

O T T A W A October 8th, 1931.

R E P O R T
of the
ORE DRESSING AND METALLURGICAL LABORATORIES.

Report No. 419

**The Production of Low Sulphur Sponge Iron
from Ore-Coal Mixtures.**

By

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Object of Investigation:

In the production of sponge iron from a mixture of iron ore and a solid reducing agent it has been found necessary to use ores and reducing agents substantially free from sulphur if a concentrated sponge low in sulphur is required. This is a serious limitation on an otherwise desirable method of reduction. The object of this investigation is to devise a method or methods by which a sponge

iron comparatively low in sulphur may be produced from ores and coals of commercial grades.

General Considerations:

For the production of sponge iron for subsequent conversion into steel, several processes have been proposed in which reduction is effected by heating a mixture of ore and solid carbonaceous material under suitable conditions. Among these is the Musso process in which a mixture of crushed ore and bituminous coal is fed into and carried through an externally heated rotating retort. With this process, as with others, it has been found that a large percentage of the sulphur content of the raw materials (ore and reducing agent) is found in the magnetically concentrated sponge iron.

It is at present not difficult to obtain ores so low in sulphur, that, as far as they are concerned, there should be no difficulty in producing a sponge iron comparatively low in this impurity. The obtaining of a low sulphur solid reducing agent is, however, not so simple. In some cases it has been found possible to use materials such as wood waste, but as far as the most obvious and otherwise desirable and commercial reducing agent, bituminous coal, is concerned, its use in the manufacture of low sulphur sponge iron has been found impracticable, since such coals, low enough in sulphur are not commercially available.

Since the sulphur is found in the magnetic concentrate it is clear that it must be present either as mechanically free FeS , which is magnetic, or as a FeS film or particle adhering to the reduced iron. Obviously then,

if we are to keep this sulphur out of the magnetic concentrate, it must be converted into some mechanically free, non-magnetic form, thus making it feasible to reject it in the magnetic separation. Under the limitations of the sponge iron process, this non-magnetic form must be either solid or gaseous.

In view of these considerations, it was decided to make a series of comparative tests involving the use of different possible methods of removing or lowering the sulphur content of the magnetically concentrated sponge iron. These tests, which, to provide a basis for comparison, included one in which no attempt was made to influence the sulphur content of the sponge, were four in number.

Group 1. Reduction without any attempt to desulphurize.

- " 2. Reduction in the presence of hydrogen, internally generated.
- " 3. Reduction in the presence of hydrogen, externally generated.
- " 4. Reduction in the presence of lime.

Raw Materials:

For these four groups of experiments, Bell (Mesaba Range) ore and Fairmont (Pa.) coal, both ground to pass a 20 mesh Tyler screen, were used.

The analyses of these materials are as follows:-

Bell Iron Ore (as charged)		Fairmont Coal (as charged)	
Iron	57.78%	Moisture	1.8%
Sulphur	0.26%	Volatile Matter	35.4%
		Fixed Carbon	54.6%
		Ash	8.2%
		Sulphur	1.3%

As Bell Ore, as mined, is said to carry only 0.04% sulphur, it is evident that the ore used for these tests was contaminated with sulphides in the grinding operation.

Experimental Runs:

Group 1. Reduction without any attempt to desulphurize.

This group of reductions was carried out simply to provide a standard against which the results of subsequent experiments might be compared.

In each of the tests of this group the following procedure was adopted. An intimate mixture of 50 lbs. of Bell Ore and 18½ lbs. Fairmont coal, both ground to pass a 20 mesh Tyler screen, was charged into an electrically heated rotating retort, which had an initial temperature of 500° F. when charged. The retort and its contents were then brought up to a temperature of 1700° F. in about four hours and held at that temperature for a period of exactly four hours. The crude sponge was then discharged into a container provided with a tightly sealing cover and allowed to cool. During the reduction, the distillation and reduction gases burned freely from a pipe extending from the plug that forms the door of the retort.

