Recent trends in the application and technology of refractory materials in iron and steel production

By H. J. S. KRIEK,* M.Sc. (Chem.) (Pta.), Ph.D. (Sheffield) (Visitor).

SYNOPSIS

Methods are described by which increased production is achieved whilst retaining full availability of equipment and decreased refractory cost. Refractory materials have certain limitations, and when these limitations are known the variables in operating practice having the greatest impact on refractory life can be controlled. The most important factors to be closely controlled are porosity, chemical constitution of refractory materials, slag basicity, slag volume, FeO content of slag and temperature at which the process is operated. Knowledge of the process is invaluable in deciding on the type of refractory to be used. The types of refractories used in and the operating variables of the ironmaking, steelmaking and steel finishing units are described.

The cost of refractory maintenance of furnaces in a medium-sized steelworks selling approximately 3 200 000 metric tons of steel products per annum is around R10 000 000 per annum. Figure 1 shows the contribution

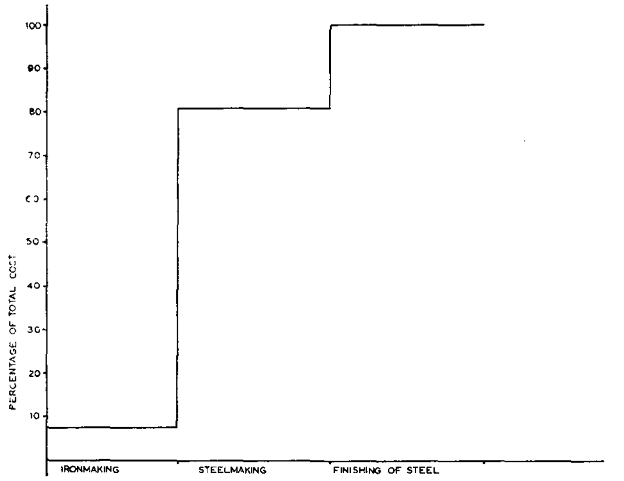

Figure 1—The contribution to the total refractory material maintenance cost made by ironmaking, steelmaking and finishing of steel.

made by ironmaking, steelmaking and finishing of steel to this total cost of refractory materials and also explains why refractory technologists concentrate on steelmaking where to obtain a saving of even approximately 10 per cent on R10 000 000 is substantial. Unfortunately, the long-term forecasts of the demand for steel over a period of 10 years or so, have, in spite of careful preparation and checking, invariably proved to be wrong. As a result steelmaking plants do not operate at their maximum economic rating (or the capacity that the plant has been designed for) to meet a steady base load demand, but strive to meet a "peak load demand" using the same steelmaking units.[1] This results in a conflict between objectives of sub-systems, mainly production and maintenance. The refractory materials technologists and maintenance men continuously have to compromise between availability and quality of refractory materials, whereas the user continuously places greater demands on the refractory material. The cost of this conflict between optimum and maximum production is apparently not known. A major trend, especially noticeable in Germany and Japan, is to resolve this conflict by close co-operation between the steelmakers and the refractory technologists and manufacturers. This entails that all parties involved understand and know why a furnace lasts and that the responsible people control the critical factors involved. The purpose of this paper is to describe how the challenge of achieving increased production whilst retaining full availablity and decreased refractory cost is approached.

The effect of understanding, applying and controlling the how and why can best be illustrated by the figures supplied to us by a relatively small steelworks in Germany,[2] manufacturing tubes and pipes. With one 60 metric ton electric arc furnace with a transformer capable of supplying up to 32 MVA the production was pushed up from 39 502 metric tons in 1961 to 177 801 tons in 1969. Despite this increased production involving the tapping of 12 heats per day the roof life is 140 heats and the sidewall life is 270–280 heats with a refractory cost for the furnace of 70 cents per ton of steel produced. The tapping temperature varies between 1 620°C and 1 650°C and is high because of the small moulds into which the steel is cast.

A few trends in the use and technology of refractory materials will now be discussed.

