Refractories for electric arc furnace

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Introduction

Since the first commercial application for steelmaking in 1903, Electric Arc Furnace has been considered as a versatile equipment for production of Steel. It was initially caused for making high quality steels e.g. Stainless steel etc. with high cost of production. However, with the development in the engineering and technology after World War-II, cost of production through this route has become very competitive and production through this route started growing constantly. The annual growth rate has been indicated as 2.5 - 3% currently and a world production level of around a billion tone is expected by the turn of the century. The increase in the share of EAF steelmaking process has been made possible because of introduction of furnaces with large capacity, availability of power at a comparatively lower rate and also the change in process technology which has allowed to use various types of input material. However, with high power rating in the furnaces, the conditions towards the refractory became very severe. Continuous development in Refractories technology as well as in the process engineering, specific consumption of refractories gradually came down. Further in many areas, use of refractories materials have been replaced or minimised with the introduction of water cooled panels.

In fact, a modern electric arc furnace is having around 85% of roof and 70% of side walls lined with water cooled panels. Thus, the specific refractory consumption has come down considerably and has been reported to be around 2 kg/ton of steel against 10-12 kg without any water cooled panel.

The reduction in the refractory consumption has been made possible by the development and use of high quality refractories with precise control in various properties, design modification and also by changing the process parameters for making them more compatible with the refractories. The various technical innovations which have helped in reducing the refractory consumption are as follows :

1. Introduction of LF in reducing the thermal loaded in EAF
2. Application of water cooled panels
3. Introduction of E.B.T system for reducing the thermal fluctuations
4. Introduction of DC furnace in eliminating hot spots

However, for introducing the above changes, special refractories also have to be developed which has been reviewed in this communication.

Feature of an electric arc furnace

Though the capacity of electric arc furnace vary from 5 tonnes to 400 tonnes, the shape of an arc furnace is typically having a circular shallow bath with a dish shaped bottom with cylindrical side walls and dome shaped roof with circular openings for introducing the electrodes, fume extraction etc. The charging was located suitably and the metal was tapped through tap hole. Since the service condition of various areas are different which requires different types of refractory materials to be used, the furnaces can be divided into various parts e.g. roof, side wall, hearth, tap hole.

Roof :

The roof of the arc furnace is one of the most affected portion as it is subjected to all kind of stresses, e.g. thermal, chemical and mechanical. The roof is exposed to very high tempeature often exceeding 1700°C. It is also exposed to corrosive action of slag and metal oxides, specially iron oxide fumes which is deleterious towards the refractories. Since the design is also complicated because of the openings of the electrodes etc. it is subjected to considerable mechanical stresses.

The problem has been tackled in two ways (a) by improving the quality of refractories, (b) by changes in the design of laying.

Conventionally, for many years Silica Bricks were used in the EAF roof which however could not fulfil the requirements with the changed severe environments. High alumina materials (up to 95% Al_2O_3) replaced silica bricks and later on basis bricks - direct bonded and chemically bonded Mag-carbon bricks have also been used (Table-1).

Initially, only shaped bricks were used which however got to be changed because of manufacturing difficulties and higher cost. The delta section was tried with monolithic material, both ramming masses and castables have been used. Later pre-fabricated shapes have also been used (Fig.1A & 1B).

Wear of roof refractories was mainly due to spalling because of thermal fluctuation and corrosion due to low melting liquid formation. Absorption of slag and iron oxide fumes alters the chemistry of the bricks and results in low melting liquid formation. The phase assemblages as can be found from the phase diagrammes indicate the probable path of reactions (Fig 4&5).

Initially the roof frame which was used for the support of roof refractories was having water cooling arrangement. Water cooling was extended to the other openings in the roof by providing water cooling rings. Later almost the entire roof is constructed with water cooling panels. Currently, almost all the roofs are constructed in the same way with a thin protective layer of refractory material gunned over it and monolithics used in the delta portion (Fig.2).

Side Walls

The side walls of an electric furnace are subjected to severe thermal shock corrosive slag action and mechanical abuse during charging etc. It can be classified in three different zones e.g. slag zone, roof drip zone and zones of hot spots. However, the most severe condition is existing in the hot spot area where it is exposed to very high temperature from the arc as well as it gets corroded with the slag. The main causes of hot spots are :

a) Radiation from arc flames
b) Arc position and blow out
c) Reflected heat from bath surface
d) Duration of power input
e) Absence of protecting over from radiations by charged scrap etc.

Various types of refractories e.g. Dolomite, Magnesite, high purity magnesite, direct bonded basis bricks with or without tar impregnation and fusion cast blocks have been used in the construction of side walls.

