A Thesis

Experiments on the Manufacture of Cast Iron from Katahdin and Manhattan iron ores in the Institute Blast Furnace.

'78

Abstract of the Thesis T. Dan '78

This thesis is divided into 3 Sections.

Section I contains a detailed account of a metallurgical treatment of Katahdin iron ore:

The ore treated was Limonite partly roasted and partly raw.

The first Smelt.

The slag used had the following composition

SiO_2	42.06	per cent
Al_2O_3	16.21	" "
CaO	32.50	" "
MgO MnO &c	9.23	
	100.00	

Charcoal used as fuel.

We obtained from our first tap about 16 lbs of white cast iron, the rest of iron being lost in slag.

We concluded that the failure as a whole, is chiefly due, to the charging of fine ores with large lumps of charcoal; thus the ore being sifted through to the melting zone, without being

Abstract

reduced & carburetted. and also due to the too rapid settling of the charges.

A production of pig iron in the beginning is accounted for, by the presence of sulphide of ~~iron~~ lead which was left sticking on the sides of the furnace, from a previous lead smelt; the excess of sulphur having a peculiar influence in a formation of a sulphur rich cast iron, above a certain temperature and under conditions, when cast iron is not expected. This conclusion is drawn from a similar experience of I. Lothian Bell.

The Second Smelt:

The slag used contained the following proportion of

SiO_2 40.25 per cent
Al_2O_3 15.62 " "
CaO 32.96 " "
$\left\{ \begin{array}{l} MgO \\ MnO \\ \&c \end{array} \right.$ 11.17
100.00

Charcoal used as fuel.

Abstract

No cast iron obtained; but when front of the furnace was torn down a huge "salamander" consisting of metallic iron & slag was found, showing that the part of iron was reduced. We concluded that the failure is mainly due to the fast rate of settling.

Section II contains an account of a metallurgical treatment of Manhattan iron ore:
The ore treated was Limonite, much more compact & siliceous than the Katahdin iron ore.
The ore was roasted in kiln, in order, to render it porous & crumbly by expelling the water of hydration &c.
The slag used had the composition

SiO_2	39.14	per cent
Al_2O_3	13.22	" "
CaO	47.64	" "
MgO MnO &c	0	" "
	100.00	" "

Abstract

Coke used as fuel.
Dimeter of tuyere was reduced to only $\frac{3}{4}$'' in order to reduce the rate of melting, thus securing slower settling of charges. As the furnace was very hot in the begining, melting took place even above the boshes & when cooled down the refractory slag was deposited on the sides of the furnace forming a scaffolding.
No cast iron obtained.
The failure seems to depend chiefly on the want of fuel during the smelt.
Succeeded in settling the furnace quite slowly.

Section III contains discussions on Blast Furnaces.

This these is divided, according to the order of treatment, into three sections.

Section I

A metallurgical treatment of Katahdin iron ore

division 1 - - - - - - - - - - - - - Pages 1 to 9 inclusive

An account of the preliminary treatment of the ore, outlines of the methods used for the analyses of the ore and Limestone with a table showing their compositions.

Division 2 - - - - - - - - - - - Pages 10 to 33 incl.

A detailed account of the workings and outlines of calculations used in connection with the first smelt.

(a) Calculation for slag, composition and formula of the slag used - - - - Pages 10 to 14 inclusive

(b) Details of assays made with mixture of the ores - - - - - - - - - - - - - - - - - - Pages 15 to 17 incl.

(c) Amount of fuel calculated by Bell's table of absorption and by a method devised for the occassion ... Pages 18 to 21 incl.

(d) Dimensions of the blast furnace used diameter of the tuyere and its position &c. ---------- Pages 22

(e) Feed and tap records in full, and a charging table ------- Pages 23 to 28 incl.

(f) Analyses of pig iron obtained &c Page 31

(g) Probable reasons for the failure of the run as a whole and a production of the small amount of cast iron in the beginning --------- Pages 29, 30, 32, 33.

Division 3 ------------- pages 34 to 55 incl

An account of the workings and outlines of calculations used in connection with the second smelt

(a) Methods of agglomeration of the fine ore and its final treatment --- Pages 35, 36

(b) Calculations for fuel by Bell's Table and by the method devised -------- pages 40, 41

(c) Dimensions of the furnace used - the diameter of the tuyere used &c Pages 34, 42, 43

(d) Calculation for desirable slag, the composition and formula of the slag used --- pages 37 - 39 incl.

(e) Charging table, feed and tap records in full ----- charging table on 36, Pages 44 - 49 incl.

(f) A survey of the burnt part of the furnace &c ---------- Pages 50 - 52 incl.

(g) Partial analyses of the slags from the earlier and the latter part of the run and conclusions based upon the results &c Pages 54 - 55 incl.

Section II

A metallurgical treatment of Manhattan iron ore

Division 1 ---------- pages 57 - 59 incl.

An account of the preliminary treatment of the ore; outlines of the methods used in the analysis of the ore and a table showing the compositions of the ore and Magnetite ore from Cheever bed ore Port Henry N.Y.

Division 2 ------------ pages 60 - 80 incl.

A detailed account of the workings and outlines of calculations used in connection with the Second Smelt.

(a) Roasting of the ore in detail & remarks. pages 60-65 incl.

(b) Calculations for slag; the composition and formula of the slag used ---- Page 66

(c) Necessary amount of fuel calculated by Bell's table of absorption and by our original method. pages 67 to 69 incl.

(d) Dimensions of the furnace used; the diameter of the tuyere &c ideas for charging in the next run &c. Pages 70, 71

(e) Charging tables; Feed and Tap records in full and remarks ------ pages 72-78 incl.

(f) Analysis of tap-cinder obtained page 79

(g) Calculation for necessary of coke, after the run ---------------- pages 79, 80

Section III

Discussions

A Experiments on the rate of deoxidation by passing pure Co at different temperatures and a table showing the rate of deoxidation in different furnaces producing gray or white iron — adopted from Bell's "Chemical Phenomena of Iron Smelting" — and conclusions drawn from the above -------- pages 81 to 85 incl.

B Relations between different part of the furnace and its capacity under different conditions &c - - - - - - - - - - - - - - - - - - - pages 86, 87

C Calculations of the dimensions of a coke and a charcoal furnace producing 40lb iron per hour from the ore mixtures used in the smelting of Manhattan iron ore, & remarks. pages 87 to 95 incl.

D Calculations for necessary amount of blast for the calculated furnaces, taking into consideration the diameter of the tuyere and the pressure of the blast. - - - - - - - - - - page 96, 97

E The capability of the Institute furnace discussed - - - - - - - - - - - - pages 98. 99

F Table showing ratios of different parts in different furnaces. - - - - - - page 100

Section I

A Metallurgical treatment of Katahdin iron ore

There are two kinds of bed at Katahdin Me.
No 1 bed is reported be pyrites bed oxidized insitu. Frequently lumps of the ore are found only oxidized on the surface.
No 2 bed is deposited from the water charged with iron dissolved from No 1 bed.
Several pieces of twigs were found imbedded in the ore, the interior of which were completely replaced by the ore with bark still remaining.
As the consequence of pyritical origin the ore contains a large amount of sulphur.

Division 1

We received from Katahdin Maine:
461 lbs of No 2 bed ore (Raw)
343 lbs " " " " " (Roasted)
306 lbs " No 1 " " (Raw)
251 lbs " No 1 " " (Roasted)

120 lbs of Manganese ore
286 lbs of Dolomite from Rockland Me.

A greater part of the ore were reduced to powder during its transportation.

No 1 bed ore (Raw and Roasted) and Manganese ore being wet, I dried them on steam table

No 2 bed ore (Raw and roasted), Limestone and Manganese ore were put through the Blake crusher.

No. 1 bed ore (Raw and Roasted) containing a large amount of fine stuff; hammer was used for crushing a few large lumps.

In sampling the ore and the limestone, I used the method of quartering ~~was used~~:-
After reducing the amount of the ore to about 5 lbs the ore was passed through $\frac{1}{4}$" sieve, which was again reduced to a very small quantity and was passed through $\frac{1}{60}$" sieve, to be ready for analyses. The same was done with the limestone.

As a rough analysis of charcoal to be used in the smelting is necessary, I sampled it by picking several pieces here and there and then reducing them to about $\frac{1}{4}$" in size and as quartered down to a small quantity which was passed through $\frac{1}{60}$" sieve, ready for

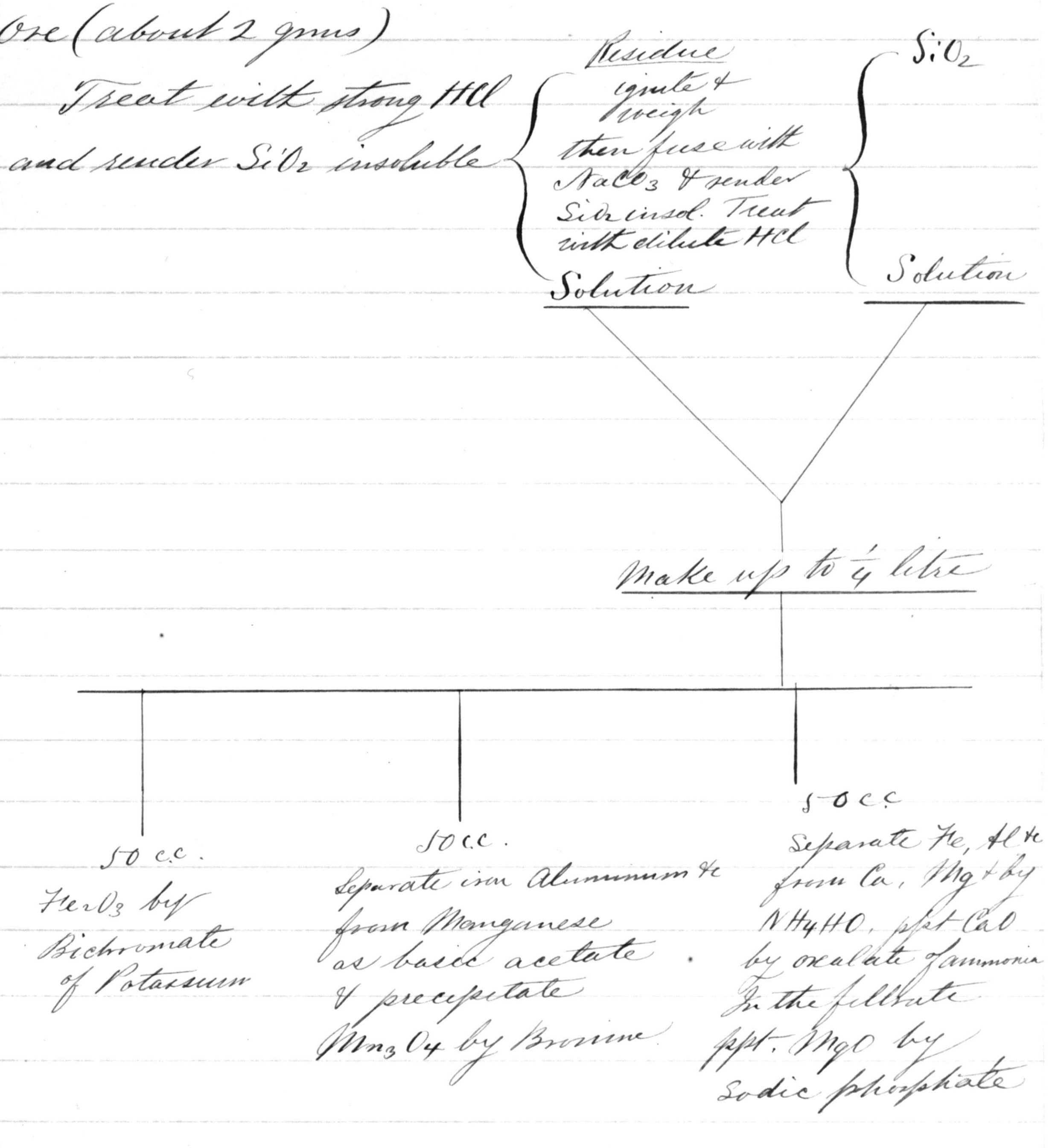
Division 1

analysis. It is not necessary to reduce charcoal so finely.