When cold, the crude sponge iron was magnetically concentrated on a Stearns Drum Type Magnetic Separator. Since the problem of obtaining a sponge iron concentrate low in sulphur is necessarily influenced by the efficiency of the magnetic separation, it was necessary to adopt a concentrating practice that would eliminate the iron-magnetic material as completely as possible, and, at the same time, see that all

the runs of this and other groups of experiments were concentrated under precisely similar conditions. The procedure adopted in concentrating the crude sponge iron in all the experiments recorded in this report is as follows:-

The crude retort product was first given two passes on the Stearns Drum Type Machine, which operations removed the bulk of the excess coke and ash. The rough concentrate was then ground to pass a 40 mesh Tyler screen after which it was given three more passes on the Stearns Magnetic Separator. The final minus 40 concentrate and the combined tailings from the five passes were then carefully sampled and chemically analyzed.

In order to measure the efficiency of the dry concentration, a small scale wet magnetic separation test was also made on the minus 40 mesh material. This wet concentration test was made in the Davis Magnetic Tube, special precautions being taken to prevent the oxidation of the products during the test. While the results of these Davis Tube tests probably cannot be duplicated in commercial practice, they are of interest here in indicating the efficiency of our dry separations.

Separations were also made on this material ground to pass a 100 mesh Tyler screen. For these tests the final minus 40 mesh concentrate was ground to minus 100 mesh and given two passes on the Stearns Machine. The concentrate and tailing were then sampled and analyzed. In the tabulated results the analyses and weight given for the 100 mesh tailing are not those of the product of these two final passes but are

TABLE I

Group I Mixture Ore and Coal Only.

Concentration Practice

Charge heated to 1700°F. and held for 4 hours.

Charge—Bell Ore 50.0 lb.
Fairmont Coal 18.2 lb.A. Separation of minus 40 mesh material

1. Dry Magnetic Separation.
 - (a) Retort Product, 2 Passes, Stearns Machine
 - (b) Rough Concentrate, (a) ground to -40 mesh
 - (c) -40 mesh Rough Concentrate - 3 passes on Stearns Machine

2. Wet Magnetic Separation
 - (a) -40 mesh Dry Concentrate treated in Davis Tube.

B. Separation of minus 100 mesh material.

1. Dry Magnetic Separation.
 - (a) Retort Product - 2 Passes, Stearns Machine
 - (b) Rough Concentrate (a) ground to -40 mesh
 - (c) -40 mesh Rough Conc. - 3 passes Stearns Machine
 - (d) -40 mesh Conc (c) ground to -100 mesh
 - (e) -100 mesh Product (d) - 2 passes.

2. Wet Magnetic Separation.
 - (a) -100 mesh Dry Conc. - Davis Tube

Grude Sponge Iron					Dry Magnetic Concentration								Wet Magnetic Concentration								Iron Recovery		Sulphur Distribution									
Analysis					Concentrate				Tailing				Concentrate				Tailing				Dry	Wet	Dry Separation				Wet Separation					
Test No.	Wt. Percent	Total Iron	Metallurgical Iron	Sulphur	Wt. Percent	Total Iron	Metallurgical Iron	Sulphur	Wt. Percent	Total Iron	Metallurgical Iron	Sulphur	Wt. Percent	Total Iron	Metallurgical Iron	Sulphur	Wt. Percent	Total Iron	Metallurgical Iron	Sulphur			Separation	Separation	Retort Charge	Gases	Conc.	Tail.	Retort Charge	Gases	Conc.	Tail.
Minus 40 mesh Separation																																
100	100	62.86	59.87	0.62	72.10	82.00	81.20	0.68	27.90	13.43	4.78	0.47	69.69	83.08	82.59	0.71	30.31	16.40	7.62	0.41	94.04	92.11	100.	29.39	55.85	14.76	100.	29.39	59.24	11.37		
101	100	63.35	59.99	0.61	72.55	82.40	80.80	0.64	27.45	13.00	4.99	0.54	70.08	82.60	79.20	0.63	29.92	18.25	15.01	0.57	94.37	91.38	100	29.71	53.43	16.86	100	29.71	50.88	19.41		
102	100	63.04	59.89	0.62	71.90	81.85	80.80	0.65	28.10	14.90	6.40	0.54	68.50	82.60	82.60	0.64	31.50	20.51	10.51	0.59	93.35	89.75	100	28.55	53.76	17.69	100	28.55	50.51	20.94		
-Minus 100 mesh Separation																																
100	100	62.86	59.87	0.62	71.00	83.60	82.50	0.63	29.00	12.14	4.48	0.61	64.84	87.06	86.47	0.55	35.16	18.23	10.82	0.74	94.40	89.80	100	29.39	50.93	19.68	100	29.39	40.54	30.07		
101	100	63.35	59.99	0.61	71.13	83.60	82.50	0.62	28.87	13.46	4.53	0.59	65.91	85.76	84.16	0.55	34.09	20.13	13.26	0.73	93.88	89.20	100	29.71	50.82	19.47	100	29.71	41.77	28.50		
102	100	63.04	59.89	0.62	69.70	82.90	82.90	0.58	30.30	17.39	6.96	0.71	62.94	87.00	86.70	0.54	37.06	22.35	14.36	0.75	91.66	86.86	100	28.55	46.55	24.90	100	28.55	39.17	32.28		

