## ILLUSTRATION OF "REPRESENTATIVE" METHOD IN COMPLETE IRON FURNACE PROBLEM.

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The following problem is taken, as to data and conditions, from the *Engineering and Mining Journal* of New York, August 24, 1907. It is there presented by Prof. Bradley Stoughton, of Columbia University.

The method of solution is of course totally different. From the nature of the "representative" method, there are no trial results and no re-calculations.

An impossible analysis forms part of the original data, viz: in ore No. 1, which by some slip is represented as containing 21 per cent. impurities and 60 per cent. metallic iron. This implies the existence of an oxide containing over 75.9 per cent. iron. The analysis is retained, however, so as to make the problems identical.

The slight variant in the answer is due partly to method, and partly to omission of certain small data in the original solution in the *Journal.*

The materials to be used are two iron ores, coke and limestone. Analyses of the ores and limestone, also of the *ash of the coke,* are as below.

| | Ore No. 1. | Ore No. 2. | Coke ash. | Limestone. |
|---|---|---|---|---|
| $SiO_2$ | 11.00 | 16.00 | 50.00 | 4.00 per cent. |
| $Al_2O_3$ | 2.00 | 12.00 | 18.00 | 2.00 per cent. |
| Fe | 60.00 | 50.00 | 10.00 | 2.00 per cent. |
| CaO | 5.00 | 2.00 | 20.00 | 46.00 per cent. |
| MgO | 3.00 | ..... | ..... | 3.00 per cent. |

It is settled that we shall use 10,000 lbs. coke to 18,000 lbs. ore. As allowance for silicon in the pig metal it is agreed that we shall subtract *one per cent.* from the silica in each ore. That is, in the calculation we take 10 as $SiO_2$ per cent. in No. 1, and 15 as $SiO_2$ per cent. in No. 2.

In order to reduce bases (hence complication of calculation) we first apply the factor 1.4 to the magnesia, and add result to the lime figures in ore No. 1 and limestone. Neglecting the fraction 0.2, this gives us 9 per cent. lime in ore No. 1 and 50 per cent. lime in the limestone. *The ash is ten per cent. of the coke.*





**Condition for the Slag.**—We are to mix the ores for the 18,000 charge and add limestone so as to produce slag of the following composition:

| | |
|---|---|
| Silica | 30.00 per cent. |
| Alumina | 15.00 per cent. |
| Lime | 55.00 per cent. |
| | 100.00 per cent. |

Remember that the *total weight* of ore is fixed at 18,000 but the *relative weights* of the two kinds are to be determined. The coke is a fixed weight, *i.e.,* 10,000 lbs. The "unit" of the equations is *in lbs.*

Let $100x$ = lbs. of ore No. 1., $100y$ = lbs of ore No. 2.

Let $100z$ = lbs. of limestone. Weight of coke is 10,000 lbs.

*First.* Equate sum of ore weights with given figures, *i.e.,*

$$100x + 100y = 18{,}000 \qquad (\text{Or, } x + y = 180)$$

*Second.* Equate the condition that $SiO_2 = 2 \times Al_2O_3$, *i.e.,*

$$10x + 15y + 4z + 500 = 4x + 24y + 4z + 360$$

In this equation the 500 in first member is absolute weight in lbs. of the silica in the coke, *i.e.,* 50 per cent. of 10 per cent. of 10,000 = 500.

The 360 in second member is *twice* weight of alumina derived in exactly the same way from the 10,000 lbs. and the 18 per cent.

The "$z$" eliminates at once, so that we solve these two with $x$ and $y$ only, readily obtaining:

$$x = 98.6667 \text{ or } 100x = 9866.67 \text{ lbs. of No. 1 ore}$$
$$y = 81.3333 \text{ or } 100y = 8133.33 \text{ lbs. of No. 2 ore}$$

But as we must get a value for $z$, we next equate the condition that

$$SiO_2 : CaO = 30 : 55$$

That is, putting the expressions for total $SiO_2$ and total CaO in their places, and equating product of means with product of extremes, we have:

$$55\,(10x + 15y + 4z + 500) = 30\,(9x + 2y + 50z + 200)$$

But we have already the values of $x$ and $y$ and have only to substitute them, thus getting:

$$z = 86.9888 \text{ and } 100z = 8698.88 \text{ lbs.}$$

*Charge for the furnace:*

| | |
|---|---|
| Ore No. 1 | 9866.67 lbs. |
| Ore No 2 | 8133.33 lbs. |
| Limestone | 8698.88 lbs. |
| Coke | 10000.00 lbs. |

It remains only to check these results, *e.g.*, figure by substitution actual silica and actual alumina, and compare according to condition for the slag. They should be as two to one in weight. So also for lime.