Sampling by picking is very commonly done though can not be as accurate as the method of quartering.

Division 1

The method of analysis adopsted for the iron ore, is graphically shown below.



Ore (about 2 gms)

Treat with strong HCl and render SiO_2 insoluble

Residue
ignite & weigh
then fuse with $NaCO_3$ & render SiO_2 insol. Treat with dilute HCl

SiO_2

Solution

Solution

Solution

Make up to $\frac{1}{4}$ litre

50 c.c.
Fe_2O_3 by Bichromate of Potassium

50 c.c.
Separate iron Aluminium &c from Manganese as basic acetate & precipitate Mn_3O_4 by Bromine

50 c.c.
Separate Fe, Al &c from Ca, Mg & by NH_4HO. ppt CaO by oxalate of ammonia In the filtrate ppt. MgO by Sodic phosphate

Division 1

Al_2O_3 is determined by weighing $Al_2O_3 + Fe_2O_3$ and subtracting Fe_2O_3 obtained by titration.

The analysis of limestone was done as shown below.

Limestone [about 2 gms taken]
treat with dilute HCl
{ Residue
{ Solution

Separate Al_2O_3, Fe_2O_3 &c from Ca & by ammonia. ppt. CaO by oxalate of ammonia, ppt. MgO by sodic phosphate.
$Al_2O_3 + Fe_2O_3$ is weighed if Fe_2O_3 is present titrate for Fe_2O_3 & subtract the weight of Fe_2O_3 from $Al_2O_3 + Fe_2O_3$. –

Division 1

I found that it is necessary to reduce the ore still finer than $\frac{1}{60}''$ in size in order to have the ore dissolve completely and easily in HCl. Therefore I had to grind it in agate motor and sift through fine cloth before treated with HCl.

Before treating with HCl, I calcined raw ores in order to oxidize the organic matter present, which would otherwise greatly hinder the titration of iron with bichromate. The same can be done by boiling HCl solution with small quantity of Chlorate of Potassium, which would oxidize the organic matter.

Division 1

Table showing the compositions of iron & Manganese ore & Limestone

	SiO_2		Al_2O_3		CaO		MnO		Fe_2O_3		MgO	
	%	wt. in lbs	%	wt in lbs	%	wt in lbs	%	wt in lbs	%	wt in lbs	%	wt in lbs
No. I roast	4.14	10.39	3.01	7.55	0	0	0	0	86.67 Fe 60.669	151.669	0	0
No. I raw	3.56	10.90	2.14	6.55	0	0	0	0	71.51 Fe 50.057	153.35	0	0
No. 2 roast	7.34	25.18	7.89	27.07	0	0	0	0	77.97 Fe 54.579	187.27	0	0
No. 2 raw	3.96	18.29	4.35	20.08	0	0	0	0	71.53 Fe 50.071	245.19	0	0
Mn Ore	33.03	39.63	16.24	19.48	0	0	3.26	3.912	21.58 Fe 15.106	18.12	5.91	7.09
Limestone	3.03	8.66	1.02	2.91	50.04		0	0	trace		3.36	9.60
	SiO_2	Ash										
Charcoal	trace	1.27										

The total weight of the ore including Mn ore weighs 1480 lbs. and the total weight of metallic iron 755.59 lbs, hence in 1480 lbs there is 51% of iron. In 1480 lbs there are 104.39 lbs of SiO_2 and 80.73 lbs of Al_2O_3, and 3.91 lbs of MnO.

By mixing the ore and the limestone in proportion to their respective weights as given on page 2 I get slag of following composition without any addition of free slag:

SiO_2	Al_2O_3	CaO	MgO	MnO
31.61%	22.57%	39.77%	4.66%	1.09%

and the proportion of slag to pig will be about 1:3.

Kerl gives the slag of the following formula $4(CaO\,SiO_2) + Al_2O_3\,3SiO_2$ containing the following proportion of

SiO_2	CaO	Al_2O_3
56	30	14

as producing from pure ore good gray or mottled iron with charcoal

With charcoal a more acid slag can be used

With coke " " basic must be used.

The slag as I will get without addition of free slag seems altogether two basic compared with Kerl's normal slag, although slag from a furnace in Ormesby England recorded by Bell is of almost exactly same composition, and that from a Clarence furnace was even more basic, containing 27.65% of SiO_2. However, both were running from large Coke furnaces with heated blast.

It seemed that an addition of free slag was necessary for two purposes. 1° to increase the ratio of slag to pig: the slag is not enough, according to different authorities, to protect the iron from oxidation by CO_2 &c. Ratio of pig to slag varies between 1:1 to 1:4. Higher the pressure more slag required.

2° To make slag somewhat more acidic if possible

Division 2 (a)

Slag from West Stockbridge, Mass. which by analysis containing the following proportion of was used as an additional slag. On account of the lack of time I was not able to determine MgO and MnO.

SiO_2	Al_2O_3	CaO
47	12.59	29.11
Fe_2O_3	MgO	MnO
1.52		

If we make the ratio of slag to pig as 8:7 we have

Composition of slag

SiO_2	Al_2O_3	CaO
40.09%	18.52%	33.55%

Charge ..... No 1

ore ------ 29.6

lime ---- 5.6

Stockbridge slag --- 10.0

If we make the ratio of slag to pig as 11:7 we have

Composition of slag

SiO_2,	Al_2O_3,	CaO
42.06	16.21	32.50.

Charge ... No 2

ore --------- 29.6

lime ------- 5.6

Stockbridge slag ---- 15.

If we make the ratio of slag to pig as 13:7 we have

Composition of slag			Charge	No. 3
SiO_2	Al_2O_3	CaO	ore	29.6
44.50%	17.67%	31.80	lime	5.6
			Stockbridge slag	20.0

If I use Charge No 2 I shall have slag of following formula

$5.2(2CaO\,SiO_2) + 3.1(2Al_2O_3\,3SiO_2) + 1.2(2MgO\,SiO_2) + .7(2MnO\,SiO_2)$ leaving about 3.8% SiO_2 free. I assigned imaginary values to MgO 7% MnO 2.23% thinking they will not be far from the true values. If the ratio of MgO to MnO is entirely different from the above supposed values, the molecular condition of the slag will not greatly deviate from the above formula.

The slag produced by Charge No. 2, whose formula is given on page 12 is essentially monosilicate slag.

Sometimes monosilicate mixed with subsilicate is used, as in the case of the Clarence slag to avoid SiO_2 from going into iron, in the manufacture of gray iron.

Bisilicate is rather too acid even with charcoal furnaces - too much Si enters iron.

Subsilicate is rarely used being too basic.

Iron assays. I made four assays
First two assays.

Proportion of mixture

No. 1 bed ore raw	2.51 grms
No. 1 " " roast	3.06 "
No. 2 " " raw	4.61 "
No. 2 " " roast	3.42 "
New ore	1.20 "
Limestone	2.86 "
Charcoal	4.00 "

The mixture of ore and limestone to their respective weights as given on page 2 the assays were unsuccessful. the particles of iron did not collect into one globule and also great deal of iron went into slag.
The percentages of iron obtained are given below.

No. 1 Assay	No. 2 Assay
Fe = 30.7%	Fe = 22.08%
4.54 grms	3.27 grms.

The theoretical percentage based upon my analyses is about 50 % and ought to contain 7.54 gms of Fe.
The failure seems to be caused by lack of sufficent amount of slag - and also perhaps heat was not hot enough.

The Second assays.
The proportion of the mixture is same as before with the exceptions that I added 5 gms of slag and the crucibles were brasqued.
The result is given below

	No I assay		No 2 assay
Fe =	7.92 gms	Fe =	7.92 gms
Slag =	7.89 "	Slag =	7.84 "

As seen by the result the assays were a complete success.
The weights of the iron are even a little

more than the theoretical weight, owing to the addition of carbon and to the adhering slag.

The proportion of slag to pig is nearly 1:1

Division 2 (c)

The minimum amount of charcoal necessary for smelting of iron, can be approximately calculated, according to I. Lothian Bell as follows: using 100 by weight of Fe. and the ratio of slag to pig as 8:7

Class I Chemical Action and Fusion

	No. of units per 100 of pig by weight		No. of Calories per unit		Calories absorbed
Evaporation of H_2O in charcoal	H_2O X	×	540	=	X
Evap. H_2O in ore	H_2O 31	×	+540	=	16740
Reduction of Fe	Fe_4 100	×	1780	=	178000
Carbon impreg F_4C	C 4	×	2400	=	9600
Expulsion CO_2 from $CaCO_3$	$CaCO_3$ 37	×	370	=	13690
Decomp. of CO_2 to CO	C in $CaCO_3$ 4.4	×	3200	=	14080
" " H_2O in blast	H X	×	34000	=	X
Reduction of P. S. Si	P .01	×	5747	=	57
from P_2O_5, SO_3, &	S .1	×	8000	=	800
SiO_2 – imajinary	Si 1.	×	2500	=	2500
Fusion of pig	Fe_4C 100	×	330	=	33000
" " slag	Slag 114	×	550	=	62700

Class II Loss regarded as chiefly unavoidable

transmission through wall	No. of square feet of the surface of radiation Sq. 96'	×	118 average	=	11328
off in gases	wt. of blast .5 lbs	×		=	500
Carried off in tuyere water	X	×		=	X

Total calories absorbed = 342995

Division 2 (c)

Evap. of H_2O in charcoal, decomposition of H_2O in blast and heat carried off by tuyere water being unknown and uncertain, I have omitted to add the calories absorbed by the above, which will of coarse reduce the total number of Calories somewhat.

To calculate the ratio of charcoal to pig or to whole charge following steps are taken

100 charcoal evolves about 408000 calorific units
For smelting 100 Fe absorbs 342995 "
hence 15 lbs of Fe absorbs about 12.6 lbs of charcoal.

In 29.6 lbs of ore there is about 15 lbs of iron present

	Charge No. 1	Charge No 2	Charge No 3
Ore	29.6	29.6	29.6
Limestone	5.6	5.6	5.6
Slag	10	15	20
Mixture	45.2	50.2	55.2
Charcoal	12.6	13.50	17.55
	mixture : charcoal	mixture : charcoal	mixture : charcoal
	3.5 : 1		

Division 2 (c)

Very approximate result can be arrived at by using the rough method given below.