Attempts have also been made to contain the hot spot by suitably altering the process parameters e.g. 1) balancing the increased arc power of central electrode by adding reactance. 2) operating the furnace under positive pressure by which shielding of arc by fumes and smoke is effected. 3) Controlling the arc length i.e. operating with shorter length. 4) Controlling the arc flames to be directed away from the wall by deep slag process etc. However, most effective way was to use a highly conductive material in the lining so that heat is dissipated away fast. This coupled with water cooling to enhance the heat dissipation has helped in prolonging the side wall life. Thus Mag-carbon bricks with 10-15% carbon (Table-2) completed with water cooling arrangement has become almost universally accepted mode of lining (Fig.3)

Bottom/Hearth

The hearth or bottom of electric furnace actually acts as a receptacle of the liquid metal and slag. It has to withstand very arduous service condition like high temperature, slag and metal corrosion, mechanical abuse during charging, thermal stresses due to fluctuation in tempeature before and after tapping etc. In the conventional tilting type furnaces lot of structural stresses are also induced during tapping when the maximum tilt is effected.

Normally the bottom hearth is divided into two sections viz. subsequently and working hearth or bottom. The sub-hearth is constructed with few layers of high fired magnesite bricks along with a fire bricks lining against the shell for thermal insulation. The working hearth is made by ramming with either dolomite or magnesite suitably graded to provide a monolithic, joint free surface. With the use of high purity magnesite ramming mass the life of hearth could be increased considerably. The thickness of the working hearth is normally around 250-300 mm, which used to be replaced after about 5000 - 10000 heats depending upon the size of the furnace and operating parameters.

Initially the ramming materials used to be mixed with water and then rammed into position. However, currently dry ramming materials have been developed which do not require any water. Such material can be suitable graded to give maximum packing density when put in position. It requires either ramming or vibration with a vibrator. This has an advantage as no drying time is lost and sintered layer thickness can be precisely controlled.

Considerable change have taken place after the introduction of gas stirring (Fig.7) through the bottom and EBT system (Fig.6) for draining out the furnace.

Permeable blocks or porous refractory elements are introduced through the bottom for introducing inert gases for stirring the bath which helps in faster melting and refining of liquid metal thus increasing the productivity. The injection of injection of oxygen and natural gas through the hearth also has been found beneficial for reducing the electrical energy consumption (Fig.3).

One or more such porous elements can be fixed at the bottom. Radix DRP system has a well block surrounding the porous plug made of resin bonded mix of graphite, fused magnesia grains and metal powders used as anti-oxidant. Such a plug can be used up to 300 heats.

Further, development of this idea has taken place which is known as Thyseen-long time stirrer (TLS) system. In this system the gas introduced through tuyer brick containing single steel pipe which discharges the gas in the permeable hearth and the effecting the stirring at a very low flow velocity. This system requires to use a specially developed hearth material which has a very thin sintered layer and provides the mechanical stability whereas it is permeable at the same time to allow the inert gases to flow through it for stirring action.

Such system offers the following advantages :

a) Long life time of the stirring elements.
b) Flexibility of gas injection during operation
c) Cooling of hearth with reduction in consumption of refractories

Eccentic bottom tapping system (EBI)

Conventionally, the furnace required tilting during tapping for proper evacuation of liquid metal. However, this mode of tapping was posing problem as considerable thermal stresses with consequent spalling used to occur during this operation, also tap hole maintenance required additional time which obviously was affecting the productivity.

Eccentric bottom tapping system, in which the tap hole is provided at the bottom eccentrically and made with specially designed blocks which can be opened and closed through a lever was found to be very useful and did not require any tilting. Introduction of this system has resulted in eliminating the problems and helped in reducing the consumption of refractories (Table 3).

D.C. furnace

Electric arc furnace with direct current (DC) operation has become popular in the recent days mainly because of its lower electrode consumption, stability of the arc, lower noise generation etc. In this furnace only one electrode is required to be located centrally which acts as a cathode and the anode is connected to a contact in the bottom of the furnace, for this either a conductive refractory bottom or metallic elements embedded in the bottom may be used. Electrical conductivity of the bottom thus has become a very important property in such furnace. Hence, it is necessary to develop a suitable material or lining method for fulfilling the above needs.

Conductive refractories material to be used at the centre of the bottom to act as anode requires to process:

a) Low electrical resistance (20.5m ohms)
b) Lower thermal conductivity
c) High wear resistance.

The central position is normally made with pretreated Mag-carbon bricks over which bonded magnesia ramming mass with carbon content of 5-10% are used. The pretreated bricks contain about 10-14% of carbon by weight.

Other ways of making DC Arc furnace bottoms are :

a) to provide billet electrodes
b) use of multiple pins (25-50 mm Dia)
c) use of steel fines (1.7mm)

Magnesia ramming mass is provided for fixing the specially designed metallic components (Fig. 8-11).

Maintenance

Effective maintenance is required during the operation for prolonging the life and reducing the refractories cost, gunning maintenace of heart and side wall is practised for a long time. Currently with the use of water cooled panels the use of gunniting materials have increased as it provides a protection layer over the panels and prolong their lives. Injection of dolomite as a slag conditioner has also been reported to be effective for increasing the life.

Summary

The total requirement of refractory material for electric arc furnaces operation is gradually coming down due to the successful use of water cooling panels. However, with the severe conditions existing in a modern electric arc furnace, it is necessary to use high purity materials with tailor made properties to suit the exact service conditions.