1st. Figure out total silica. To do this, take weights of the various constituents as found, and percentages of silica as given by the analyses. Remember the subtractions of 1 per cent. from each ore.

| | |
|---|---|
| Silica from ore No. 1 | 986.667 lbs. |
| Silica from ore No. 2 | 1220.000 lbs. |
| Silica from coke | 500.000 lbs. |
| Silica from limestone | 347.955 lbs. |
| Total silica | 3054.622 lbs. |

2nd. Figure out total alumina. Proceed exactly as above.

| | |
|---|---|
| Alumina from ore No. 1 | 197.3334 lbs. |
| Alumina from ore No. 2 | 975.9996 lbs. |
| Alumina from coke | 180.0000 lbs. |
| Alumina from limestone | 173.9776 lbs. |
| Total alumina | 1527.3106 lbs. |

Now compare these two weights:

$1527.31 \times 2 = 3054.62$ exactly as required, since the proportion of silica in slag is to be twice that of alumina, *i.e.*, 30 : 15.

3rd. Figure out total lime and compare it with either silica or alumina. We here make the comparison with silica.

| | |
|---|---|
| CaO from ore No. 1 | 888.0003 lbs. |
| CaO from ore No. 2 | 162.6666 lbs. |
| CaO from limestone | 4349.4400 lbs. |
| CaO from coke | 200.0000 lbs. |
| Total lime | 5600.1069 lbs. |

The "proof" then is absolute.

Total $SiO_2$ as above 3054.622.

The numbers for total silica and total lime are as 30 : 55, as they should be.



## Useless Complications in Slag Calculations.

In many works when a method of slag computation is introduced, the data for the slag being given *in percentage* (as in problems above), it is nevertheless given as part of the procedure to adjudicate between elements in the same flux addition, and determine "excess."

This mixture of methods is useless, and attention is especially called to the fact that in the present method, when once the percentage (or what is the same thing, the ratio of elements in the required slag) is a fixed requirement, *all chemical questions vanish.*

It is worse than useless to bring in any question of "excess" in the representative method. It is a mere complication, with no compensating advantage.

*E.g.*, suppose that our limestone contains nothing but carbonate of lime and silica—lime 53.2, and silica 5 per cent.

Figuring on "singulo" basis this gives lime excess of 43.9 per cent.

But in the "representative" method this cuts no figure. The silica and the lime of this and any other ingredient of the charge *are all included in the equations*, and the result is a perfect adjudication of all the elements on the basis of the required composition.

Again there are no "trial" figures, and no "re-adjustments" in the method. The statement once made, the solution of the equations gives the final figures. It is recommended that no variation be made from the basis of 100 lbs. as the ore unit of calculation. This was indeed violated in some examples, but uniformity of practice leads to greater safety.

The method, however, is independent of any rule or usage of this kind.

### Type Slags often Found in Metallurgical Practice.

Necessity, or the proper selection of the most economical material, may often determine the composition of a furnace charge, especially in cases where a considerable latitude is allowable without danger to the running.

**Iron.**—Almost invariably, the sole addition for fluxing purposes in iron smelting is limestone. Excepting manganese, in smelting for "spiegel eisen" (on special manganiferous ores), alumina will be the chief base in the ore, and is often insignificant in amount. *The general rule is followed to figure for a "singulo" slag,* without reference to the proportions of bases among themselves. Beyond this it is hardly necessary to go.

No fear need be entertained because of the presence of a moderate percentage of magnesia in the limestone. Many iron men prefer to use a magnesian lime. However, it is well known that lime reduces the sulphur contents of the pig iron more certainly than magnesia, so that, in smelting sulphurous ores, a limestone low in magnesia should be selected.

**Copper.**—In matte smelting it is rarely possible to select material so as to produce a slag of exact pre-arranged formula or percentage. It has already been remarked that in pyritic smelting there is a wide margin for the outcome, owing to the single fact that we cannot predict just what the oxidation of iron will be (*i.e.*, from pyrites), hence a corresponding variation as to ratio between slag and matte.

A table is here given showing allowable variations of the constituents of slags from the copper furnace. According to the principles of replacement, manganese classes as iron, barium and magnesium as lime.

| Slag constituent. | Minimum. | Maximum. |
|---|---|---|
| Silica | 26 | 45 per cent. |
| Alumina | 0 | 20 per cent. |
| Iron oxide (FeO) | 18 | 65 per cent. |
| Lime | 0 | 28 per cent. |
| Zinc oxide (ZnO) | 0 | 14 per cent. |

**Lead.**—The following table, as well as the preceding one (for copper slags) is taken from the "Manual of Practical Assaying" of the late Howard van F. Furman. (Sixth edition, 1908.)

A great number of "formulæ" for slags in lead smelting have been published, but as their discussion is somewhat outside of our scope, we content ourselves with the presentation of the following figures.