COKE OVENS

The increased use of oxygen in steelmaking has resulted in increased demands for hot metal from the blast furnaces and consequently for coke from the coke ovens. If the moisture content of the coking coal blend is reduced from 10 per cent to approximately zero an increase in throughput of about 20 per cent can be achieved.[3] A further improvement in production rate can be achieved by going over to tall coke ovens, i.e. six to seven metres tall instead of the normal four metres and the use of higher coking temperatures of up to 1 450°C. A refractory material with a higher heat transfer than that of the normal dense silica is also required. Problems of heat transfer can be reduced by the use of thinner walls but stability of the structure must be maintained. Magnesia has a thermal conductivity approximately $2\frac{1}{2}$ times that of silica, and the low silica, dicalciumsilicate-bonded magnesia, low in iron and alumina, has mechanical strengths at 1 600°C to 1 700°C exceeding that of silica and may well prove to be the refractory of the future in the construction of coke ovens. In Germany[3] an experimental 300 kg oven constructed with magnesia bricks was run for one year in order to gain experience

*South African Iron and Steel Industrial Corporation.

for the planned construction of a battery of commercial-scale ovens. This experiment showed an increase of 40–50 per cent in production rate, depending on the coking temperature used, through the use of magnesia.

However, some doubt exists as to the stability of MgO, and the accompanying small amount of dicalcium-silicate, in strongly reducing atmospheres for prolonged periods of time i.e. from 20 to 30 years. Thermodynamically MgO is more stable than SiO_2 in reducing atmospheres up to 1 700°C and experiments with magnesia in LD units[4] have shown no deterioration after one year in use, that is provided no hydration occurs. The cost of magnesia is approximately three times that of silica but the improved production rate with magnesia may well far outweigh the increased installation cost of the coke ovens. Silicon carbide has also been tried in experimental ovens but it does not appear to be very successful, and a further problem is the high cost of this material which is approximately 11 times that of silica. It is evident that the use of magnesia in coke ovens must be properly evaluated.

BLAST FURNACES

The success of the LD-process depends upon the consistent quality and supply of hot metal from the blast furnace. For continuity of the steelmaking process spare LD vessels have become the norm, whereas with blast furnaces the number is being decreased and the size increased, without "spare" blast furnaces being erected. The continuity of operation of a steelworks, will therefore be dependent on the ability of the blast furnaces to keep up a constant flow of consistent quality hot metal without interruption. The contribution of the blast furnace to the total refractory cost per ton of steel is relatively small, but a very high loss in production occurs when a blast furnace is off. The loss in production when a blast furnace, capable of producing 5 000 tons of pig iron per day, is off for repair for 30 days, can be taken as around R3 000 000. It is no wonder that world-wide attempts are made to reach a figure of 10 000 000 tons per campaign without any repair. In some circles[5] the objective is to keep a blast furnace on line indefinitely, and in order to achieve this, blast furnace linings are becoming increasingly sophisticated.

When one stands next to a blast furnace in Japan that has made 7 940 000 tons without repair, with the knowledge that the refractory used was made of South African flint clay, and that some of the iron ore used also comes from this country, and realises that the average life of blast furnaces in this country is 1 500 000 tons, then one is inclined to speculate about the causes for this difference. At the Fairless Works[6] of U.S. Steel one blast furnace has already made 7 000 000 tons and it is hoped that it will make 10 000 000 tons, and the refractory used in the bosh and stack is of similar quality to that used in the bosh and stack of local blast furnaces.

The refractory materials used in the bosh and stack of blast furnaces have turned full circle, from 42 per cent Al_2O_3 to 95–99 per cent Al_2O_3 and back again to the dense low alkali 42–44 per cent Al_2O_3, without any apparent improvement. The main improvement overseas in blast furnace life has come about as a result of two important factors, viz.

(*a*) More and improved water cooling, and

(*b*) Method of heating up, quality of burden and operation of the furnace.

On the experimental rotor furnace at Iscor we have shown that the dense 42–44 per cent Al_2O_3 brick when exposed to a blast furnace slag at 1 350°C wears away at a rate of 0.33 inches in six hours. This means that the $13\frac{1}{2}$ inch bosh will be gone in 245 hours when the blast furnace is operated at 1 350°C. If the temperature is 1 600°C to 1 800°C, as found in the bosh, then it is clear that the refractory will not last for 24 hours, unless effective water cooling is applied, as proved by the Tobata No. 3 bosh that made 7.94 m tons. Trials in Japan (Yawata, Kawasaki and Sumitomo)[7] and Great Britain were made and are still going on with fused cast alumina without as yet any high degree of success. Trials are also in progress with the 90 per cent Al_2O_3 brick but it appears that the majority of blast furnace stacks and boshes will be lined with the dense 42–44 per cent Al_2O_3 with a shift towards increased and more effective water cooling.

