BASIC OXYGEN STEEL MAKING CONVERTER LIVES.
(2000 TO 40,000)

D L Amoss
Vesuvius

1. Abstract

B.O.F converter life, reliability and costs are vital to the smooth operations of Steel plants Worldwide. In many ways the techniques of Primary Steel making were neglected in favour of Secondary processes but with these developments logistics and the flexible utilization of the converters became more critical. Converter life varies from plant to plant around the World from only a few hundred heats to 40,000 heats. With continuing over-capacity and low selling prices for steel there remains a driving force and a motivation to optimize life, availability and costs in the Primary Steelmaking.
Basic Oxygen Furnaces.

2. An Introduction to the BOF Process

BOF (Basic Oxygen Furnaces) or Basic Oxygen Steelmaking contributes to the vast majority of World Steel Production. The process uses as its major Raw Material, Blast furnace iron, which will contain, to a varying degree, the elements Carbon, Silicon, Manganese, Phosphorus and Sulphur depending upon the raw materials used in the manufacture of the Iron.

Fig 1: Charging a BOF Converter with Blast Furnace Iron

Blast fce iron or Hot Metal, as it is termed, has little practical use in this day and age and has to be converted to Steel usually by the Basic Oxygen Steelmaking Process. For those less familiar with the Process I will briefly describe the main features of the process as they heavily influence the Refractory Costs and the life of the steelmaking converter.

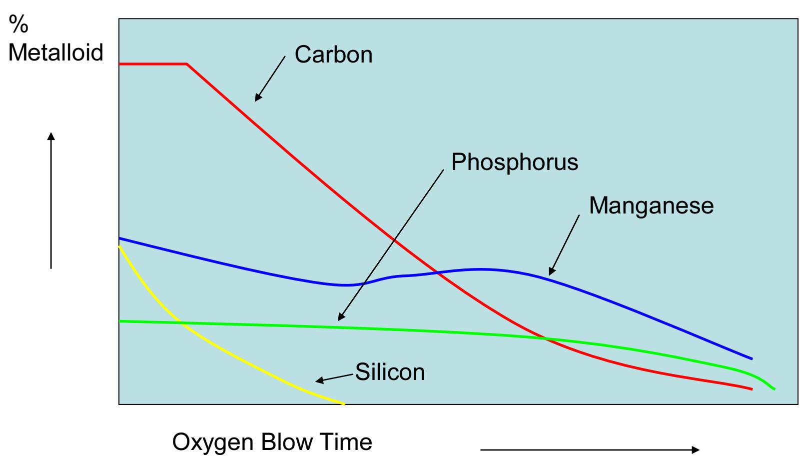
Blast fce iron is generally delivered to the steelplant at a temperature of around 1350C. It will contain typically.(Fig 2)
4 - 4.5%C
0.2 – 1.2% Silicon

0.3 – 0.8%Mn
0.04 – 0.12%P
0.02 – 0.08%S
Depending on the raw materials used and the operating parameters.

To manufacture any grade of steel the metalloids within the Hot metal must be reduced particularly the Carbon content and the Sulphur and Phosphorus contents. Sulphur is removed external to the BOF process as the thermodynamics and kinetics of the reaction are not suited to the BOF.

