THE SURIGAO IRON ORE AND IT'S METALLURGICAL TREATMENT

Foreword

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Mining industry provides the necessary supply of valuable metallic and non-metallic materials for global consumptions. Metallurgical industry processes the ore for distribution to different industrial plant. The existence of these two significant industries is imperative to the benefit of the general public, especially here in the Philippines where the land is rich of mineral resources.

The three technical papers presented in this issue feature some of the important applications in the field of mining and metallurgical engineering. The two articles written by Professor Enrique Ostrea tackle the potential benefits of the gold refinery and the proposed metallurgical treatment in the production of pig iron for steel manufacturing in the country. Professor Ostrea, who played an active part in the development of mining and metallurgical engineering in the Philippines, strongly believed that these kinds of undertakings will be profitable and essential to the government. Unfortunately, we are not able to fully capitalize this kind of proposition. The article written by Dr. Manolo Mena described the reduction behavior of nickel in high-iron.

The pioneering role of mining and metallurgical engineering in national development is inevitable. With the mandate of corporate social responsibility and the advocacy of sustainability, the mining and metallurgical industries will provide economic benefits and at the same time follow compliance in the other aspects at stake on the operation such as environmental, social, health and safety. It is therefore a challenge for every sectors involved; the government, the mining and metallurgical industries, the engineers, the local government units and the socio-civic organizations to fully maximize the use of our resources.

THE SURIGAO IRON ORE AND ITS METALLURGICAL TREATMENT

By Enrique Ostrea[1]

THE ORE BODY

Discovery.

The Surigao Iron Ore was first recognized by H. P. Cameron, Chief Engineer of the Department of Mindanao and Sulu in 1912. This deposit was reserved in 1915 under Executive Order No. 63 for the use of the Philippine Government.

Pratt & Lednicky.[2]

In 1915, this deposit was examined by Pratt and Lednicky, Engineers of the Bureau of Science, and reported 500,000,000 metric tons of ore having an average value of 47 percent metallic iron. It was felt at that time that the industrial demand didn't justify the openning of the deposit.

Act 2862.

On March 12, 1919, the Philippine Legislature passed Act 2862 creating the National Iron Co., a corporation which will undertake the exploitation and development of Philippine Iron Ores in general, and Surigao Iron Deposit in particular. Nothing has been done toward the incorporation of the National Iron Co., nor the exploitation of the ore deposit.

W. D. Smith.

In 1922, W. D. Smith, the then Chief of the Division of Mines under the Bureau of Science, recommended to the then Gov. Gen. Leonard Wood, that the reservation be lifted and that the deposit be leased to a private owner and royalties, taxes or rentals be collected and used as income to the University of the Philippines or a School of Mines, or for the support of the Division of Mines. Nothing was done in the way of accomplishing any of the above suggestions.

Bureau of Mines.

In 1937, the Bureau of Mines "pressed for a lease", undertook a detailed, geological study and exploration program. A summary of the report[3], in parts stated:

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[1] Acting Head, Mining Dept., College of Engineering, University of the Phil.

[2] Pratt, W. E. & V. E. Lednicky, Iron Ore in Surigao Prov., Phil. Journal of Science, No. A-10 (1915) p. 335.

[3] Origin of the Surigao Iron Ore, Dean C. Fasche, Econ. Geology, Vol. XXXVI No. 3, May 1941, p. 304.

"The lateritic iron ore of Surigao Province, Mindanao, occur as superficial mantle covering a plateau-like area. The ore varies in thickness from nothing to as much as 30 meters .... Analyses of 2000 samples taken from the area studied show the ore to be rather uniform in grade. Metallic iron averages 47.77%; Phosphorous - 0.03%; Alumina - 7.93%; Chromic oxide - 4.19%; Ni-Co - 0.78%; Silica - 1.33%; Sulphur - 0.17%; hygroscopic water - 26.77%; and combined water 13.61%.

"The iron ore are residual in origin, having been formed in situ by the subaerial decomposition of the serpentine rock.

