4.

These data show definitely that under the laboratory procedure employed in these tests, fine high-grade manganese oxide ore can be sintered successfully, using two-thirds minus-100-mesh pyrolusite and one-third return sinter, with 5.8 percent coke, a depth of pugged charge of about 20-1/4 inches, and a draft of only 12 to 16 inches of water or less. The sintering of these materials on an industrial scale is believed to be feasible and in some instances more economical than nodulizing, provided that the conversion of sinter or nodule to ferromanganese is taken into consideration.





TABLE 2. - Manganese oxide sintering tests on down-draft, 8-inch circular hearth, using crushed high-grade manganese pyrolusite ore from Cleveland, Idaho

Test No.	Raw-ore charge, grams	Percent of total charge		Minus-4-mesh return sinter	Depth of bedded charge, inches	Draft, inches of water	Rate of air used, cu. ft. <sup>1</sup>	Percent sieve size of feed, mesh					Return sinter, minus-100-mesh percent	Weight of sintered product, grams	Percent sieve size of sintered product, inches and mesh				
		Coke	Water					Raw ore							Plus 1 inch	Minus 1 inch plus 4 mesh	Minus 4 plus 20-mesh	Minus 20 plus 100-mesh	Minus 100-mesh
								-4 +8	- 8 +14	-14 +40	-40 +100	-100							
1	8,000	6.1	7.1	-	7-3/4	4	23	36.0	24.0	22.0	10.0	8.0	-	-	-	-	-	-	-
2	7,500	6.0	8.0	-	7-1/2	4-1/2	23	36.0	24.0	22.0	10.0	8.0	-	6,489	40.0	-	-	-	-
3	7,500	6.0	8.0	-	7-1/2	5	23	36.0	24.0	22.0	10.0	8.0	-	6,438	45.0	-	-	-	-
4	7,500	3.1	8.3	-	7-1/2	10	23	36.0	24.0	22.0	10.0	8.0	-	-	4.8	-	-	-	-
5	3,375	6.0	8.0	47.3	7-1/2	5	23	32.0	36.5	16.6	8.6	6.3	4.9	7,147	68.8	-	-	-	-
6	5,350	6.0	8.0	24.6	7-1/2	5	23	30.4	28.6	23.1	10.2	7.7	3.2	6,576	67.2	-	-	-	-
7	5,450	6.0	8.0	23.5	7-1/2	25 5	7 23	7.0	35.0	32.0	15.0	11.0	2.0	6,620	9.3	-	-	-	-
8	7,500	6.0	8.0	-	7-1/2	25 6	5 23	-	36.8	31.7	16.8	14.7	-	6,800	8.0	-	-	-	-
9	7,500	6.0	8.0	-	7-1/2	22 4	6 23	19.0	15.0	11.0	5.0	50.0	-	6,480	9.3	-	-	-	-
10	7,500	6.0	8.0	-	7-1/2	20 5	4 23	28.5	22.5	16.5	7.5	25.0	-	6,500	7.8	-	-	-	-
11	7,500	6.0	8.0	-	7-1/2	10 8	23	32.0	26.0	18.0	9.0	15.0	-	6,450	32.6	-	-	-	-
12	7,500	6.0	8.0	-	7-1/2	10 7	23	32.0	26.0	18.0	9.0	15.0	-	6,472	32.9	-	-	-	-
13	1,875	6.0	8.0	64.5	7-1/2	6	23	-	-	-	-	100	None	6,567	20.2	11.1	56.0	6.4	6.3
14	3,750	6.0	8.0	43.0	7-1/2	8	23	-	-	-	-	100	None	7,116	4.4	15.3	54.5	9.9	15.9

<sup>1/</sup> Rate of air used (cu. ft. at 0° C. and 760 mm. pressure per minute per square foot of grate area).



