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CHEAPEST METHOD OF STEEL PRODUCTION

BY J. K. JAFRI

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INTRODUCTION

In Pakistan steel melting industry has not come in as a result of technological growth of steel melting process. Immediately after independence there were two electric arc furnacees left over by Makand Lal iron and steel works at Badami Bagh and the other one at Moghalpura. Total per shift production capacity of these two furnancees was less than ten tons. It was the first introduction of the steel melting industry in this country. It was easiest method of steel making and therefore it grew rapidly and now over .5 million tons of steel is made by this expensive method. In this process electrical energy is converted into heat by striking an arc in an electric furnace. In view of its simplicity involoving no technological knowledge of thermal chemistry metallurgy, no other process was adopted by the steel melters. Most of the steel melters are unaware of the fact that highly expensivefuel in the form of electricity is going waste. At present 700 to 1100 KWHs are consumed for the production of one ton of steel. Taking an average consumtion of 850 KWHs per ton, 500 million KWHs electricity is consumed.

In this paper melting pratice for the cheap production of steel is discussed which revolutionalized the steel industry in Europe and America and held the supreme position in the steel making industry for many decades since 1856 when Sir Henery Bessment made known to the world his process of converting iron into steel in a few minutes without the aid of external fuel. This process stood out quite distinctly from the other melting processes. The great importance of the revolution Bessemer made in the manufacture of steel could be appreciated on making a comparison between the output and costs of steel produced before introduction of Bes:emer Converter and subsequent production and costs levels achieved after the introduction of this practice.

The following particulars give some idea of the development of steel manufacture before introduction of Bassemer Converter and after its introduction. Output of Ingots in tons in the world during 1890 and 1910 is given below.

	1890	1910
U.S.A.	1,175,110	25,017,281
GERMANY	760,000	15,315,437

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U.K.	1205,382	6,010,084
FRANCE	384,026	3,361,517
RUSSIA	307,305	3,239,616

The principle of the process was wonderful and far-reaching discovery. In the beginning many types of convertors were used, having capacities ranging from a few cwt to several tons. Initially air was blown in for burning out the impurities in the molten pig iron. This process has advanced to such a level that it has taken the form of basic oxygen furnaces wherein oxygen is blown in at very high velocity for the elimination of impurities. In Pakistan, steel is manufactured by this method.

The Bessemir Converter Process:-

The outstanding features of this process are better appreciated by contrasting this process with other processes. All steel manufacture is based upon the elimination of certain metalloids from the molten iron by means of oxidation by the use of external fuel. This process differs from the other processes in carrying this into effect by means of exothermic reactions which raise the temperature without external fuel. As regards steel melting by electric arc furnaces is concerned, steel scrap is used whereas in Bessemer Convertor, steel scrap is used whereas in Bessemer Convertor Process molten iron straight from, the blast furnace or from cupolas is used. In this process rapid oxidation of the metalloids in the molten metal takes place, not because heat is applied from external source as is necessary in the other processes of steel manufacture but because of the enormous and extremely rapid generation of the internal heat due to the chemical actions and reactions produced by the principal heat giving elements in the molten pig iron under the influence of a volume of air passing through the metal at high pressure, without the assistance of any external heat whatsoever. The principal heat giving elements are silicon, manganese and carbon. Other elements such as phosphorus and Sulphur do not oxidize by the oxygen in the same way as silicon, manganese and carbon.

The oxidation of the silicon in the first stage of the process provides more heat than any of the other elements and consequently raises the temperatrue of the bath and makes possible the rapid conversion of the carbon at a later stage to CO_2 and Co. The manganese in the iron is also oxidized in the first stage as well as a portion of the iron and a very small amount of carbon. The order may be briefly stated as follows:-

1. The conversion of a large percentage of silicon to silicate of iron, together withthe oxidation of manganese, both of which form slags.
2. The carbon which has been slightly oxidized soon after the commencement of the blow, now passes off as CO_2 and Co at a gradually increasing rate, violent ebullitions taking place meanwhile during that part of the process known as the "boil".
3. The final period is confined almost entirely to the elimination of the carbon, the heat being most intense and carbon being burnt chiefly to CO.

These three periods are also defined by the colour and the form of the flame which issues from the mouth of converttor.

