1907

Design of a lead blast furnace

Walter Irving Phillips

Andrew Jackson Seltzer

Department: Chemistry; Materials Science and Engineering

THESIS

FOR THE

Degree of Bachelor of Science

IN

Chemistry and Metallurgy.

SUBJECT:

"Design of a Lead Blast Furnace."

WALTER I. PHILLIPS.

A. J. SELTZER.

JUNE, 1907.

DESIGN OF A 100 TON LEAD BLAST FURNACE.

Calculations for the charge.

Calculations for the inside dimensions of Furnace.

Calculation of the Furnace gases.

Calculation of the size of the tuyers.

Drawings of the Furnace.

In order to get the approximate size of the Furnace we made the following assumptions, being guided as far as possible by the practice of the Globe Smelting Works at Denver, Colorado whenever that could be ascertained.

The coke used is that made at Tuscarawas, Ohio, and has the following composition: water 0.13%, volatile matter 2.75%, fixed carbon 84.2%, ash 12.4%, sulphur 3.7%. It was assumed that the S. was distributed thus: in volatile matter 1.8%, in ash 1.8% as FeS_2 and $CaSO_4$.

The ash analysed as follows: SiO_2 40.3%, Fe_2O_3 29.4%, CaO 6.9, MgO 1.4%, Al_2O_3 20.1%, FeS_2 and $CaSO_4$ 1.8%

The lead ore delivered to the furnace comes from Leadville and has been previously roasted down to 6.8% S and its composition is

SiO_2	FeS	Fe_2O_3	MnO	CaO	MgO	ZnS	Al_2O_3	As	PbS	Cu_2S
36.4	6.6	19.3	4.3	4.4	5.26	2.4	2.5	.5	14.0	1.83

Ag	Au
50.5oz.	Trace.

The iron ore is a dry oxidized silver ore from Leadville, Colo., of the following composition:

SiO_2	Fe_2O_3	MnO	$CaCO_3$	Ag	Au.
5.3	79.28	1.7	5.5	8.26z.	.IIoz.

The limestone is of dolomitic character and barren of values, obtained from a quarry near Denver and is of the following composition:

SiO_2	$FeCO_3$	$CaCO_3$	$MgCO_3$
3.7	7.2	75.5	10.3

In order that these metals shall enter the slag they must become oxides, and iron will enter the slag only as FeO hence the other oxides of iron will have to be calculated over to that oxide when figuring up the charge for the furnace. These calculations are made by means of simple ratios of atomic weights and will not be gone into in detail further than to give one example; thus, to determine the amount of FeO in ~~19.3#~~ 19.3 Fe_2O_3 of the lead ore we have:

Fe_2O_3 : 2FeO = 160: 144 = 19.3# : X

X = 17.4# FeO in 100 lbs of ore.

The 6.6 lbs FeS burned to FeO = 5.4 lbs. FeO. Total Feo = 17.4+ 5.4 = 22.8 lbs FeO.

In this manner the following table of adjusted oxides was obtained:

	SiO_2	FeO	CaO	ZnO	Al_2O_3	S	As	Pb	Cu.
Lead Ore	36.4	22.8	11.8	2.0	2.5	6.8	.5	12	1.5
Iron "	5.3	73.1	3.1						
Limestone	3.7	4.5	49.2						
Coke Ash	40.3	26.5	8.9		20.1				

Since MnO acts much like FeO in the slag, it is counted as FeO in the adjusted table. Its atomic weight is so near that of FeO that no appreciable error was introduced by adding the weight of the two oxides directly without figuring them over from their atomic weights. MgO acts like CaO in many respects hence it is counted as lime in the table. The weights were figured however from the atomic weights thus:

multiply the weight of MgO in the ore by 1.4 to get the equivalent weight of CaO for combining with SiO_2.

The slag to be calculated is to be 30- 40- 15, which will be liquid, fairly easily fusible at a low temperature and at the same time decrease the amount of barren limestone put into the charge.