The most effective method of cooling in the bosh and stack is still a matter of controversy but the flat plate cooler is still very popular and effective. An interesting development at Nippon Steel Corporation is the use of a Russian stave cooling system which apparently is more effective than other types of stave cooling. These stave coolers are at present in use at Nagoya No. 3 and Muroran No. 4 blast furnaces,[7] and apparently offer more resistance to probable gas leakage in furnaces employing higher top pressures. It seems that in some quarters a somewhat despairing attitude, or a complete faith in water cooling, is adopted in that at Appleby-Frodingham serrated stave coolers were installed in the bosh of their Queen Bess furnace. A further interesting development is the proposed use of periclase at Koninklijke Nederlandsche Hoogovens en Staalfabrieken (K.N.H. & S.) where the principle of effective cooling is completely accepted. The main objective of cooling is to establish a freeze line of 1 150°C as far away from the shell in the brickwork as possible, and this is achieved by more and closer spaced coolers. However, the heat must be taken from the brickwork itself and the bricks must convey the heat to the coolers. Periclase with a high thermal conductivity and excellent resistance to both alkalies and blast furnace slag is a most suitable refractory. At Iscor we have demonstrated the superior resistance of high quality periclase to alkalies as compared with the resistance of fireclay. Also, the resistance to blast furnace slag at 1 350°C of periclase is approximately 10 times that of the dense 42–44 per cent Al_2O_3. This low iron, high strength dicalciumsilicate-bonded periclase will be used in the bosh and stack of blast furnace No. 7 at K.N.H. & S.[8] with a semi-graphite block between the periclase and the shell. Incidentally this furnace, which is at present under construction, will have no lintel. Once again the problem with periclase in blast furnaces is that of the effect of prolonged reducing atmospheres. High-quality pitch-impregnated periclase was used on an experimental basis in the bosh of blast furnace No. 2 of the Société Metallurgique de Normandie (S.M.N.) in France and although it did not perform as well as carbon, the magnesia did better than zirconium-corundum, dense 42–44 per cent Al_2O_3, sillimanite and electrically fused zirconium-corundum.[9] The fact that the carbon did better than periclase can perhaps be related to the difference in thermal conductivity, or the efficiency of the water cooling employed, as carbon has not done consistently well in the bosh of blast furnaces. The use of periclase in blast furnaces is an interesting development and should be closely watched or followed up as soon as possible, although the results from K.N.H. & S. may only become available in five or perhaps more years.

A further objective is to balance the life of the stack, bosh and hearth of the blast furnace. With the hearth long lives are obtained with the all-carbon hearth (Tobata No. 3), as well as with the ceramic plug carbon annulus hearth (U.S. Steel Fairless), provided that the cooling is effective. Spray cooling of the hearth as well as underhearth cooling is becoming the norm on the new large blast furnaces. With underhearth cooling effective use is made of an electro-graphite pad some 12–18 inches thick between the carbon blocks and the bottom plate and in close contact with the bottom plate. Some controversy exists as to the relative solubility of carbon and graphite in iron but the majority view is that the higher solubility of graphite in iron is of no importance once the 1 150°C isotherm has been established. Consequently the graphite content of carbon blocks is being increased in order to obtain increased thermal conductivity. The following properties of carbon blocks appear to be the most important:

1. High bulk density and low true porosity.
2. Low permeability.
3. High thermal conductivity.
4. Volume stability up to 1 500°C.
5. Made from anthracite coke.
6. Good shape.

Slow and good drying out of a furnace is considered in many circles as of great importance,[10] and United States Steel believe that this has, to a large extent, contributed to the average 3 500 000 ton life of their blast furnaces. Normally no expansion allowance is made in the lining of blast furnaces despite the fact that the brickwork expands as much as 1.1 per cent up to 1 300°C. The old belief that the supports and the lintel hold the stack up is erroneous and in effect the steelwork holds the stack down. The stresses developed in the brickwork on heating up (especially rapid heating up) results in cracks developing at the point of knuckle loading[11] in the brickwork if the stresses cannot be relieved by creep. This can result in appreciable loss of brickwork. The low alkali, high purity materials used, and the higher firing temperatures employed during the manufacture of the bricks, result in bricks with much greater strength at higher temperatures and also greater resistance to creep. This ability to lessen or dissipate stresses through creep without failure is important in all types of refractory materials. Hence to avoid dangerously high stresses in brickwork it is desirable to compensate for the rigidity of hard fired brickwork by the use of more accommodating cements, i.e. cement that is rigid up to 1 000°C at which temperature it starts to deform to accommodate the knuckle loading. With fast heating up the rate of loading can be such that the brick fractures before it can start to creep. Attempts[12] have been made at K.N.H. & S. to reduce the stresses in the brickwork by making a radial expansion allowance of 0.3 per cent with Perspex. The thermal expansion characteristics of fireclay, its mechanical strength at various temperatures up to the operating temperatures, and its ability to creep under various loads at different temperatures, are becoming increasingly important and a large amount of research is at present under way. The failure up to now of fusion cast blocks can be mainly attributed to a failure to take the necessary steps to decrease stresses in the structure, and the use of smaller fusion-cast bricks will result in more joints and a greater possibility of stress relief. The use of the smaller blocks is contemplated[13] but the cost will be extremely high.