TYPICAL LEAD SLAGS.*

| Number. | Silica, per cent. | FeO, per cent. | Lime, per cent. | ZnO, per cent. |
|---|---|---|---|---|
| 1 | 35 | 28 | 28 | .... |
| 2 | 34 | 34 | 24 | .... |
| 3 | 34 | 34 | 17 | 7 |
| 4 | 30 | 40 | 20 | .... |
| 5 | 30 | 48 | 12 | .... |
| 6 | 28–30 | 54 | 6 | .... |

## Additional Examples of "Representative" Method.

In these examples we give cases for each of the metals, iron, copper and lead, also a case for the mixing of three ores ("self fluxing").

Whole units only are given in the analyses. The supposition is that the analyses have been adjusted to the nearest units to simplify calculations.

These alterations of less than the half of one per cent. on any one constituent can never materially affect the outcome.

Thus, if we have material analyzing as below, viz:

| | |
|---|---|
| Silica | 10.7 per cent. |
| Alumina | 8.2 per cent. |
| Magnesia | 3.9 per cent. |
| Ferric oxide | 77.2 per cent. |
| | 100.00 per cent. |

We "adjust," in order to get simple coefficients, by dropping or adding, so as to get the nearest unit, keeping summation at 100, thus:

| | |
|---|---|
| Silica | 11.00 per cent. |
| Alumina | 8.00 per cent. |
| Magnesia | 4.00 per cent. |
| Ferric oxide | 77.00 per cent. |
| | 100.00 per cent. |

* These percentages do not sum to 100. The deficit is supposed to be made up by bases not indicated in the analysis, or at least neglected in the calculations. It is a common though not accurate method of figuring slags.

The subject of matte estimation is of practical bearing, and too closely connected with local or special conditions to be made part of a work on calculations except in the broad way already indicated. The student is referred to Professor Peters' works, "Modern Copper Smelting" and "Principles of Copper Smelting," also to Lang's "Matte Smelting," for information.

(1) **Slag Calculation for Iron Blast-Furnace.**—Assume that coke will be one-half the weight of the ore. The ash of the coke is twelve per cent. of the coke weight.

*Analyses:*

| | Ore. | Coke ash. | Limestone. |
|---|---|---|---|
| $SiO_2$ | 13.00 | 82.00 | 4.00 |
| $Al_2O_3$ | 9.00 | 18.00 | .... |
| $Fe_2O_3$ | 78.00 | .... | .... |
| CaO | .... | .... | 43.00 |
| MgO | .... | .... | 9.00 |

*Take 3 per cent. of silica from ore analysis, for silicon in the pig.*

Condition for the slag is simply that it shall contain 35 per cent. silica. Find weight of limestone to be taken per 100 lbs. of ore. Also find weight of slag for each 100 lbs. of ore taken, and calculate analysis of the slag. Work out a "check" on the whole computation.

This is to be worked under the "representative" method with one unknown quantity.

Let $100x$ = lbs. of limestone required per 100 lbs. ore.

Charge will be 100 lbs. ore + 6 lbs. coke ash + $100x$ lbs. limestone.

Silica from ore figured at $13 - 3 = 10$ per cent.

As the requirement is for percentage of silica only, all of the bases are added together without regard to their chemical equivalencies.

Neglect fraction in calculating silica and base from the coke ash.

Note that since the coke is assumed at one-half the ore, we have 50 lbs. coke to the charge of 100 lbs. ore, hence 6 lbs. ash to the charge.

*Charge in pounds:*

| | Silica. | Bases. |
|---|---|---|
| From ore | 10.00 | 9.00 |
| From coke | 5.00 | 1.00 |
| From limestone | $4x$ | $52x$ |
| Totals | $15 + 4x$ | $10 + 52x$ |



But, since silica is to be 35 per cent., bases must be 65 per cent., that is:

$$15 + 4x : 10 + 52x = 35 : 65$$

Whence $x = 0.4$ and $100x = 40$ = lbs. limestone to the charge.

Total charge is, *Ore, 100 lbs.; Coke, 50 lbs.; Limestone, 40 lbs.*

*Proof.*—Silica in lime being 4 per cent., its weight in 40 lbs. = 1.6 lbs.

Bases in lime are 52 per cent., their weight in 40 lbs. = 20.8 lbs. Hence:

| | |
|---|---|
| Silica = 10 + 5 + 1.6 | 16.6 lbs. |
| Bases = 9 + 1 + 20.8 | 30.8 lbs. |
| Weight of slag | 47.4 lbs. |

Also, since 16.6 is 35 per cent. of 47.4, the slag "checks."

*Composition.*—By multiplying by the various percentages of alumina, lime and magnesia and adding, we get:

| | | |
|---|---|---|
| Silica | 16.6 lbs. or | 35.02 per cent. |
| Alumina | 10.0 lbs. or | 21.09 per cent. |
| Lime | 17.2 lbs. or | 36.29 per cent. |
| Magnesia | 3.6 lbs. or | 7.60 per cent. |
| | 47.4 lbs. | 100.00 per cent. |

Variation in the coke burden would call for some change in the limestone, though a silica variation in the slag of a unit or two is nothing.