1. The issue of brown - flames accompanied with sparks, the lighting of the gases into a short flame and burning to a bright yellow and longer flame are the significant features.

2. The boil during which so much internal disturbance takes place, sometimes having large masses of slag from the vessel, is accompanied by a more intense and more luminous flame of varying length.
3. The carbon stage which is of, long or short duration according to the carbon left after the boil is over, is quite distinct from the two earlier stages. It is characterised by a clear long white flame tinged with blue, curbing the woolly form at the mouth of the convertor and having long, fork shaped tongues of fire several feet long. When the carbon is nearly exhausted, a pronounced "drop in the flame takes place and the flame becomes discoloured with fumes of iron oxide, the definite sign to turn down the vessel.

The Progress and duration of the Process:

The rate of oxidation of the impurities in the metal during the process is dependent upon at least three things:- Ist the analyses of the pig iron employed. Pig Iron produced in the world has very wide range of analysis. It contains from 2 to 4.5% carbon, 1 to 3 percent slilicon and .5 to 3 percent manganese. Sometimes Pig Iron charges with low silicon and low manganese are made. Such charges take nine to ten minutes for convertion to steel. Whereas pig iron charges with high silicon and low manganese take nearly 18 minutes for conversion to steel. 2nd important factor is temperature of the molten metal at the commencement of the blow and the third, the rate of production or the interval between each blow.

Comparison of heat requirement in electric arc and induction furnaces and convertor process:-

Electric Furnaces: In Pakistan electric consumption varies beteen 700 KWH to 1100 KWH/850 KWHs may be taken as an average consumption of electricity per ton of molten steel.

1 KWH is equivalent to 3412 British Thermal units. As such per ton molten steel requirement of electric furnaces is 850x3412 = 2900 200 B.Th.u.

Molten Metal Direct from Blast Furnace

When the molten metal is taken directly from the blast furnace, no external heat is required for the conversion of pig iron to steel. Oxidation of carbon, manganese and silicon under the air causes extremely rapid generation of internal heat. In case silicon content is high and sulphur and phosphorus are low converter with acid lining is used. Where silicon content is low and sulphur and phosphorus are to be eliminated, converter with basic lining is used. Basic and acid lined converters differ principally one from the other in the kind of lining used. In the design, general arrangement and mechanical features, these two kinds of converter plants are not necessarily unlike each other. The basic lined converter is usually larger than the acid-lined converter of the same capacity, to allow for the use of lime and oxides, but without exception both plants can be made practically identical.

Molten Metal From the Cupolas.

The locality and situation of most of the iron and steel works, make it necessary to use cupola for melting pig iron, which is subsequently used in converter for the elimination of impurities. Properly designed and well operated cupolas influence the cost of steel manufacture. In Pakistan most of the cupolas are not properly designed and therefore fuel to metal ratio is uneconomical. As the cost of melting pig iron in cupola has a great influence on the cost factor of steel, therefore heat balance calculations of melting in a cupola are given in detail. Heat balance of O size cupola.

Coke (90%C) burned per Hr	= 220 lbs.
Average Co2 in effluent gases	= 13%
Carbon burned = 220x0.90	= 198
Average tapping temp at spout	= 1455 C or 2650° F
Blast pressure	= 8 oz
Temperature of waste gases	= 800°F

Theoratical Heat input

Wt of coke 220	= 220 lbs
Carbon (fixed) in coke 220x.9	= 198.0 lbs
Heat in burning 11b carbon to Co_2	= 14550 B.Th.U.
Total Calorific value 198x14550	= 2880900 B.Th.U.

Actual Heat developed:

a) Analysis of effluent gas

Co_2 by the actual analysis	= 13.0%
Co	= 13.2%
N_2	= 73.8%
Total	- 100%

b) Fraction of 11bc durned to Co_2 and Co

C to Co_2	= 0.4961 lbs
C to Co	= 0.504 lbs

c) Heat developed and combustion of 1 lbc

C to Co_2 .496x14550	= 7217 Btu
C to Co = .504x4350	= 2192 Btu
Total = 9409 Btu	
Total Heat developed Co_2	= 198x7217 = 1428966
Co	= 198x2192 = 434016
Grand Total	= 1862982

Heat developed by oxidation of silicon Manganese and heat absorbed in decomposition of CaCo3 are not accountd for to simplify the calculations.