the values for the combined tailings resulting from the seven passes to which the retort product was subjected. In other words the weights and analyses given for the products of the 100 mesh concentration are those obtained from the concentration of the crude retort product, ground to 100 mesh.

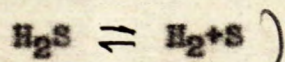
As in the case of the minus 40 mesh material, wet magnetic concentration tests in the Davis Tube were also made on the minus 100 mesh material.

The results obtained in this group of tests are given in Table 1. These results are discussed later in this report.

Group 11. Reduction in the presence of hydrogen.

Hydrogen generated within the retort by the action of steam on carbon.

In view of the opinion held by some that sulphur may be removed from sponge iron by hydrogen as hydrogen sulphide, it was decided to make a series of reductions in the presence of hydrogen. (It was felt, however, that desulphurizing by this method was not feasible since, even if hydrogen sulphide were temporarily formed, it is dissociated when heated to temperatures such as obtain in the reduction of iron ores



In each run of this group the charge was subjected to the action of hydrogen gas during a considerable part of the reduction period, the hydrogen being generated within the retort by the action of steam on the carbon charged with

TABLE II

Group 2. Mixture Ore and Coal.

Reduction in presence of Hydrogen
Generated within the retort.

Concentration Practice

Charge heated to 1700°F. and held constant for a 4 hour period.
At the end of the 2nd hour of the final period, 1800CC of Water
ure added to the retort over a period of 45 minutes.

Charge -

Bell Ore 50.0 lb.
Fairmont Coal 24.2 lb.
Water 1800. C.C.

A. Minus 40 Mesh Separation

1. Dry Magnetic Separation.

(a) Retort Product - 2 Passes, Stearns Machine

(b) Rough Concentrate (a) ground to -40 mesh

(c) -40 mesh Rough Concentrate, -3 Passes.

2. Wet Magnetic Separation.

(a) 40 mesh dry concentrate treated in Davis Tube

B. Separation of Minus 100 mesh material

1. Dry Magnetic Separation.

(a) Retort Product - 2 passes, Stearns Machine

(b) Rough Concentrate (a) ground to -40 mesh

(c) -40 mesh Rough Concentrate - 3 passes

(d) -40 mesh Concentrate ground to -100 mesh

(e) -100 mesh product (d) - 2 passes.

2. Wet Magnetic Separation

(a) -100 mesh Dry Concentrate
treated in Davis Tube.