(2) **Slag Calculation for Copper-Matte Operation.**—The charge is confined to ore, coke and limestone. Coke to be twelve and a half per cent. of the ore. The coke has 16 per cent. ash. As shown by the analysis, the ore is supposed to be partly roasted or else partly oxidized as mined. Analyses as below:

| | Ore. | Ash of coke. | Limestone. |
|---|---|---|---|
| Silica | 30.00 | 80.00 | 7.00 |
| Alumina, etc | 13.00 | 20.00 | CaO, 52.00 |
| Iron (metallic) | 28.00 | .... | .... |
| Copper | 6.00 | .... | .... |
| Zinc | 6.00 | .... | .... |
| Sulphur | 12.00 | .... | .... |
| Oxygen (deficit) | 5.00 | .... | .... |
| | 100.00 | | |

The following assumptions are made as to division of the elements in the matte and slag:

All copper goes into matte as $Cu_2S$.

One-half of the iron goes into matte as FeS.

One-half of the zinc goes into matte as ZnS.

Half of the iron and half of the zinc go into the slag as FeO and ZnO, respectively. All other bases go into the slag ($Al_2O_3$, CaO).

Slag condition limited to: "Silica 40 per cent., all bases 60 per cent." That is, no stated ratio as between lime and other bases is called for.

The assumptions as to matte do not account for all of the sulphur. The excess is supposed to be burnt or dissipated. Thus, on the usual basis of 100 lbs. ore:

| | |
|---|---|
| Iron, 14 lbs., requires for FeS | 8 lbs. sulphur |
| Copper, 6 lbs., requires for $Cu_2S$ | 1.5 lbs. sulphur |
| Zinc, 3 lbs., requires for ZnS | 1.5 lbs. sulphur |

Thus the total matte produced per 100 lbs. ore is assumed as 34 lbs. Percentage composition as follows:

| | |
|---|---|
| Iron | 41.2 per cent. |
| Copper | 17.6 per cent. |
| Zinc | 8.8 per cent. |
| Sulphur | 32.4* per cent. |
| Total | 100.00 per cent. |

**Slag Computation.**—The slag may now be calculated by one equation with one unknown quantity. Statement is as follows:

| | |
|---|---|
| Ore | 100 lbs. |
| Coke | 12.5 lbs. |
| Limestone | $100x$ lbs. |

Now assemble the constituents and sum them, as below:

| | Silica. | Iron oxide. | "Bases." |
|---|---|---|---|
| Ore | 30.0 | 18.0 | 17.0† |
| Coke | 1.6‡ | .... | 0.4‡ |
| Limestone | $7x$ | .... | $52x$ |
| Totals | $31.6 + 7x$ | 18.0 | $17.4 + 52x$ |

* Few mattes will contain such a percentage of sulphur. This does not invalidate the problem as an exercise in *computation on fixed assumptions.*

† $Al_2O_3$, 13 lbs.; ZnO, from 3 lbs. zinc (not quite), 4 lbs.; total, 17 lbs.

‡ Coke has 16 per cent. ash, 12.5 lbs. are used, making 2 lbs. ash. Eighty per cent. of this = 1.6 lbs. silica. Twenty per cent. = 0.4 lb. bases.



Statement is "Silica is to bases as 40 : 60 (or as 2 : 3). Adding the 18 lbs. iron oxide to the other bases, we have:

$$3\,(31.6 + 7x) = 2\,(35.4 + 52x)$$

Hence, $x = 0.2892$, and $100x = 28.92$ = *lbs. of limestone to be added for each 100 lbs. of ore.*

*Proof.*—Silica in limestone is 7 per cent. of 28.92 or 2 lbs.

Lime in limestone is 52 per cent. of 28.92 or 15 lbs. Hence summation for the slag is as follows:

| | Silica. | Bases. |
|---|---|---|
| Ore | 30.0 | 35.0 lbs. |
| Ash of coke | 1.6 | 0.4 lbs. |
| Limestone | 2.0 | 15.0 lbs. |
| Totals | 33.6 | 50.4 lbs. |

Finally: $33.6 \times 3 = 100.8$, and $50.4 \times 2 = 100.8$, that is, the requirement is fulfilled that silica: bases = 40 : 60.

(3) **Slag Calculation for Lead Smelting.**—The requirement in this case will be for a slag proportioned thus: Silica, 30 per cent., iron oxide, 40 per cent.; lime, 20 per cent.; which practically assumes 10 per cent. of bases other than FeO and CaO.