"The Surigao & Cuban Laterites are very similar in physical character, mineralogy, and chemical composition, both having been formed by the katamorphic alteration of serpentine,"

The ore estimated confirms that of Pratt and Lednicky, 500,000,000 metric tons.

Present.

Today more than ever before the need for the exploitation of this deposit is imperative, even in a modest way. Enormous needs for reconstruction, vital needs for our new Republic just born and great needs in East Asia, now that Japan is prohibited to engage in heavy industries, these needs contribute their share in urging our people, or at least our government to start the exploitation of the Surigao Iron Ore. And the Geological Society of the Philippines should urge our government to acquire as part of our reparations from Japan, a complete machinery for Iron and Steel production.

METALLURGICAL TREATMENT OF THE SURIGAO IRON ORE

In a modest way I am submitting this paper on the Blast furnace treatment of Surigao Ore (theoretically) based on known facts regarding the ore body and based on the Blast furnace Practice of Mayari Ore, as found in available literature.

Mayari Ore and Surigao Ore Compared.

The analyses of Mayari ore is given by Richard V. M. Mackay[4] and that of the Surigao Iron Ore is given by Dean C. Frashhe[5] . The two analyses are given on the next page (Table I) for comparison.

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[4] Progress in Smelting of Mayari Ore by Richard V. M. Mckay, the Iron Age, June 4, 1914.

[5] Origin of Surigao Iron Ore by Dean C. Frasche, Economic Geology Vol. XXXVI, No. 3, May 1941, pp. 304, 305.

Table I.

Analyses of Mayari Iron Ore and Surigao Iron Ore.

Constituents	Mayari Ore, Cuba	Surigao Ore, P. I.
SiO_2	2.00%	1.33%
Al_2O_3	10.00%	7.93%
Fe	38.14%	47.77%
Cr	1.46%	4.19%
Ni	0.57	0.78%
P	0.013%	0.03%
Mn	0.57%	-----
S	0.15%	0.17%
H_2O (comb.)	11.50%	13.61%
H_2O (hygros.)	23.22%	26.77%

It is seen that the two ores are very similar in composition, that one ore can almost substitute for the other and therefore we can safely assume that the method of treatment of the Surigao ore will follow that of Mayari ore.

Treatment of Mayari Ore.

Briefly the flowsheet of the treatment of Mayari ore is as follows: Mine ore is air dried in Allis-Chalmers "direct heat" coal dryer, then sintered in Dwight-Lloyd sintering machine, - both processes are done in Cuba. The sinter is shipped to Sparrows Point, Maryland, where it is smelted in regular blast furnaces producing pig iron and slag. The former is excellent for casting and fair for steel manufacture while the latter are easily fusible altho of bigger bulk than ordinary. Typical analysis of those two products as given by Quincy Bent[6] are shown in Table II.

Table II.

Blast Furnace

Pig Iron		Slag.	
Constituents	%	Constituents	%
P	0.05	SiO_2	18
S	0.025	Al_2O_3	30
Mn	0.09	CaO	35
Cr	2.9	MgO	15
Ni	1.5	S	1.8

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[6] The Use of Mayari Iron on Foundry Mixtures by Quincy Bent, Yearbook, American Iron and Steel Institute 1912.

The subsequent treatment of the pig iron was described by Lines[7], as follows: The pig iron was first Bessemerized in an acid lined vessel. Here most of the chromium was oxidized and slagged, while none of the nickel was removed.

The blown metal and the slag showed the following average composition; (after Lines)

Table III.

Bessemer Furnace

Bessemer Steel		Slag	
Constituents	%	Constituents	%
C	0.10- 0.15	SiO_2	22.80
P	0.06	MnO	7.70
Mn	0.10	FeO	24.16
S	0.04	Cr_2O_3	27.65
Cr	0.20- 0.30		
Ni	All		

The above Bessemer steel is further refined in an open hearth. The charge consists of 90% blown steel 10% molten pig iron fluxed with roll scale and burnt lime. The final product is as follows: (after Lines)

Table IV.