		Dry Magnetic Concentration												Wet Magnetic Concentration												Iron Recovery		Sulphur Distribution								
Crude Sponge Iron		Concentrate				Tailing				Concentrate				Tailing				Dry		Wet		Dry separation		Wet separation												
Test	Wt.	Analyses			Wt.	Analyses			Wt.	Analyses			Wt.	Analyses			Wt.	Analyses			Percent	Total Iron	Metallic Iron	Sulphur	Percent	Total Iron	Metallic Iron	Sulphur	Percent	Total Iron	Metallic Iron	Sulphur	Percent	Total Iron	Metallic Iron	Sulphur
No.	Percent	Total Iron	Metallic Iron	Sulphur	Percent	Total Iron	Metallic Iron	Sulphur	Percent	Total Iron	Metallic Iron	Sulphur	Percent	Total Iron	Metallic Iron	Sulphur	Percent	Total Iron	Metallic Iron	Sulphur	Feed'n	Separ'n	Refract. Charge	Gases	Conc.	Tail.	Refract. Charge	Gases	Conc.	Tail.						
103	Minus 40 Mesh Separations		100.	60.95	58.16	0.68	72.70	79.60	78.21	0.64	27.30	11.29	4.75	0.77	70.04	80.98	78.01	0.69	29.96	14.12	11.75	0.66	94.95	93.06	100.	34.34	44.83	20.83	100.	34.34	46.66	19.00				
104	100.	58.64	55.32	0.65	69.70	79.00	77.52	0.67	30.30	11.84	4.28	0.61	67.60	78.63	74.72	0.65	32.40	16.97	14.84	0.65	93.89	90.64	100.	33.58	47.71	18.71	100.	33.58	44.90	21.52						
105	100.	60.04	55.80	0.65	68.58	80.13	78.63	0.68	31.42	16.20	5.97	0.57	66.90	80.13	76.61	0.71	33.10	19.43	13.74	0.53	91.53	89.28	100.	33.94	47.40	18.66	100.	33.94	48.26	17.80						
103	Minus 100 Mesh Separations		100.	60.95	58.16	0.68	71.23	80.70	79.99	0.63	28.77	12.06	4.10	0.80	64.82	85.14	83.06	0.55	35.18	16.37	12.29	0.92	94.31	90.54	100.	34.34	43.33	22.33	100.	34.34	34.42	31.24				
104	100.	58.64	55.32	0.65	68.90	80.40	78.70	0.61	31.10	10.42	3.50	0.74	63.62	82.78	81.79	0.55	36.38	16.43	9.04	0.82	94.47	89.81	100.	33.58	42.95	23.47	100.	33.58	35.75	30.67						
105	100.	60.04	55.80	0.65	67.68	81.00	80.55	0.62	32.32	16.17	3.97	0.71	60.64	85.37	84.18	0.54	39.36	21.04	12.08	0.82	91.30	86.22	100.	33.94	42.65	23.41	100.	33.94	33.28	32.78						

the ore. To provide this carbon, an additional amount of coal, and hence of sulphur, was added.

In the carrying out of these tests conditions were kept as far as possible the same as obtained in the comparison tests of Group 1, the object being to eliminate all variables but the one being investigated. The procedure adopted was as follows:

A mixture of 50 lbs. Bell Ore and $24\frac{1}{2}$ lbs. Fairmont coal, both ground to pass a 20 mesh Tyler screen, was charged into an electrically heated rotary retort, which had an initial temperature of 500° F. The retort and its contents were then brought up to a temperature of 1700° F. in about four hours and held at that temperature for exactly four hours. At the end of the second of these final four hours, the introduction, drop by drop, of 1800 c.c. (3.97 lbs.) of water into the retort through a pipe in its rear axis, was begun and continued for an hour, so that the final hour of reduction was free from any unusual circumstance. The crude sponge iron was then discharged into the special container, and, when cold, concentrated in precisely the same manner as described for the tests in Group 1.

The results obtained in this group of tests are given in Table 11, and are discussed later in this report.

Group III. Reduction in the presence of hydrogen.

Hydrogen externally generated and supplied in the form of city gas.

The method of generating hydrogen within the retort by the action of steam on carbon is open to criticism

on two grounds; first, the problem of desulphurization is greatly increased because of the additional sulphur introduced by the carbon provided for the water gas reaction and second, the steam may react with the reduced iron instead of the carbon and thus make reduction more difficult.