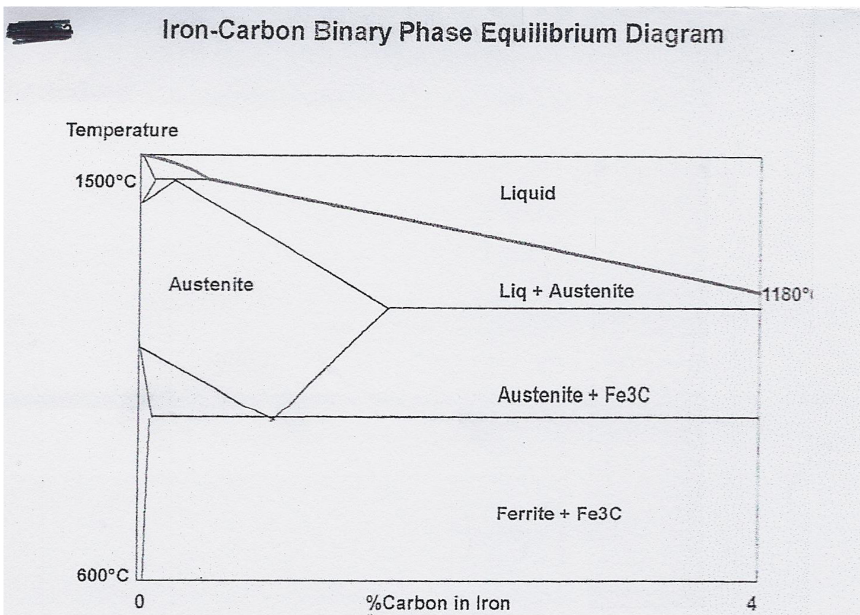
The oxidation of Silicon and Manganese occur based on the affinity for Oxygen of these elements, according to the Ellingham Oxidation reactions regardless of the need to eliminate them. The main BOS metallurgical work therefore is to reduce the C content to variable levels based on steel grade but in the range .02 to .2% and with more difficulty the Phosphorus content to levels as low as .005% depending on steel grade. Typical rates of metalloid removal are seen in Fig 4

Fig 4: Metalloid Removal



This removal is done by blowing a supersonic jet of Oxygen into the furnace through a water-cooled, copper nozzled lance at a rate up to 1200 m3/min depending on furnace size (the smallest converters I have seen are in Peru where a tap weight of 30t is achieved and the largest I have seen are in a Severstahl plant in Russia which have 400t monsters) for around 16-18 mins. A basic slag is generated by the addition of soft burnt lime to facilitate the removal of the metalloids. An emulsion of the slag, metal and gas phases is generated which brings the different elements into intimate contact thereby achieving rapid refining.

As indicated by the Binary Fe-C phase diagram (fig 5) the temperature of the melt must be elevated from that of the Hot metal to in excess of 1550C to generate a liquid but then depending on the downstream activities and associated heat losses a superheat is also required which may necessitate the steel being taken to temperatures in excess of 1700C. Achieving these temperatures is no problem as the oxidation reactions of the metalloid removal are extremely exothermic, such that coolant is required to avoid overheating, such as Scrap or DRI or Iron ore.



The Process speed is extremely fast and equilibrium conditions are never achieved and hence many plants introduce an inert gas stirring system through the bottom of the converter which assists with homogenization and if operated effectively can reduce the state of oxidation of the melt by reducing the C*O product from something like 35 to as low as 18.

Fig. 6. Schematic Active Oxygen versus Carbon Content of the Melt

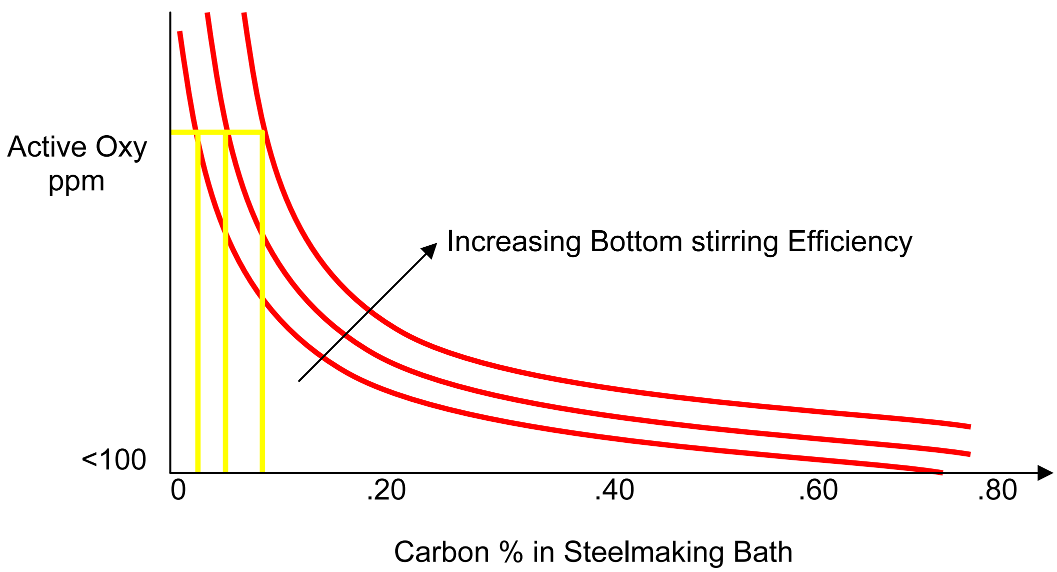


Fig 7: Effect on Tapping Oxygen Content for a Given C content with C*O Product as derived by Inert Gas Stirring - BOF