Reference

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3. DC arc furnace, general overview of the refractory configuration, Claus Braunhuber *et. al.*, Elec. Fce. Prod, vol. 151, pp. 333-339.
4. A new generation of prefabricated refractories and their use in steel ladles and E.A.F., H. Hoffgen et. al. Uinter'91, pp. 165-172.
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Table-1 : Typical properties of roof bricks from unburnt materials[2]

	High alumina bricks			Basic brick	High alumina precast		
	A	B	C	D	E	F	G
Apparent specific gravity	3.40	3.62	3.66	3.47	3.14	3.09	3.65
Bulk density ($gm.cm^3$)	2.73	3.02	3.18	3.05	2.77	2.69	3.15
Apparent porosity (%)	19.9	16.8	13.1	12.1	14.0	12.9	13.7
Cold crushing strength ($kg.cm^2$)	340	770	780	870	340	400	500
Refractoriness (SK)	≥ 37	≥ 37	≥ 38	-	≥ 37	≥ 38	≥ 38
Thermal expansion (%) 1500°C	1.75	0.45	1.27	1.89	1.16	1.35	1.62
Refractories under load (T_2(°C) 2 kg cm^2	≥ 1550	≥ 1650	≥ 1700	≥ 1600	≥ 1550	≥ 1600	≥ 1700
Chemical composition (%)							
SiO_2	15.7	20.3	7.0	4.2	24.5	20.9	0.3
Al_2O_3	78.3	76.2	82.1	11.5	68.8	75.7	86.4
MgO	-	-	-	63.1	-	-	9.2
Cr_2O_3	-	2.0	9.9	11.5	-	-	-
Application	Outer ring roof	Outer ring roof top roof	Top roof	Outer ring roof top roof	Top roof	Top roof Dust collector hole	Dust collector hole
Kind	Alu-mina	Syn-thetic alumina	Syn-thetic alumina	MgO chrome	Alumina	Synthetic mullite	Sintered alumina

Table -2 : Trypical properties of wall refractories for electric arc furnace(2)

	Unburnt MgO-C brick				$MgO\text{-}Cr_2O_3$ direct bond	
	K	L	M	N	O	P
Apparent specific gravity	3.06	3.09	2.95	2.81	3.75	3.78
Bulk density (gm.cm^3)	2.98	2.99	2.83	2.72	3.25	3.27
Apparent porosity (%)	2.5	3.3	3.9	3.2	13.4	13.4
Cold crushing strength (kg.cm^2)	448	507	352	270	883	953
Modulus of rupture(kg cm$^{2)}$ at 1400°C	45	146	42	46	114	127
Chemical composition (%)						
SiO_2	-	-	-	-	1.2	1.5
MgO	83.6	86.7	72.9	62.7	61.9	64.7
Cr_2O_3	-	-	-	-	20.0	19.8
FC	14.8	9.5	24.4	34.2	-	-
Application	Hot spot tapping hole	Hot spot tapping hole	Hot spot	Hot spot	Slag line tapping hole	Slag line tapping hole
Kind	Unburnt low carbon type	Unburnt low carbon type	Unburnt high carbon type	Unburnt high carbon type	High temp. burnt brick	High tem. burnt brick

Table -3 : Properties of wall refractory around taphole of EBT[2]

	MgO	Al2O3-SiC-C	MgO	$MgO\text{-}Cr_2O_3$ stamp material
	Tube	Terminal	Sleeve	Bottom and round tube
Bulk density ($gm.cm^3$)	2.85	2.98	3.00	>2.85(1700°C C/3 hrs)
Cold crushing strength ($kg.cm^2$)	390	600	872	>400 (-do-)
Modulus of rupture($kg\ cm^{2)}$	150	180	-	>100 (-do-)
Chemical composition (%)				
SiO_2	-	-	4.1	2.5
SiC	-	9.0	-	-
Al_2O_3	-	74.8	-	-
MgO	75.0	12.78	93.4	95.0
FC	18.5	-	-	
Refractories (SK)	> 40	>38	>38	
Apparent posority (%)	3.8	9.1	9.0	
Apparent specific gravity	2.95	3.38	3.30	Density (gm cm^3) Dry tamp 2.9-3.0
Thermal expansion (%) 1500°C	< 1.90	<1.20	<2.20	Wet tamp 2.8-2.9 PLC (1700°C/ 3 hrs) -2.00-2.20
Refractoriness under load 2kg cm^{-2} T_2(C)	>1700	>1650	>1550	