In view of these possible objections it was deemed wise to carry out a few tests in which reduction took place in the presence of hydrogen, externally generated. Since Ottawa city gas contains 40 to 45 percent hydrogen, and it was convenient to use, it was utilized as the source of hydrogen.

In the carrying out of each run of this group, the following method was followed:

A mixture of 50 lbs. of Bell Ore and $18\frac{1}{4}$ lbs. of Fairmont coal, both ground to pass a 20 mesh Tyler screen, was charged into an electrically heated rotary retort which had an initial temperature of about 500° F. The retort and its contents were then brought up to a temperature of 1700° F. in about four hours and held at this temperature for exactly four hours. During the last two of this final four hour period a stream of city gas containing 45% hydrogen was passed through the retort. At the end of the four hour reduction period the crude sponge iron was discharged into a special container and allowed to cool.

In each case, the crude sponge iron was magnetically concentrated in precisely the same manner as described for the tests of Group 1.

The results obtained in this group of tests are given in Table 111 and are discussed later in this report.

TABLE III

Group 3 Mixture Ore and Coal.

Reduction in presence of Hydrogen.
Generated externally.Charge heated to 1700°F. and held constant for a period
of 4 hours. City gas was passed into the retort during
the final 2 hours.Charge
Bell Ore 50 lb.
Fairmont Coal 182 lb.

Concentration

- A. Minus 40 mesh Separation
1. Dry Magnetic Separation.
(a) Retort Product - 2 passes, Stearns Machine
(b) Rough Concentrate (a) ground to -40 mesh
(c) -40 mesh Rough Concentrate - 3 passes.
2. Wet Magnetic Separation.
(a) -40 mesh dry concentrate treated
in the Davis Tube.

Practice

- B. Separation of Minus 100 mesh material.
1. Dry Magnetic Separation
(a) Retort Product - 2 passes, Stearns Machine
(b) Rough Concentrate (a) ground to -40 mesh.
(c) Rough Concentrate (b) - 3 passes
(d) -40 mesh concentrate ground to -100 mesh.
(e) -100 mesh Concentrate (d) - 2 passes.
2. Wet Magnetic Separation.
(a) -100 mesh Dry Concentrate treated
in Davis Tube.

		Dry Magnetic Concentration												Wet Magnetic Concentration												Iron Recovery								Sulphur Distribution							
		Concentrate				Tailing				Concentrate				Tailing				Dry		Wet		Dry Separation				Wet Separation															
Test	Wt	Analyses		Sulphur	Wt	Analyses		Sulphur	Wt	Analyses		Sulphur	Wt	Analyses		Sulphur	Wt	Analyses		Sulphur	Dry	Wet	Dry	Separation			Wet	Separation													
No.	Percent	Total Iron	Metall. Iron		Percent	Total Iron	Metall. Iron		Percent	Total Iron	Metall. Iron		Percent	Total Iron	Metall. Iron		Percent	Total Iron	Metall. Iron		Percent	Total Iron		Metall. Iron	Percent	Separat'n		Separat'n	Report Charge	Gases	Conc.	Tail.	Report Charge	Gases	Conc.	Tail.					
-40 Mesh Separations																																									
106	100	64.14	62.72	0.55	79.02	78.69	77.69	0.54	20.98	9.32	6.34	0.58	76.91	79.38	77.99	0.54	23.09	13.38	11.87	0.59	96.95	95.19	100	37.85	48.22	13.93	100	37.85	46.93	15.22											
107	100	63.50	61.75	0.57	77.35	79.28	78.29	0.55	22.65	9.61	5.25	0.65	74.51	80.37	78.78	0.52	25.49	14.20	11.97	0.72	96.57	94.35	100	33.27	49.84	16.89	100	33.27	45.38	21.35											
108	100	63.43	61.88	0.59	77.92	78.79	77.97	0.57	22.08	9.22	5.09	0.68	75.58	79.48	78.56	0.53	24.42	13.76	10.23	0.78	96.79	94.70	100	31.32	51.70	16.98	100	31.32	46.63	22.05											
-100 Mesh Separations																																									
106	100	64.14	62.72	0.55	78.30	80.07	78.69	0.51	21.70	6.68	5.12	0.69	72.82	82.46	81.08	0.49	27.18	15.06	13.54	0.71	97.77	93.62	100	37.85	45.12	17.03	100	37.85	40.32	21.83											
107	100	63.50	61.75	0.57	76.48	79.50	78.49	0.54	23.52	11.22	7.32	0.67	69.60	83.26	82.06	0.48	30.40	18.25	15.25	0.78	95.85	91.27	100	33.27	48.36	18.37	100	33.27	39.10	27.63											
108	100	63.43	61.88	0.59	77.22	79.68	78.76	0.59	22.78	8.35	4.66	0.58	72.07	81.64	80.96	0.48	27.93	16.44	12.63	0.86	97.00	92.76	100	31.32	53.03	15.65	100	31.32	40.27	28.41											