Heat disposition:-

In solid state wt of iron melted per hr.	= 2204 lbs
Temp of iron charged	= 62°F
Melting Range	= 2150°F
Temp difference	= 2088°F
SP heat of iron (60 to 2150oF)	= .166 Btu/1 b/F
	= 2204x166x2088= 7639
During Melting:-	
Heat of fusion	= 41.4 Btu per lb
Heat absorbed	= 2204x41.4 = 91246
In liquid state:-	
Maxm temp	= 2650 ° F i.e. at spout
Melting Range	= 2150°F
Diff	= 500° F
Heat absorbed	= 2204 x .23 x 500 = 263460 BTU

Total Heat absorbed by iron 763924+91246+263460 = 1118630 The balance heat is absorbed in decomposition of lime, formation of slag, absorption by the moisture in the blast, sensible heat carried by effluent gases and conductive and radiation losses. For calculation purposes we have to take inside temp which is 50°F higher than the spout temp. The heat requirement on account of the above is another 21346 BTU

Total heat absorbed	= 1118630+21346 = 1139976
Thermal	= 1139976 = 39.57 %
	2880900

Thermal efficiency in case of melting in electric are furnaces = 25x60 = 15%

25% is of electric generation and 60% is of electric are furnaces, but in Pakistan in most of the cases it is lower than 60%

Comparison of energy consumption in both the cases can be made as follows:-

Total energy consumption for melting one ton steel in converter = 2880900

and in electric arc assuming 30% electric generation afficiency

= 850x3412x100/30 = 9600666

Obviously energy utilized in electric are furnaces is more than three times the energy demand of converter.

Comparison of the equipment required for convertor plant and equipment required for

electric are furnaces or induction furnaces.

The items for convertor plant are as follows:-

2- Ton convertors	2
Cupolas	2
High pressure blower	1
Low pressure blower	2
Electric Hoist	1
Weight bridge for raw materials	1
Weighing machine for weighing molten metal	1
5-ton overhead crane	1
3 ton laddles	5

One small heating furnace.
One coke fired crucible melting furnace with three 2 pot holes.
crucibles 3
Total output of the liquid steel 7500/Annum

Equipment for 5 Tons electric are furnaces.

5 Ton electric are furnaces	2
20 / Ton electric Cranes	2
15 Ton electric cranes	2
Laboratory equipment for determination of C,S,P, Mn. silicon	
Weighing machine for weighing alloys	1
charging buckets	3 Nos.
10 ton laddles	3 Nos.
Ingot Moulds	42 moulds/Heat
Temperature measuring thermo-cuples	2 Nos.
Transformers	2 Nos.
Complete equipment for hydraulic system	2 sets
3 Electrode grophite or amorphous carbon	14 lbs/Ton
Total production of liquid steel per year	= 7500 Tons

Labour comparison of the two systems.

Labour on Bessemer Convertor System

Convertors Convertor men	2
Cupola attendant	1
Cupola charger	1
cupola charge wheeler	4
electrician	1
Patching repair of	3
crucibles	1
Mason	1 + 2

Crane operator	2 + 2 Helpers
Foreman	1
Pitman	4

Labour on electric are system per shift

Melter	4 trained 2 helpers/shift
charger	3 Nos
Crane dirver	7 No + 6 slingman
Mason	2
Helper	2+2 per shift
Electrician	3
Pit men	9
Scrap Handling	15
Chemist	3
Lab assistant	3
Ladle man	1 Helper 1

From the above it becomes clear that manufacture of structural steel for building industry by converter process is cheaper as compared with the electric process.

In view of this fact details for conducting this process are given for the use of steel melters in Pakistan for cheap production of steel. Side blown and bottom blown are two types of converters in use for steel melting each one of them is split into the acid process and the basic process.

Side blown Converter

General Design of Converter

Side blown converters vary in size but are generally about 2 tons capacity. Frequently they are provided with two rows of tuyeres, which can be operated independently. This double row of tuyeres assists in production of a higher percentage of carbon dioxide in the gases issuing from the conveter thereby raising the temperature of the metal.

The general design of a side blown converter is shown in Fig I, converter is mounted on pedestals with roller bearings, arranged with tipping gear operated by electric motor and with hand turning gear.