IRON ORE CALCULATIONS. When buying iron ore for fluxing purposes only the "available" iron is paid for, i.e. the SiO_2 in the flux is not wanted hence the FeO, needed to slag this silica, is deducted before paying for the flux.

1 In 100 lbs. of ore we have 66 lbs FeO available. This result was obtained as follows:- slag is to be 30 - 40 - 15, hence

30 : 40 = 5.3 : X, or X = 7.1# FeO to slag 5.3# SiO_2

73.1 - 7.1 = 66.0# FeO available. This 66.0 lbs Feo. carries 51.1 lb Fe.

To determine how much lime should be added we used the following proportion:

30 : 15 = 5.3 : X, X h 2.6 lbs. CaO. The iron ore carries 3.1 lbs CaO hence it is self fluxing as regards lime.

11 IRON FOR SPEISS. As. is very undesirable in the lead bullion, and if it is present in the ore it must be provided for. Iron forms several alloys with As but the only one which is liquid when fused is Fe_5As. This is termed "Speiss" and goes with the matte, in the furnace, thus preventing the As from going into the Lead. In 100 lbs. of lead ore we have .5 lbs As. The iron needed for speiss is obtained thus:

(5x 56) : 75 =X : .5, X = 1.9 lbs Fe.

100 lbs iron ore 51.1 = X : 1.9, X = 3.71 lbs. of iron ore necessary to form the speiss for 100# lead ore.

IRON FOR MATTE. The Matte fall should be kept low as considerable lead will otherwise go into it.

The matte fall was calculated at 10% and its composition was assumed as follows:

Pb	20%
Ag	.06%
Au	Trace
Zn	"
SiO_2	4,2% (Carried mechanically)
Cu	15.0
Fe	37.0
S	28.0

In 10 lbs matte have

.38	Lbs. S	from	1.88	lbs	Cu_2S
.30	"	"	"	2.30	"	PbS
2.12	"	"	"	5.82	"	FeS.
2.80	"	"	"	10.00	"	matte.

5.82 lbs FeS contains 3.7 lbs Fe which is equivalent to 7.2 lbs iron ore.

IV. COKE-ASH CALCULATIONS. Use 12.4% fuel. Charge to be 1500 lbs
12.4% X 1500 =210 lbs coke containing 26.1 lbs. ash composed of the following

	SiO_2	FeO	CaO
	10.5#	6.9	2.3

30 : 40 = 10.5 : X, X= 14.0 lbs FeO

FeO present in ash 6.9

" needed 7.1 lbs = 10.8 lbs. iron ore.

30: 15 = 10.1 : X = 5.05 lbs CaO needed for 10.5 lbs SiO_2 CaO present in the ash = 2.3#, CaO needed = 5.05 - 2.3 = 2.75 lbs CaO or 5.5 lbs limestone.

V. LEAD ORE.

4.2 lbs SiO_2 go to the matte, 100 lbs ore carries 36.4 lbs. SiO_2, SiO_2 to be fluxed = 36.4 - 4.2 = 32.2 lbs.

30 : 40 = 32.2 : X, X = 42.9 lbs FeO.

Have in ore 22.8 " "

Want 20.1 " " or

30.4 lbs iron ore to be added.

30 : 15 = 32.2 : X, X = 16.1 lbs CaO necessary.

Have in the ore 11.8

Want 4.3 lbs CaO or

8.7 lbs of limestone.

100 lbs lead ore requires.

30.4 " iron ore for fluxing SiO_2

11.9 " " " to furnish Fe for speiss and matte

8.7 " limestone

151.0 " charge per 100 lbs of lead ore, which gives 10 lbs of matte, and 10 lbs of bullion, hence have 151.0 -20 = 131.0 lbs of slag. Assume that the slag carries 1.5% S. 131.0 X .015 = 2.0 lbs. Assume that the flue dust is 3.5% of the ore charge and that the dust carries 6.23% S. then S in flue dust = 150.0 x .035 x .0623 = .32 lbs S.