It will be seen that *exact* compliance with such a condition is not practicable, since it would be only by accident that materials fitting precisely into the specified composition could be found.*

In practice, this allowance meets actual average fairly well.

The "90 per cent." adjustment is a mere convention, but as it is often used, it is well to show that the "representative" method adapts itself to the same without the slightest modification.

*Analytical Data.*—Materials to be used on above requirement.

| | Ore. | Iron flux. | Limestone. |
|---|---|---|---|
| Silica | 55.0 | 12.0 | 10.0 per cent. |
| Alumina | 3.0 | 3.0 | .... per cent. |
| Lime (CaO) | .... | .... | 50.0 per cent. |
| Iron | 9.1 | (FeO) 85.0 | .... per cent. |
| Lead | 19.0 | .... | .... per cent. |
| Zinc | 4.0 | .... | .... per cent. |
| Copper | 2.0 | .... | .... per cent. |
| Sulphur | 5.7 | .... | .... per cent. |
| Deficit (oxygen ?) | 2.2 (summation for ore = 100 per cent.) | | |

* The three mentioned can be brought in, in proper ratio, not the "accident."

Before calculating the slag let us "take out" the matte. Assuming the usual 100 lbs. (ore) as basis:

| | |
|---|---|
| $Cu_2S$ (Cu, 2 lbs., S, 0.5 lb.) | 2.5 lbs. |
| ZnS (Zn. 4 lbs., S, 2 lbs.) | 6.0 lbs. |
| FeS (Fe, 5.6 lbs., S, 3.2 lbs.) | 8.8 lbs. |
| Total matte | 17.3 lbs. |

The iron sulphide in this case is computed as follows. After taking out the copper and zinc sulphides, there remains 3.2 sulphur, which is calculated to its required iron on the formula FeS.

We now subtract the 5.6 iron from the total iron:

$9.1 - 5.6 = 3.5$ = iron to be computed into the slag.

This 3.5 iron is equivalent to 4.5 FeO, viz:

$$56 : 72 = 3.5 : 4.5 \text{ (Fe : FeO = Fe : FeO)}$$

Neglect the ash of the fuel in this case.

*Statement for Slag Computation.*— Let $100x$ = iron flux, $100y$ = limestone. We now get the usual expressions for silica, iron, and lime. We assume that the alumina and such other bases as may find their way into the slag are included in the 10 per cent. allowance, as already explained.

The conditions to be equated are:

$$SiO_2 : FeO = 30 : 40, \text{ or } 4 \times SiO_2 = 3 \times FeO \quad (1)$$
$$FeO = 2CaO \quad (2)$$

Tabulate all expressions for the constituents, and sum up:

| | Silica. | Iron oxide. | Lime. |
|---|---|---|---|
| Ore | 55.0 | 4.5 | ... |
| Iron flux | $12x$ | $76.5x$ | ... |
| Limestone | $10y$ | ... | $50y$ |
| Totals | $55 + 12x + 10y$ | $4.5 + 76.5x$ | $50y$ |

Equating according to conditions (1) and (2) as given above we have:

$$4\,(55 + 12x + 10y) = 3\,(4.5 + 76.5x) \quad (1)$$
$$4.5 + 76.5x = 2 \times 50y \quad (2)$$

These equations give us:

$x = 1.356$, or, $100x = 135.6$ *lbs. for iron flux*
$y = 1.082$, or, $100y = 108.2$ *lbs. for limestone*

*Check:*

$SiO_2 = 55 + 12x + 10y = 55 + 16.27 + 10.82 = 82.1$ lbs. $SiO_2$
$FeO = 4.5 + 76.5x = 4.5 + 103.73 = 108.2$ lbs. FeO
$CaO = 50y = 54.1$ lbs. CaO



We now find that:

$$82.1 : 108.2 : 54.1 = 30 : 40 : 20 \text{ (or } 3 : 4 : 2)$$

The conditions are therefore satisfied by the values found.

In practice it would be the aim to secure as the "iron-flux," an ore carrying "values." If an oxide ore could not be found, then a pyritous ore, roasted to ferric oxide, might be the available material.

The case is quite as good for an exercise as one of greater "probability."

(4) **Mixture of Ores for "Self-Fluxing."**—Three ores, supposed to be each obtainable in suitable quantities, are to be mixed so as to afford a slag of the following composition:

| | |
|---|---|
| Silica | 40 per cent. |
| Iron oxide | 30 per cent. |
| All other bases | 30 per cent. |

Analyses of the three are as below (per cent.):

| | I. | II. | III. |
|---|---|---|---|
| Silica | 50 | 10 | 20 |
| Iron oxide | 20 | 70 | 10 |
| All other bases | 10 | 5 | 40 |

None of these analyses give "summation" to 100. The deficits are supposed to include all elements which are reduced, volatilized, or enter the matte.

Assume 100 lbs. of "I" as basis for the mixture. Find weights of Nos. II and III required for the formation of the stated slag.