Consistent and good operation of the blast furnace is regarded as of the utmost importance and this perhaps also explains the rigid specifications of the Japanese for raw materials. I personally believe that the permeability of the burden is of the utmost importance and that higher wind rates, and oil injection will have no beneficial effect on the production rate if proper attention is not paid to the permeability of the burden. The only effect of higher wind rates, higher blast temperatures and oil injection with a low permeability burden, will be an extremely high wall activity with a consequent extremely low refractory life unless the rate of water flow through the coolers can be substantially increased. The main factor affecting the permeability of the burden is the uniformity of size of the raw materials. It has perhaps become clear that the quality of the refractory materials used and the quality of workmanship during bricklaying are of little importance, if it is not followed by the same quality and standard of operation. Unfortunately no figures are available to supply positive proof of this statement except the belief of a large number of operating people.

HOT BLAST STOVES

The increased demands on the blast furnace have also affected refractory usage in the hot blast stoves. With the increased temperatures prevailing in the stoves the internal combustion stoves suffered as a result of the instability of the wall between the combustion chamber and the checker chamber. This resulted in the development of the external combustion chamber stove. The instability is related to the long-term ability of the refractory to resist creep at various loads and temperatures, and refractories are selected according to their resistance to creep.

For dome temperatures up to 1 400–1 450°C 60 per cent Al_2O_3 bricks are used in the combustion chamber, dome and top setting of the checkers, followed in the checkers by 50 per cent Al_2O_3 bricks and then 42 per cent Al_2O_3 bricks. For dome temperatures of the order of 1 600–1 650°C the lower part of the combustion chamber is lined with 98 per cent Al_2O_3 bricks followed by silica bricks and again 98 per cent Al_2O_3 and mullite bricks in the lower setting of the checkers.

HOT METAL MIXERS

In many respects torpedo ladles and mixers are very similar. This also applies to the factors affecting the lives obtained on the bricks used in lining these units. The conditions prevailing in these units determine the life of the unit and in mixers 42 per cent Al_2O_3 bricks, 60 per cent Al_2O_3 bricks, 85 per cent Al_2O_3 bricks, low quality magnesia, high quality magnesia, dolomite and high quality magnesia-chrome bricks have been used with varying degrees of success. This perhaps is one of the reasons why mixers are slowly disappearing from the scene apart from the fact that a mixer only mixes under special conditions.

In order to clarify the differences in mixer lives which may range from 200 000 to 1 500 000 tons throughput a considerable amount of work, which will be published in detail at a later stage, has been done at Iscor. Figure 2 is a summary of this work and clearly shows the susceptibility of magnesia to slag basicities lower than 1.1 : 1, and the susceptibility of 42–85 per cent Al_2O_3 bricks to changes in FeO content of the slag. When magnesia is used the slag must be kept at a $CaO:SiO_2$ rate of not less than 1.1 : 1 whereas when high alumina is used the basicity need not be increased to 1.1 : 1 by the addition of reactive lime, but the FeO content of the slag must remain

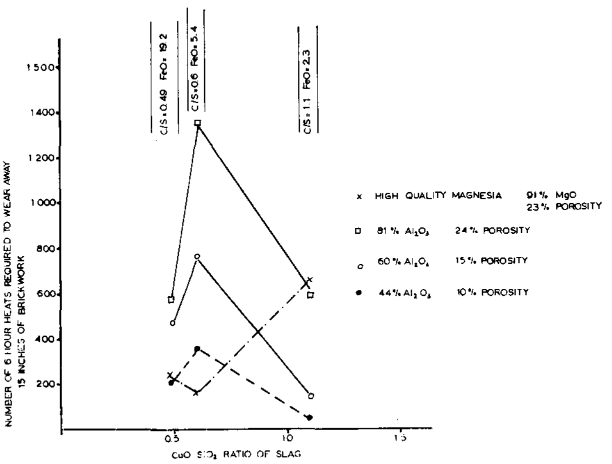

Figure 2—The effect of CaO: SiO_2 ratio and FeO content of the slag on the rate of wear of 91% MgO, 81% Al_2O_3, 60% Al_2O_3 and 44% Al_2O_3 bricks.