15 lbs Fe needs 4.8 lbs carbon to reduce it from Fe_2O_3, provided whole of Carbon is burnt to Co and no Co is wasted. Of coarse, such a thing can never be, but for the sake of approximation I imajined to be such.

15 lbs Fe needs .8 lbs carbon to carburet to Fe_4C

To melt 50 lbs of mixture at the rate of 4 part of mixture to 1 part of charcoal needs 12.5 lbs charcoal

Putting in tabular form

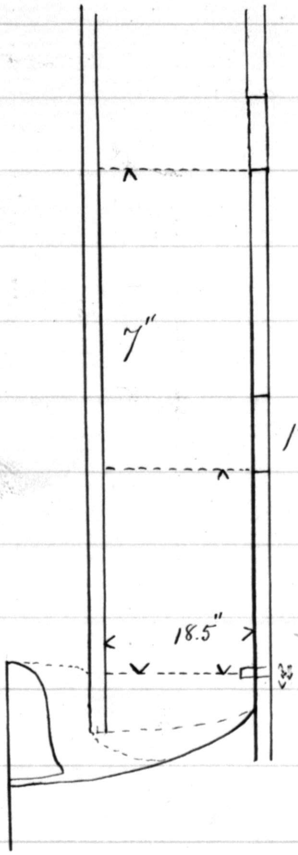
15 lbs Fe needs	4.8 lbs carbon to reduce
" " "	.8 " " " carburet
Melt 50 lbs Mixture @ mixture 4 : 1 charcoal	12.5 " "
Total amt. charcoal for smelting 15 lbs of iron	18.1 lbs charcoal

Ratio of mixture to charcoal will be about 3 : 1 ; if 7 mixtures to 1 coal is used for melting 80 lbs mixture, the ratio of mixture to charcoal will be about 4 : 1 I made the use of the word charcoal to represent carbon, which is, of coarse, erroneous. Amount of moisture, ash, &c must be subtracted from charcoal.

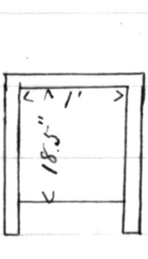
The first Smelt.

No 1 bed ore raw and roast, No 2 bed ore raw and roast and Manganese ore were mixed in layeres.

The dimensions of the blast furnace is given below.



Contains 10.79 cu.ft. from tuyere to the charging door.



The dimensions of the crucible are almost exactly the same as given on page with the exceptions of there being no projection of tuyere and the tuyere itself was 1½" in diameter

Charges used in the smelting

	I	II	III
Ore		29.6	29.6
limestone		5.6	5.6
Slag	40	15.	15.
Total	40	50	50
Coal	coke 10	charcoal 25	charcoal 20
Ratio of Charcoal to mixture	1:4	1:2	1:2.5

The ratio of charcoal to mixture is very much higher than calculated according to Bell, as the excess of charcoal seemed to be necessary for many reasons.

division 2 (e)

Feed and Tap Records of the first Smelt

Feed Record				Tap Record			
Time	Interval	Charge	Depth	Time	Interval	Buggy slag	Pig
9-30 AM							
10-13 "		I	2'				
10-17 "	4	I	3½'				
10-30 "	13	I	3½'				
10-40 "							
10-42 "	12	I	4'				
10-50 "							
10-58 "	16	I	3'				
11-2 "	4	I	3½"				
11-7 "	5	I	4'				
11-14 "	7	I	4.3'				
11-30 "	16	II	5'				
11-45 "	15	II	full 7'				
12-2PM	17	II	do.	12-0M		9th	
12-18 "	16	II	do.	12-10PM	10	10	
12-32"	14	III	do.	12-18 "	8	11	
12-50 "	13	III	do.	12-25 "	7	12	
1-0 "	10	III	do.	12-30 "	5		¼ pig 16lbs
1-15 "	15	III	do.	12-35"	5	13	
				12-45"	10	14	

Notes

Blast on

Slag sealed front

Slag began to run

Division 2 (e)

Feed and Tap Records of the first Smelt (continued)

Feed Record Tap Record

Time	Interval	Charge	Depth	Time	Interval	Buggy slag	pig
				12-50 P.M.	5	15th	
				12-55 "	5	16	
				1~~2~~-5 "	10	17	
				1-10 "	5	1	
				1-17	7	18	

Notes

Slag stopped coming
Slag coming freely

An incident of rather a serious nature occurred during the smelting from carbonic oxyd escaping from the furnace, which stifled us more or less causing us to give up the smelting altogether by 1-17 P.M. The great amount of the gas generated by using an excess of charcoal found its way into the room by charging door.

As we had to stop the smelting on account of the gas, we gave up the smelt as a failure.

The first ore charge was made at 11.30 A.M. at 12.30 P.M. I got a pig. This shows that the ore was dried, warmed, reduced and carburetted and melted in less than one hour between 7'. I only got one pig from the first tap; the next tap gave nothing but tap-cinder.

The reason why we got only one pig and the rest of the iron went into tap-cinder, we could not at first imagine, but Professor Richards concluded the following reasons as the cause of the failure:

In the first place, the ore being charged onto the slag and coke mixture, and having nearly the same size as the slag and coke, did not sift through them, but slowly went down the furnace, going through the steps necessary for becoming cast iron; hence the first tap give pig. On the other hand, the subsequent charges were made onto the previous ore charges, which consisted of small pieces of ore with great deal of fine stuff and large pieces of charcoal, so the ore sifted right through the charcoal, without going through necessary steps for becoming a cast iron — hence the the resulting tap-cinder.

The above reasons seems well founded but subsequent investigations convinces me that the above reasons are by no means the only ones and also ~~convinces me~~ that the production of the pig is entirely accidental.

The reason will be found on pages 32 and 33

The pig obtained showed itself to be white cast iron which by analyses contained the following proportion of

Si	S	P	C { Combined C Graphite
1.53%	1.52%	.33%	2.30%

being white cast iron, carbon is mostly combined. I did not determine Graphite partly on account of the lack of time and partly thinking that the amount of free carbon can not be but very small.

Analyses of Gray cast iron obtained from the same ~~furnace~~ ores at the Katahdin furnace is given below

Si	S	P	C	Mn
2.04%				.94%

The analyses of the pig iron show ~~that~~ that the amount of Sulphur is extraordinary high, while Silicon and phosphorus are very fair: Carbon seems rather low. –

The high percentage of Sulphur is accounted for by the fact that sulphide of lead sticking on the side of the furnace from a previous lead run, gave its sulphur to the iron and partly, perhaps, from by the sulphur containing in the ore itself.

The reason for the production of the white cast iron itself, in the small furnace seem to depend entirely upon this high percentage of Sulphur contained in it, according to Experiment of I. Lothian Bell which is essentially as follows:

Bell was trying to recover the Sulphur used in the Manufacture of Soda". This was done by fusing the soda waste with oxide of iron left after the expulsion of the S from iron pyrites and in this way a compound of Fe and S was obtained to be used again as source of S."

"While engaged in this manufacture it was noticed that whenever the temperature of the blast furnace, which was 25 ft high and 10 feet at the boshes, driven with hot air rose above a certain point, white cast iron instead of a sulphide made its appearance." "This was remarkable seeing that the quantity of S introduced was sufficent to give & frequently afforded a sulphide of iron containing 30% of S."

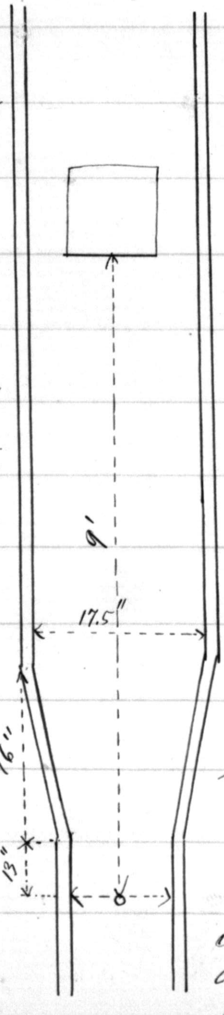
A Specimen of this white cast iron contained 1.78% of Sulphur.

I quote the statement of Bell here, illustrating the similar conditions which attended the production of my white cast iron containing 1.52% Sulphur and the white iron obtained by Bell

Second Smelt.

Since the last smelt the furnace was almost completely rebuilt except the lower part of the furnace. The following is the rough sketch of the furnace giving the dimensions. Section and plan of the crucible, in detail, will be found on pages 42 & 43.

Tuyere $1\frac{1}{4}$" in diameter



The contents of the furnace from the twyere to the upper charging door is about 18.9 cu.ft.

The upper charging door is two feet higher than it was before

The lower door is about 1 foot higher

The flue which conducts the waste gas is also enlarged

This drawing is not in scale an accurate drawing is given on page 92)

As a great part of the ore mixture consisting of No 1 raw and roast, No 2 raw and roast and Manganese ore left from the last smelt, is reduced to fine powder, we thought that it is necessary either to reject ~~them~~ it altogether or to agglomerate it.

In view of agglomerating it, I have consulted different authorities on the subject. Among them Dr Hermann Wedding's Eisenhüttenkunde.

He gives following methods of agglomeration:

1° Argillaceous ores can be agglomerated by moistening with water and roasted in tiles.

2° Siliceous and calcareous ores by lime water.

3° Dross products of the furnace can be resmelted by sticking them with lime water in conjunction with coal or coal slack, with, or without subsequent heating.

I intended to employ the second case, but for the lack of time, I was obliged to reject the fine stuff altogether, weighing 216 lbs, through $\frac{1}{12}$" sieve.

I had the charcoal crushed to about the sizes of the ore, before charging.–

Charges employed during the Smelt.

	I	II	VII	III	IV	V	VI
Ore		$29\frac{5}{8}$	---- "		$29\frac{5}{8}$	$29\frac{5}{8}$	$29\frac{5}{8}$
lime		$5.\frac{5}{8}$	---- "		$5\frac{5}{8}$	$5\frac{5}{8}$	$5\frac{5}{8}$
Slag	60	10.	---- "	90	4	4	4
New Mn Ore		$3\frac{1}{2}$	---- "		$3\frac{1}{2}$		
Total	60	$48\frac{3}{4}$	$48\frac{3}{4}$	90	$42\frac{3}{4}$	$39\frac{1}{4}$	$39\frac{1}{4}$
	Coke	Charcoal	Charcoal	Coke	charcoal	Charcoal	Charcoal
	15	15	20	15	20	20	$13\frac{1}{2}$
Mixture: Fuel	4:1	3.2:1	2.4:1	6:1	2.1:1	2:1	3:1

Division 3 (d)

The new Manganese ore sent from the mine containing following proportion of

S.	SiO_2,	Al_2O_3,	Fe_2O_3,	CaO,	MgO	MnO
.07%	35.84%	7.45%	14.07%	3.49%	0	35.13

was recommended as beneficial.