TABLE 3. - Manganese oxide sintering tests on down-draft 8-inch circular hearth, using various thicknesses of bedded charge on finely crushed, high-grade, pyrolusite ore from Cleveland, Idaho

Test No.	Raw ore charge, grams	Percent of total charge		Minus-4-mesh return sinter	Depth of bedded charge, inches	Draft, inches of water	Rate of air used, cu. ft. <sup>1</sup> / <sub>min</sub>	Percent sieve size of feed, mesh					Return sinter, minus-100-mesh percent	Weight of sintered product, grams	Percent sieve size of sintered product, inches and mesh				
		Coke	Water					Raw ore							Plus 1 inch	Minus 1 inch plus 4 mesh	Minus 4 plus 20-mesh	Minus 20-plus 100-mesh	Minus 100 mesh
								-4 +8	- 8 +14	-14 +40	-40 +100	-100							
1	3,750	5.8	12.1	41.1	7-1/2	5	23	-	-	-	-	100	None	6,602	37.8	20.2	35.7	2.7	3.6
2	7,500	5.8	12.1	41.1	14	6	23	-	-	-	-	100	None	13,433	52.7	23.3	20.3	2.1	1.6
3	10,000	5.8	12.1	27.4	13-1/2	10 8	23	-	-	-	-	100	3.7	13,257	48.2	26.7	21.9	2.2	1.0
4	15,000	5.8	12.1	27.4	20-1/4	16 14	23	-	-	-	-	100	7.2	20,762	50.9	24.4	21.3	2.1	1.3
5	15,000	4.2	12.3	27.9	20	18 16	23	-	-	-	-	100	7.2	20,625	10.6	23.8	49.5	10.4	5.7
6	22,500	5.8	12.1	-	21	22 6	23	12.0	8.0	7.3	3.3	69.4	-	20,224	10.6	20.4	45.9	16.4	6.7

<sup>1/</sup> Rate of air used (cu. ft. at 0° C. and 760 mm. pressure per minute per square foot of grate area).



Recent sinters produced in the laboratory from fine iron ores were very similar to those produced on a commercial Dwight-Lloyd sintering machine with the same feed.

Some of the fine manganese ores and the mill- or leaching-plant products that will be sintered or nodulized contain manganese carbonate (rhodochrosite) in various percentages. Two sintering tests were made on a hand-picked sample of Drum Mountain ore. Only pieces of ore containing the pink mineral, rhodochrosite, were selected. The maximum addition of water was 8 percent. The conditioning and pugging of the charges were the same as in the tests shown in table 3.

In these tests, satisfactory sinters were produced with no difficulty using 6 percent coke (crushed to minus-4-mesh) on raw, fine rhodochrosite (approximately 60 percent minus-100-mesh size) or on charges where all the raw rhodochrosite was minus-100-mesh and 28.7 percent of the total charge was minus-4-mesh return sinter.

The analysis of the sinter produced from test 2 in table 4 was 52.1 percent manganese, 7.8 percent iron, 2.4 percent silica, 3.8 percent alumina, 7.1 percent lime, and 0.3 percent sulfur.

#### SINTERING COMMERCIAL MANGANESE PRODUCTS ON A LABORATORY HEARTH

##### Manganese Carbonate Flotation Concentrate

Approximately 500 pounds of a manganese carbonate flotation concentrate was received for experimental sintering tests. A sieve-size analysis of this product was 1.6 percent plus-100-mesh, 19.2 percent minus 100-plus-200-mesh, and 79.2 percent minus-200-mesh. Table 1 gives the chemical analysis. The weight per cubic foot of raw, dry concentrate was 111 pounds.

Satisfactory sinters were produced from bedded charges 8 to 16 inches deep. All charges were prepared by pugging 30 percent return sinter into the wet raw-ore charge and adding 8 percent coke. The charge, when properly prepared for bedding on the sintering hearth, contained 8 percent moisture. A vacuum of 16 to 18 inches of water was required to draw 30 cubic feet of free air at standard conditions per minute per square foot of grate area through a bedded charge of 16 inches. The time of travel of the heat through a 16-inch bedded charge was 50 minutes.



In sintering this concentrate the manganese content was increased from 37.4 to 58.9 percent. In amenability to sintering, the flotation product is very similar to the crushed carbonate in table 4.

#### Calcine from Deleaching a Manganese Oxide Flotation Concentrate

This calcined product was obtained by heating a manganese oxide flotation concentrate mixed with calcium chloride in a rotary kiln at 1,000° C. under oxidizing conditions. The particle size of this calcine was slightly larger than that of the original raw concentrate, as shown by the following size analysis:

Sieve sizes, mesh:	<u>Raw concentrate,</u> <u>percent</u>	<u>Calcine,</u> <u>percent</u>
Plus-20.....	-	7.5
Minus-20, plus-65.....	21.8	28.0
Minus-65, plus-100.....	24.0	24.3
Minus-100, plus-200.....	35.2	21.2
Minus-200.....	19.0	19.0

#### Calcined Manganese Sulfate

The calcined manganese sulfate employed in these sintering tests was produced from the roasting of manganese sulfate in a Herreshoff furnace. The chemical analysis of the calcine is given in table 1. This material is quite fine, granular, and very porous and weighs 73 pounds per cubic foot of dry material.