low. This explains why a mixer lining burns through in less than two weeks when it cannot be tilted and is maintained at high temperatures. This is an excellent example of the problem of why and how. High fired magnesia-chrome bricks should do extremely well in the mixers, as will become clear at a later stage in the paper. At Tobata[14] in Japan high-fired, low silica, low porosity magnesia-chrome bricks give mixer lives ranging between 1.0 and 1.5 million tons throughput, without the troublesome operation of adding lime to the slag to ensure a $CaO:SiO_2$ ratio of not less than 1.1:1. When desulphurization with soda ash is carried out in the mixer high alumina bricks are not used as the rate of wear due to Na_2O is very high.

For the sake of interest the effect of the quality of cement used for the installation is shown by Figure 3, which clearly shows that the quality of cement used also plays an important part in the determination of the life of the unit. Figure 3 also explains why more attention is paid at present, both by research people and operational people, to the properties of the various types of cement used.

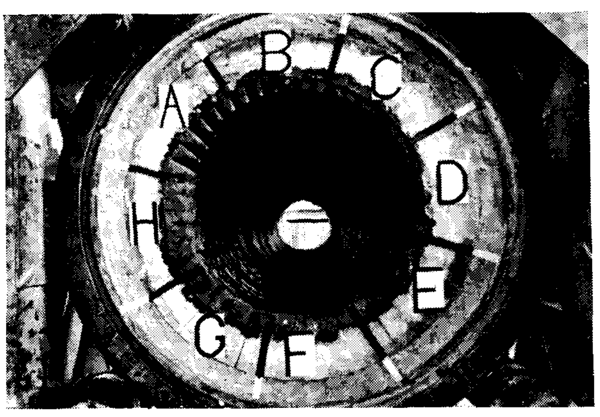

Figure 3—The effect of different cement qualities on the rate of wear of the same quality of brick. In section G no cement was used for laying the bricks.

OXYGEN BLOWING PROCESSES

Henry Bessemer can be called the father of all the oxygen blowing processes except that he did not have pure oxygen available at the price and quantity of today. The principle, however, remains the same in that oxygen is supplied to convert the impurities to oxides to stabilize some of these oxides by combination with lime. The ways in which this is achieved are fairly numerous, with varying degrees of success, speeds and efficiency and at quite different costs. Once again the circle appears to have been closed with the new OBM-process.

The unit that really suffered as a result of the introduction of bulk oxygen has been the open-hearth, as this furnace invariably has not been designed, nor can the construction be readily modified, to cope with oxygen blowing. Admittedly some furnaces produce up to 118 tons[15] per clock hour, with a brick consumption of 10 lb or less, but these are large furnaces with the crown of the roof some 14 feet from sill level and with huge fans capable of supplying the necessary draught. The most exotic and expensive refractory materials have been used in open-hearth furnaces not designed to cope with oxygen, but with little effect except making the annual report of the refractory manufacturers look very good. The biggest advance made in refractories for hard-driven open-hearths has been the realization that they can be driven at an optimum rate and that nothing is achieved by the steelmaker by exceeding this rate. At Ijmuiden[16] with two roof lances and a 30 per cent hot metal practice the roof life is 550 heats at a production rate of 27 tph and an oxygen consumption of 40 cubic metres per ton of steel produced. With all cold charges and 50m^3 oxygen per ton of steel produced and a production rate of 21 tph the life is 450 heats. The roof temperature, which is the critical factor, is strictly controlled not to exceed 1 730°C. At A.T.H.[17] the roof life used to be 800 heats at a production rate of 31 tph but fell to 400 heats at 33 tph. Dr König did a vast amount of research without being able to improve roof life despite the fact that the best quality roof bricks were used, and the problem was eventually solved by the realization that at 33 tph the decrease in life was excessive and by going back to a production rate of $\pm$31 tph the maximum roof life was obtained. The objective of the steelmaker should be to produce steel and not to burn refractories and iron. It will be exceedingly difficult and costly to improve the qualities of the best types of refractory materials available at present for open-hearths by as much as ten per cent.

As a result of the difficulties with the operation of the rotor process we started some ten years ago a long research programme which has resulted in a number of papers in which perhaps not a great deal of originality may be apparent, but which we regard as very good perspective modifiers. All this work is summarized by Figures 4 and 5, and the refractory usage in the proposed LD units will also become clear from a discussion of these figures.