Division 3 (d)

Calculations for Slag

By using Charges II and VII given on page

	lbs.		Fe	SiO_2	Al_2O_3	MnO	MgO	CaO
Ore (mixed)	$29\frac{5}{8}$	contain	15	2.11	1.63	.07	.14	
Dolomite	$5\frac{5}{8}$	"		.17	.06		.19	2.8
Slag	10	"	.15	4.69	1.26			2.91
New Mn ore	$3\frac{1}{2}$	"	.38	1.25	.26	1.23		1.02
Total		"	15.53	8.22	3.21	1.93	.33	6.73

Slag elements

Slag by weight		%
SiO_2	8.22	40.25
Al_2O_3	3.21	15.62
MnO	1.93	9.45
MgO	.33	1.61
CaO	6.73	32.96
Total	20.42	100.00

By weight		%
$2CaO\,SiO_2$	10.33	50.53
$2Al_2O_3\,3SiO_2$	6.01	29.40
$MnO\,SiO_2$	3.53	17.16
$2MgO\,SiO_2$	.57	2.91
Total	20.44	100.00

$50.53(2CaO\,SiO_2)+29.4(2Al_2O_3\,3SiO_2)+17.16(MnO\,SiO_2)+2.91(2MgO\,SiO_2)$
by calculating as above lacks only a very little SiO_2

The formula as given on last page is nearly mono silicate, containing a small amount of bisilicate. As seen in the formula all except MnO are in the form of mono-silicate; MnO being bisilicate.

Ratio of pig to slag is 1 : 1.31

Calculation for fuel

15.53$^{\text{lb}}$ Fe needs 5$^{\text{lb}}$ carbon for reduction
" " " .83$^{\text{lb}}$ " " carburetting
Melt @ $\overset{\text{fuel mixture}}{1:7}$ needs 7$^{\text{lbs}}$ "
Mixture 48$\frac{3}{4}^{\text{lbs}}$
Melt @ 1:4 needs 12$\frac{3}{16}$ "

Using 1:7 requires 12.83$^{\text{lb}}$ carbon
" 1:4 " 18.03$^{\text{lb}}$ "

Calculation of Fuel by Bell's Table – using 100 by weight of iron. Ratio of pig to slag is 1 : 1.31

Table of heat Absorption

Class I

CHemical Action and Fusion

	no. of units per 100 of pig by weight		No. of calories per unit		Calories absorbed
Evap. of H_2O in coke		×	540	=	
Evap. H_2O in charge	H_2O 31	×	540	=	16740
Reduction of Fe	Fe 100	×	1780	=	178000
Carbon impreg.	C in Fe_4C 4		2400	=	9600
Expulsion of CO_2 from $CaCO_3$	$CaCO_3$ 37		370	=	13690
Decomposition of CO_2 to CO	C in $CaCO_3$ 4.4		3200	=	14080
" " H_2O in blast	H		34000	=	
Reduct. of P. S. Si	P . .01		5747	=	57
from P_2O_5, SO_3 & SiO_2	S .1		8000	=	800
	Si 1.		2500	=	2500
Fusion of pig	Fe_4C 100		330	=	33000
Fusion of slag	Slag 131		550	=	72050

Class II

Losses regarded as chiefly unavoidable

Transmission through walls of the furnace	96'sq	118 average	=	11328
off in gases			=	600
carried off in tuyere water			=	

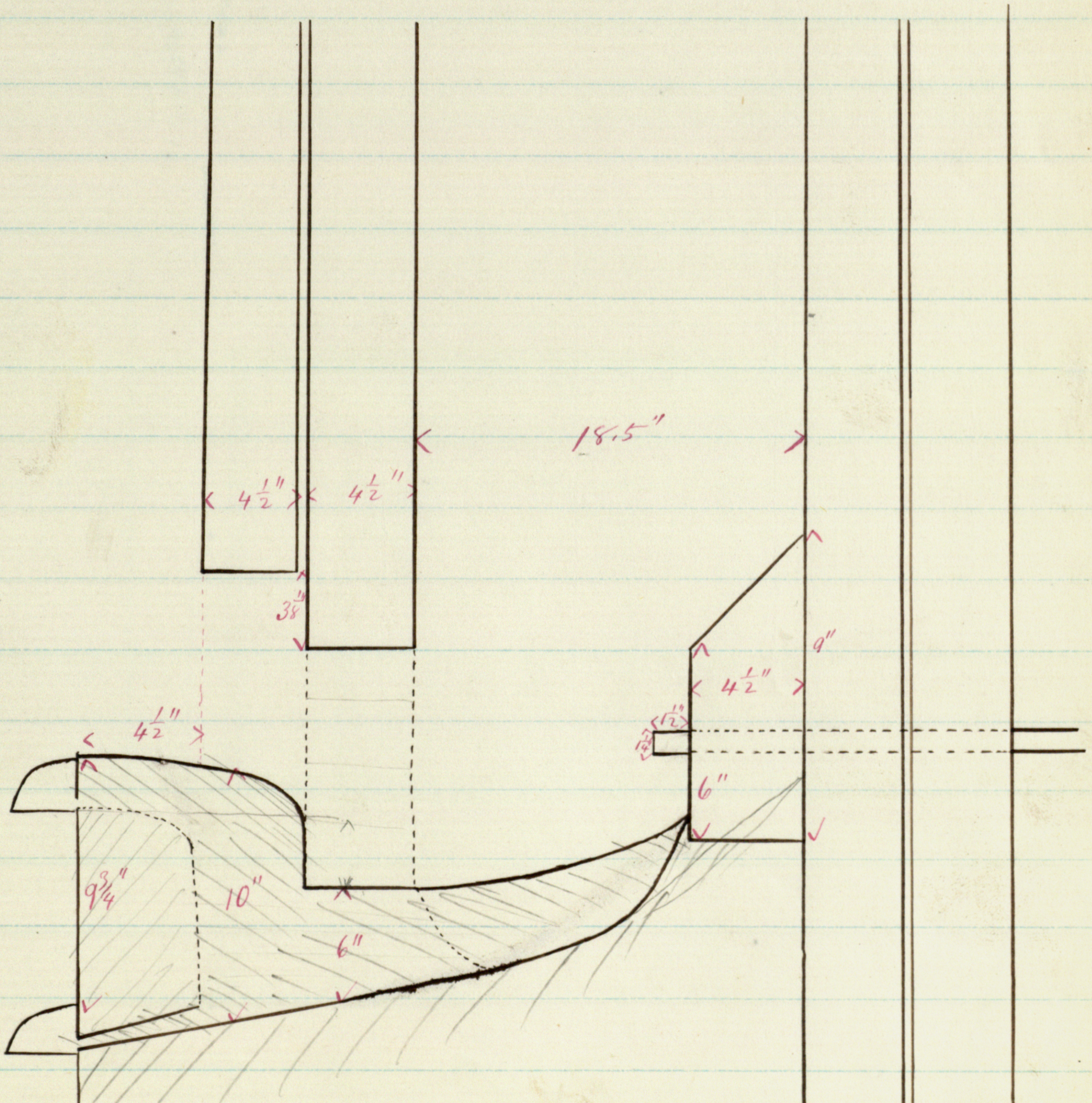
Total Absorption = 352445 cal.

Division 3 (b)

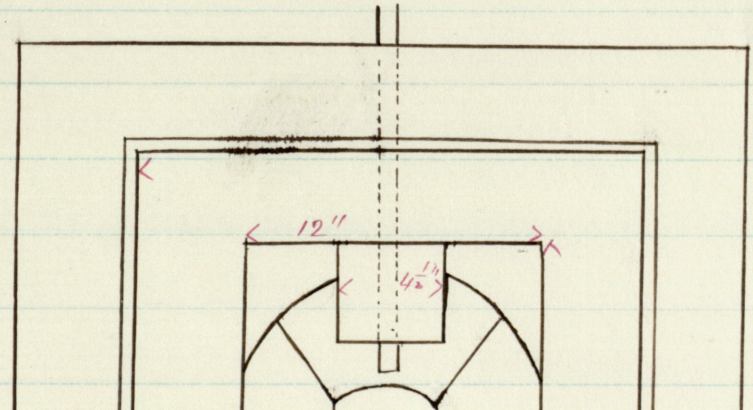
It requires to smelt 100 lbs of iron 352445 cal.
100 coal evolve 408000 calories. hence
100 iron requires 86.5 carbon and
15.53 iron " 13.43 "

Evaporation of H_2O in coke, decomposition of H_2O in blast & heat carried off by tuyere water are omitted. Reduction of P. S. Si, transmission through walls of furnace and off in gases are very roughly calculated. For the the above reason, the result obtained will be lower then it ought to be.

Side Section of Crucible



Plan of the crucible



division 3 (e)

Feed and Tap Records
of the Second Smelting of Katahdin iron ore

Feed Record				Tap Record			
Time	Interval	Charge	Depth	Time	Interval	Buggy slag	Pig
8-0 AM							
9-35 "							
9-53 "		I					
9-58 "	5	I					
10-02 "	4	I					
10-04 "	2	I					
10-06 "	2	I		10.-15 AM			
10-20 "	14	I					
10-26 "	6	I					
10-30 "	4	III					
10-36 "	6	III					
10-40 "	4	III					
10-44 "	4	I	full 9'				
10-57 "	13	II	do.				
11-08 "	11	II	do.				
11-30 "	22	II	do				
11-45 "	15	II	do.				
12-0 M	15	II	do.				
12-22 P.M.	22	II	8'				

Notes.

March 27th at 6 P.M. 2 hods charcoal, 2 hods coke
7 hods coke
Blast on

Slag sealed front

Tap and Feed Records (Continued)

Feed Record				Tap Record			
Time	Interval	Charge	Depth	Time	Interval	Buggy slag	Pig
12-37 P.M.	15	II	8'				
12-54 "	17	II	8'	12-55 P.M.			
1-10 "	16	II	8'				
1-15 "	5	II	full	1-16 "			
1-20 "	5	IV	do.				
1-26 "	6	IV	do.				
1-34 "	8	IV	do.				
1-38 "	4	IV	do.				
1-50 "	12	IV	do.	1-52 "			
1-55 "	5	IV	do.				
2-06 "	11	IV	do.				
2-16 "	10	IV	do.				
2-22 "	6	V	do.				
2-32 "	10	VI	do.				
2-40 "	8	VI	do.				
2-47 "	7	VI	do.				
2-58 "	11	VI	do.				
3-04 "	6	VI	do.				
3-14 "	10	VI	do.				
3-18 "	4	VI	do.				

Notes.