In the true surface blown convertor or side blown converter the blast is admitted through tuyres to one side of the converter.These tuyers are either above or at the surface of the metallic bath. Usually they are just above the level of the bath and are arranged in the shape of a fan, so that the blast is evenly distributed over the whole of the converter.

Owing to the acidic nature of the normal charge these converters are lined with acid materials. Three types of lining can be employed.

1) Silica rock or ganister which can be rammed around a suitable former. A lining of

this type will frequently give a life of 100 to 120 heats, although in some cases as many as 230 heats have been obtained. With lining of this type the tuyers may either take the form of specially shaped tuyer bricks of the tuyers may be rammed by means of formers. In most cases these ramed linings are backed with a 41/2 in layer or brick work.

2) A similar type of lining may be prepared by employing a mixture of sand and fireclay in which case the fireclay acts as a bond to the more refractory sand.

3) The more modern method is to line the converter with high grade silica bricks. When a brick lining is employed, the layers are invariably formed of specially shaped bricks.

The lining usually requires some patching after each heat. Athough in many plants, the converter is operated for 7 to 12 heats after which repairs to the lining are made.

The chief erosion occurs in the vicinity of the Tuyers and in order to facilitate repairs to this portion, drop bottom converters are designed.

Converter Practice:

The molten metal is transferred from cupolas to the converter at 1350°c. The blast is commenced and the vessel is rotated into a vertical position. At first there is very low flame. After 3 to 5 Min the silicon and some of the manganese having been removed, the flame lengthens and grows in luminousity due to carbon elemination. After about 14 to 16 min the flame drops, indicating the end of decarburization.

1. During the early stages of the blow, an execssive temperature due to high silicon content of the original metal may result in early elimination of carbon before the silicon is eliminated. The carbon flame appears and drops in a normal manner, but the blown metal contains a high residual silicon which makes the steel unserviceable. This excessive temperature may be corrected by turning the convertor down after a few minutes blowing, and making a cold scrap addition before proceeding with the blow.

Rate of oxidation of Silicon, Manganese and Carbon.

The heat absorbed and evolved by the chemical reactions during the removal of carbon, silicon and manganese can be calculated approximately only. Heat input is heat in the molten metal, heat of oxidation and heat of slag formation. Heat of oxidation is 60 to 65% of the total heat input. Heat expended is heat lost in gases, heat in the molten slag, heat lost by radiation and heat in the finished steel. Heat in the finished steel is 40 to 45% of the total heat expended. The balance of heat after deducting all losses is such as to raise the temperature of the bath several hundred degrees centrigrade during the conversion of one charge of metal.

Graphic representation of two types of metals one low in silicon content and the other high in silicon content is shown in fig 2 and fig 3.

The low silicon charge cycle is completed in 9 min 10 see, because silicon content is only 0.94

percent in the charge. The temperature of the metal at the commencement of the charge is not given for either of the figures shown above, but this has an important bearing on the rate at which the impurities are removed. If the temperature is lower than usual, it may be a few minutes before any appreciable amount of silicon is removed and little if any carbon, the iron meanwhile being oxidised. On the other hand, when the temperature is high, the silicon rapidly oxidised,. It has been found that when the temperature of the metal is very high, the carbon is attacked before the silicon, leaving a silicious steel as the result of the blow.

Reaction in the Converter.

In the normal blown convertor practice the reactions taking place can be divided into three stages.

1. When the blast impingas on the surface of the metal a layer of iron oxide is formed. Some silicon and manganese may be oxidized at this stage and their oxides combine with the iron oxide to form a ferrous-manganous silicate slag. The slags formed initially however are chiefly Fco.

2. When the surface of the metal is completely covered with slag, the oxidation of the silicon and Manganese is accelerated. The oxidation of these elements is essentially a slag/metal reaction and is similar to those reactions which occur in the acid open hearth furnace.

3. When the silicon had been removed or very largely removed, the elemination of carbon becomes rapid. The temperature increases very rapidly at this stage.

The oxidation of carbon by the FcO or other oxides in the slag results in the formation of carbon oxide at the bath level. This carbon oxide is converted to carbon dioxide by the excess of air within the converter. This feature is the essential difference between the bottom and side blown convertor practice. In the bottom blown converter all the blast passes through the metal and all the oxygen is absorbed.