Figure 4 shows the effect of the lime to silica ratio on the slag resistance of two qualities of magnesia, on both a medium quality magnesia-chrome and direct-bonded magnesia-chrome as well as a medium-quality chrome-magnesia. The effect of the $CaO:SiO_2$ ratio of the slag on periclase and magnesia bricks is particularly marked in that the life obtained with periclase and magnesia, when subjected to a slag with a basicity of 3:1 is some ten times that obtained when the basicity is 1:1. The FeO content of the slag was kept constant at 20 per cent as this is the average FeO content of the slag when the steelmaking practice is good. The susceptibility of periclase and magnesia to a lowering in C/S ratio of the slag (also indicated by Figure 2 at much lower C/S ratio and temperature) explains why everybody is paying more and more attention to the reactivity of the lime used in steelmaking.

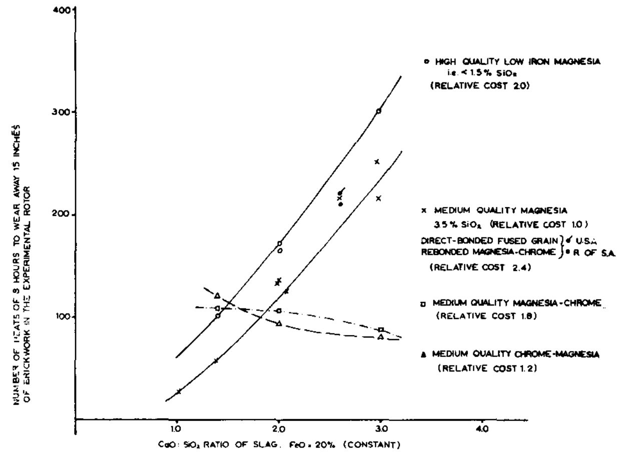

Figure 4—The effect of the basicity of the slag at constant FeO on the rate of wear of periclase, magnesia, magnesia-chrome and chrome-magnesia as determined in the experimental rotor at 1 700°C.

The introduction of chrome-ore to magnesia results in a much decreased susceptibility to changes in slag basicity and exhibits a pendulum effect similar to that shown by the effect of changes in C/S ratio of the silicate in chrome-bearing refractories on the high temperature strength. The life of mag-chrome and chrome-mag at low basicities (i.e. less than 1.5:1) of the slag is better than that of both high and low quality magnesia whereas at high basicities the life is decreased and is very much lower than that of magnesia. The direct-bonded magnesia-chrome, although much more expensive than medium quality magnesia, is about as good as the latter brick at high basicities. However, if the steelmaker does not succeed in obtaining a basic slag very soon during the steelmaking process, as does at times happen in electric furnaces or when lime of low reactivity is used, then the direct-bonded magnesia-chrome does offer distinct advantages over that offered by magnesia or periclase. Lime injection, periodic charging of lime during the heat, throwing lime onto the banks or walls of the furnace, reactivity of the lime, bauxite and iron oxide addition to lime to prevent the formation of a dicalciumsilicate crust on the lime particle and dolomite fettling, are all related to the desire to obtain a basic slag as soon as possible. If this is achieved then both the steelmaker and the refractories' technologist achieve their respective non-conflicting objectives. All over the world positive attempts are made to produce a highly basic slag as soon as possible but the rate at which this is achieved varies considerably with considerably different end results.

Figure 5 is derived from results obtained with different types and qualities of magnesia and periclase bricks used in various campaigns in the works rotor at Pretoria. Nearly every point on the graphs is the average for a number of campaigns except for the points on the right hand side of Figure 5. These results were so disastrous that they were not repeated. The relationships shown by Figure 5 were verified by experimental work in the experimental rotor and are consequently believed to be correct. The silica content of the brick is of the utmost importance as the life increases as the silica content decreases. Both Mr Hubble[18] of United States Steel and I agree that the optimum results are obtained at silica contents of around one per cent as no improved results were obtained at silica contents as low as ± 0.5 per cent. This can perhaps be related to the increased difficulties of making bricks with the required porosities and silicate constitution at these low silica contents. The increased cost, if these bricks can be made properly, may not be balanced by a related increase in life.