Carbon Content(%)	C* O Product	Oxygen ppm
0.05	18	360
0.05	24	480
0.05	30	600
0.05	35	700

Effectively what this means is that at a given tap Carbon the ppm of Oxygen in the melt is reduced whilst the homogenization allows for better contact between Phosphorus atoms and Oxygen atoms to more effectively de-Phosphorise the melt, which is the most difficult chemical reaction to achieve. Fig 7 shows the effect on Oxygen ppm with varying degrees of Inert Gas stirring, which is extremely important in cost terms as when tapping steel for Continuous casting the steel must be killed (de-oxidation must be carried out with Aluminium or Silicon or in some cases Manganese – depending upon steel grade.

Since one of the greatest contributors to wear of BOF Linings is the State of Oxidation of the melt, one would therefore expect that lining life would be increased with effective bottom stirring and yet in the U.S. 40,000 heats have been achieved without stirring and yet the more normal lining life for a stirred vessel, is around 4000 heats maximum.

Why should this be? We will discuss some aspects of BOF process management that influence life.

Let us first consider the Refractories employed in BOF steelmaking. When I first came into the industry although it is rumoured I was acquainted to Mr. Bessemer this is in fact not true, but it was not until the 1970's that Magnesia Carbon Refractories were introduced to the World of Steelmaking. Various Basic Mag-Doloma and fired Mag Refractories were used which could withstand temperatures of typically 1600-1620C for lives between 250-500 heats, but the demands of continuous casting instead of ingot casting and the introduction of Secondary Metallurgy (Degassing and Stirring and Various Injection processes) meant that tapping temperatures had to increase to facilitate much greater superheats prior to casting. These humble refractories would not have coped with tapping temperatures of well in excess of 1700C which are sometimes required.

In a very old industry like Steelmaking major innovations are few and far between, unlike I.T. a new industry where innovation is rapid and continuous, the steelmaking horse trudges on more slowly, but the development of Mag Carbon refractories was a major step toward product development and cost reduction. Within a decade lining lives in Japan for example were reported above 10,000 lives and Europe moved from a few hundred to several thousand heats per campaign to the point where I believe all BOF converters worldwide and almost without exception had moved to Mag – Carbon by the early 1980's.

Today there are many Magnesia Carbon manufacturers and suppliers worldwide and relative to the 70's materials all are superior in performance to the previous generation but some are more superior today to others.

4. **What are the key wear mechanisms of the BOF converter?** (fig 8)

Fig 8: BOF Wear Mechanisms

- Temperature
- Residence Time
- State of Oxidation of the Melt (Corrosion)
- Slag Chemistry (Corrosion)
- Erosion of Slag and Metal during blowing and vessel tilting.
- Abrasion (Dust and Gases)
- Impact of Scrap and Metal during charging
- Thermal cycling
- Mechanical damage by cleaning equipment
- Impact & Penetration of Oxygen Jet

VESUVIUS SOUTH AFRICA

a) The ultimate temperature of the melt varies significantly with the superheat needed to cast a particular grade of steel, and the secondary steelmaking facilities available to a particular plant. In the late 1980's in the plant where I was brought up we had an 8 strand billet caster which would cast a 300t ladle of steel in 2 and a quarter hours given that 8 strands were casting. In some cases tapping temperatures were required above 1750C, which was beyond the capacity of the temperature measuring equipment to measure. This was unsustainable and was a disaster until a Ladle fce became the mandatory route.