In normal side blown convertor practice, it is necessary to have sufficient silicon in the molten metal supplied to the vessel to raise the temperature of the metal to 1400°c before satisfactory elimination of carbon . When the metal has attained this temperature carbon elimination proceeds rapidly.

The Oil-Fired, Side blown Converetr.

The general design is identical to normal side blown converter. Its main feature is that it is also designed to melt the charge by means of burners. During charging and melting, the converter is turned down into a horizontal position and oil burners are introduced through the blowing layers. The nose of the converters is turned towards an air heater which consists of a series of cast iron pipes contained in firebrick structure. The air required for burning the oil is supplied preheated through this heater at a pressure of 3/4 lb per sq in. The gases issuing from the converter are drawn through this heater by chimney draught. The oil is delivered to the converter at a pressure of 30 to 33 lb pe sq in.

When the solid charge is melted, the oil burners and pipes are withdrawn, the vessel is turned up and the blowing operation conducted in the usual manner. The blast pressure normally employed is 2 to 4 1/2 lb pe sq in.

The chief advantage of this type of converter appears to be the fact that it dispenses with the need for the cupolas for melting the solid charge and provides a finished steel.

Dephosphatization and Desulpherization

For the elimination of phosporus and sulphur, the slag should be highly basic and basic converter are used for this purpose. Phosphorus oxide can be fixed and retained in a basic slag but not in acid slag and the basic Bessemer process will remove phosphorus. The phosphorus does not oxidize until the Manganese, silicon and carbon are all gone and it oxidises during the after blow

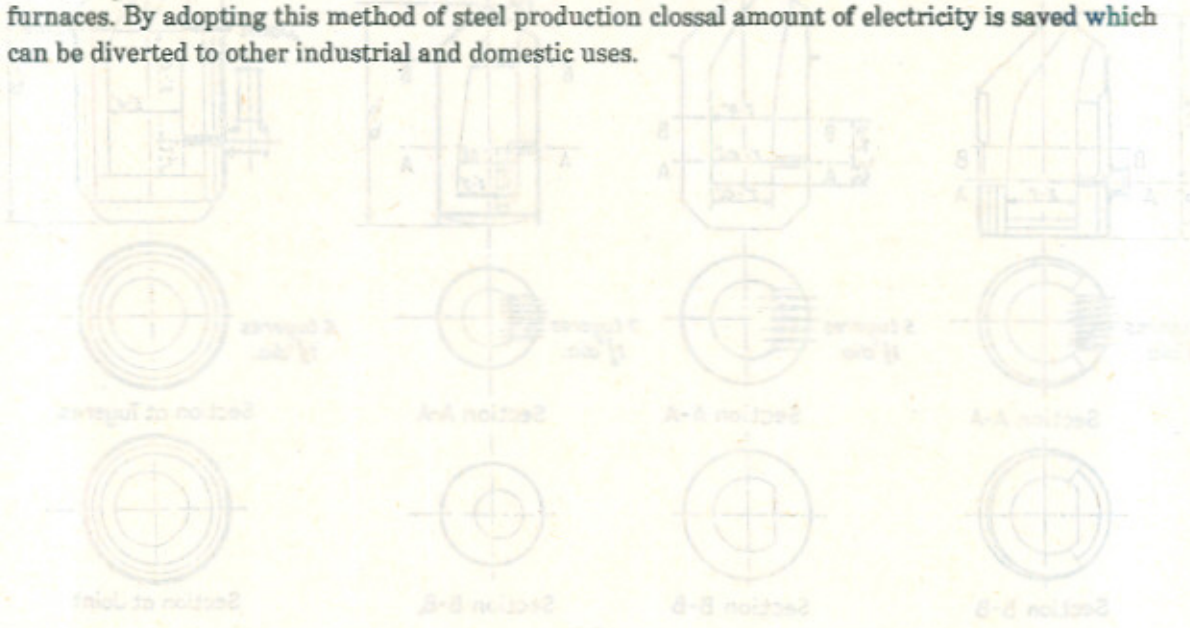
$$4P + 5O_2 = 2P_2O_5 + 82{,}000 \text{ cal}$$
$$P_2O_5 + 3CaO = Ca_3(PO_4)_2$$