The effect of pitch-impregnation of magnesia bricks containing various amounts of silica is extremely interesting as when the silica content is low, pitch-impregnation improves the life by approximately 30 per cent. When the silica content is approximately 3 per cent the improvement is only 15 per cent whereas at a silica content of 7.3 per cent the improvement is minus 290 per cent. The reason for this has been explained elsewhere. The rate of wear which is closely related to the rate of decarbonization of the lining is also closely related to the chemical constitution of the brick. The graph also indicates a possible future trend to penalize the refractory manufacturer with a certain amount if the bricks supplied do not meet specifications. The B_2O_3 content of low-silica dicalciumsilicate containing periclase bricks is also of great importance as the life is decreased when the B_2O_3 content is increased. The rate at which the life is decreased with increased B_2O_3 is, however, not as great as that of the high-temperature strength. The practical implication of this is that bricks made from seawater magnesia must be exceptionally low in B_2O_3 in order to compete with natural magnesite. Iscor specifies a B_2O_3 content of not higher than 0.05 per cent but I believe that a maximum B_2O_3 content of 0.01 per cent must be specified. If boron has such a disastrous effect, what will be the effect of other trace impurities? The boron must be removed from the seawater magnesia to the required levels and this is a costly process. More and more users of periclase go for the natural product which is becoming scarcer and at the same time the price goes up.

The position in South Africa is all but rosy as everybody maintains that millions and millions of tons of low quality magnesite is available, yet nobody can supply a specific figure. The exact size of the reserves of low quality magnesite in this country used to be academic as it was not possible to beneficiate the magnesite. We[19] have developed a froth flotation process which is capable of beneficiating magnesite obtained from nearly all the known worthwhile deposits in the Transvaal. The process works in the laboratory and on a small pilot plant scale, but the economy of the process must be determined as well as the cost of pelletization and deadburning.

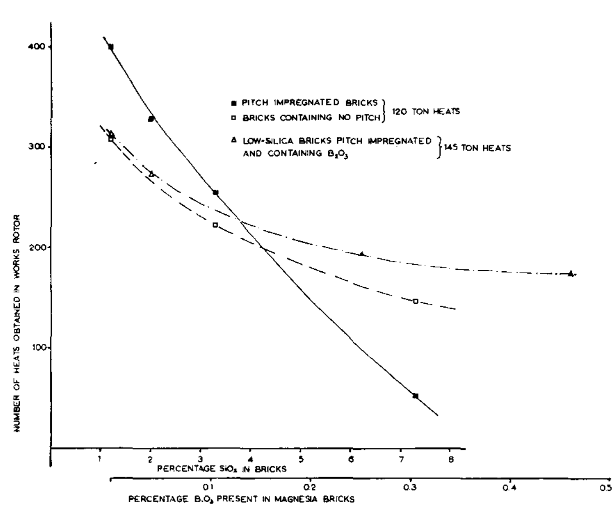

Figure 5—The effect of the silica content and pitch impregnation on the lives obtained with the Pretoria rotor as well as the effect of the B_2O_3 content of high-purity pitch impregnated magnesia bricks on the lining life.

Work is in progress in order to obtain the required information. This work is of the utmost importance as the impurities in South African dolomites are such that these dolomites can not be considered as an alternative to magnesite. The combined ($SiO_2 + Al_2O_3 + Fe_2O_3 + MnO$) content of South African dolomites exceeds eight per cent whereas it should be less than two per cent.

In order to clarify the use of dolomite in LD units high-quality dolomite bricks were imported from Germany and subjected to various slags in the experimental rotor. The dolomite bricks were made from the same grain but of different grain sizes with consequent differences in porosity. The results obtained are shown by Figure 6. This figure clearly shows that with constant FeO in the slag the periclase shows a marked improvement in the life with increased basicity of the slag whereas dolomite is not as susceptible to changes in slag basicity. The life of periclase is markedly affected by a substantial increase in the FeO content of the slag whereas the effect of FeO on dolomite is disastrous. These two factors, viz. basicity of slag and FeO content of the slag, clearly explain why at some plants dolomite is economically competitive with magnesite and why there is an insistence by metallurgical operators as well as refractory technologists on low FeO contents in slags. With comparatively low FeO in the slag it is generally accepted that magnesite is twice as good as dolomite and the choice of refractory is made on the basis of price differential and availability at the furnace. It also clarifies the various results obtained in different steelmaking plants all over the world, namely that the results obtained follow from the type of housekeeping employed and type of steel made. A third factor of great importance is temperature and a large number of steelworkers are progressively going over to periclase and magnesia as a result of the higher tapping temperatures required. Increases of 30°C to 50°C in tapping temperature have become necessary as a result of vacuum degassing and continuous casting. Figure 6 also shows the effect of increases in true porosity of dolomite bricks which are chemically similar.