Ore slag first coming

tap gave tap-cinder

tap gave tap-cinder

Division 3 (e)

Tap and Feed Records (continued)

Time	Interval	Charge	Depth	Time	Interval	Buggy slag	Pig
3-25 P.M.	7	VI	full				
3-33 "	8	VI	do				
3-41 "	8	VI	do				
3-49 "	8	VI	do				
4-10 "							
				4-20 P.M.			
				5-15 "			
				5-30 "			

Notes

4 hods of coke
Tap gave tap-cinder

Tap gave tap-cinder, Furnace run out

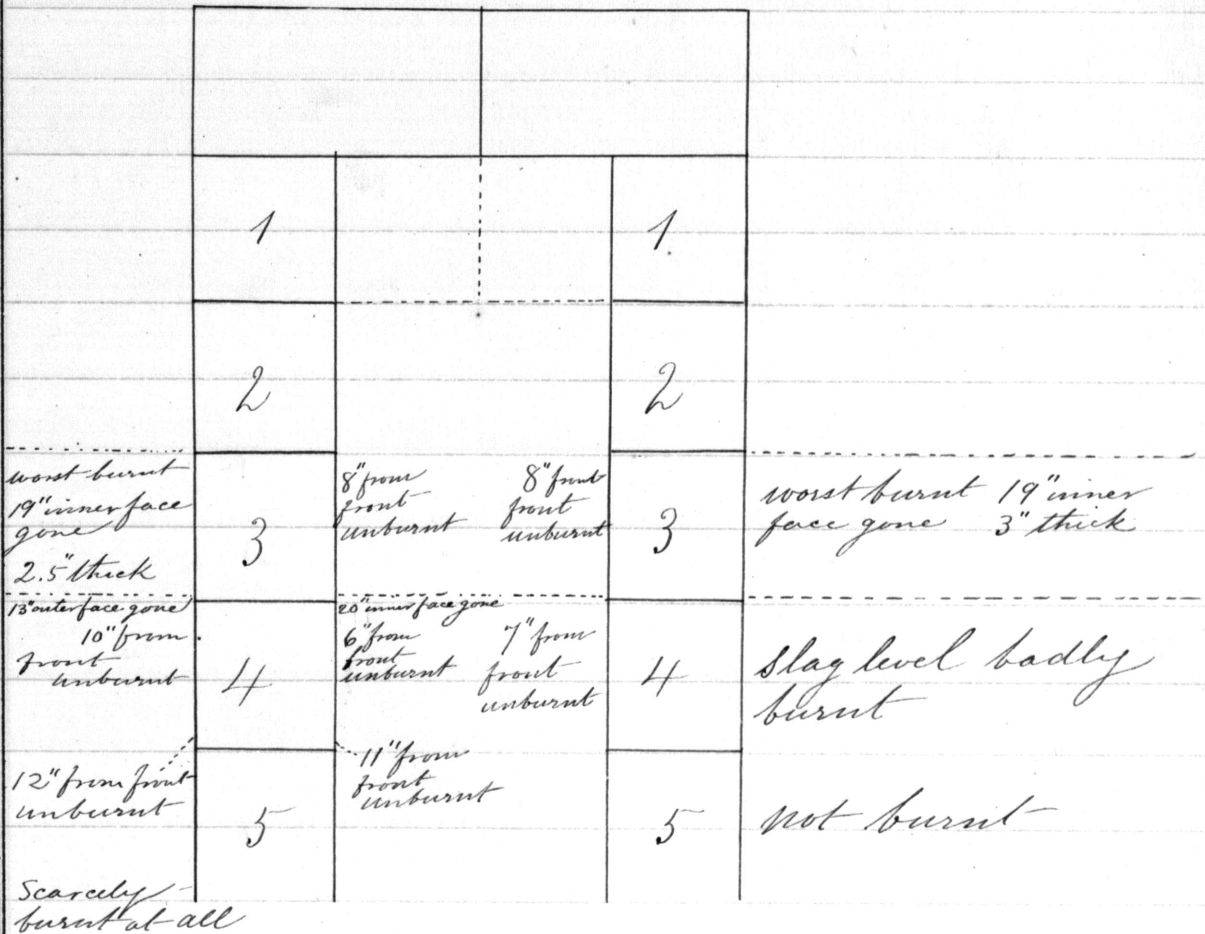
Tore down front and found a huge salamander consisting of wrought iron and slag. Had we a squeezer and a roller we might have got bar iron.
Fire bricks burnt right and left.

The intense heat at the crucible combined with the fluxing action of FeO melted the twyre completely, which was of brick and the projecting portion of the wrought iron blast pipe. The wrought iron melts, for the reason, that it is oxidized at the high heat produced in the furnace and the oxide forms with SiO_2 a very fusible silicate.

In the treatise of Metallurgy of iron and Steel Osborn says:
Twyres are made of Clay, Brass, Copper, or Cast iron (grey cast iron the best)
Clay is not durable and is employed only for charcoal furnaces, & is used great deal in the United States for the reason that it is very easy to replace, in case the twyere is not of desirable shape and size.
Twyres at the Port Henry furnaces was made of Phospho-Bronze.

The Survey of the burnt part of the furnace

The annexed figure represents the different courses of bricks in the front of the furnace



The furnace scarcely burnt at all beyond the second course above the tuyeres.

The slag level seems to have suffered the most.

Division 3 (g)

The salamander weighed 189 lbs.
The salamander, no doubt, resulted from the latter part of the run; mostly from the charges VI in which the fuel was reduced to a minimum as calculated by Bells' table given on pages 40 & 41. The proportion of slag was also greatly reduced.
To proove the above statement I have analysed two samples of tap-cinder or slag, one from the earlier part of the run, and the other, from the latter part, after the charge VI slag began to run.

Slag from the earlier part		Slag from the latter part	
FeO	42.20%	FeO	29.03%
SiO_2	26.59%	SiO_2	32.90%
Total %	68.79%	Total %	61.93%

The rest is mostly CaO and Al_2O_3 with little MgO and MnO.

Thus, by the analyses of the slags conclusively proove, that the salamander was chiefly formed from the latter part of the run, especially after the Charge VI began to report.

Section II

A Metallurgical treatment of Manhattan iron ore

Iron ore from Manhattan differs from the Katahdin ore by being more compact. It is oxidized carbonate ore.

A large amount of free quartz is found mixed with the ore.

Division 1

In sampling the ore, I have adopted the method of picking precisely same as given on page 3 in sampling charcoal.-
Picking up several different specimens from each barrel &c.

In analysing the iron ore, I have adopted precisely the same method as given on page 5
In addition, I examined for sulphur and phosphorus, the method of examination is given as follows:
Before analysis the ore which has passed through $\frac{1}{60}$" sieve must be sifted through very fine cloth. Weigh out about 2 grms (in this case of course the weighed portion must not be calcined as in the case of the other portion for FeO, Al_2O_3, SiO_2 &c)
The weighed portion is then digested

with fuming Nitric acid on a block of wood on the steam table. After a few hours standing, add some HCl and heat nearly to boiling till all the ore is dissolved. Evaporate to dryness and render SiO_2 insoluble; dissolve the residue in very dilute HCl and filter. Neutralize the filtrate with NH_4HO precipitating the hydrous ferric oxide of iron and P_2O_5 with it, and filter. The filtrate is acidified with HCl and Sulphur precipitated as Sulphate of Barium. The residue on the filter is throughly washed free from Cl and dissolved in little Nitric acid ~~and~~ diluted. Precipitate the phosphorus by Molybdate of Ammonia, the precipitate is washed with 80 pts ~~N~~H_2O + 100 pt NH_4NO_4 sol + 20 ~~p~~pt. HNO_3 and then dissolved in ~~little~~ small quantity of ammonia and then P precipitated as Ammonio-phosphate of Soda by adding mixture of Chloride of Ammonia & Magnesium.

The analysis of the Manhattan iron ore

SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	S	P	MnO
18.62%	62.88%	7.24%	0	0	trace	trace	0

H_2O + Volatile matter
10.6%

The analysis shows that the ore is not ~~nu~~ so rich as the Katahdin ore.

We concluded to smelt the ore mixed with Magnetite ore from Cheever ore bed Port Henry N.Y., using nearly pure lime stone for flux.

The composition of the Magnetite ore

SiO_2	Fe
8.92%	55.26%

The limestone was obtained from a marble work shop in Boston, which contains not over .5% of SiO_2

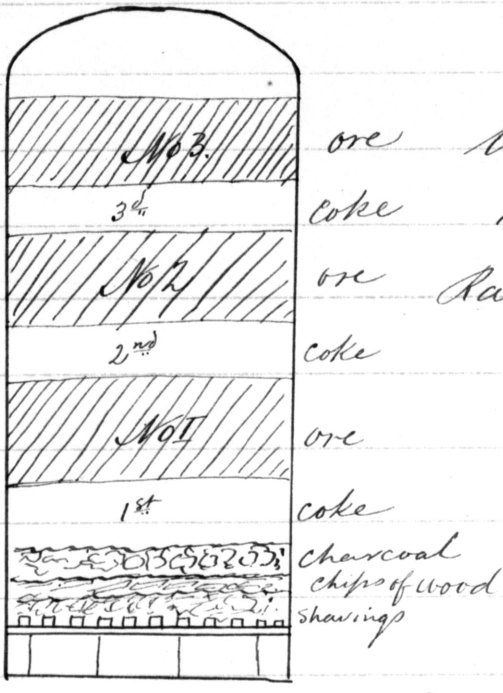
Division 2 (a)

We concluded to roast the ore in the kiln, in order to expell the water of hydration, and to make the ore porous and crumbly, Thinking that the failure of the previous runs, were greatly influenced by the charging of the raw ores. Even in high furnaces, the raws ores are injurious and is avoided if possible.

Division 2 (a)

The First Roast. April 4th 1878

After putting shavings and chips of wood onto the grate $3\frac{3}{8}$ lbs of charcoal was charged



Weight of ore charged $357\frac{1}{8}$ lbs
" " coke " 42 lbs
Ratio of ore to coke 8.5 : 1

April 5th 1878

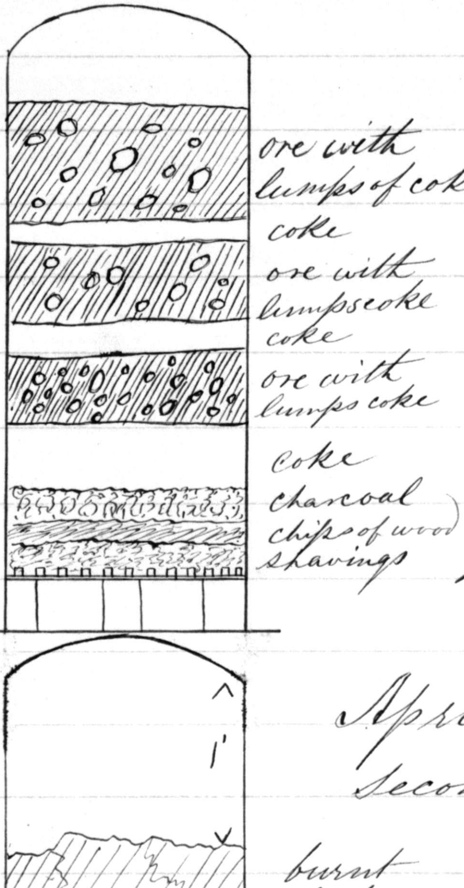
When front was torn down 1st layer of coke was but slightly burnt, the layers 2d and 3d were not at all burnt No 2 and No 3 layers of ore were slightly smoked in the centre. No I layer of ore were more or less roasted in the centre.

Amount of the ore considered sufficently roasted = $82\frac{1}{8}$ lbs

The failure resulted from my not using enough ~~chips~~ wood and charcoal to begin with.