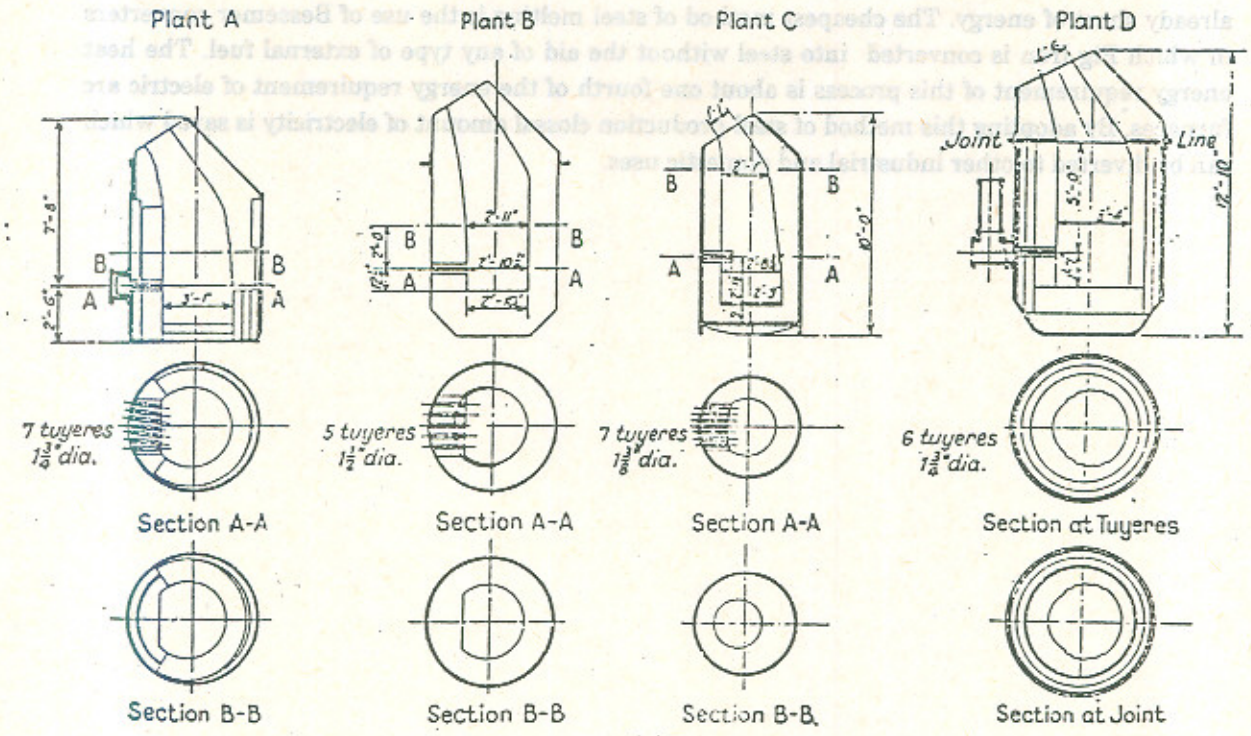
The first reaction adds heat to the bath but the reaction goes on inspite of the high temperature because the carbon had been removed. The after blow is a short blowing period after carbon flare had dropped. Lime is added with the charge to insure a very basic slag and the phosphorus is fixed as a calcium phosphate. The end of the blow should be carefully regulated.