Open Hearth Furnace

Open Hearth Steel		Slag	
Constituents	%	Constituents	%
Ni	1.0- 1.5	SiO_2	14
C	0.2- 0.7	FeO	16
		MnO	4
		Cr_2O_3	7
		CaO	45
		P_2O_5	0.75

The steel produced is a Nickel steel which is superior to ordinary carbon steel having an ultimate strength of 10,000 lbs. per sq. in. more than carbon steel.

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[7] The Duplex Process of Steel Manufacture at Maryland Steel Work, Lines, AIME, Transaction Vol. LIII, 1915, p. 359.

Treatment of Surigao Iron Ore.

If we may now assume that the Surigao Iron be treated in a similar manner as that outlined above for Mayari ore we would expect to obtain similar products. With these assumed products we can calculate theoretically the amount of the raw material required to smelt the ore and the products obtained during smelting in the blast furnace.

CALCULATION OF THE CHARGE

ORE.

The analysis of the raw ore after it is air dried, and again after it is sintered are given in Table V.

Table V. Surigao Ore, Percentage Composition

Constituents	As Mined	Dry Basis	Sintered Ore, basis
SiO	1.33	1.33	1.61
Al_2O_3	7.93	8.22	9.58
Fe.	47.77	70.69	82.37
Cr_2O_3	4.19	4.34	5.06
Ni	0.78	1.03	1.20
P	0.03	0.07	0.08
S	0.17	0.17	0.10 [8]
H_2O (comb.)	13.61	14.10	0.00
H_2O (hygro.)	26.77	0.00	----

Assuming the pig iron to be composed of:

Constituents	%	Constituents	%
Fe	92.05	Si	0.75
Cr	2.9	C	2.70
Ni	1.5	P	0.07
		S	0.03

which is similar to the pig iron produced at Mayari ore the weight of sintered ore required per 1,000 kg. of pig allowing 0.3% Fe going to slag amounts to 1601.2 kg. (sintered ore) equivalent to 1927 kg. of raw ore.

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[8] Assuming 1/2 of the sulphur has been driven off during sintering.

% Fe in the sintered ore = $\frac{2Fe}{Fe_2O_3}$ (82.37 = 57.66

% Fe going into slag 57.66 x 0.003 = 0.17

% Fe available for the pig ------------ 57.49%

% Fe in pig ----------- 92.05%

Sintered ore required per 1000 kg. pig will be

$$\frac{.92\ 05}{.5749} \times 1000 = \underline{\underline{1601.2 \text{ kg. sintered ore}}}$$

$$\text{Raw ore will be } 1601.2 \left(\frac{57.79}{47.77}\right) = \underline{\underline{1927 \text{ kg. raw ore}}}$$

CHARCOAL.

Inasmuch as no coking coal has been found so far in the Philippines, and we have available charcoal from coconut shell and from "bacawan", and since charcoal is known to be used successfully in Sweden in smelting iron ore, I have therefore chosen charcoal as the fuel used in the blast furnace, in order to develop another possible industry, "The Charcoal Industry".

No analysis of charcoal from either coconut shell or "bacawan" is available. I have therefore assumed that our charcoal will be similar in composition to the charcoal now used in Sweden in their iron smelting which analyzed as follows:

C	80.31%	O	3.54%
N	3.54"	CaO	0.89"
Fe_2O_3	0.32"	SiO_2	0.19"
MgO	0.10"	P_2O_5	0.0068%
S	0.017%	H_2O	14.04%
K_2O	0.50 "		

The minimum amount of carbon necessary to be charged in the furnace will be the sum of the carbon present in the pig plus the carbon necessary to reduce the ore as given in the following equation:

$$Fe_2O_3 + 6CO \text{ --- } 2Fe + 3CO + 3CO_2$$

plus excess carbon to take care of the consumed CO gas by the CO_2 gas coming from the charge in the furnace.

This amount would be per 100 parts of pig iron containing 92.05 parts iron, 2.70 parts carbon and using 80.31 per cent carbon.

$$\text{Carbon burned at tuyeres} = \frac{6C}{2Fe}(92.05) \text{ parts}$$

$$= \frac{72}{112}(92.05) = 59.17 \text{ parts}$$

$$\text{Carbon in pig} = \underline{2.70}$$

$$\text{Total fixed carbon necessary} = 61.87$$

Total charcoal necessary to supply this = $\frac{61.87}{.8031}$ = 77.04 parts, allowing 10% excess to take care of the consumed CO gas by the CO_2 gas coming from the charge and to furnish more heat due to higher temperature required in the reduction of chromite.