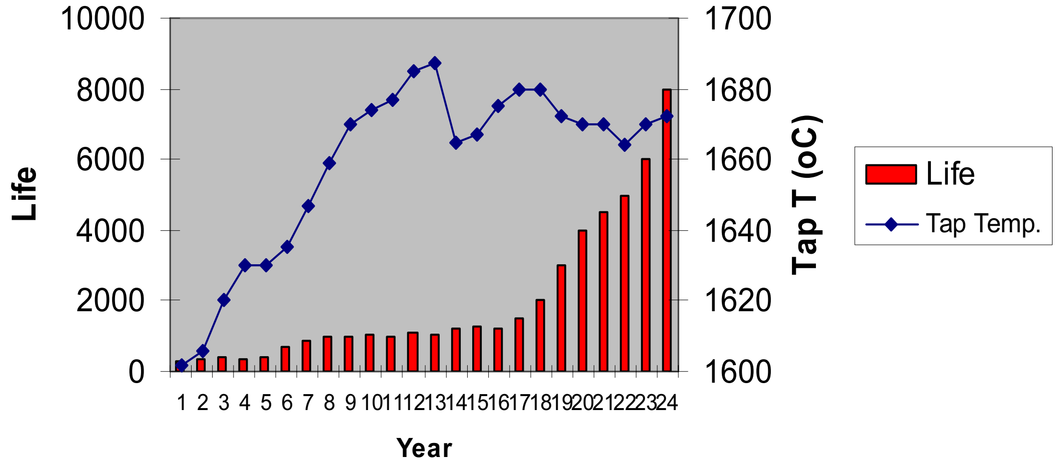
b) The State of Oxidation of the melt is extremely significant in terms of BOF lining wear and is exacerbated by high temperature.. Oxygen increases in the melt asymptotically with reducing Carbon content as there is nothing else to oxidize apart from iron so yield is also lost. Slag FeO levels indicate a state of oxidation but Oxygen can also be measured directly with an Oxy probe in ppm.

   Bottom stirring helps as we saw earlier, but heat balance adjustments must be made to accommodate stirring as the extra turbulence outside of the blow and the injection of ambient temperature gases into the melt causes cooling. In some plants bottom stirring has not helped as heat balance changes have not been allowed for in the heat balance calculations and hence a heat that might tap at .05%C without stirring will have an Oxy content of 700ppm, is blown to .02%C with stirring and achieves 1000ppm, which thereby achieves little. Had the stirred heat also tapped at .05%c then the tap Oxy would be about 400ppm. (see Fig 7)

c) Slag Chemistry is important in several ways. Mg-C bricks are basic refractories and require a basic slag, which is also required for Phosphorus removal. The basicity ratio required depending on Hot metal Phosphorus and steel grade will be between 3.0 and 4.0. (Simple Basicity ratio = CaO/ SiO2). The Basic slags formed will also attempt to dissolve up to their saturation level of MgO from the brick. Typical MgO saturation will occur around 8% again depending on temperature and state of oxidation, so if MgO is not added, usually in the form of Burned Calcined Dolomite the slag will dissolve the lining preferentially and thereby increase vessel wear. There are very few plants that can quantify the effect of using burnt dolomite and the question is often asked if it is value for money. A few year ago a plant not too far away from here effectively demonstrated that a BOF life would reduce to a third of its previous life without burnt dolomite and of course those relying on slag splashing for huge longevity as in the USA in the 90's would never have approached 20-30-40,000 lives without dolomite, their lives would have been reduced by an order of magnitude. Slag chemistry is again related to state of Oxidation and temperature as Basicity and MgO slag content are diluted by high levels of FeO and temperature increases the kinetic reaction rates.
d) Erosion and abrasion effects are much related to the practices and hardware the shop employs. As one example sublance technology reduces the need to turn a vessel down for sampling and improves end point control thereby reducing residence time and state of oxidation often eliminating reblows.
e) The other effects on the slide displayed are more obvious but all these variables interact with each other.

So the converter operation has a huge effect on converter lining life. So does the plant configuration. Ideally one would want one converter feeding a single fast casting machine with long sequence ratios and a second vessel feeding a second caster with the same. In reality the market does not allow this in many situations and particularly in First World Countries where plants are becoming very much less competitive. In the plant I managed production capacity was over 5 million tons per year and more than 50% of the plant was designed for ingot casting (in the 1980's) but as casters replaced ingots on an existing site the logistics became extremely difficult. Imagine trying to feed 4 casters with cast times of 50 to 160 mins from 2 vessels with a cycle time of 40-45 mins. It was impossible. To move in the right direction Scunthorpe needed 3- vessel availability all the time and in trying to achieve this, European record lining lives were achieved which still stand today.