Sieve sizes, mesh:	<u>Calcine analysis, percent</u>
Minus-20.....	28.4
Minus-20-, plus-65.....	25.0
Minus-65-, plus-100.....	5.4
Minus-100-, plus-200.....	8.8
Minus-200.....	32.4

This calcined manganese sulfate product is not only light and fluffy but contains 6 percent soluble salts. Although the percentage of these salts is not great, they aid in sintering the product. Better quality sinters were produced from the calcines containing the soluble salts than from the calcines from which they had been removed; however, most salts have a deleterious effect on sintering, in that they migrate toward the bottom of the sinter cake and tend to clog the porous structure, thus preventing passage of air through the charge. They also coat some of the fuel and prevent ignition to a certain extent. A partial chemical analysis of these soluble salts is 16.5 percent manganese, 1.0 percent calcium oxide, 18.1 percent sulfur, 2.5 percent magnesium oxide, 0.1 percent chlorine, and 9.5 percent sodium.





TABLE 4. - Manganese carbonate sintering tests on down-draft, 8-inch circular hearth, using a hand-picked sample of rhodochrosite ore from Drum Mountain, Utah

Test No.	Raw ore charge, grams	Percent of total charge		Minus 4-mesh return sinter	Depth of bedded charge, inches	Draft in-ches of water	Rate of air used, cu. ft. $\frac{1}{2}$	Percent sieve size of feed, mesh					Return sinter, minus-100-mesh percent	Weight of sin-tered product, grams	Percent sieve size of sintered product, inches and mesh				
		Coke	Water					Raw ore							Plus 1 inch	Minus 1 inch plus 4 mesh	Minus 4 plus 20-mesh	Minus 20-plus 100 mesh	Minu 100 mesh
								-4 +8	- 8 +14	-14 +40	-40 +100	-100							
1	7,500	6.0	8.0	-	6-3/4	4	23	21.4	8.8	6.4	3.6	59.8	-	5,140	29.6	25.1	37.8	5.0	2.5
2	5,000	6.0	8.0	28.7	7	5	23	-	-	-	-	100	5.2	5,838	48.6	24.8	22.6	1.9	2.1

<sup>1/</sup> Rate of air used (cu. ft. at 0° C. and 760 mm. pressure per minute per square foot of grate area).



The addition of water to these calcines causes them to swell or increase in volume. They will absorb water up to 30 percent of their original weight, increase in volume 65 percent, and still seem relatively dry. When more than 30 percent water is added they begin to look wet, and the volume decreases as more water is added.

Owing to the high manganese and low silica content of this calcined manganese sulfate, it is quite refractory to sintering. Nevertheless, the material was sintered by a double sintering treatment into a product that was quite brittle, and when handled it broke into pieces about 1/2 inch in size. The quantity of minus-20-mesh sinter is less than 5 percent.

Should such a sintered product be acceptable under Government specifications for a ferromanganese product, it can be produced by first treating the calcines with 30 percent return sinter, 30 percent water, and 7 percent coke on a sintering machine using an 8-inch bed and a 9-inch water vacuum. This first sinter must be crushed and mixed with 6 percent coke and 20 percent water, then it must be bedded 16 inches deep on a sintering hearth and an average of 10 inches of water vacuum applied. Approximately 80 percent of the second sinter is a finished product, and 20 percent must be returned to the first sintering operation. Such a sinter will assay 68.2 percent manganese, 0.5 percent sulfur, 1.4 percent silica, and 0.5 percent calcium oxide. The loss of manganese in sintering this product should be less than 2 percent.

To produce a hard sinter the melting points of the ingredients or their compounds must not be higher than the temperatures obtainable from burning of the fuel used. Coke is the standard fuel and gives temperatures up to 1,400°C. The melting point of manganous oxide is slightly below 1,300°C. Thus, to sinter high-oxide manganese products successfully, these oxides must be largely reduced to MnO. The reducing condition obtained by burning an excessive quantity of coke on a sintering machine is quite low.