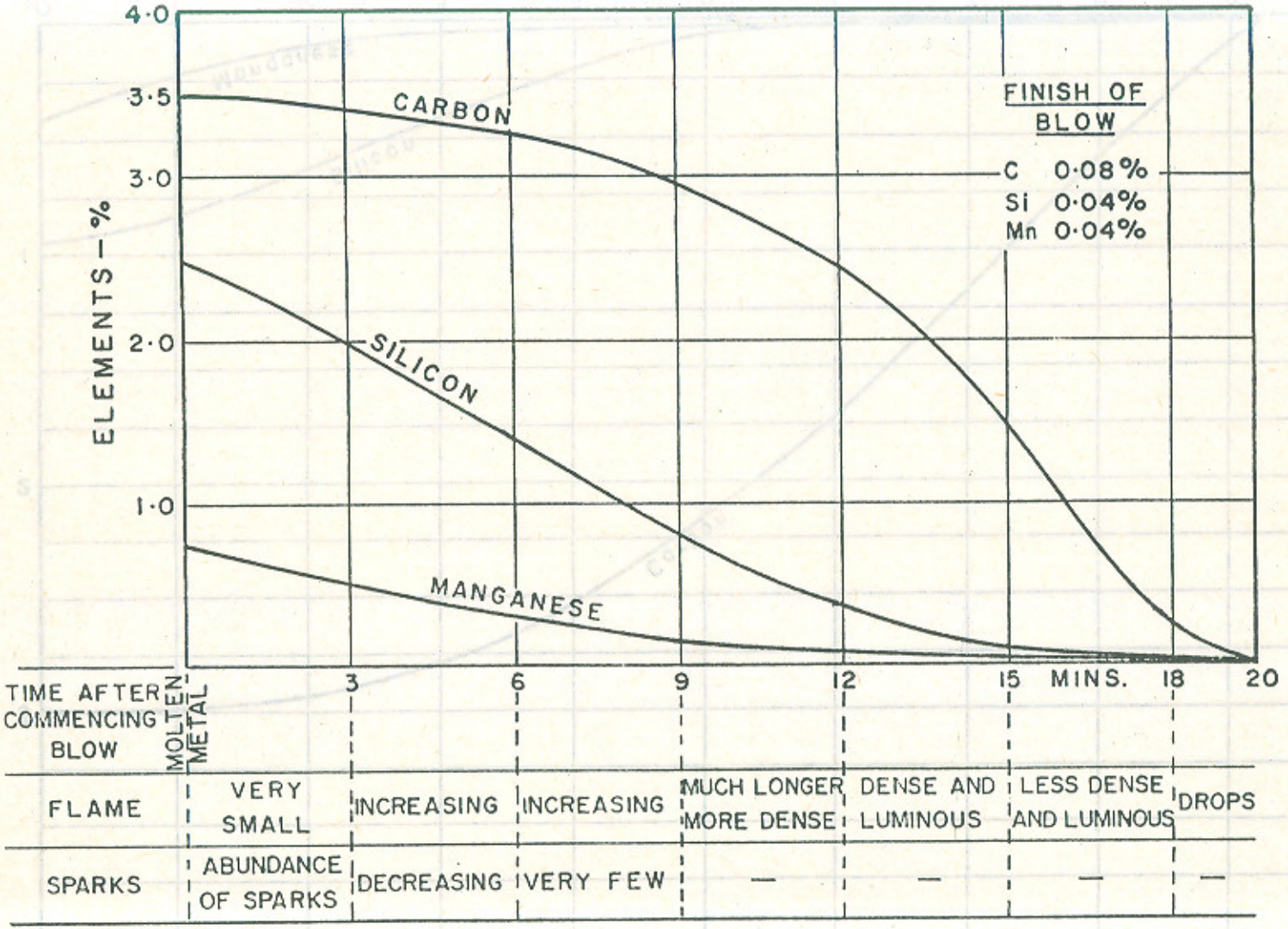
For sulphur elimination it is essential that the slag should be rich in lime and its elimination is enhanced by the presence of carbon. The presence of Manganese also accelerate the removal of sulphur. Manganese reduces the FcO concentration and thereby favours the formation of CaS.