S in matte = 2.8 lbs.

S " slag = 2.0 (Iles Pb. Smelt. p 131)

S " dust = 0.3 " " " " 150)

S burned off 1.7 or 25%

Total S 6.8 lbs in 100 lbs of ore.

Want each charge to weigh 1500 lbs. This shall consist of slag

Slag	200 #	
Ash	26.1	
Iron ore for ash	10.4	
Limestone " "	5.8	242.3
Bead ore and flux		1257.7
		1500.0

151.0 X = 1257.7 lbs.,) = 8.3, then the full charge will be —

Lead ore	830 lbs (100x 8.3)
Iron ore for flux	256.4 " (30.9x 8.3)
" " " As-S	99. " (11.9x 8.3)
Limestone	72.2 " (8.7 x 8.3)
	1257.6 "

We want to smelt 100 tons of ore per day. Since the iron flux carries values we include it under this classification, as ore, hence the ore per charge of 1500 lbs is 830 lbs. lead ore
366 " iron "
1196 " ore

100 tons = 200,000 lbs

200,000 1196 = 168 charges per day of 24 hours.

Material		SiO_2		FeO		CaO	
Name	Dry Weight	%	lbs	%	lbs.	%	lbs.
Coke Ash	26.1	40.3	10.5	26.5	6.9	8.9	2.3
Slag	200.0	30.0	60.0	40.0	80.0	15.0	30.0
Lead Ore	830.0	32.2	266.6	22.8	189.2	11.8	97.0
Iron " for Pb" 256.5 " Ash 10.8	266.9	5.3	19.4	73.1	195.1	3.1	11.3
Iron ore for As-S	99.0			0.0	0.0		

	Dry Weight	%	lbs	%	lbs.	%	lbs
Limestone for ore 72.2 " ash 5.8	78.0	3.7	2.9	4.5	3.5	49.2	38.4
	1500.0		385.6		475.0		179.9
Factor $40 \div 475.1$ = .084			30.09		40		15.1

Dimensions of the Furnace.

In order to determine the inside of the furnace it is necessary to assume that, when full, the furnace will hold about 54 charges. The total weight of these charges will be

200 lbs slag X 54 = 10800 lbs.

830 " ore X 54 = 44820 "

366 " iron ore X54= 19760 "

78 " limestone X54 = 4212 "

210 " coke X54 =11340 "

Total 97932 "

1 cu. ft. slag weighs 120 lbs (est.)
1 " " hematite broken 150 " (Richards Ore Dressing)

1 " " limestone weighs 100 " " " "

1 " " coke " 30 " " " "

1 " " ore " 119 " calculated as follows.

The weight of one cubic foot od lead ore was calculated from Vezin's rule(Richards Ore-Dressing)page 1190) as follows:

14% PbS X Sp. Gr. 7.5 = 1.06

6.6" FeS X " " 2.6 = 0.17

17.04% Fe_2O_3 and Fe_3O_4 X 5.0 = .95

11.8% CaO X Sp. Gr. 2.7(est)=.22

36.4% SiO_2 X " " 2.6 = .93

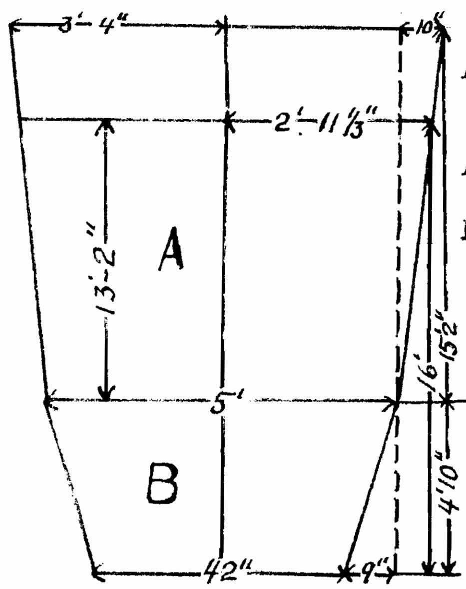
3.33

$3.33 \times .57 = 1.89$

$62.5 \times 1.9 = 118.7$ lbs/cu. ft. of ore.