10% of 77.06 = 7.7
plus ---- = 77.04
Total charcoal necessary = 84.74 or for 1000 kg. of pig we need
per 100 parts pig 847.4 kg. charcoal.

FLUX.

We will assume to make a slag similar to the slag produced by the Mayari ore, the composition of which is as follows (see Table II):

SiO_2 ----- 18%
Al_2O_3 ---- 30%
CaO ------ 35%
MgO ----- 15%
S ------- 1%

The Acid constituents of the above slag:

Richards[9] states that in in slags low in silica (below 30%) alumina behaved like silica, in regards to fusibility.

Silica in slag ---------------------------------- 18
Silica equivalent of alumina
$\frac{3\ (SiO_2)}{2\ (Al_2O_3)}$ (30) = $\frac{180}{204}$ (30) ---------- 26
Summated silica -------------------------- 44

The basic constituents of the above slag.

CaO in slag ---------------------------------- 35
CaO equivalent of MgO
($\frac{CaO}{MgO}$ x 15 = $\frac{56}{40}$ (15) ------------ 21
Summated Cao ------------------------------- 56

Therefore the ratio of acid to base in the above slag will be equal to summated silica over summated CaO equals $\frac{44}{56}$ = 0.8

Using 0.8 as slag ratio the flux which is required to slag the sintered Surigao Iron ore and the ash produced by the charcoal, may now be calculated.

From 1601.2 kg. of sintered ore the products are

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[9] Metallurgical Calculation by Richard, 1918, p. 257.

Fe_2O_3

Fe in pig = 920.5 kg.

Fe_2O_3 equivalent of iron in pig $\frac{Fe_2O_3}{2Fe}$ (920.5) kg.

$= \frac{160}{112}$ (920.5) = 1315.0 kg.

Fe_2O_3 present in ore = 1601.2 (.8239) = 1318.9 kg.
Fe_2O_3 equiv. going to pig iron -------- = 1315.0 kg.
Fe_2O_3 remaining and going to slag ----- = 3.9 kg.

FeO to slag - $\frac{2FeO}{Fe_2O_3}$ (3.9) = $\frac{144}{160}$ (3.9) = 3.5 kg. to slag

O_2 going to gases = 1315-920.5) + (3.9 - 3.5)
= 394.5 + 0.4 = 394.9 kg. to gases.

SiO_2

Si in pig iron = 1000 (.0075) = 7.5 kg.

SiO_2 equiv. of Si in pig = $\frac{SiO_2}{Si}$ (7.5)

= $\frac{60}{28}$ (7.5) = 16.1 kg.

SiO_2 in ore = 1601.2 (.0161) = 25.8 kg.
Less SiO_2 equiv. in pig ---------- = 16.1 kg.
SiO_2 to slag --------------- = 9.7 kg. SiO_2 to slag

O_2 given off = 16.1 - 7.5 = 8.6 kg. O_2 to gases.

Al_2O_3

Al_2O_3 present in ore 1601.2 (.0958) = 153.4 kg. to slag
All of which goes to slag.

Cr_2O_3

Cr in pig iron = 1000 (.029) = 29 kg.

Cr_2O_3 equiv. of Cr. in pig = $\frac{Cr_2O_3}{2\ Cr}$ (29)

= $\frac{152}{104}$ (29) = 42.4 kg.

Cr_2O_3 in ore = 1601.2 (0.0506) = 81.0 kg.
Cr_2O_3 equiv. going to pig = 42.4 kg.
Cr_2O_3 going to slag -------- 38.6 kg. Cr_2O_3 to slag

O_2 given off = 42.4 - 29 = 13.4 kg. O_2 to gases.

NiO

Ni in pig iron = 1000 (.015) = 15 kg.

NiO equiv. of Ni in pig iron = $\frac{NiO}{Ni}$ (15)

= $\frac{75}{59}$ (15) = 19.1 kg.