Fig 9 - Lining Life and Tapping Temperature



This involved not only process improvement, refractory improvement, lining maintenance practice improvement but also engineering improvement and less tangible of all operator attitude and flexibility modifications, which I will refer to later. Ijmuiden had to make serious decisions about change in their converter philosophy when their plant was upgraded in the late 90's. 2000 heats from their own home made bricks was no longer satisfactory; they needed 4000 heats plus to achieve their objectives. Even here is SA there is a huge difference in the requirements of the VDBP operation with a potential BOF output of 3 million tons relative to the current configuration at Newcastle who are iron constrained by only one Blast fce.

In fast moving, high productivity plants vessel availability is vital as my next slide shows:

Figure 10: Upward Spiral

INCREASED LIFE

IMPROVED AVAILABILITY

IMPROVED PRODUCTIVITY

IMPROVED PROFITABILITY

5. Mag Carbon Refractories

So let us now move back to Refractory considerations as they pertain to the BOF. We have seen that Plant configuration demands and operational issues have a marked effect on lining life but the solid foundation must come from the choice of Mag Carbon refractories employed. Let us look briefly at the variables (fig. 11).

Fig 11: Important Parameters of the Magnesia-Carbon Brick

- Type of Magnesia Grain used (Chemistry, Crystal Size, Density)
- Bonding Type and Size of brick press. (Friction / Hydraulic)
- Bonding Agent (Pitch, Resin, Amount, Re-impregnation)
- Type of Graphite used (Purity, Sizing, Amount)
- Antioxidants (Type, Amount, Sizing)
- Brick Physical properties (Density, Porosity, Hot & Cold strength)
- Obviously the type and size of press be it Friction or Hydraulic influences brick properties.

- There are many suppliers, thousands of variants; the best price/performance ratio is achieved with experience and by mutual understanding of supplier and consumer – it does not necessarily come Overnight.

5.1 The Magnesia grain employed:

Since the largest component of a Mag C brick is the Magnesia grain, the composition and properties of the grain play an important role in the characteristics of the brick. There are dozens of types of Magnesia grain available today, with widely differing properties and prices. The best choice for any particular purpose cannot possibly be made commercially; the operator and the Refractory expert must be in perfect communicative harmony if success is to be achieved. But we live in a high pressure World still with a very confrontational management style between consumers and suppliers and yet it is so obvious that working together with trust and honesty cannot be challenged as the ultimate way to go for ultimate best performance and cost effectiveness. I have attempted from both sides of the table to encourage this for 25 years with only small success.

In terms of Magnesia grain the higher quality grain for withstanding basic slags, erosion, abrasion, temperature etc as we have discussed will normally be the most cost effective. The grain density, size, and chemistry are vital.
In terms of Chemistry, the lime/silica ratio of the grain is important. You either need zero or in excess of 2:1 $CaO:SiO_2$ to ensure the formation of dicalcium silicate, a high melting point phase. Some MgO grains have a ratio as high as 6:1 but these then become more susceptible to hydration. Low basicity will result in low melting point phases and the loss of hot strength can be catastrophic. The amount of secondary

minerals formed in the grain is also important so the overall SiO2 should be as low as possible (<0.3%). High Boron content is also very critical for example and will destroy the grain's hot strength.

5,2 Grain Density
Grain density can vary from 3.2 to over 3.5g/cc. Low grain density means high porosity making the grain susceptible to slag penetration.

5.3 Crystallite Size
Large grained crystallite will normally outperform low crystal size due to a reduction in interstitial porosity thereby reducing the chance of slag penetration into the grain boundaries and by lowering the susceptibility of the MgO to reduction by the C present in the brick during high temperature service. The reduction process destroys both the Carbon in the brick and the MgO in the grain producing MgO metal vapour and CO gas.
Large crystallite size is generally considered to be over 140 Microns in size. Fused MgO grain can exceed 1000 Microns. However all fused grain material are not the same varying in chemistry, crystallite size and price.

5.4. Bonding agent
All are carbon bonded with the residue of finely divided C remaining after the coking of the binder – this is what holds the brick together.