Volume of limestone	in the furnace			$\frac{4212}{100}$	= 42.12 Cu. Ft.
" " coke	"	"	"	$\frac{11340}{30}$	= 376.00 " "
" " iron ore	"	"	"	$\frac{19760}{150}$	= 131.00 " "
" " slag	"	"	"	$\frac{10800}{120}$	= 90.00 " "
" " lead ore	"	"	"	$\frac{44820}{119}$	= 376.40 " "
Total volume of " " in cu ft.					= 1015.00

Assume the width at the tuyers as 42", height of ore columne 16' height of feed floor above tuyers 20', bosh of water jacket 18" height of water jacket above the tuyers 4'10", bosh of furnace walls above jacket 10". The walls at the ends of the furnace are boshed the same as at the sides but the water jackets are straight.



Area A = $\frac{5'5\frac{1}{3}" + 5'}{2} \times 11'2" = 58.48$ sq ft.

Area B = $\frac{5' + 3.5'}{2} \times 2.41' = 22.48$ sq ft.

Bosh at the ends volume = av width X height X 10"

$5'8\frac{2}{3}" \times 13' . " \times 10" = 63.6$ cu. ft.

Volumne for the rest of the furnace =

1015- 63.6 = 951.4 cu ft.

End area of the furnace = 22.48+ 58.12 = 80.6 sq. ft.

Length = 951.4 ÷ 80.6 = 11.8' = 141.6"

Volumne of gases given off and of air supplied.

We want to smelt 100 tons of ore per day, which requires 168 charges.

S in one charge.

In ore	56.4
" coke	.5
	56.9 #

Assuming 1/4 the total S burns off we have for one day

$\frac{56.9 \times 168}{4}$ = 2389.8 lbs S burned to SO_2 which requires

2389.8 lbs O_2 giving 4779.6 lbs SO_2 (since the molecular weights of S and O are equal).

Assume that two thirds of the ZnS is burned off to ZnO then

$2/3 = \frac{1.6 \times 8.3 \times 168}{1} \; \frac{16}{65} = 328.8$ lbs O_2 needed to form ZnO (8.3 is the factor by which a 100 lb charge is increased to 1500 lbs).

In a 100 lb charge we have 2.3 lbs PbS going into the matte,hence in 1500 lb charge we have 2.3 X 8.3 = 19.09 lbs PbS in the matte.830 lbs. lead ore carries 14% PbS or 116.2 lbs.

	116.2 lbs
PbS in matte	19.09
PbS to be reduced	= 97.11 lbs.

PbS is first reduced to PbO or 97.11 lbs PbS becomes 90.6 lbs PbO and contains 6.47 lbs O_2 thus

$240 : 16 = 97.11 : X, \; X = 6.47$

97.11 - 6.47 = 90.6 lbs. PbO since the automic weight of O is 1/2 that of S.

6.47 X 168 = 1086.7 lbs O_2 needed for this reaction.

O needed to burn 6.6 lbs FeS to FeO = 1.2 lbs. hence for one day 1.2 X 8.3 X 168 = 1671.3 lbs O_2

210 lbs of coke carries 177.7 lbs of fixed carbon (210X 84.2%)

Assume that 40% of this C burns to CO and 60% to CO_2

$$177.7 \times 168 = 29854 \text{ lbs C.}$$

40% of this requires 15921 lbs O_2 forming 27862 lbs CO.

$29854 \times .40 \times 4/3 = 15921$ lbs O_2 $\left(\frac{16}{12} = \frac{4}{3}\right)$ forming $15921 + 11941 =$ 27862 lbs of CO.