NiO in ore = 1601.2 (0.012) = 19.2 kg.
NiO equiv. going to pig iron = 19.1
NiO going to slag (negligible) 0.1 kg. NiO to slag
O_2 given - off = 19.1 - 15 = 4.1 kg. O_2 to gasses

P_2O_5

P in pig iron = 1000 (.0007) = 0.7 kg.

P_2O_5 equiv. of P in pig iron $= \frac{P_2O_5}{2P}(0.7) = \frac{142}{62}(0.7) = 1.6$ kg.

P_2O_5 in ore = 1601.2 (.008) = 1.3 kg.
P_2O_5 equiv. in pig iron = 1.6 kg.
P_2O_5 going to slag --------- None

P equiv. of 1.3 P_2O_5 $= \frac{2P}{P_2O_5}(1.3) = \frac{62}{142}(1.3) = 0.6$ kg.

O_2 given off = 1.3 - 6 = 0.7 kg. O_2 to gasses

S

S in pig iron = 1000 (0.003) = 0.3 kg.
S in ore = 1601.2 (0.001) = 1.6 kg.
S in pig ------------------ 0.3 kg.
Excess sulphur ----------- 1.3 kg. which goes to slag.
in the form of CaS. or $\left(\frac{CaS}{S}\right)(1.3) = \frac{72}{32}(1.3)$

= 2.9 kg. CaS to slag.

Ca required by CaS $= \frac{Ca}{CaS}(2.9) = \frac{40}{72}(2.9) = 1.6$ kg. Ca.

CaO required by Ca $= \frac{CaO}{Ca}(1.6) = \frac{56}{40}(1.6) = 2.3$ kg. CaO

O_2 given off from CaO = 2.3 - 1.6 = 0.7 kg. O_2 to gasses.

From 847.4 kg. charcoal the products are:

C

C in pig iron = 1000 (0.027) = 27.0 kg.
C in fuel = 847.4 (.8031) = 680.5 kg.
C in pig ---------------- 27.0
C burned to gasses ------ 653.5 kg. all go to gasses.

O

O_2 in fuel = 847.4 (0.0354) = 30.0 kg. All to gasses

N

N_2 in fuel = 847.4 (0.0008) = 0.8 kg. all to gasses.

Fe_2O_3

Fe_2O_3 in fuel = 847.4 (0.0032) = 2.7 kg.

FeO equiv. = $\frac{2FeO}{Fe_2O_3}$ (2.7) = $\frac{144}{160}$ (2.7) = 2.4 kg. FeO to slag

O_2 given off = 2.7 - 2.4 = 0.3 kg. to gases.

SiO_2

SiO_2 in fuel = 847.4 (.0019) = 1.6 kg. SiO_2 to Slag.

MgO

MgO in fuel = 847.4 (0.001) = 0.8 kg. MgO to slag.

K_2O

K_2O in fuel = 847.4 (0.005) = 4.2 kg. K_2O to slag

P_2O_5

P_2O_5 in fuel = 847.4 (.000068) = 0.06 kg. P_2O_5

P equiv. = $\frac{2P}{P_2O_5}$ (0.06) = $\frac{62}{144}$ (0.06) = 0.026 kg.

Since there was 0.3 kg. still unsatisfied in the Pig all the P in fuel will go to the pig.

O_2 given off = 0.06 - 0.026 = 0.034 kg. O_2 to gases

S

S in fuel = 847.4 (0.00017) = 0.144 kg. which goes into the slag as CaS. or $\left(\frac{CaS}{S}\right)$ (0.144) = $\frac{72}{32}$ (0.144)

= 0.32 CaS to slag.

$\frac{Ca}{CaS}$ (0.32) = $\frac{40}{72}$ (0.324) = 0.18 kg. Ca.

$\frac{CaO}{Ca}$ (0.18) = $\frac{56}{40}$ (0.18) = 0.25 kg. CaO.

CaO

CaO in fuel = 847.4 (.0089) = 7.5 kg.