The success obtained in sintering this high-manganese product can be attributed partly to the silica introduced into the charge through the ash content of the relatively high percentage of coke used. It is evident that the charge must contain a small percentage of silica to produce a hard sinter.

#### Calcined Manganese Sulfate Plus 5 Percent of Deleaded Raw Ore

The calcined manganese sulfate product was more difficult to sinter than any other ore or product investigated, owing to its relative purity. Double sintering was required with 15 to 16 percent coke as fuel.

It was evident that the silica in the fuel ash aided considerably in producing a hard sinter. Any desired percentage of silica could be introduced into the charge by adding various percentages of a deleaded manganese raw ore. A little lead was present in the ore, but the small amount of ore required would not warrant the cost of removing the lead, although it is relatively easy to remove by chloride volatilization.

Sintering tests were made on calcined manganese sulfate plus 5 percent deleaded ore that contained 31.1 percent manganese and 29.0 percent silica. Charges containing 95 percent manganese sulfate calcine, 5 percent deleaded ore, 9 percent coke, 25 percent return sinter, and 35 percent water were sintered on a 16-inch bed; 16 to 18 inches of water vacuum was used. These first sinters were mixed with 4 percent coke and 25 percent water and sintered on a 36-inch bed. An initial vacuum of 22 inches of water was required, and as sintering progressed the required vacuum averaged 15 inches of water. The sintering time for the first sinter was 30 minutes and for the second sinter, 45 minutes. The amount of return sinter to the first roast may be varied as conditions warrant. Excellent sinters were produced without adding return sinter to the original charge.

The percentage analysis of the sinter produced was as follows:

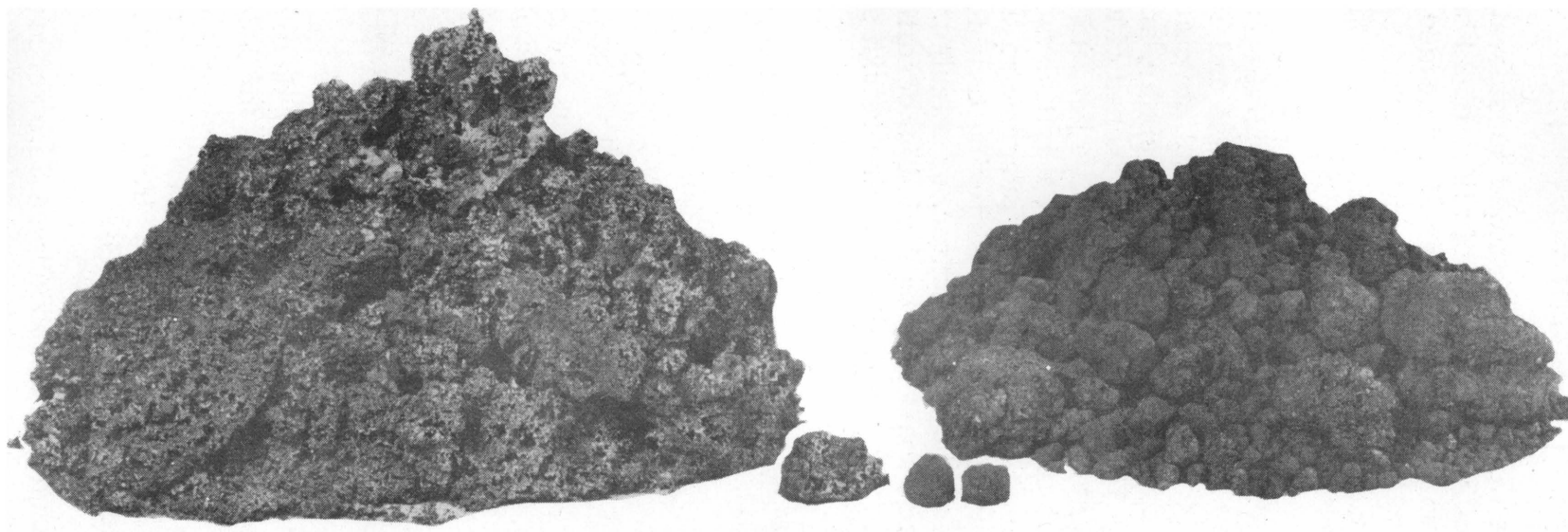
<u>Mn</u>	<u>Fe</u>	<u>SiO<sub>2</sub></u>	<u>CaO</u>	<u>MgO</u>	<u>Al<sub>2</sub>O<sub>3</sub></u>	<u>C</u>	<u>S</u>
67.5	1.2	2.8	1.6	1.7	1.6	0.3	0.1

It is believed that a higher percentage of deleaded raw ore or raw ore added to the charge would be effective in lessening the percentage of coke required for sintering. It is doubtful whether a sinter that is acceptable physically can be produced in less than two sintering treatments.