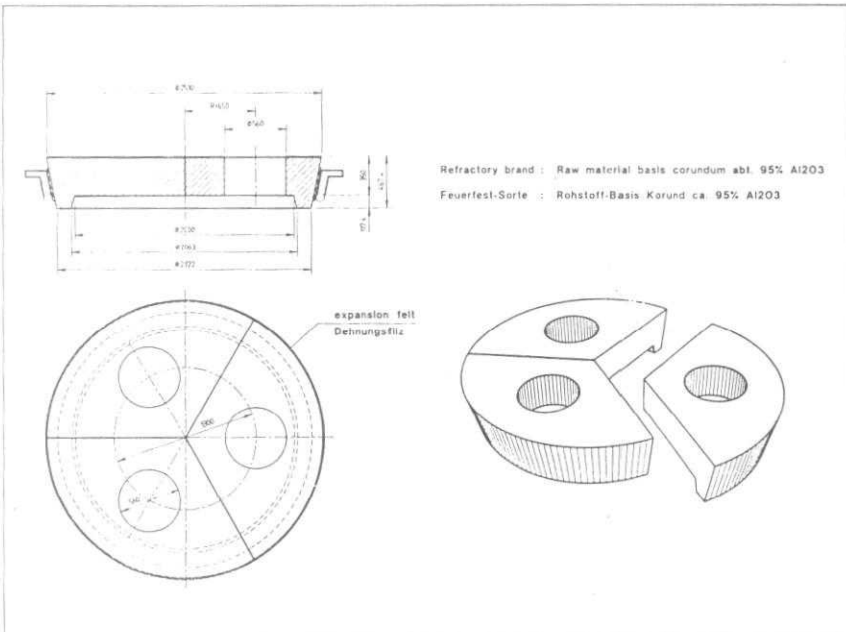

Fig. 1A: Prefabricated shapes for electric-arc-furnace-roof

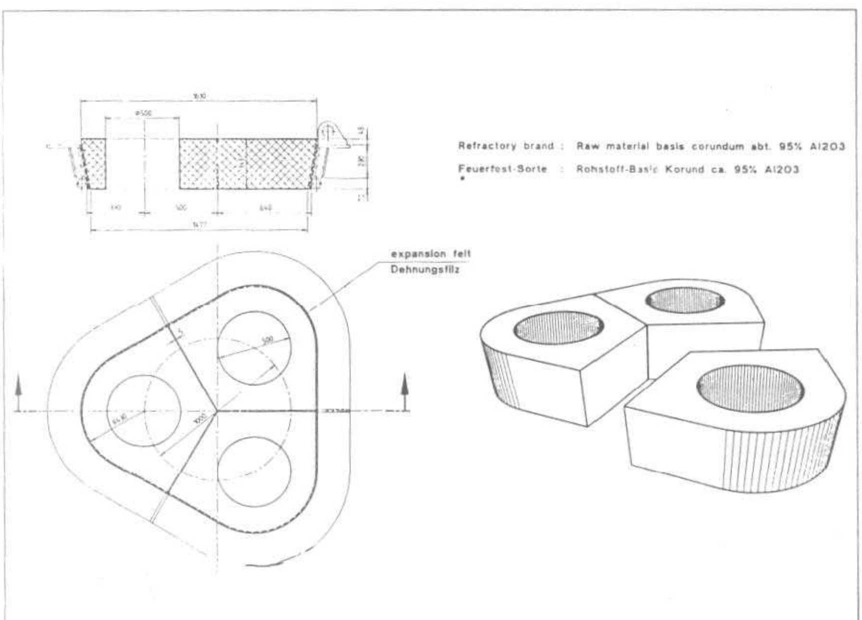

Fig. 1B : Prefabricated shapes for electric-arc-furnace-roof

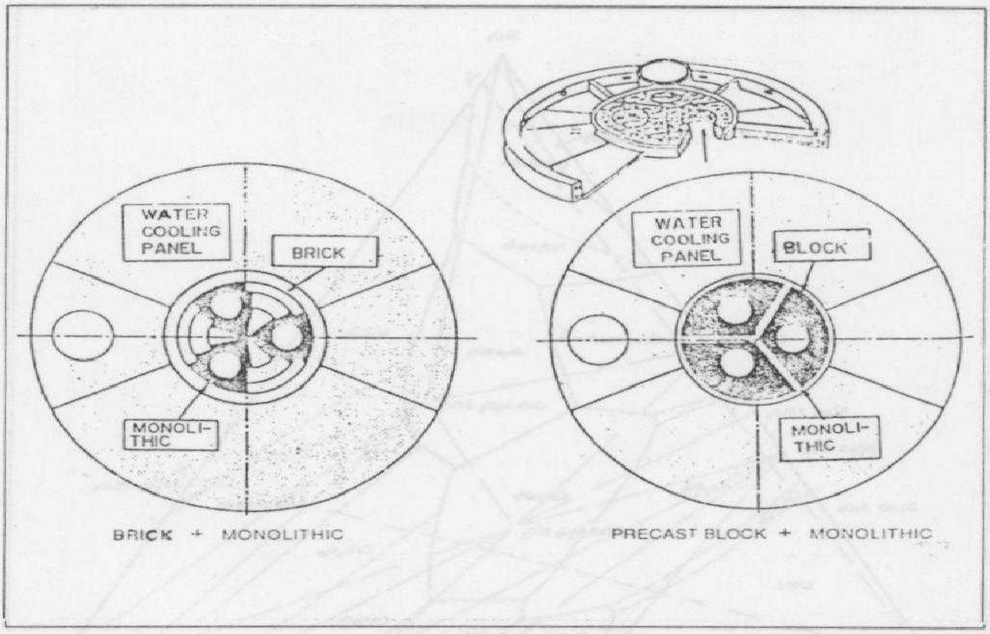