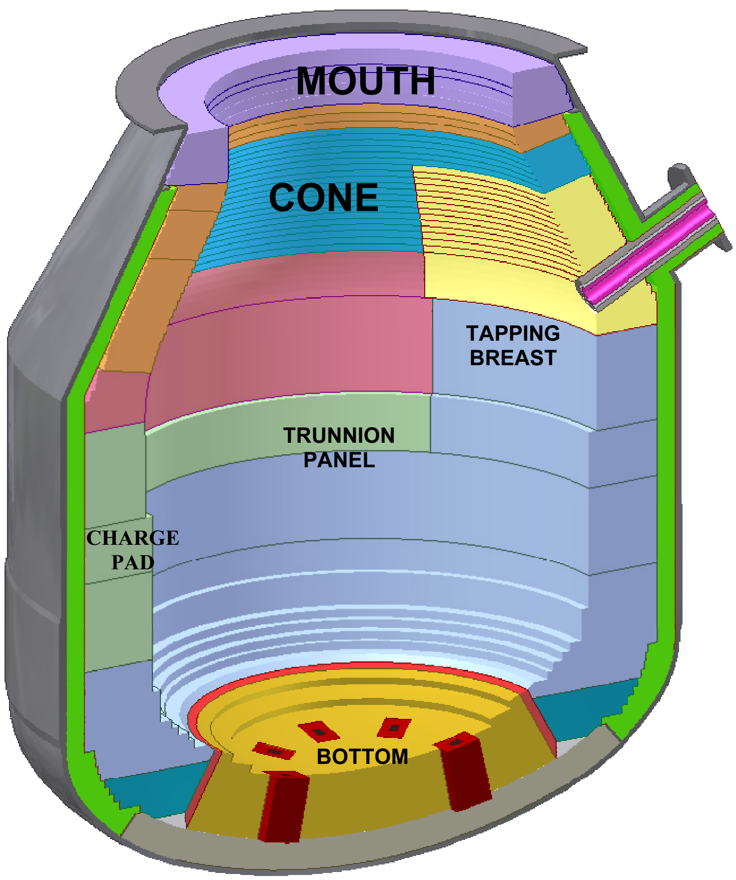
5.5. Type of Graphite Used
Graphite is non wetting to steelmaking slags preventing slag penetration into the brick and subsequent dissolution of the Magnesia grains. The graphite also is very thermally conductive transferring heat away from the brick surface thereby reducing the kinetics of aggressive reaction.
Chemically all graphites are pure Carbon but all contain some ash (clay minerals found in the graphite deposits). Impure graphite adds fluxes such as Silica and Alumina to the brick which generates only negative effects. Flake graphite is usually used as it has a higher resistance to oxidation than amorphous graphite and a higher thermal conductivity. Graphite size and purity again vary cost/price significantly. Generally the amount of graphite used can vary fro 5-25% and everything else being equal the higher the graphite content the higher will be the slag resistance and thermal conductivity of the brick.

5.6. Anti-oxidants
Metal powders added to Mag-C bricks act as scavengers for Oxygen delaying oxidation of the graphite and C-bond. The powders improve hot strength markedly by forming complex metallic – carbide – oxide bonds in the brick.