#### NODULIZING OF FINELY GROUND MANGANESE ORE AND MILL PRODUCTS

A 100-pound sample of a finely crushed manganese oxide ore did not nodulize in a rotary kiln when heated to 1,100° to 1,200° C. for 1-3/4 hours. When the same ore was mixed with a manganese ore containing 12.7 percent silica (see analysis, table 1), the mixed charge nodulized in 1 hour at 1,100° to 1,180° C. The nodules were hard and well-fused. In both tests, an oxidizing atmosphere was maintained in the furnace.

The sieve analysis of this nodulized product was 32.5 percent minus-4-inch, plus-1-inch; 28.8 percent minus-1-inch, plus-1/2-inch; 33.7 percent minus-1/2-inch, plus-20 mesh; and 5.0 percent minus-20-mesh.



50 pounds sinter

60.2	Mn (percent)
3.0	SiO <sub>2</sub> (percent)
.5	Fe (percent)
54.0	Wt. per cu. ft. (lb.)
45.0	Time of treatment (min.)

50 pounds nodules

45.2
10.8
4.5
120.0
175.0

Figure 1.- Manganese oxide sinter and nodules.



### Calcine from Deleading a Manganese Flotation Concentrate

The calcine from the treatment of a manganese flotation concentrate, in which sodium chloride and sulfuric acid were employed to remove the lead, nodulized when heated in a rotary kiln for 1-3/4 hours at 1,170° C. These nodules were not hard and well-fused, but they were strong enough to stand considerable handling.

A sieve analysis of the product was 13.7 percent plus-4-inch; 18.6 percent minus-4-inch, plus-1-inch; 46.4 percent minus-1-inch, plus-4-mesh; 9.1 percent minus-4-mesh, plus-20-mesh; and 12.2 percent minus-20-mesh.

### Comments

The nodulizing of ferrograde manganese products is a high-temperature process. To obtain the temperatures necessary for semifusion of the various manganese oxides, an oxidizing flame must be used. Considerable advantage would be gained if the charge contained low-melting-point compounds that would act as binding material for the manganese oxides. A small percentage of an organic reducing agent might be used to form a certain percentage of MnO in the charge, which would lower its melting point materially.

The physical properties of the nodules differ considerably from those of sinter. Figure 1 shows manganese oxide nodules and a manganese oxide sinter.

### CONCLUSIONS

From the experimental data presented in this paper, it is concluded that fine, high-grade manganese oxide and carbonate ores, manganese carbonate concentrate, calcines from deleading manganese oxide flotation concentrates, and calcines from the treatment of manganese sulfate can be sintered to meet ferrograde specifications, provided proper care is taken in the preparation of the charge.

A properly sintered ferromanganese blast- or electric-furnace charge will be of appreciable value in increasing the rate of production of ferromanganese in any furnace unit because of the increase in mineral surface exposed to the reducing atmosphere of the furnace.

Iron metallurgists are beginning to be "sinter-minded," consequently more research is being done on the effect of soft and hard sinters on blast-furnace operation. It is claimed that a hard sinter contains an excessive

quantity of iron silicates and is more difficult to reduce in the blast furnace. At some future date the producers of ferromanganese might make similar claims for manganese oxide sinters.

The physical properties of sinters are affected by (1) the amount of fuel used, (2) the depth of the bedded charge, (3) the ratio of the volume of air drawn through the cake to the percentage of fuel in the charge, (4) the particle size of the materials employed, and (5) the moisture content of the charge.

Several factors should be taken into account when the sintering of fine manganese ores or mill products is considered. The following are most important: (1) Higher-grade products are more readily sintered than nodulized, (2) a sintered product has a greater mineral surface, (3) a well-sintered product will always show a gain in weight of a few percent when heated at elevated temperatures in an oxidizing atmosphere, and (4) less manganese is lost by sintering than by nodulizing ferrograde manganese products.



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