Let $100x$ = pounds of No. II. Let $100y$ = pounds of No. III.

Collect as usual the expressions for silica, iron-oxide and "bases."

| | $SiO_2$. | FeO. | Bases. |
|---|---|---|---|
| I | 50 | 20 | 10 |
| II | $10x$ | $70x$ | $5x$ |
| III | $20y$ | $10y$ | $40y$ |
| | $50+10x+20y$ | $20+70x+10y$ | $10+5x+40y$ |

We select as conditions to be equated, first, that silica is to iron-oxide as 40 is to 30 (or as 4 is to 3); second, that the iron-oxide equals all the other "bases" in weight.

$$3\,(50 + 10x + 20y) = 4\,(20 + 70x + 10y) \quad (1)$$
$$20 + 70x + 10y = 10 + 5x + 40y \quad (2)$$

Hence:

$x = 0.371$ or $100x = 37.1$ = lbs. of No. II in the mix.
$y = 1.137$ or $100y = 113.7$ = lbs. of No. III in the mix.

The mixture, then, will be:

| | |
|---|---|
| No. I | 100 lbs. |
| No. II | 37.1 lbs. |
| No. III | 113.7 lbs. |
| Total weight of charge | 250.8 lbs. |

*Proof:*

| | $SiO_2$. | FeO. | Bases. |
|---|---|---|---|
| I | 50.0 | 20.0 | 10.0 |
| II | 3.7 | 25.97 | 1.85 |
| III | 22.74 | 11.37 | 45.48 |
| Totals | 76.44 | 57.34 | 57.33 |

These totals are in the ratio 40 : 30 : 30, so that the proof is perfect.

(5) The following, with an *unnecessary condition of solution* annexed, is given to accustom the student to reasoning on the whole subject of ratios and excess. Afterward the same data are treated by the equation method, by way of contrast.

*Example.*—The ore contains 40 per cent. $SiO_2$, and no slagging bases.

Take in this case *1,000 lbs.* ore instead of the usual 100 lbs.

Iron-ore flux....... $SiO_2$ = 8 per cent.; FeO = 82 per cent.
Limestone......... $SiO_2$ = 5 per cent.; CaO = 53 per cent.

Required slag $(FeO)_2,SiO_2 + (CaO)_2,SiO_2$. That is, a singulo, with iron oxide and lime in equal *chemical* ratio.

The requirement of solution is, that two numbers showing the *relative* weights of these two fluxes must be first obtained, *without working out the analysis from the formula.*

The absolute weights are then to be deduced, using the $SiO_2$ of the main ore in doing so. The final weights serve of course for the deduction of the analysis, it being part of the condition that it is *only in this way that the analysis may be figured.*

*Solution* (1) Excess FeO in the iron flux.

$$60 : 144 = (5 : 12) = 8\,SiO_2 : 19.2\ FeO$$

Next, 82 − 19.2 = 62.8, which is excess of FeO in the iron flux in *terms of its own percentages.*

(2) Excess CaO in limestone.

$$60 : 112 = (15 : 28) = SiO_2, (5) : 2CaO, (9.33)$$

Then, 53 − 9.33 = 43.67 CaO excess in *terms of limestone percentage.*



(3) Find $SiO_2$ required by excess iron oxide, and $SiO_2$ required by excess lime, each in terms of percentages of respective fluxes.

(*a*) $144 : 60 = (12 : 5) = 2FeO, (62.8) : SiO_2, (26.17)$

which is $SiO_2$ required for the iron flux in terms of its own percentages.

(*b*) $112 : 60 = (28 : 15) = 2CaO, (43.67) : SiO_2, (23.39)$

which is $SiO_2$ required by limestone in terms of limestone percentages.

These two amounts of $SiO_2$, at present purely abstract, have to come from the main ore.

Call weight of iron flux $100x$, weight of limestone $100y$.

Evidently, since there is neither iron nor lime in the main ore:

$$82x : 53y = 72 : 56 = 9 : 7$$

Whence:

$$574x = 477y, \text{ otherwise } x : y = 477 : 574$$

These numbers, then, are the *relative* weights of iron flux and limestone. If they be respectively multiplied by their percentages of $SiO_2$ deficit we shall have two numbers, still abstract, denoting the *relative amounts of* $SiO_2$ to be taken from the main ore by the two fluxes.