Likewise

$29854 \times .60 \times 8/3 = 47756$ lbs O_2 $\left(\frac{32}{12} = \frac{8}{3}\right)$ making 65665 lbs CO_2

Total O_2 needed for the coke = $15921 + 47756 = 63677$ lbs.

Summary.

O_2 needed to burn	S to SO_2	per	day	2389	lbs.
" " " "	Zn " ZnO	"	"	329	"
" " " "	Pb " PbO	"	"	1087	"
" " " "	40%C" Co	"	"	15921	"
" " " "	Fe " FeO	"	"	1671	"
" " " "	60%C" CO_2	"	"	47756	"
Total O_2 needed		"	"	69153	" or

N_2 " $= \frac{77}{23} \times 69153 = 231524$ lbs.

48.00 lbs per minute O_2.

$32 \times 22.22 \times \frac{48.00}{2}$ = 17065.0 cu ft. O_2 per minute at standard pressure 760 mm or 29.93". Pressure at Denver is 25.5" hence at that altitude 17065.0 cu ft. becomes $\frac{29.93}{25.5} \times 17065.0 = 20017$ cu ft. at 0°C.

At 12°C volume = $20017 \left(1 + \frac{12}{273}\right) = 20898$ cu ft.

N_2 by vol. $= \frac{79}{21} \times 20898$ = 78575 " "

Total vol. of air per minute= 99473 " "

Size of Tuyers.

At 30 degrees F. 1 cu. ft of air weighs .0868 lbs at sea level. At 32 degrees F. or 0 degrees C. it weighs $.0868 - \left(\frac{2}{461} \times .0868\right)$ or .0864 lbs. Pressure at Denver is 25.5 hence one cu. ft. of air in that locality weighs $.0864 \times \frac{25.5}{29.93}$ or .073 lbs.and one cu. ft. of water weighs

$\frac{62.32}{.073}$ or 846 times as much as one cu. ft of air.

Assume 2.6 sq. ft. hearth area for each tuyers. Number of tuyers equal $\frac{42X\ 141.6}{144X\ 2.6} = 16$. Air per second per tuyer $= \frac{99473}{60 \times 16} = 103.6$ cu ft.

Let the area of a tuyer be y sq. ft. Let the pressure be 2 lbs. per square inch = 2 X 144 y lbs. per tuyer, then 12: X = 62.32 : (2 X 144 y), X = water guage reading, = 55.44 y inches.

The pressure of a column of water 55.44 y inches high is equivalent to that of an air column 3908.5 feet high, thus: $\frac{55.44\ y}{12} \times 846 = 3908.5\ y$

At 12 degrees C it is equivalent to 3908.5 y $\times \frac{285}{273}$ or 4064.8 y feet = h.

$V = \sqrt{2\ gh} = 8\sqrt{4064.8\ y} = 509.6\sqrt{y}$.

Area = volume ÷ velocity or $y = \frac{103.6}{509.6\sqrt{y}}$, y = .089 sq ft. or 12.82 sq. in. Diameter of tuyers = 4.0 inches.

Oxygen furnished within the charge itself.

From the slag table we have 6.9 lbs FeO+195.1 lbs. FeO in the ash and flux for the ores = 202.0 lbs. 2 FeO : O = 144 : 16 = 202.0 :X

X = 22.4 lbs.O. This oxygen is given off by

Fe_2O_3 in being reduced to FeO by C.

O given off by Fe_2O_3 in forming speiss and matte is determined as follows:since the iron ore contains 81% Fe_2O_3 of 99 lbs of ore =80.2# Fe2O3.

O in 80.2 lbs Fe_2O_3 = 24.06 lbs,thus 160 : 48 = 80.2 : X, X = 24.06

Total oxygen given off from one charge = 22.4+24.1 = 46.5 lbs O_2

For 168 charges we have 46.5 X 168 = 7812.0 lbs. O_2.