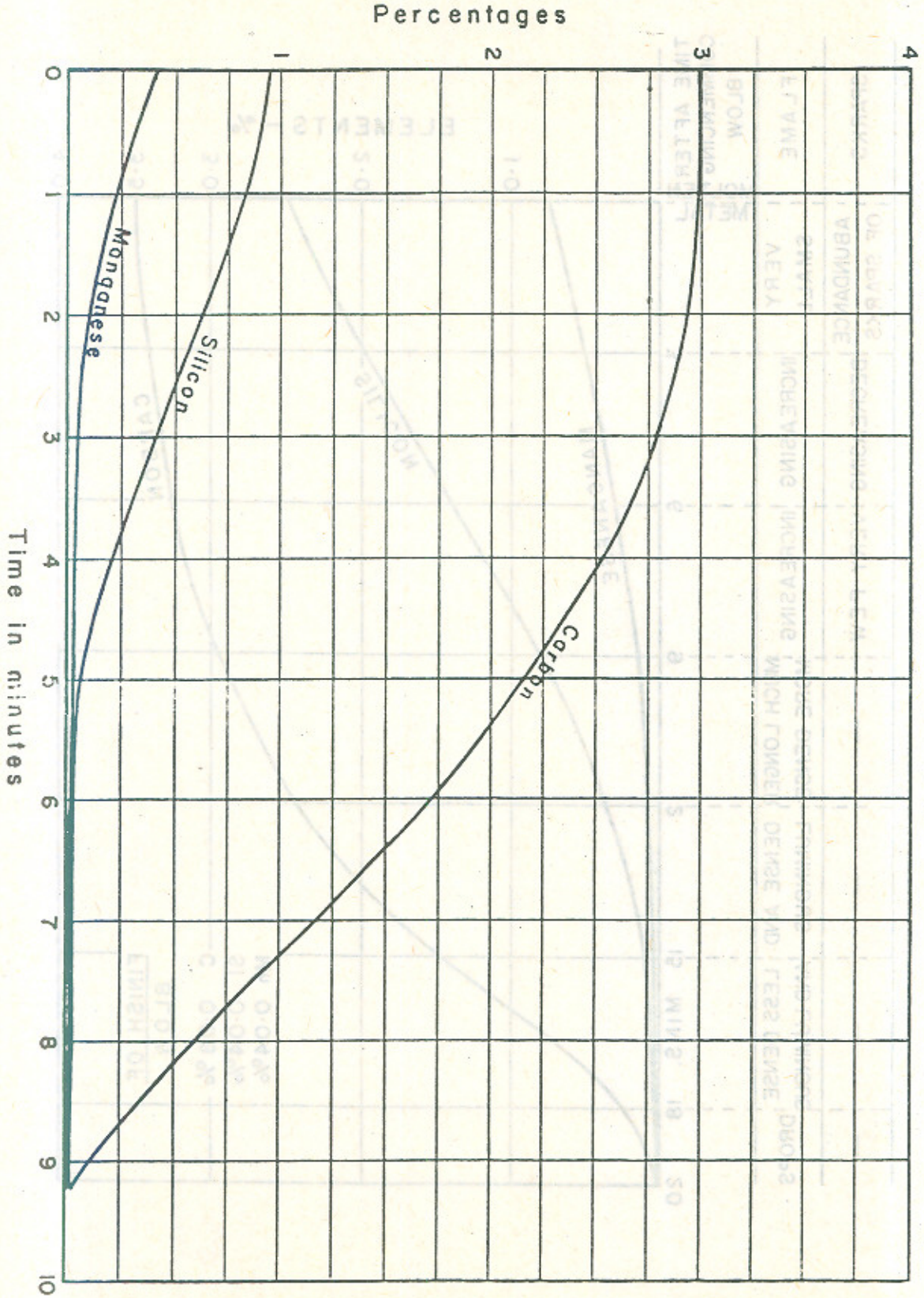
Conclusion

The use of electricity as fuel for melting steel is most uneconomical in a country which is already short of energy. The cheapest method of steel melting is the use of Bessemer converters in which Pig Iron is converted into steel without the aid of any type of external fuel. The heat energy requirement of this process is about one fourth of the energy requirement of electric arc furnaces. By adopting this method of steel production clossal amount of electricity is saved which can be diverted to other industrial and domestic uses.




Plant A
Plant B
Plant C
Plant D
Joint Line
7 tuyeres 1 3/8" dia.
5 tuyeres 1 1/2" dia.
7 tuyeres 1 3/8" dia.
6 tuyeres 1 3/4" dia.
Section A-A
Section A-A
Section A-A
Section at Tuyeres
Section B-B
Section B-B
Section B-B
Section at Joint


4·0
3·5
3·0
2·0
1·0
ELEMENTS — %
CARBON
SILICON
MANGANESE
FINISH OF BLOW
C 0·08%
Si 0·04%
Mn 0·04%
TIME AFTER COMMENCING BLOW
MOLTEN METAL
3
6
9
12
15 MINS.
18
20
FLAME
VERY SMALL
INCREASING
INCREASING
MUCH LONGER MORE DENSE
DENSE AND LUMINOUS
LESS DENSE AND LUMINOUS
DROPS
SPARKS
ABUNDANCE OF SPARKS
DECREASING
VERY FEW
—
—
—
—


Percentages
1
2
3
4
0
1
2
3
4
5
6
7
8
9
10
Time in minutes
Manganese
Silicon
Carbon