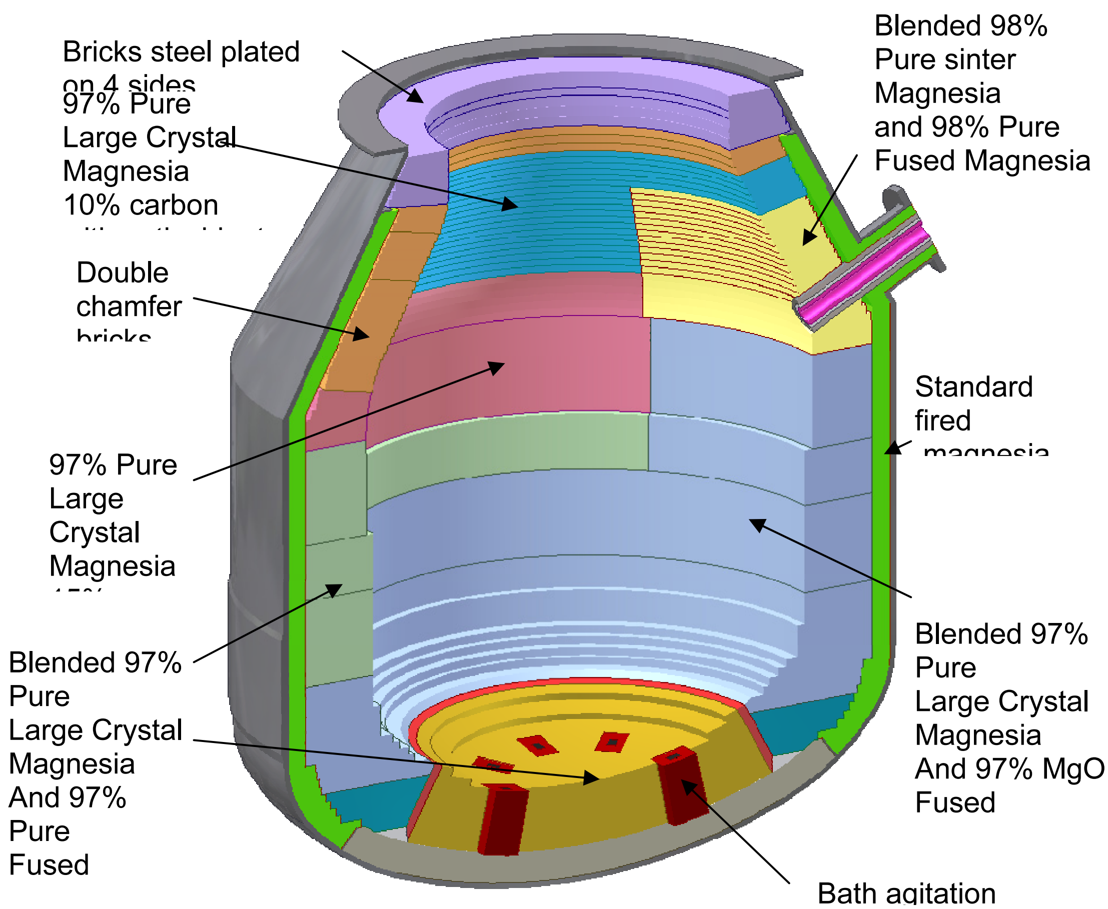
Limited detail is given here but suffice to say that Magnesia Carbon refractories revolutionized the BOF steel costs, BOF availability and thereby overall process cost efficiency.

Design of a BOF lining varies from plant to plant each with the intention of generating a lining that will achieve desired life and availability, and to attempt to equalize wear from the different wear mechanisms in the different areas of the BOF.

Fig 12: Typical Zoned Lining



BOV Material Arrangement



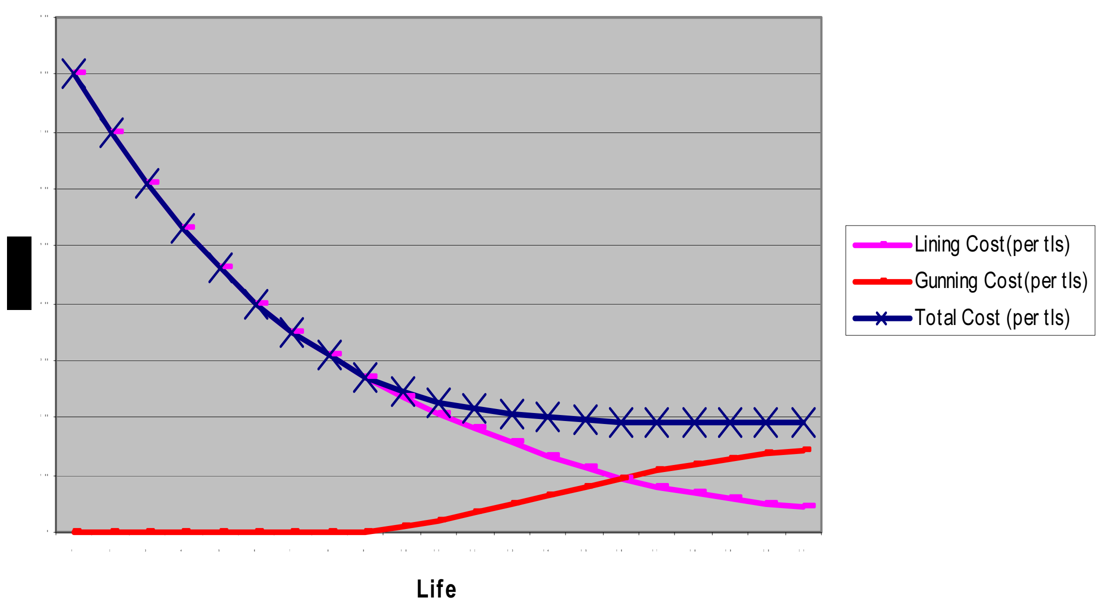
The schematics (fig 12) attempts to describe how the converter lining can be zoned by varying thickness and quality of Brick to attempt to equalize wear.