Making these multiplications, we have for:

Iron flux...................... 477 × 26.167 = 12482+

and for:

Limestone..................... 574 × 23.391 = 13426+

Sum of products.......................... = 25908

It is evident that if we divide the total silica of the ore, 400 lbs., into 25,908 parts, the iron flux will take 12,482 and the limestone 13,426 of them. However, to bring decimals of pounds into their proper position we call the two numbers 124.82 and 134.26. Divide the 400 lbs. by the sum of products, which has now become 259.08; we get 1.5439 lbs. This is "*one part*" of silica. We now multiply it by the relative "demands" of the two fluxes.

| | |
|---|---|
| 1.5439 × 124.82 = for FeO......... | 192.709598 lbs. |
| 1.5439 × 134.26 = for CaO......... | 207.284014 lbs. |
| Total.......................... | 399.99+ or 400 lbs. |

Adjudicate back from these *actual* weights, as follows:

For CaO . 60 : 112 = (15 : 28) = 207.3 : 386.96 CaO
For FeO . 60 : 144 = ( 5 : 12) = 192.7 : 462.48 FeO

Divide the first of these results by .4367 we get limestone *886.9 lbs.* Divide second result by .628 we get iron-ore flux *736.4 lbs.* (These divisors are the original basic excesses already obtained.)

Proof will be worked out after the second solution is given by equation method. To this we now proceed.

*Solution* (*by equations*) *of the last problem.*

Same data and same requirements as above.

Iron-ore flux = $100x$. Limestone = $100y$.

Take ratios directly from formula, without reducing same to 100 per cent. basis. We get:

| | |
|---|---|
| $2SiO_2$ | 120 |
| $2FeO$ | 144 |
| $2CaO$ | 112 |

These numbers reduced to their lowest terms are as 15 : 18 : 14. Take as indicated by the method, the representations of the elements of the slag, and equate according to these ratios:

$$(400 + 8x + 5y) : 82x = 15 : 18 = 5 : 6 \qquad (1)$$

$$82x : 53y = 18 : 14 = 9 : 7 \qquad (2)$$

$$100x = 736. \qquad 100y = 886.$$

The case is wholly exceptional, as it would be rare indeed to find an ore with nothing but silica entering the slag.

*Proof.*—We take the original figures from solution first given:

| | |
|---|---|
| Actual charge. $SiO_2$ from 1,000 lbs. ore | 400.00 lbs. |
| $SiO_2$ 5 per cent. from 886.96 lbs. limestone | 44.345 lbs. |
| $SiO_2$ 8 per cent. from 736.4 lbs. iron flux | 58.912 lbs. |
| Total silica in actual charge | 503.257 lbs. |

Compare this with $SiO_2$ deduced by adjudication with bases:

| | |
|---|---|
| (CaO) 112 : 60 = 28 : 15 = 470.057 : | 251.81 lbs. |
| (FeO) 144 : 60 = 12 : 5 = 603.848 : | 251.60 lbs. |
| Total calculated silica | 503.41 lbs. |

Dropped decimals account for certain trivial discrepancies here and in the checking of the answers by the two methods.



As to the relation of FeO to CaO it should be as 72 : 56 = 9 : 7.

CaO in charge = 53 per cent. of 886.9 = ..... 470.057 lbs.
FeO in charge = 82 per cent. of 736.4 = ..... 603.848 lbs.
603.8 : 470 = 72 : 56 = 9 : 7. Q.E.D.

In spite of the fanciful restrictions laid upon the first solution, we recommend the student to master it. A hundred formal rules for the solutions of a hundred cases are not worth one fundamental principle. Considerations very similar to those used in this "fancy" case are not uncommonly required. Ratios and stoichiometric relations are easy, but it is only after "handling" them in every style that the student is prepared to meet any possible problem—and to meet it easily and correctly.

(6) The following somewhat elaborate example is a good case for the equation method. As will be seen it results in too large an addition of fluxing material, a fact that has nothing to do with the correctness of the operations in a mathematical sense.

We here apply all the "simplifications" exemplified, adding also ash of the fuel. The example, with its proof by assembly of all constituents, forms a general "type" case for similar problems.

Analyses of material, ore, fuel and fluxes. *The ash of the coke constitutes 12 per cent. of same.*

Ore charge, 1000 lbs.; coke (additional to ore), 150 lbs. Weights of iron ore flux and limestone to be found from conditions.*

| | Ore. | Ash of coke. | Iron ore flux. | Limestone. |
|---|---|---|---|---|
| $SiO_2$ | 56.00 | 70.00 | 6.00 | 4.00 |
| Fe | 22.00 | (FeO)20.00 | (FeO)81.00† | .... |
| Cu | 5.00 | .... | .... | .... |
| Mn | 2.00 | .... | .... | .... |
| As | .40 | .... | .... | .... |
| S | 4.00 | .... | .... | .... |
| CaO | 3.00 | 10.00 | .... | 48.16 |
| MgO | .... | .... | .... | 4.76 |
| $Al_2O_3$ | .... | .... | 4.00 | .... |
| Deficit (O, etc.) | 7.60 | .... | .... | .... |
| | 100.00 | 100.00 | 100.00 | |

* The usual 100 lbs. for basis of calculation is not adopted in this particular case. There is no especial reason for departing from our usage, except to show that in doing so we are making a little trouble for ourselves, also slightly increasing liability to error. For, in taking weights of constituents from ore analysis, we are apt to forget to multiply by ten.