Second Roasting April 5th 1878

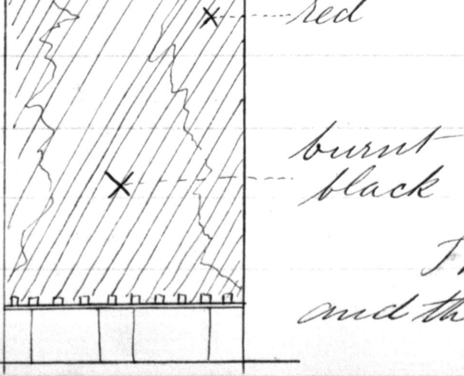
Unusually large amount of kindling was used



wt of charcoal used		$8\frac{3}{8}$ lbs
" " Coke	"	46 "
Total Fuel	"	$54\frac{3}{8}$

wts of ore used

part of the ore were slightly burnt	$299\frac{5}{8}$ lbs
Ratio of ore to fuel	5.5 : 1



April 6th 1878

Second roast after the roast

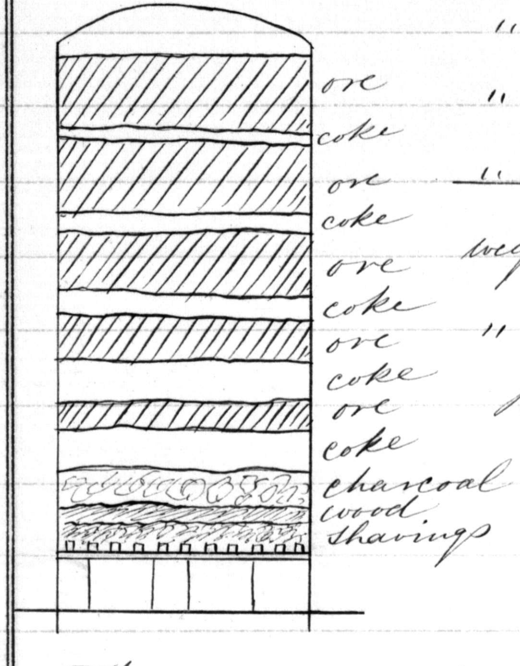
Before roast weight of ore	$299\frac{5}{8}$ lbs
after " " " "	$258\frac{1}{2}$ lbs
loss of weight =	$41\frac{1}{8}$ lbs

which is about 13%

The loss is cheefly water and the part of the ore seem to

~~to~~ be reduced to Magnetic oxide which would also reduce the weight somewhat.

3d Roast April 6th 1878



weight of shavings	1 lb
" " wood	$6\frac{7}{8}$ lbs
" " charcoal	$10\frac{1}{4}$ lbs
" " Coke	$49\frac{5}{8}$ lbs
weight of total fuel	$68\frac{3}{4}$ lbs
" " ore	$337\frac{3}{4}$ lbs
Ratio of ore to fuel	5 : 1

The ore increasing upwards
coke diminishing upwards

April 7th 1878

When torn down – In the lower part of the kiln ore was more or less caked together. The part of the ore was turned black ~~which~~ as in the last roast.

weight ore before roast	$337\frac{3}{4}$ lbs
" " after "	$288\frac{1}{2}$
loss of weight	$49\frac{1}{4}$ lbs = 13.8%

In the third roast the loss is even greater than in the second, which may be accounted for by the facts that more ore was reduced to Magnetic oxide as the caking of the ore shows and ~~the~~ a part of the ore employed for the second roast was slightly roasted beforehand.

On the disadvantages in charging the ore and fuel in alternate layers Practical Treatise on Metallurgy by Crookes and Röhrig has the following: "These furnaces make a perfect use of the fuel charged, but do not admit of a strongly oxidizing reaction as the carbonic oxide produced prevents it. At the points where ore and fuel come into contact a caking of the ore easily takes place even with ores containing peroxide of iron which becomes reduced

to Magnetic oxide. The ash of the fuel may also contaminate the ore with noxious substances."
"This mode of firing is therefore chiefly adopted for compact ores containing peroxide and free from sulphur requiring only a disintegration."

The caking of the ore may due in great measure to the formation of basic silicate of ~~the~~ protoxide of iron as the ore contained a large amount of free silica.
It seems that the ratio of ore to fuel was too high in the second and third roasts.

Division 2 (b)

Taking 13% as the loss by roasting 26.55 lb of ore = 23.1 lbs roasted ore

			Fe	SiO_2	Al_2O_3	CaO
Roasted ore	23.1 lbs	contains	11.68 lbs	4.94 lbs	1.92 lbs	
Magnetite	7.7 lbs	"	4.25 lb	.68 lbs		
Limestone	12.4 lbs	"		.06 lbs		6.91 lbs
Total			15.93 lbs	5.68 lbs	1.92 lbs	6.91 lbs

Slag elements

Composition of the slag

SiO_2	Al_2O_3	CaO
39.14%	13.22%	47.64%

The above composition is nearly represented by the following formula:

$$74(2CaO\,SiO_2) + 26(2\,Al_2O_3\,3SiO_2)$$

leaving 1.99% of free silica.

The above is decidedly a mono-silicate slag resembling the slag whose formula is given on page 13

The ratio of slag to pig is 1 : 1.1

Division 2 (c)

Estimation of amount of coke needed by the same method as explained in more detail on page

15.9^{lbs} Fe
14.5^{lbs} slag

30.4^{lbs} total non volatile
$43.^{\text{lbs}}$ total charge

15.9^{lbs} Fe needs 5.1^{lbs} carbon for reduction
" " " $.8^{\text{lbs}}$ " " carburetting to Fe_4C
Melting at the rate of $1^{\text{fuel}} : 4^{\text{mixture}}$
requires 7.35^{lbs} carbon for 30.4^{lbs}
11.00^{lbs} " " $43.^{\text{lbs}}$

Taking 30.4^{lbs} @ $\overset{\text{fuel}}{1} : \overset{\text{mixture}}{4}$ total carbon $= 13.25^{\text{lbs}}$
" $43.^{\text{lbs}}$ @ $1 : 4$ " " $= 16.90$

Division 2 (c)

Estimation of amount of coke needed by the table of minimum absorption adopted from I. Lothian Bell's Chemical Phenomena of Iron Smelting. Using 100 by weight of iron. Ratio of slag to pig is 1 : 1.1

Class I. Chemical Action and Fusion

	No. of units per 100 of pig by weight			No. of calories per unit		Calories absorbed
Evap. of H_2O in Coke	H_2O			540		
Evap H_2O in ore charge	H_2O 0		×	540		
Reduction of Fe	Fe 100		×	1780	=	178,000
Carbon Impregnation	C in Fe_4C 4		×	2400	=	9,600
Expulsion of CO_2 from $CaCO_3$	$CaCO_3$ 77		×	370	=	28,490
Decomp. of CO_2 to CO	C in $CaCO_3$ 9.24		×	3200	=	30,492
" " H_2O in blast	H X			34000		
Reduction of P. S. Si from P_2O_5, SO_3 and SiO_2	P .01	very rough	×	5747	=	57
	S .1		×	8000	=	800
	Si 1.		×	2500	=	2,500
Fusion of pig	Fe_4C 100		×	330	=	33,000
" " slag	slag 91		×	550	=	50,050

Class II Losses regarded as chiefly unavoidable

Transmission through walls of the furnace	96^{sq}		×	118 average	=	11,328
Off in gases					=	600
Carried off in tuyere water						
						total calories absorbed 344,917

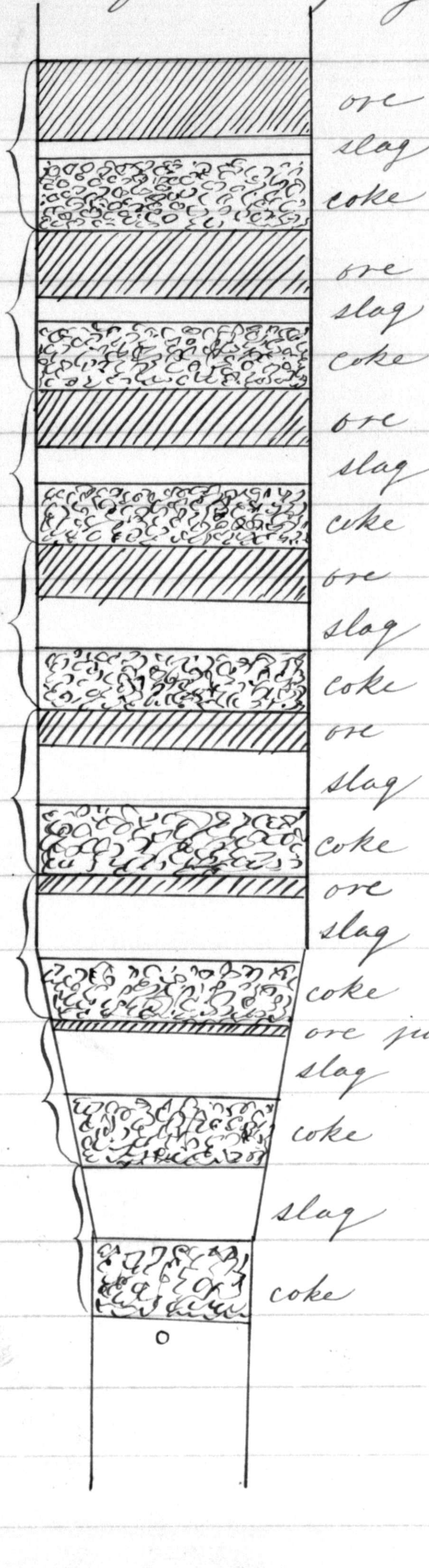
Division 2 (C)

In smelting 100 lbs of iron requires 344,917 Cal.
100 coal ~~evolve~~ about 408000 calories hence
85 coal needed for smelting 100 iron and
15.9 iron will need 13.51 pure carbon

Calories absorbed by evaporaton of water in coke, decomposition of water in blast, & heat absorbed & carried off ~~in~~ tuyere water are entirely omitted and others like reduction of P. S. Si, transmission through walls and & heat carried off in gases are but very roughly and perhaps incorrectly calculated, hence the amount of carbon needed as calculated by the table will be much lower than ought to be.

Division 2 (d)

Idea for charging the furnace in the next ~~time~~ run of the Manhattan iron ore



I { Charge coke well up at first 4'

II { then Slag to the top

III { then feed in little ore much slag which shall change only gradually to much ore & little slag

IV { then regular charge

Division 2 (d)

The dimensions of the blast furnace are given on page   the dimensions of the crucible are nearly same as given on pages 42 and 43. The dimetor of the blast-pipe was reduced to only $\frac{3}{4}$" which was substituted for $1\frac{1}{4}$" in order to reduce the rate of melting at the crucible, thus securing slower sinking of the charges, exposing the ore ~~particles~~ ~~of~~ to the reducing action of CO for a longer period of time. ~~The~~ A discussion upon the subject will be found on pages 98 and 99

Charges used during the Smelt

	I	II	III
Ore (roasted)		23.1	
Limestone		12.4	
Slag	60		60
Magnetite ore		7.7	
Total	60	43.2	60
Coke	15	18	10
Ratio fuel to mixture	1:4	1:2.4	1:6
" " to pig		1.13:1	

Division 2 (e)

Tap and Feed Records of the Manhattan iron Smelting

Feed Record				Tap Record			
Time	Interval	Charge	Depth	Time	Interval	Buggy slag	Pig iron
Early morning							
9-35 A.M.							
9-49 "							
10-22 "							
10-24 "	2	I					
10-30 "	6	I					
10-35 "	5	I	4'				
10-41 "	6	I	4.7'				
10-47 "	6	I	5.4'				
10-52 "	5	I	5.9'				
10-57 "	5	I	6.5'				
11-02 "	5	I	7'				
11-05 "	3	I	7.5'				
11-14 "	9	I	8.4'				
11-19 "	5	I	full 9'				
11-31 "	12	II	do.	1-15 P.M.		2	
1-24 P.M.	$113 = 1^{h}\,53^{m}$	III	8.5'	1-20 "			
1-32 "	8	II	full	1-32 "	17	3	

Division 2 (e)