Fig.2 : Example of lining of top roof when the outer ring roof is water-cooled

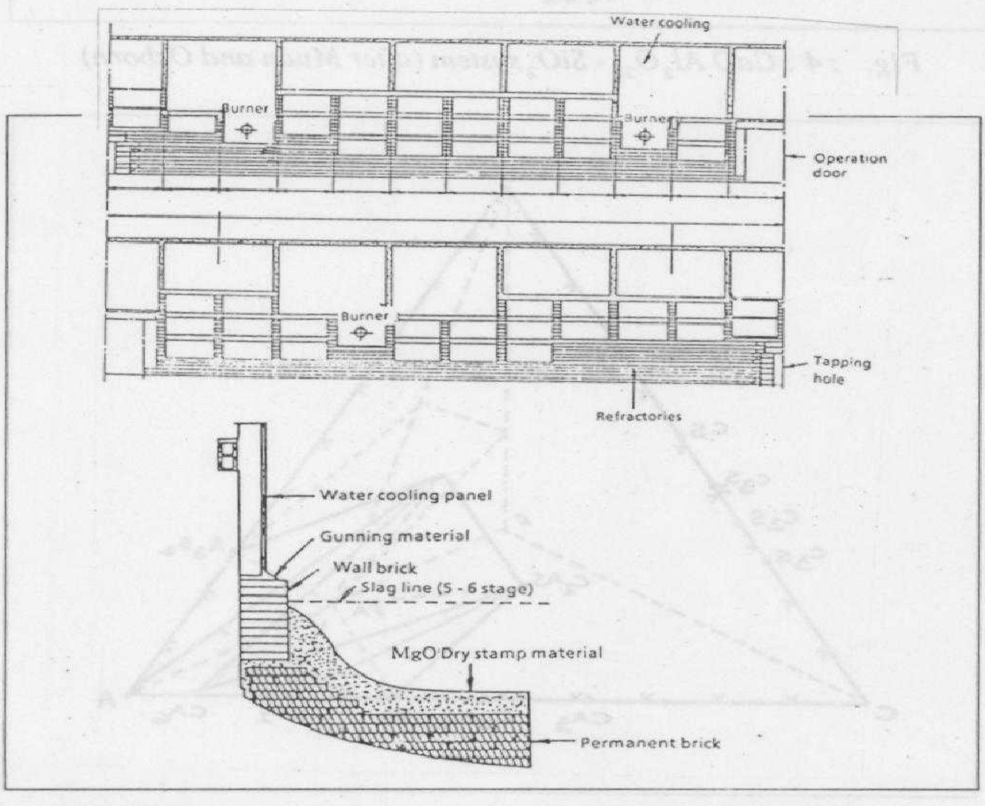

Fig.3: Water cooling panel for wall (top); lining example (bottom)

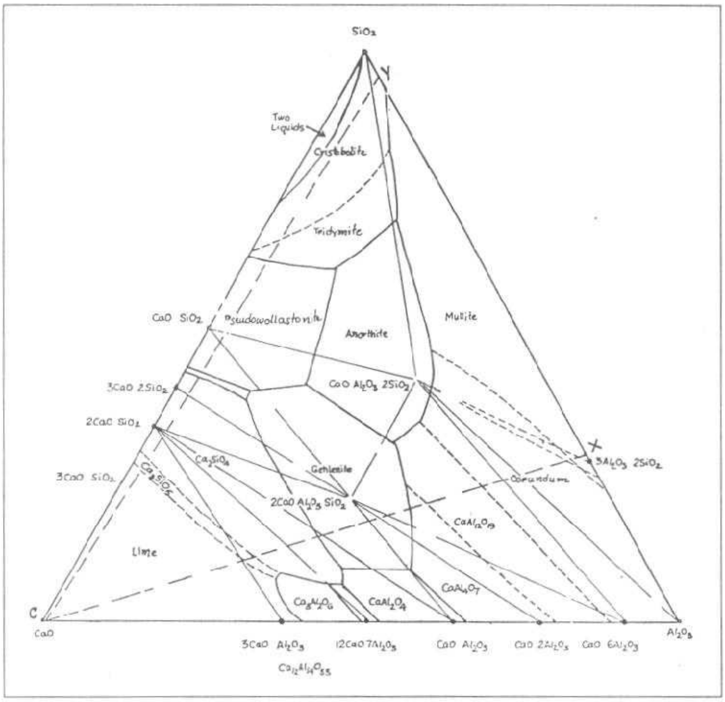

Fig. : 4 : CaO Al_2O_{23} - SiO_2 system (after Muan and Osborn)