CaO used by S in ore -- 2.3

CaO used by S in fuel - 0.25

Total CaO ------------ 2.55 - 2.6

CaO available & going to slag 4.9 kg. to slag

Ca equiv. of 2.6 CaO = $\frac{Ca}{CaO}$ (2.6) = $\frac{40}{56}$ (2.6) = 1.8 kg. Ca.

O_2 given off = 2.6 - 1.8 = 0.6 kg. O_2 to gases.

From X-Kg. Limestone flux the products are:

The X- Kg. limestone comes from Licos, Cebu which analyses is as follows:[10]

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[10] Analyses of Phil. Limestone, Mineral Resources of P. I., 1908, p. 33.

SiO ------------ 0.38%
Al_2O_3 ---------- 0.18%
CaO ----------- 55.62%
CO_2 ----------- 43.50%
H_2O ------------ 0.17%

The slag forming constituents from 1601.2 kg. sintered ore, from 847.4 kg. charcoal and from X-Kg. limestone may now be tabulated and is shown in Table VI.

Table VI. - Slag Forming Constituents

Constituents	Ore	Fuel	Ore + Fuel	Flux	Total
SiO_2	9.7	1.6	11.3	0.0038X	11.3 + 0.0038X
Al_2O_3	153.4	---	153.4	0.0018X	153.4 + 0.0018X
Cr_2O_3	38.6	---	38.6	-------	38.6
FeO	3.5	2.4	5.9	-------	5.9
CaO	---	4.9	4.9	0.5562X	4.9 + 0.5562X
NiO	0.1	---	0.1	-------	0.1
MgO	---	0.8	0.8	-------	0.8
K_2O	---	4.2	4.2	-------	4.2
CaS	2.9	0.3	3.2	-------	3.2
			222.4	0.5618X	222.4 + 0.5618X

The summated silica constituents.

SiO_2 -------------------------------- 11.3 + 0.0038X

SiO_2 equiv. of Al_2O_3 present

$$= \frac{3SiO_2}{2\,Al_2O_3}\,(153.4 + 0.0018X)$$

$$= \frac{180}{204}\,(153.4 + 0.0018X) \text{ ------------ } \underline{135.3 + 0.0016X}$$

Summated silica -----146.6 + 0.0054X

The summated lime constituents.

CaO -------------------------------------- 4.9 + 0.5562X

CaO equiv. of Cr_2O_3 present

$$= \frac{3\,(CaO)}{Cr_2O_3}\,(38.6) = \frac{168}{2(52)+48}\,(38.6) = \frac{168}{152}\,(38.6) = 42.6$$

$$CaO \text{ equiv. of FeO present} = \frac{CaO}{FeO}\,(5.9) = \frac{56}{72}\,(5.9) = 4.6$$

$$CaO \text{ equiv. of MgO present} = \frac{CaO}{MgO}\,(0.9) = \frac{56}{40}\,(0.9) = 1.3$$

$$CaO \text{ equiv. } K_2O \text{ present} = \frac{CaO}{K_2O}\,(4.2) = \frac{56}{94}\,(4.2) = 2.5$$

$$CaO \text{ equiv. of NiO present} = \frac{CaO}{NiO}\,(0.1) = \frac{56}{75}\,(0.1) = \underline{0.1}$$

Summated CaO ----------- 56.0 + 0.5562X

$\frac{\text{Summated silica}}{\text{Summated lime}} = 0.8$ (based on Mayari Slag.)

Therefore $\frac{146.6 + 0.0054X}{56.0 + 0.5562X} = 0.8$

$146.6 + 0.0054X = 0.8(56.0 + 0.5562X)$

$146.6 + 0.0054X = 44.8 + .44496X$

$0.43956X = 101.8$

$X = \frac{101.8}{0.43956}$

$= \underline{\underline{231.6 \text{ kg. limestone.}}}$

From 231.6 kg. of limestone the products are:

SiO_2

SiO_2 present in flux = 231.6 (0.0038) = $\underline{\underline{0.9 \text{ kg. } SiO_2 \text{ to slag}}}$

Al_2O_3

Al_2O_3 present in flux = 231.6(0.0018) = $\underline{\underline{0.4 \text{ kg. } Al_2O_3 \text{ to slag}}}$