Notes

April 11th 1878 in evening 4 hods coke 1 hod charcoal

April 12th 1878

2 hods coke

Blast on

4 hods coke

4 hods coke

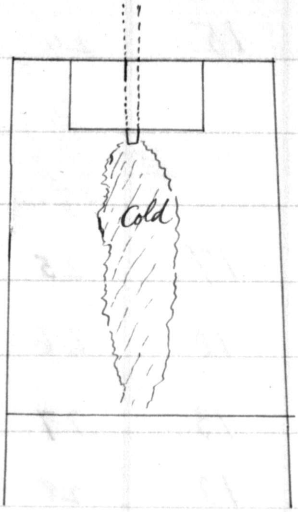
Slag tending to overflow

Feed Record				Tap Record			
Time	Interval	Charge	Depth	Time	Interval	Buggy slag	pig iron
				1-40 P.M.	8	4	
1-55 p.m.	13	I	full	1-55"	15	5	
				2-01"			
				2-05"	10	6	
				2-14"	9	7	
2-23"	28	II	do.	2-30"	16	8	
2-49"	26	II	do.	2-47"	17	9	
				2-58"	11	10	
3-15"	26	II	do.	3-14"	16	11	
				3-25"	11	12	
3-36"	21	II	do.	3-35"	10	13	
				3-46"	11	14	
				4-49"	3	15	
4-06"	32	II	do.				
4-07"				4-05"	16	16	
				4-12"	7	17	
4-34"	28	II	do.	4-30"	18	18	
4-40"				4-40"	10	19	
				4-46"	6	20	
				4-50			

Notes

Slag coming decidedly faster

Since 12 o'clock twyere became cold



Flame disappeared, ore setted about 6" suddenly

Entire change in slag running more freely - Evidently run slag

Time	Interval	Charge	Depth	Time	Interval	Slag Buggy	Pig iron
				4-59 P.M			
				5-0 "	14	21	
				5-01 "			
				5-15 "	15	22	
				5-23 "	8	23	
				5-38 "	15	24	
				5-43 "			
				5-47 "			
				5-50 "	17	25	
				6-0 "	10	26	
				6-13 "	13	27	
6-25 P.M	$1^{h}-45^{m}$		8'	6-25 "	12	28	
				6-35 "	10	29	
				6-45 "	10	30	
6-50 "	25		7'	6-55 "	10	31	
				7-05 "	10	32	
				7-15	10	33	
7-20 "	30		6'	7-32	17	34	
7-35 "	15		5.8'	7-45	13	35	
7-45 "	10		5.6'	8-05	20	36	

Division 2 (e)

Notes

Blast off

Transition slag

Blast on

Transition slag

Transition slag

Tap – gave tap-cinder

Plug

3 hods of coke

Tore out the lower door

Feed Record   Tap record

Time	Interval	Charge	Depth	Time	Interval	Buggy slag	Pig iron
8-15 P.M			5'	8-20 P.M "	15	37	
8-37 "		2 shovels salt cake	4.7'				
8-50 "		"	4.'				
9-0 "			3.6'	9-0 "			
				9-5 "			
9-10 "			3.'				
9-20 "							

Division 2 (C)

Notes

Co flame free at top. At 3' there seems to be a hard mass right across the furnace. Poker wont go through

Strong flame - Slag stopped flowing

Tap - gave top only on buggy of slag

Blast off, tore down front

When front was torn down found a small piece of metallic iron weighing about

We succeeded in letting down the charges very slowly as the records show. A main trouble seems to arise from not using enough fuel. In calculating for fuel I entirely disregarded the ash and moisture in the coke, the amount of the latter was considerable as the coke was quite wet. An allowance must be ~~used~~ made in using coke instead of charcoal as the coke does not burn to CO so readily. Calculations made afterwards will be found on next page

Furnace was too hot in the early part of the run and melted just about the bosh, and when cooled down, the refractory slag was deposited all around, thus forming a scaffolding. The scaffolding may have had something to do in letting the charges settle so slowly and rather irregularly.

Division 2 (f) & (g)

In analysing the tap-cinder or slag obtained, I treated very finely pulverized sample with strong HCl which completely dissolved the iron leaving gelatinous silica.

Partial analysis of the slag

FeO 35.88 %
SiO_2 29.93 %

Calculation for fuel after the run

15.53^{lbs} iron needs 5.1^{lb} carbon for reduction
" " " $.8^{lbs}$ " " carburetting
12.4^{lb} $CaCO_3$ or
5.45 CO_2 to $2CO$ needs 1.5^{lb} "
to melt 43 @ $\overset{\text{fuel mixture}}{1:4}$
requires $11.^{lbs}$

Total 18.4^{lb} carbon necessary for smelting 15.53^{lbs} iron

Now the coke, which I used, contained a large amount of water as it was wet and ~~of~~ a certain amount of ash;

Division 2 (g)

Calling the amount of ash 12%
and the amount of water 13%
The total amount of coke necessary will be 24.5^{lbs} Thus showing according to this calculation, that the amount of coke used was in sufficent.

Section III

Discussions.

A

One of the most important facts, which influence the smelting of iron is the rate of reduction. Of course longer the time the ore remains in the zone of reduction, the more complete will be the reduction.

Several experiments were performed by Bell on the rate of deoxidation upon different kinds of ore passing pure CO at different temperatures. I shall give the results of experiments tried on pure precipitad Fe_2O_3 and on Cleveland iron stone.

A.

Fe_2O_3 ppt	141°C	deoxidation begins
Clev. ore calcined	199°C	

B.

Fe_2O_3 ppt.	243° @ 265°C	2 hours	lost	19.4%	of the original	O
"	232° @ 254°C	6 "	"	49.3%	"	"

C.

	Zinc melted					
Calc. Cleveland ore	417°+little	7 hours	"	9.4%	"	"
Fe_2O_3 ppt.	417°+little	7 "	"	66.7%	"	"

A

D.

	since softened		original
Calc. Clev. ore	410 C	7½ hours lost	20.7% of O
Fe_2O_3 ppt.	410 C	6 " "	49.2% " "
Calc. clev. ore	410 C	6 " "	37.3% " "

E.

Calc. clev. ore	410° with 245 litres CO	6 hours lost	50.6% of O
Fe_2O_3 ppt.	" " " "	" "	80.% of "

F

Calc. clev. ore	visibly red by daylight	8 hours lost	63% of O
"	bright red	3¾ " "	90% O

The results are very irregular may be partly due to the different rates in passing CO. Experiments E were permosmed with definite amount of CO, thus the comparison of the rates of reduction between Cleveland ore and pure Fe_2O_3 can be more safely depended upon ~~i~~them.

A

Table showing rates of deoxidation adopted from Bell.

Authority	Ebelmen	Tunner	Tunner
Furnace	Clerval.	Wrbna.	St. Stephan.
Temp. of blast	180°C	200°C	200°C
Descrip. ore used	Supposed pisolitic & hydrated Fe_2O_3	Calcined Spathose ore	$\frac{1}{2}$ calcined Spath $\frac{1}{2}$ argillaceous
Ore, Kilo per 100 Kilo. pig	381	200	281
Flux " " " " "	37	10	13
Charcoal " " " " "	148	70	95 – 100
Make of pig per 12 Hours kilo.	4357 Kilos.	12000 Kilos	5827 Kilos.
Quality	Grey	White	Grey
Ore begins to loose O	in 2 hours	1 hour	not given
First sign metallic Fe	in 5 – 6 hours	1 $\frac{3}{4}$ hours	6 hours
50% O removed in	6 $\frac{1}{2}$ hours	2 $\frac{1}{2}$ hours	6 $\frac{1}{2}$ "
Complete reduction	not given	3 – 4 hours	supposed 9 hours
Time ore passing through the furnace	not given	4 $\frac{1}{2}$ to 5 hours	12 hours

As shown in the table given on last page, ~~At~~ Wrbna furnace driven with blast, heated to 200°C producing white iron, it only took $4\frac{1}{2}$ to 5 hours ~~to~~ for a charge to go through the furnace; thus I have reason to believe that pig iron can be produced in a small furnace 9' high, provided we can let the charges go down slowly and at the same time the temperature at the reducing zone of the furnace can be kept high enough with a sufficent quantity of CO.

In Crookes and Röhrig's Treatise on Metallurgy following statements are found. Average time which one charges requires to pass through the furnace.

For Charcoal 16 hours, Coke 40 hours, Coal 48 hours. Three quarters of the time is required when producing white iron either with charcoal or with coke.

A

Judging from the last statements coke is not a suitable fuel to use in a small furnace. It is impracticable to let the charges settle very slowly, and at the same time keeping sufficient heat at the reducing zone with enough Co. If we can produce pig iron with charcoal, for instance, it would no doubt be white cast iron.

Relations between the Different Parts of Iron Blast Furnace and its capacity are of great importance.

In general, there are two different forms of blast furnaces have been adopted; one for easily fusible ores and one for more refractory ores.

1° Furnaces for easily fusibles ore, have their hearth proportionally wide with narrow mouth and narrow belly.

2° Furnaces for refractory ores have their hearth narrow, with large belly and mouth. If easily fusible ore is smelted in narrow hearth, fusion of ore takes place before sufficently reduced and carbonized; if attempts are made to prevent this by charging ore and fuel in suitable proportion, grey pig iron is produced instead of white.

In smelting refractory ores if furnace mouth is too narrow the gases in the lower part of the furnace will become of too great pressure

B and C

and impede the combustion whilst white pig iron is produced:----------

The above statements are taken from Crookes and Rohrig's Metallurgy.

C

In order to fix a mathematical relation between amount of daily production of iron from a certain kind of ore or mixture of ores and dimensions of the blast furnace to be employed Lindauer deduced the following formulae:—

For charcoal furnaces.—

$$D = 0.8448 \sqrt[3]{\left[\frac{K}{100y'} + \frac{100+C}{q'y}\right]\frac{Z}{24}E}$$

For coke furnaces—

$$D = 0.8883 \sqrt[3]{\left[\frac{K}{100y'} + \frac{100+C}{q'y}\right]\frac{Z}{24}E}$$

For coal furnaces—

$$D = 0.9728 \sqrt[3]{\left[\frac{K}{100y'} + \frac{100C}{q'y}\right]\frac{Z}{24}E}$$

In the formulae given on the last page, the letters have the following Value:-

D = diameter of the belly in Austrian feet

E = the production of pig iron in 24 hours in Austrian pounds

Z_1 = the time which one charge requires to pass the furnace

K = consumption of fuel per 100 lbs of pig iron

c = the addition of limestone to 100 lbs of ore mixture

y = Weight of 1 cu.ft. of mixture

y' = weight of 1 cu.ft. of fuel

q' = Average amount of iron contained in mixed ores after deducting the loss in smelting.

Diameter of the belly being most important, he first deduces its value, and then the other dimensions of blast furnaces being in a certain proportion to the diameter of the belly, Lindauer gives the average ratios to be as given on next page.