† The $Fe_2O_3$ equals 90 per cent.

As the charge is one thousand lbs., the weight in pounds of any constituent is the percentage multiplied by ten. It will be convenient to calculate in lbs., so we start by putting the analysis of the coke ash in that shape. The coke being fifteen per cent. of the ore charge, weight of the ash is 18 lbs., viz:

| | |
|---|---|
| FeO | 3.60 lbs. |
| $SiO_2$ | 12.60 lbs. |
| CaO | 1.80 lbs. |
| | 18 lbs. |

This is presently to be added into the ore weights.

The $Al_2O_3$ of the iron flux is now put into the lime column, factor 1.65. Thus, $4 \times 1.65 = 6.6$ "conventional" lime coming from iron flux.

The MgO of the limestone is similarly treated. Thus, $4.76 \times 1.4 = 6.66$, and $48.16 + 6.66 = 54.82$, which is to be taken as the CaO figure from the limestone.

Next we put the ore into shape, taking out matte and speiss.

As these operations have been fully illustrated we here give results, to be verified by the student.

| | |
|---|---|
| Calculation for $Cu_2S$ gives | 62.5 lbs. |
| For FeS | 51.56 lbs. |
| For $Fe_5As$ | 18.93 lbs. |
| | 132.99 lbs. |

Or say 133 lbs. matte and speiss per charge. (This on the assumption that neither sulphur nor arsenic will be volatilized.)

Finally we put manganese and iron into the shape of their protoxides, and then add these together, the sum becoming the FeO of the ore. Again we give results only—*i.e.*, FeO, 232.71 lbs.; MnO, 25.82 lbs. To this is added the FeO from the coke ash, 3.60 lbs.

To the $SiO_2$ of the ore add 12.60 from coke ash. To its CaO add 1.8 from coke ash. The coke ash is now disposed of, and, like the matte and speiss, no longer enters into the calculation.

The revised analyses, omitting the elements just spoken of, now read:

| | Ore, lbs. | Iron flux, per cent. | Limestone, per cent. |
|---|---|---|---|
| $SiO_2$ | 572.6 | 6.00 | 4.00 |
| (Fe, Mn,) O | 262.13 | 81.00 | .... |
| CaO | 31.80 | 6.60 | 54.82 |



*Conditions.*—Mix for a singulo silicate slag, whose iron oxide shall be twice the lime (chemically), that is for formula:

$$(FeO)_4, (SiO_2)_2 + (CaO)_2, SiO_2$$

This formula reduces to an analysis showing $SiO_2$, 31+ per cent; FeO, 50+ per cent.; CaO, 19+ per cent.

To simplify the calculation, we take one per cent. from silica and add one to lime, making the ratios:

$$SiO_2 : FeO : CaO$$
$$3 : 5 : 2$$

The silica looks rather too low for safe running. But we have three facts that make for greater tractibility than the percentage might suggest. The first is that the weights of bases are *less than shown by the revised analyses*, since $Al_2O_3$ and MgO have been multiplied "to make lime of them." The second is that large iron percentage makes for fluidity. The third is that the slag is poly-basic (Fe, Mn, $Al_2O_3$, CaO, MgO); this also favors fusion.

The statement with the usual proviso: "iron flux = $100x$, and limestone = $100y$," is made as already exemplified.

$$2(572.6 + 6x + 4y) = 3(31.8 + 6.6x + 54.82y) \quad (1)$$
$$2(262.13 + 81x) = 5(31.8 + 6.6x + 54.82y) \quad (2)$$

(1) reads : "Silica is to lime as 3 : 2."
(2) reads : "Iron oxide is to lime as 5 : 2."

The solution gives: $x = 10.325$ and $y = 6.195$, or

*Iron ore flux 1032.5 lbs. and limestone 619.5 lbs.*

*Proof.*—Assemble all expressions for the three constituents. Multiply the literal expressions by values of $x$ or $y$, add and compare according to the condition

"$SiO_2 : FeO : CaO = 3 : 5 : 2$."

$$SiO_2 = 572.6 + 61.95 + 24.78 = 659.33 \text{ lbs.}$$
$$FeO = 262.13 + 836.325 = 1098.455 \text{ lbs.}$$
$$CaO = 31.80 + 68.45 + 339.610 = 439.555 \text{ lbs.}$$

Multiply $SiO_2$ by 2 and CaO by 3.

$$659.33 \times 2 = 1318.66 \qquad 439.555 \times 3 = 1318.66$$

Multiply $SiO_2$ by 5 and FeO by 3.

$$659.33 \times 5 = 3296.65 \qquad 1098.455 \times 3 = 3295.36$$