CO_2

CO_2 present in flux = 231.6(0.4350) = $\underline{\underline{100.7 \text{ kg. } CO_2 \text{ to gases}}}$

CaO

CaO present in flux = 231.6 (0.5562) = 128.8 kg. $\underline{\underline{\text{CaO to slag}}}$

H_2O

H_2O present in flux = 231.6 (0.0017) = 0.4 kg. $\underline{\underline{H_2O \text{ to gases}}}$

THE BLAST

Assume the gases at the throat (dried) analyze:

N_2-------- 57.3%
CO -------- 23.1%
CO_2 ------- 14.8%
H_2 -------- 4.3%
CH_4 ------- 0.5%

The fixed carbon of the fuel, only, furnishes the carbon in the pig iron, the rest going into the gasses. The blast is therefore calculated as follows:

C in CO_2 of flux = $\frac{C}{CO_2}$ (100.7) = $\frac{12}{44}$ (100.7) = 27.5 kg.
C in gasses from fuel = $\underline{653.5 \text{ kg.}}$
C in gasses altogether -------------------- 681.0 kg.

In 1 cu. m. (1000 liters) of the gas there are:

CO --- 1000 (0.231) = 231 l.
CO_2 -- 1000 (0.148) = 148.1.
CH_4 -- 1000 (0.005) = 5 l.

$$\begin{array}{llll} C + O & \text{------------} & CO & \\ 12 & & 22.4 & 1. \\ X & & 231 & \\ \multicolumn{4}{l}{X = 231\left(\frac{12}{224}\right)} \end{array} \qquad \begin{array}{lll} C + O_2 & \text{------------} & CO_2 \\ 12 & & 22.4 \\ y & & 148 \\ \multicolumn{3}{l}{y = 148\left(\frac{12}{22.4}\right)} \end{array}$$

$$\begin{array}{lll} C + 2H_2 & \text{-----------} & CH_4 \\ 12 & & 22.4 \\ Z & & 5 \\ \multicolumn{3}{l}{Z = 5\left(\frac{12}{22.4}\right)} \end{array}$$

∴ The C in 1000 liters of flue gases will be

$$X + y + Z = 231\left(\frac{12}{22.4}\right) + 148\left(\frac{12}{22.4}\right) + 5\left(\frac{12}{22.4}\right)$$

$$= (231 + 148 + 5)\ \frac{12}{22.4}$$

$$\text{or the C in 1 cu. m.} = \frac{231 + 148 + 5}{1000}\ \left(\frac{12}{22.4}\right)$$

$$= 0.20736 \text{ kg.}$$

$$\text{Volume of gas per 1000 of pig iron} = \frac{681.0}{0.20736}$$

$$= 3284.1 \text{ cu. m.}$$

N_2 in the gas = 3284.1 (0.573) = 1,881.8 cu. m.

Wt. of N_2 = 1881.8 x 1.26 (sp. gr.) =	2,371.1 kg.
N_2 from fuel ----------------------	0.8 kg.
N_2 from blast ----------------------	2,370.3 kg.
Oxygen from blast = 2370.3 (.3) ---	711.3 kg.
Wt. of total blast ----------------	3,081.6

OR: The blast may be calculated as follows:

Assume the gases to contain 2 1/3 parts CO and 1 part CO_2.

Therefore of the 681.0 kg. of C, $\frac{2\ 1/3}{3\ 1/3}$ parts goes to CO, $\frac{1}{3\ 1/3}$ part goes to CO_2.

O_2 required for CO is given by the equation: $\begin{array}{lll} C + O & \text{----} & CO \\ 12\ \ 16 & & \end{array}$

O_2 required for CO_2 is given by the equation: $\begin{array}{lll} C + 2O & \text{---} & CO_2 \\ 12\ \ \ 32 & & \end{array}$

Therefore O_2 required for CO = $\frac{2\ 1/3}{3\ 1/3}$ (681.0) $\frac{(16)}{(12)}$ = 635.6

Therefore O_2 required for CO_2 = $\frac{1}{3\ 1/3}$ (681.0) $(\frac{32}{12})$ = 544.9

Total O_2 required -------------------- 1180.5 kg.
O_2 derived from charge --------------- 462.2
O_2 to be furnished by the blast ------ 718.3 kg.