	Charcoal D	Coke D	coal D
Diameter of the furnace mouth	0.400	0.500	0.600
" " " upper hearth	0,350	0,250	0.250
between the tuyeres	0. 250	0.210	0. 250
Height of the hearth (boshes included)	0. 740	0.667	0 .250
" " " upper hearth	0.490	0,457	0. 146
" " " belly	0 .292	0. 113	0.506
" " " boshes	0.464	0.842	0.644
" " " shaft	3.004	2.378	1.200
Total height of the furnace	4,500	4.000	2.600
angle of the boshes	55°	65°	60°

From these numbers of the ratio the capacity of the different parts of the furnace may be calculated as follows: —

	Charcoal D^3	Coke D^3	Coal D^3
Capacity of the shaft	1.2270	1.0890	0.6158
" " " Belly	0.2293	0.0890	0.3972
" " " boshes	0.1789	0.2298	0.0659
" " " upper hearth	0.0350	0.0190	0.0072
Total capacity = $\dot{J}$ =	1.6702	1.4268	1.0861

Supposing the capacity of the whole furnace to be = I

	Charcoal J	Coke J	Coal J
Capacity of the shaft	0.7347	0.7633	0.5670
" " " belly	0.1373	0.0624	0.3658
" " " boshes	0.1071	0.1611	0.0606
" " " upper hearth	0.0209	0.0132	0.0066
$\dot{J}$ =	1.0000	1.0000	1.0000

C

According to the Lindauer's formulae I have calculated the dimensions for charcoal and coke furnaces, which would smelt the following mixture used for the last run.

Manhattan iron ore (roasted)	23.1 lbs
Magnetite	7.7 lbs
Limestone	12.4 lbs
Total	43.2

Setting...	for Charcoal furnace	for Coke furnace
E =	960 lbs or 40 lbs per hour	960 lbs
Z =	7 hours	10 hours
K =	160	280
c =	40	40
y =	90	90
y' =	12	20
q' =	50% originally 51.7%	50

Substituting the above values in the formulae I get

For Charcoal $D = .8448 \sqrt[3]{\left[\frac{160}{100 \times 12} + \frac{100+40}{90 \times 50}\right] \frac{7}{24} \times 960}$

" Coke $D = .8888 \sqrt[3]{\left[\frac{280}{100 \times 20} + \frac{100+40}{9 \times 50}\right] \frac{10}{24} \times 960}$

C

by reducing For Charcoal $D = .8448\sqrt[3]{46.04} = 3'$

" Coke $D = .8883\sqrt[3]{68.44} = 3'-7.4''$

From the above I get the following

	For Charcoal	For Coke
Diameter of furnace mouth	1'-2.4"	1'-9.7"
" " upper hearth; above the tuyers	1'	10.8"
" between the tuyeres	9"	9.1"
Height of whole hearth	2'-1.6"	2'-4.9"
" " upper hearth	1'-5.6"	1'-7.8"
" " belly	10.4"	4.8"
" " boshes	1'-4.7"	3'
" " shaft	9'	8'-7.2"
Total height of the furnace	13'-6"	14'-5.7"
angle of boshes	55°	65°

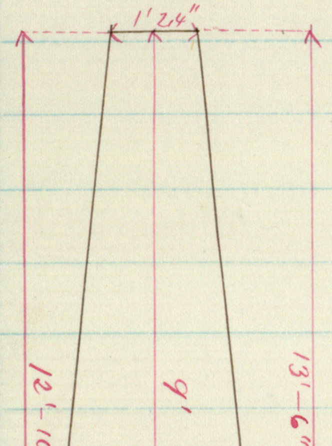
Total capacity of the furnace for

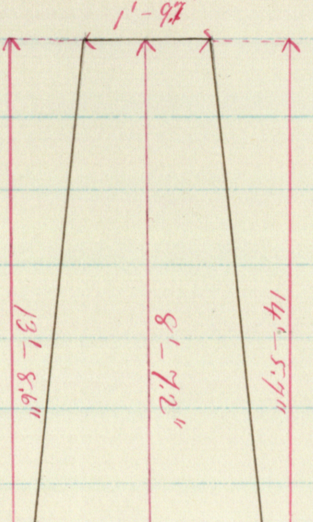
	Charcoal	Coke
$3_3 \times 1.6702 =$	45 cu ft	$3.6_3 \times 1.4268 =$ 69.6 cu ft
Capacity of shaft	33 cu ft	53.1 cu ft
" " belly	6.1 cu ft	4.3 cu ft
" " boshes	4.8 cu ft	11.2 cu ft
" " upper Hearth	.94 cu ft	.91 cu ft

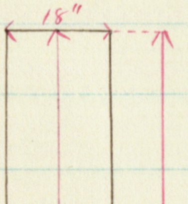
The Institute furnace

Total capacity = 18.94 cu ft that is from tuyere to charging door
Capacity of Shaft = 14.78 " "
" " boshes = 2.51 cu ft
" " upper hearth = 1.65 cu ft

Drawings of the vertical sections of the calculated charcoal and coke furnaces and the Institute furnace Scale $\frac{3}{8}$ inch = 1 foot.







Distinct theoretical rules for fixing the relations between differents parts of furnaces can not always apply to every particular case, as the number of influencing circumstances are very g~~ood~~reat. Experience is the only guide; the theoretical rules are valuable only in pointing out the means of arriving at the desired result.

I have verified the accuracy of the capacities of the furnaces by the following means.

For charcoal furnace

In using 160lbs charcoal for every 100 lbs iron.

In one charge (proportions are given on page 90) there is about 16 lbs iron, hence needs about 25.6lbs of charcoal. If charcoal weighs 12lbs per cubic foot, 25.6lbs will occupy about 2 cu ft. Mixture of ores and Limestone weighs about 45 lbs; if one cubic foot of the mixture weighs 90 lbs 45lbs will occupy .5 cu ft. Hence one charge will occupy about 2½ cu ft.

The capacity of the furnace is 45$^{\text{cu ft}}$. hence will hold about 18 charges, but in one charge there is about 16$^{\text{lbs}}$ iron, hence in 18 charges there is 288$^{\text{lbs}}$ iron. Since it requires 7 hours for a charge to pass the furnace; 288$^{\text{lbs}}$ iron is produced in 7 hours or in one hour 40.5$^{\text{lbs}}$ iron which is as originally intended.

For coke furnace

Using 280$^{\text{lbs}}$ ~~iron~~ coke for every 100$^{\text{lbs}}$ iron produced. 16$^{\text{lbs}}$ iron needs 44.8$^{\text{lbs}}$ coke. If coke weighs 20$^{\text{lbs}}$ per ~~sq~~ cu ft 44.8$^{\text{lbs}}$ will occupy $2\frac{1}{4}$ cu ft One charge weighs 45 lbs if one cubic foot of the mixture weighs 90$^{\text{lbs}}$, 45$^{\text{lbs}}$ will occupy .5$^{\text{cu ft}}$. Hence one charge including coke will occupy about $2\frac{3}{4}$ cu ft. The capacity of the furnace is nearly 70$^{\text{cu ft}}$. hence it would hold about 25 charges but since one charge holds 16 lbs iron hence in 25 charges there is 400 lbs iron, but since it requires 10 hours for one charge to pass the furnace

C

400lbs iron is produced every 10 hours or in one hour 40lbs which is exactly as originally intended. -

Now the next thing to be considered will be the exact amount of blast necessary --

Calculation for necessary amount of blast:

In using charcoal with the rate of 100 lb iron to 160 lb charcoal; 40 lb iron per hour will require 64 lb charcoal. Now calling amount of ash in charcoal 3% and moisture 8% 64 lbs charcoal will equal to 57 lbs carbon. In order to burn whole of C to CO 57 lbs carbon requires 76 lbs of oxygen, but as the air contains 23% by weight of O requires 247.8 lbs of air per hour

1 cu ft of air at 0° under 760 mm. pressure weighs nearly .0798 lb hence 247.8 lb air will occupy about 3124 cu. ft. on condition of there being no moisture.

Now according to Bornemann's graphic table founded upon Weisbach's formula (given on page 499 - Crookes & Rohrigs Treatise on Metallurgy - Edition of 1869) on the the supposition that temperature of air is 10° under 760 m.m. pressure $\frac{3}{4}''$ tuyere driven with $2\frac{1}{4}''$ mercury pressure introduce $3492^{\text{cu ft}}$ per hour.

Since it requires $3124^{\text{cu ft}}$ of air at 0° under 760 m.m. pressure per hour to produce 40^{lb} of iron per hour $\frac{3}{4}''$ tuyere driven with $2\frac{1}{4}''$ mercury pressure seems to introduce just about sufficent amount of blast; the excess of blast which is $3492^{\text{cu ft}}$ over $3124^{\text{cu ft}}$ may be counterblanced by its being more rare as the temperature being 10° instead of 0° and also by the pressence of more or less amount of moisture in the air

The correctness of the above statement can be only verified by experiments

The above calculation is applicable only to the calculated charcoal furnace. The coke furnace will require more blast

Calculation of the necessary amount of blast for the Institute furnace.

According to Bornemann's table, by using $\frac{3}{4}$" tuyere with $2\frac{1}{4}$ mercury inches pressure .97 cu ft blast is introduced per second hence 3492 cu ft of blast per hour. I have shown on the last page that 3492 cu ft of blast will produce about 40 lbs iron using charcoal at the rate of 160 lb charcoal to 100 lbs iron.

Now the furnace whose capacity is 18.94 cu ft can hold about 8 charges if I use for a charge a mixture of limestone and ores as given on page 90 or about 128 lbs of iron. But since 40 lbs iron is produced in one hour, therefore, 128 lb iron can be produced in about 3 hours & 12 minutes. or in other words one charge will take 3 hours & 12 minutes in passing through the furnace.

By using $\frac{1}{2}$" tuyere with $2\frac{1}{2}$" mercury pressure .55 cu ft of blast is introduced per second or 1980 cu ft per hour. If it requires about 3492 cu ft per hour to produce 40 lbs iron per hour, 1980 cu ft will be able to produce about 23 lbs iron per hour

If the furnace can hold 8 charges it holds 128 lbs iron; If it produces 23 lbs iron per hour 128 lbs iron will be produced in 5 hours and 33.6 m. or in other words one charge will take 5 hours and 33.6 minutes to pass through the furnace.

Inferring from this calculation, it seems that the Institute furnace driven with $2\frac{1}{2}$" mercury pressure, through $\frac{1}{2}$" diameter tuyere can produce cast iron, provided we have heat enough at the reducing zone with enough Co.

Table showing the ratios of, area of bosh to area of Crucible, of area of tuyers in sq. in. to area of bosh in sq. ft., of area of tuyeres in sq. in. to area of crucible in sq. ft. in large and small furnaces

Diameter of bosh	18'	16'	14'	1.5'	1.5'	1.5'	1.5'
area of bosh	324	256	196	2¼	2¼	2¼	2¼
area of crucible	64	36	16	1½	1½	10"×12= .83 sq ft.	10×8 .56 sq ft.
Diameter of Crucible	8	6	4				
Diameter of tuyeres	2½"	2½"	2½"	1½"	1¼"	¾"	½"
number of tuyeres	7	5	3	1	1	1	1
Areas of tuyeres	43.75 sq in	31.25" sq	18.75" sq	2.25 sq	1.56" sq	.562" sq	.25" sq
Bosh : Crucible	5 : 1	7 : 1	12 : 1	1½ : 1	1½ : 1	2.7 : 1	4.1 : 1
Sq in. tuyere per sq. ft bosh	.135	.122	.095	1	.693	.25	.111
sq in tuyere per sq ft Crucible	.683	.868	1.172	1.50	1.04	.677	.454