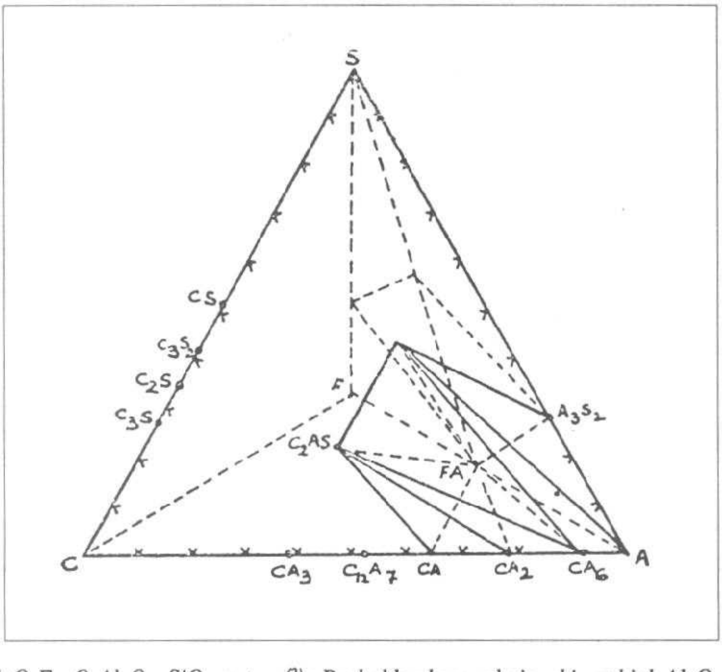

Fig 5 : CaO-Fe_2O-Al_2O_{23}-SiO_2 system[2] : Probable phase relationship at high Al_2O_3 contents