Weight of blast - $\frac{718.3}{0.232}$ = 3096.1 kg. of air

Wt of N_2 = 3096.1 - 718.3 = 2377.8 kg. N_2

SUMMARY OF SURIGAO ORE BLAST FURNACE (PROPOSED) BALANCE SHEET

SINTERED ORE: Wt. = 1601.2 kg.

Constituents	%	Wt.	Pig Iron	Slag	Gasses
Fe_2O_3	82.37	1318.9	Fe - 920.5	FeO - 3.5	O_2 - 395.8
SiO_2	1.61	25.6	Si - 7.5	9.7	O_2 - 8.6
Al_2O_3	9.58	153.4	----------	153.4	----------
Cr_2O_3	5.06	81.0	Cr - 29.0	38.6	O_2 - 13.4
NiO	1.20	19.2	Ni - 15.0	0.1	O_2 - 4.1
P_2O_5	0.08	1.3	P - 0.7	-----	O_2 - 0.7
S	0.10	1.6	0.3	CaS - 2.9	O_2 - 0.7
	100.00	1601.2	973.0	208.2	423.3

CHARCOAL: Wt. = 847.4 kg.

C	80.31	680.5	27.0	------	C - 653.5
O	3.54	30.0	------	------	O_2 - 30.0
N	0.08	0.8	------	------	N_2 - 0.8
Fe_2O_3	0.32	2.7	------	FeO - 2.4	O_2 - 0.3
SiO_2	0.19	1.6	------	1.6	----
CaO	0.89	7.5	------	CaO - 4.9	
				Ca - 1.8	O_2 - 0.6
MgO	0.10	0.9	------	0.9	----
K_2O	0.50	4.2	------	4.2	----
P_2O_5	0.0068	0.06	P - 0.026	----	O_2 - 0.03
S	0.017	0.144	------	CaS - 0.3	-----
H_2O	14.04	119.0	------	-------	H_2O - 119.0
	99.98	847.4	27.026	15.3	804.3

LIMESTONE: Wt. = 231.6 kg.

SiO_2	0.38	0.9	-------	0.9	-----
Al_2O_3	0.18	0.4	-------	0.4	-----
CaO	55.62	128.8	-------	128.8	-----
CO_2	43.50	100.7	-------	-----	CO_2 - 100.7
H_2O	0.17	0.4	-------	-----	H_2O - 0.4
	99.85	231.2	-------	130.1	101.1

BLAST: Wt. = 3069.7 kg.

Constituents	%	Wt.	Pig Iron	Slag	Gasses
O_2		718.3			O_2 - 718.3
N_2		2377.8			N_2 -2377.8
GRAND TOTAL		5775.9	1000.0	353.7	4424.7

SUMMARY OF THE CHARGE TO PRODUCE 1000 KG. of PIG IRON (1 METRIC TON)

1. Mines raw ore ------------ 1927.0 kg.
2. Sintered ore ------------ 1601.2 kg.
3. Charcoal ---------------- 847.4 kg.
4. Limestone --------------- 231.6 kg.
5. Blast ------------------- 3096.1 kg.

The pig iron thus obtained is high in Cr and Ni. The Cr will harden steel while the Ni will toughen the steel. Therefore the pig iron will be favorable for casting purposes.

If structural steel need be manufactured out of this pig, it will be necessary to eliminate the Cr by oxidizing it and fluxing it in the Bessemer convertor then followed by Open Hearth treatment in order to remove the phosphorus.

In the two processes the following drawbacks are obvious:

1. The Cr is lost in the form of slag.
2. Considerable Fe is oxidized during blowing in the convertor making Fe recovery low.

For this reason it might pay to pre-leach the ore of its chromium content and then the residue be smelted to give ~~one~~ a pig iron excellent for the manufacture of Nickel steel. This line of attack will be an excellent field for a metallurgical research, and it is suggested that the Bureau of Mines undertake such a study.