Group IV. Reduction in the presence of lime.

In view of the fact that in smelting operations the use of a high lime slag makes desulphurization commercially feasible, through the formation of calcium sulphide, the introduction of lime with the ore-coal mixture into the sponge iron reduction chamber has been suggested by several workers, although they apparently were not enthusiastic about its probable efficiency in removing the sulphur from the iron. Thus in Bulletin 270 of the U. S. Bureau of Mines, page 140, we read "In some cases ten percent of lime mixed with the ore-coal charge increased the elimination of sulphur by 10 or 15 percent but not enough experiments were made to determine the probable value of such treatment in large-scale operations. It is doubtful, however, if the use of lime will go far in solving the problem of eliminating sulphur."

In order to obtain some first hand data on the effect of lime in promoting the elimination of sulphur, it was decided to carry out a series of reductions in which lime was charged with the ore-coal mixture. It was further decided to use a considerable excess of lime with the idea in mind of cutting this excess down should this method prove successful.

In each of the tests of this group the following procedure was adopted. A mixture of 50 lbs. of Bell Ore, 18½ lbs. Fairmont coal and 12 lbs. burnt lime was charged into an electrically heated rotary retort, which had an initial temperature of about 500° F. The retort and its contents were then brought up to a temperature of 1700° F. in about four hours and held at that temperature for exactly

TABLE IV

Group 4 Mixture Ore, Coal and Lime.

Reduction in presence of Lime

Charge heated to 1700°F. and held constant
for a period of 4 hours.

Charge
Bell Ore 50. lb.
Fairmont Coal 18.2 lb.
Lime 12. lb.

Concentration Practice

A. Minus 40 mesh Separation.
1. Dry Magnetic Separation.
(a) Retort Product - 2 passes, Stearns Machine.
(b) Rough Concentrate (a) ground to -40 mesh.
(c) -40 mesh Rough Concentrate - 3 passes.
2. Wet Magnetic Separation.
(a) -40 mesh dry concentrate (c) treated in
Davis Tube.

B. Separation of Minus 100 mesh Material.
1. Dry Magnetic Separation.
(a) Retort Product - 2 passes, Stearns Machine.
(b) Rough Concentrate (a) ground to -40 mesh.
(c) Rough Concentrate (b) - 3 passes.
(d) -40 mesh Concentrate ground to -100 mesh.
(e) -100 mesh material (d) - 2 passes.
2. Wet Magnetic Separation.
(a) -100 mesh Dry Concentrate treated in
Davis Tube.