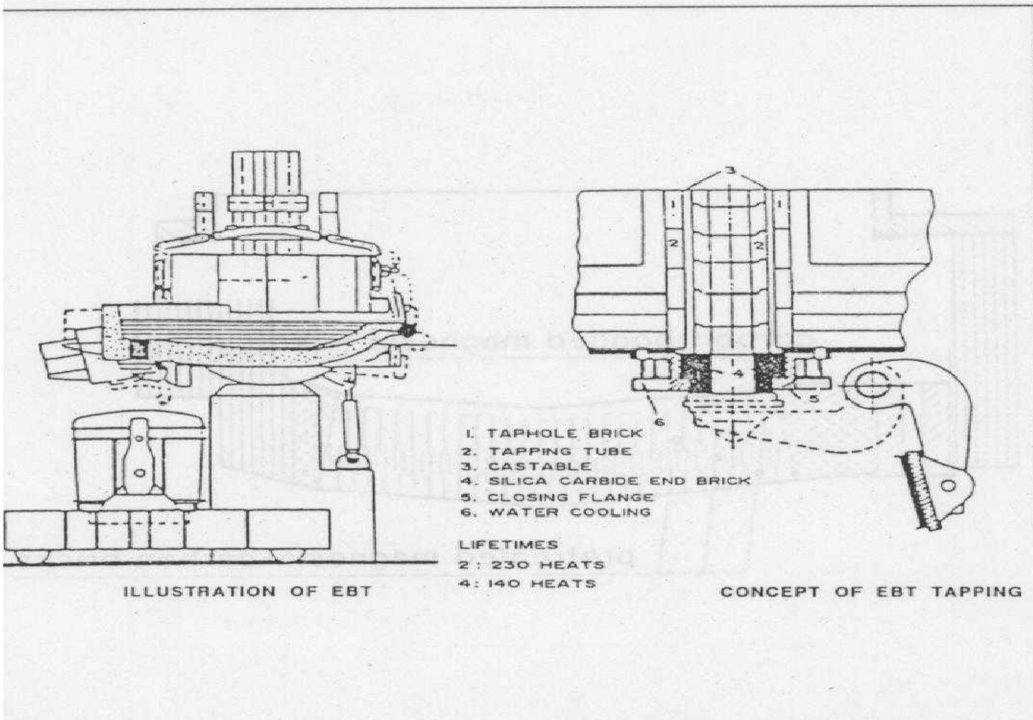

Fig.6 : Structure of EBT

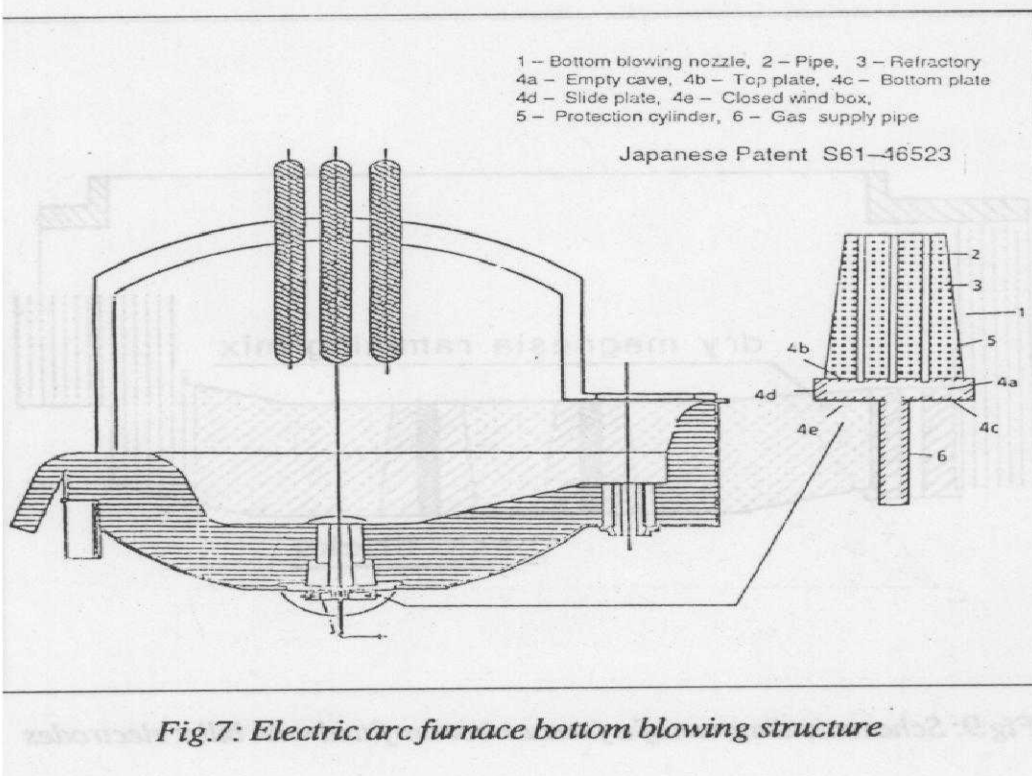

Fig.7: Electric arc furnace bottom blowing structure

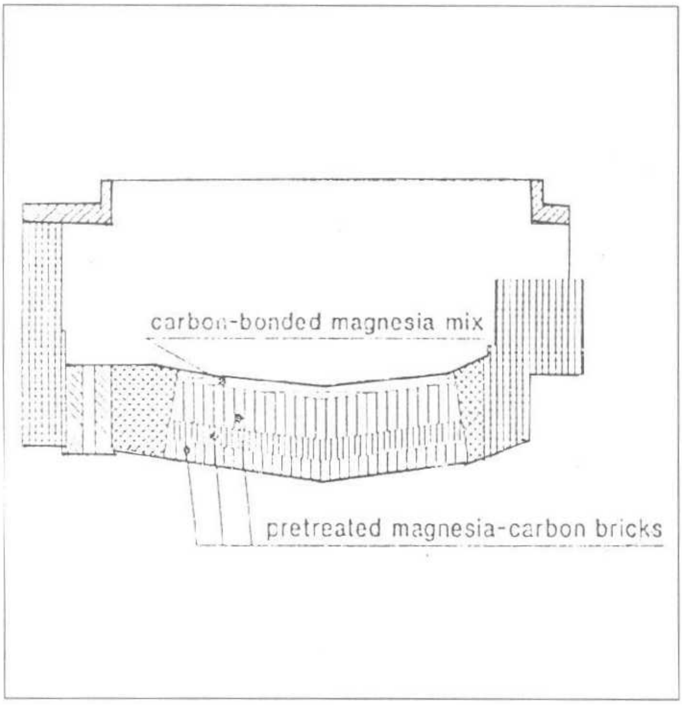

Fig.8: Schematic diagram of a furnace bottom with conductive refractory material