Some plants will design very complex linings that are difficult to build like a giant and complicated jigsaw puzzle. At the other extreme, plants that reline using automatic equipment tend to build very simply designed linings to save rebuild time. I guess because of the process variables to design the perfect lining that wears at exactly the same rate in all zones is but a dream and hence varying maintenance techniques are used which are intended to even out the wear in the most vulnerable areas.

6. Maintenance Techniques

Techniques such as gunning and Nitrogen slag splashing are the most common, but even the best gunning materials can never be as good as a well produced brick as it is applied using air as a transport gas and water to activate the bonding mechanism. The physical properties of a gunned material will not approach those of a brick but gunning has its uses to increase life and availability and if applied based on accurate laser technology measurement of lining thickness can be very valuable and cost effective and very selective in the area of the converter to be maintained. (see Fig 13: Gunning increases life and thereby availability without increasing overall cost when managed properly.

Fig 13 - Refractory Costs per tonne of Liquid Steel



Nitrogen slag splashing, is a technique where some remaining BOF slag is retained after tapping the heat of steel and is then conditioned to cool it and to increase its refractoriness. This was a revelation of the late 1980's in the U.S. initially. The main Oxygen lance blasts the conditioned slag indiscriminately on the lining to act as barrier from the erosive/corrosive slag generated in the subsequent heat. It is this technique that generated campaigns of 20, 30 and I believe 40,000 heats but the indiscriminate nature of the maintenance technique can cause process refining issues due to major changes in vessel geometry and residual slag can cause vessel bottom build up that ultimately inhibit bottom stirring gases preventing the reduction of the C*O product of the melt.

7. Concluding Remarks

Modern day steelmaking has many great tools available to it, the engineering, the refractories, the maintenance techniques, the additional equipment available to improve efficiencies such as sublances and other predictive end point equipment such as waste gas analysis, gas stirring and so on. Much effort and money is ploughed into optimizing production but I always wonder about whether we put enough time, resource and energy into the people involved. I have been lucky enough to travel the World and have seen many steelplants as a Production and Technical man within the UK steel industry and as an Independent Consultant and the one area I perceive where so much more effort is needed is in the training of Managers and operators. I make the following observations with no individual target intended:-

a) From what you have heard today is it sensible to buy the lowest price material necessarily?
b) Will the mistrust of suppliers always continue or will true partnerships evolve to improve performance and costs for both parties.
c) Standardisation of operations is often a management objective and rightly so, but is it right that standardization is attempted without reference to the guy who makes the product – is he not the practical expert? Rules in steelmaking are dangerous and costly, guidelines for motivated responsible operators are essential. Dr. Deming's teachings of Total Quality Management are as relevant today as when he originated them and yet most suppliers and Customers fail to recognize these principals.

8. Summary

My paper endeavoured to briefly outline the major steelmaking process. To explain why furnace lives vary from plant to plant by more than an order of magnitude, to discuss the variables involved within the lining, the process, the plant configuration and finally most importantly the absolute need around the World in all our business dealings to change the culture in how we manage our people and how we must as customer and supplier work together.

The Author

The author graduated from Brunel University (First Class Honours) in Metallurgy, and worked 29 years with British Steel later Corus Group, predominantly as a Production Manager. In 1999 he established his own Consultancy business, assisting Steelmakers and Refractory Companies to come together to examine all aspects of operation to optimize converter life and costs. This business was based on his experience improving B.O.F. lives from 1000 heats in the late 1980's to almost 10,000 heats by 1998, achieving numerous European records and phenomenal cost savings and plant availability gains. As a Consultant, the author has worked in 5 continents and has established a reputation for generating results in life and cost terms. He has now settled in South Africa and is employed by Vesuvius SA in a Sales and Marketing environment.