		Dry Magnetic Concentration												Wet Magnetic Concentration								Iron Recovery		Sulphur Distribution							
Crude Sponge Iron		Concentrate				Tailing				Concentrate				Tailing						Dry Separation						Wet Separation					
Test No.	Wt Percent	Analyses			Wt Percent	Analyses			Wt Percent	Analyses			Wt Percent	Analyses			Wt Percent	Analyses			Dry	Wet	Dry Separation				Wet Separation				
		Total Iron	Metall. Iron	Sulphur		Total Iron	Metall. Iron	Sulphur		Total Iron	Metall. Iron	Sulphur		Total Iron	Metall. Iron	Sulphur		Total Iron	Metall. Iron	Sulphur	Separat'n	Separat'n	Retort Charge	Gases	Conc.	Tail.	Retort Charge	Gases	Conc.	Tail.	
- 40 Mesh Separation.																															
109	100	51.13	47.89	0.55	62.48	75.99	72.22	0.12	37.52	9.72	7.38	1.26	53.53	84.24	80.56	0.03	46.47	12.99	10.27	1.15	92.86	88.19	100	22.12	10.62	67.26	100	22.12	2.27	75.61	
110	100	52.21	44.83	0.60	63.90	74.90	68.59	0.18	36.10	12.06	2.78	1.33	54.53	83.45	78.47	0.09	45.47	14.74	4.49	1.21	91.67	87.16	100	14.23	16.44	69.33	100	14.23	7.02	78.75	
111	100	52.04	48.32	0.59	62.14	77.18	74.40	0.11	37.86	10.77	5.52	1.37	52.61	86.45	81.36	0.05	47.39	13.84	11.64	1.19	92.16	87.40	100	16.06	9.72	74.22	100	16.06	3.74	80.20	
- 100 mesh Separation.																															
109	100	51.13	47.89	0.55	61.77	76.98	75.60	0.09	38.23	9.37	3.11	1.30	49.62	87.30	84.60	0.04	50.38	15.51	11.73	1.05	93.00	84.72	100	22.12	7.87	70.01	100	22.12	2.81	75.07	
110	100	52.21	44.83	0.60	63.15	75.90	69.19	0.16	36.85	11.61	3.09	1.35	50.10	85.90	83.34	0.03	49.90	18.39	6.16	1.17	91.80	82.43	100	14.23	14.44	71.33	100	14.23	2.15	83.62	
111	100	52.04	48.32	0.59	61.31	79.08	76.57	0.10	38.69	9.19	3.55	1.37	50.27	87.89	85.90	0.04	49.73	15.80	10.33	1.16	93.17	84.90	100	16.06	8.72	75.22	100	16.06	2.86	81.08	

four hours. The crude sponge iron was then discharged into a special container to cool. When cold, the crude sponge iron was magnetically concentrated in precisely the same manner as described for the tests in Group 1.

The results obtained in this group of tests are given in Table IV and are discussed later in this report.

Results Obtained:

From a study of the data presented in Table I, it is apparent that the concentrated sponge iron produced from straight ore-coal mixtures such as were used in these experiments, is so high in sulphur as to be entirely unsuitable for direct conversion into steel. The tabulated results show that over 50% of the sulphur contained in the raw materials fed into the metallizing furnace is found in the 40 mesh dry concentrate and even if we grind to minus 100 mesh and wet concentrate, the concentrates still retain about 40% of the sulphur content of the charge. The results of this group of tests show that no matter how efficient the concentration practice may be, the sulphur content of the sponge iron concentrate will average well over 0.5% which is ten times as much as the sulphur content of pig iron and scrap steel ordinarily used in steel making.

That the presence of hydrogen in the reducing atmosphere during the low temperature reduction process does not result in the lowering of the sulphur content of the sponge iron concentrate is made clear from a study of Tables II and III. In each of these groups of experiments, the sulphur content of the concentrate resulting from the

magnetic concentration of the crude sponge iron, is still well over 0.5% and on this account is totally unsuitable for direct conversion into steel.

That a low sulphur sponge iron can be obtained from such ore-coal mixtures by charging lime into the metallizing retort with the ore and coal is clear from the data presented in Table IV. A study of this data makes it clear that although the crude retort product still contains about as much sulphur as it would have, had no lime been charged, yet the sulphur has been transferred from the iron particles to the lime, with which it is apparently associated as sulphide of lime. This sulphide of lime, being non-magnetic, is largely removed from the iron in the magnetic concentration.