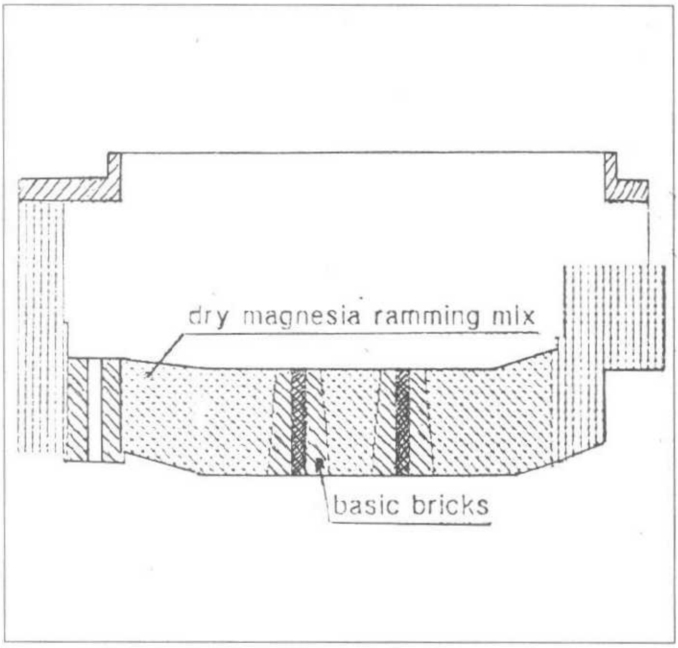

Fig.9: Schematic diagram of a furnace bottom fitted with billet electrodes

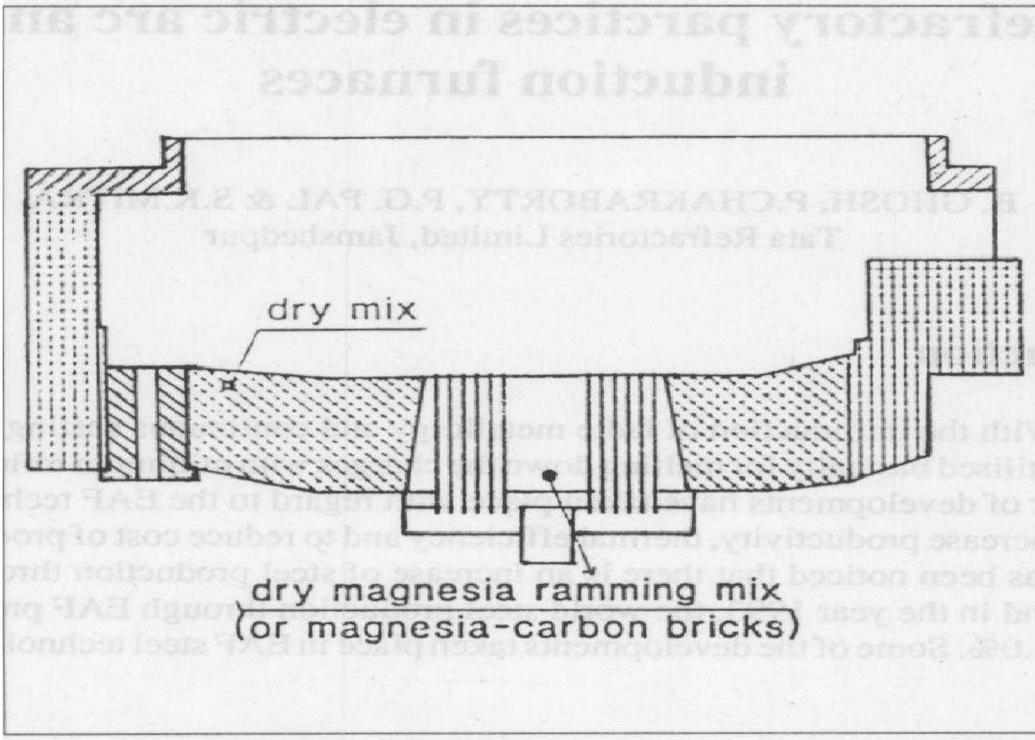

Fig.10: Schematic diagram of a furnace bottom with pin electrodes

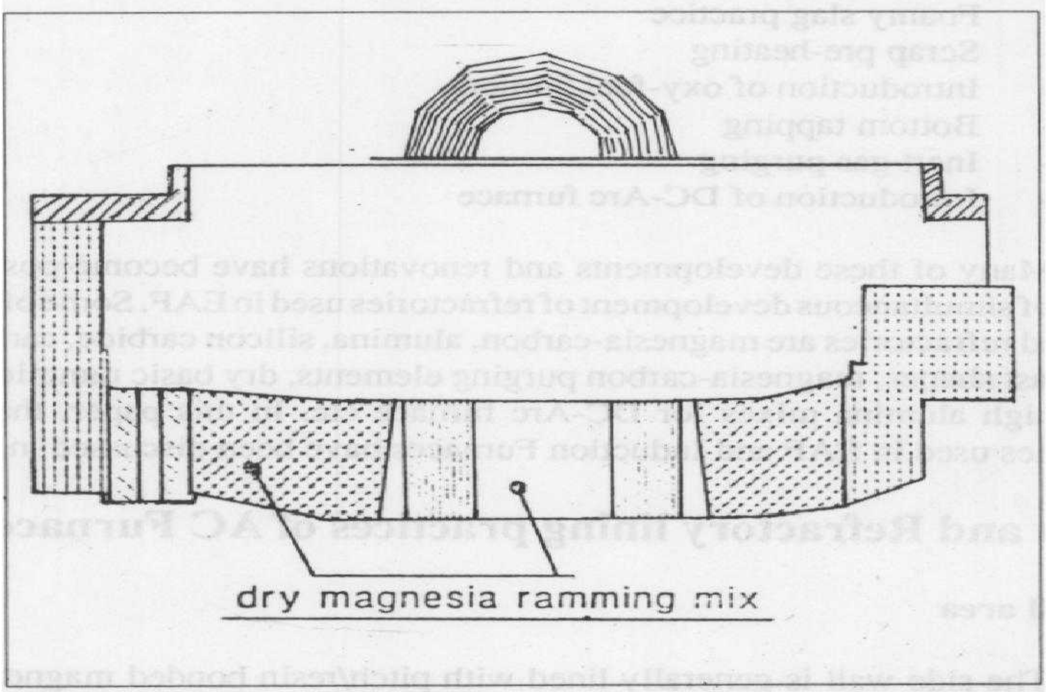

Fig.11 : Schematic diagram of a furnace bottom