O furnished by iron oxide in the lead ore.

Ore contained 6.6 lbs FeS.

17.04 " FeO from slag table

(1) Assume 2/3 of the FeO came from Fe_2O_3 of the roasted ore.

(2) and 1/3 from Fe_3O_4

(1) $144 : 16 = 11.36 : X, x = 1.26$ lbs O_2

(2) $216 : 16 = 5.68 : X, X = .42$ " "

Available O_2 in lead ore =1.68 "/100 lbe ore which is given off when the higher oxides are reduced to FeO.

$1.68 \times 8.3 \times 168 = 2342$ lbs O_2 per day.

CO_2 given off from the charge.

In 100 lbs charge we use 8.7 lbs limestone, containing 75.5 % $CaCO_3$ 10.3% $MgCO_3$ 7.2% $FeCO_3$, hence

6.6 lbs	$CaCO_3$	gives	2.9 lbs	CO_2
.9 "	$MgCO_3$	"	0.5 "	"
.6 "	$FeCO_3$	"	0.3 "	"
			3.7 "	"

$3.7 \times 8.3 \times 168 = 5157.2$ lbs CO_2 given off from one day's run.

All the oxides that were reduced were assumed to be reduced by CO though in practice some of ~~it is~~ them are reduced by C alone, but figures from actual practice were not obtainable, and probably would not effect the calculations to a very great extent anyhow.

Total O given up by iron oxides 7812

2342

10154 lbs O_2

This requires 17769 lbs CO to form CO_2, thus

$28 : 16 = X : 10154, X = 17769$

CO_2 formed $= 17769 + 10154 = 27923$ lbs.

CO to reduce 1087 lbs O from PbO, $\frac{7 \times 1087}{4} = 1902$ lbs.

CO formed by burning coke at the tuyers 27862 lbs.

CO to reduce iron oxides 17769 lbs.

" " " lead 1902. 19671

CO passing unchanged to stack 8291 lbs.

Summary of Furnace Gases Passing Through Stack.

Oxygen furnished within the charge.

From Fe_2O_3 in iron ore and ash	7812 lbs
" " " lead " " Fe_3O_4 " " "	2342 "
" PbO	1087 "
	11241 "

This oxidizes CO to CO_2 and therefore is not to be deducted from O_2 furnished at the tuyers.

CO from Coke.	27862 lbs.	27862 lbs.
11241 lbs O_2 requires 19671 lbs CO		19671
CO_2 formed by above	30,712 lbs	
" given off by carbonates	5,157	
Total CO_2	55230 "	
Total CO passing through unchanged		8291 lbs.

Total weight of gases leaving stack :

SO_2	4779 lbs	1.61%
N_2	231524 "	77.22"
CO	8291 "	2.65"
CO_2	55230 "	18.42"
	299824 "	

4779 lbs SO_2/ day means 3.3 lbs per minute

Oz molecule = 64

	cu ft.	%
$64 \times 22.22 \times \frac{3.3}{2}$ (64 oz = 2 lbs)	4346	5.55
231524 lbs N_2 per day or 1608 lbs (28oz = 1.75 lbs) per minute $28 \times 22.22 \times \frac{1608}{1.75}$ lbs	57150 57180	73.75 78.75

8221 lbs CO per day, or 5.7 lbs per min.

$$28 \text{X } 22.22 \text{ X } \frac{5.7}{1.75} \qquad 2026 \qquad 2.58$$

55230 lbs CO_2 per day, or 38.2 lbs " "

$$44 \text{ oz X } 22.22 \text{ X } \frac{38.3}{2.75} \quad (44 \text{ oz} = 2.75\text{lbs}) \quad 13944 \qquad 17.95$$

77566

The accompanying drawings are self explanatory. The details fixed by practice were derived from a blue print of a Lead Blast Furnace furnished by the Denv r Engineering Works.