It will be noted that the average sulphur content of the minus 40 mesh concentrate from the ore-coal-lime mixture is about 0.14% and from the minus 100 mesh material is about 0.12%. That these residual contents of sulphur are largely if not entirely mechanically held calcium sulphide is evidenced by the fact that by wet magnetic concentration these values are reduced to 0.06% and 0.04% respectively. In view of this fact and of what is commonly known of the difficulty of separating in a dry way finely divided magnetic materials from finely divided non-magnetics, it is reasonable to assume that with ore ground to a coarser mesh than was used in these tests, dry magnetic concentration of the sponge produced from it in the presence of lime would result in a product with a sulphur content more or less in line with that obtained from the wet separation of the finely ground materials.

TABLE V

Group 5. Coarse Ore, Fine Coal.

Reduction in presence of Lime.

Charge heated to 1700°F. and held constant
for a period of 4 hours.

Charge

Bell Ore Sinter (-6+10 mesh) 50. lb.
Fairmont Coal 18.2 lb.
Lime 12. lb.

Concentration Practice

A. As Metallized

(1) Retort product - 3 passes on
Stearns drum type machine.

B Minus 40 mesh Separation.

(1) Retort Product - 3 passes on
Stearns drum type machine.

(2) Rough Conc. (1) ground to -40 mesh.

(3) -40 mesh rough Conc. - 2 passes on
Stearns machine

		Dry Magnetic Concentration															
Crude Sponge Iron					Concentrate				Tailing				Iron	Sulphur Distribution			
Test	Wt	Analyses			Wt	Analyses			Wt	Analyses			Recovery	Dry Separation			
No.	Percent	Total Iron	Metall. Iron	Sulphur	Percent	Total Iron	Metall. Iron	Sulphur	Percent	Total Iron	Metall. Iron	Sulphur	Dry Separation	Retort Charge	Gases	Conc.	Tail.
Separation as Metallized (-6+10) mesh																	
116	100.	52.45	48.30	0.36	71.20	72.37	67.04	0.07	28.80	3.22	1.98	1.07	98.23	100.	19.87	11.15	68.98
117	100.	52.85	46.38	0.37	69.33	73.36	65.14	0.07	30.67	6.48	3.96	1.04	96.23	100	16.95	11.05	72.00
- 40 Mesh Separation.																	
116	100.	52.45	48.30	0.36	70.54	72.66	68.31	0.07	29.46	4.07	0.37	1.06	97.72	100	19.87	10.88	69.25
117	100	52.85	46.38	0.37	68.62	73.06	65.14	0.07	31.38	8.67	5.35	1.03	94.86	100	16.95	11.35	71.70

In order to confirm this assumption two runs were made similar to those summarized in Table IV except for the fact that the ore used was first sintered and crushed to a size that would pass through a 6 mesh Tyler screen and remain on a 10 mesh. In each of these runs, the crude retort product was first given three passes on the drum type separator in order to get rid of as much of the mechanically free non-magnetic material as possible. This rough concentrate was then ground to minus 40 mesh and given two passes more on the same drum type machine. The results obtained are shown in Table V. These results show that the sulphur content of the concentrate after three passes only has been reduced to 0.07%, and while it must be admitted that the sulphur content of the charge was lower than that of the previous charges due to the sinter containing only 0.06% sulphur, it is reasonable to assume that the low sulphur content of the final concentrate is due to the ready separation of the calcium sulphide from the comparatively coarse sponge in the dry magnetic concentration.

Summary:

Several suggested methods of producing a low sulphur sponge iron from ore-coal mixtures have been investigated. Of these but one proved satisfactory.

This method found satisfactory consists of charging lime with the mixture of ore and coal into the reduction chamber. By so doing the sulphur is caused to associate itself with the lime and it is therefore feasible to remove

it from the reduced iron by magnetic separation. The extent to which this removal takes place depends largely upon the efficiency of the magnetic concentration practice.

No attempt has been made to study the effect of different proportions of lime. The proportion used in these experiments was adequate to fix the sulphur as calcium sulphide and is probably unnecessarily large.