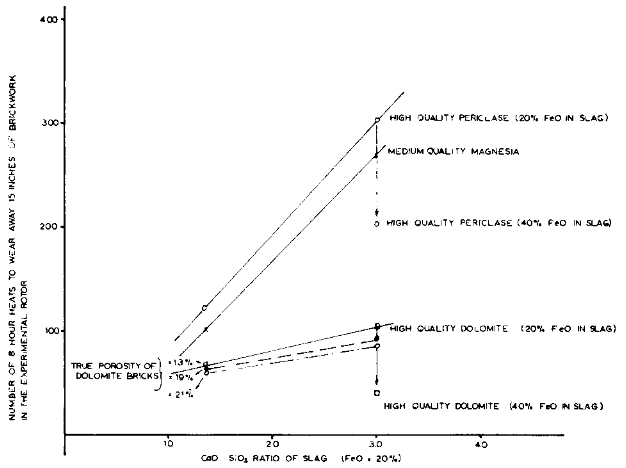

Figure 6—The effect of the basicity of the slag at constant FeO on the rate of wear of periclase and high quality dolomite bricks. At a basicity of 3:1 the effect of increasing the FeO content to 40% on the rate of wear on periclase and dolomite is also shown.

In the opinion of the author the main variables to control in refractory materials are true porosity and chemical constitution whereas the main variables in the metallurgical process that should be kept under close control are: slag basicity, FeO content of the slag and temperature of operation. This does not imply that other properties of the refractory materials and other factors in the metallurgical process should be ignored. If the variables mentioned are controlled within specific limits then the results obtained will be worth more than the effort taken to control and to ensure that control is exercised.

From the discussion so far it has perhaps become clear that the author envisages the use in the scrap charging pad and taphole of the proposed LD units, of burnt pitch-impregnated periclase with less than 1.5 per cent SiO_2 present as dicalciumsilicate. The balance will be made up magnesia bricks burnt and pitch-impregnated with less than three per cent SiO_2 present as merwinite or dicalciumsilicate. Figure 5 clearly shows that when the silicate content exceeds three per cent the increased cost of pitch-impregnation is not compensated by a comparable increase in life as a result of pitch-impregnation. The froth flotation process mentioned above promises a recovery of 60 per cent or more with a grade of magnesite containing 0.4 per cent SiO_2. The recoveries are more than 80 per cent when a grade of magnesite containing ± 1.5 per cent SiO_2 is required.

Knowledge of the cost of a particular decision is becoming of increasing importance. A theoretical case is taken of a unit that can make 10 heats of 100 tons per day with an intermediate repair taking three days (125 tons of refractory) and a major repair (250 tons of refractory) taking five days. Figure 7 represents what can happen if certain decisions are taken. If the unit life is 1 000 heats then it is clear that a decision to increase the rate of production to such an extent that the life is decreased to 500 heats, will increase the cost of refractories per ton of steel produced from 30 cents to 60 cents. The same decision taken when the unit life is 300 heats results in an increase in cost from R1.00 to R2.10 per ton of steel produced. In the first case, the increased rate of production must result in at least an increase of 3 150 tons of steel (contributing say R30 per ton) per year and in the second case 11 550 tons, to make up for the increased cost of refractory. Refractory materials

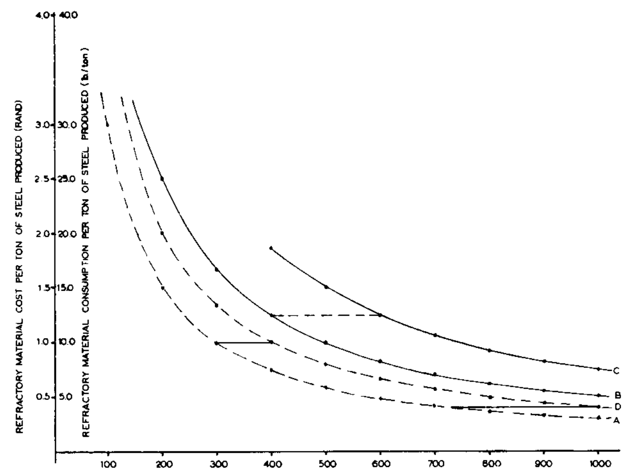

Figure 7—The change in refractory consumption and cost with increased unit life.

Curve A. Refractory material cost with increased unit life (refractory at 6 cents per pound).

Curve B: Refractory material consumption with increased unit life.

Curve C: Refractory material consumption with a 50% intermediate repair.

Curve D—Refractory material cost when using a more expensive refractory (i.e. 8 cents per pound).

cost is a progressively variable cost and increases with rate of production and this rate of change must be established.

Curve B of Figure 7 shows the refractory consumption per ton of steel produced as the unit life increases and curve C shows what happens if a 50 per cent intermediate repair is made at 400 heats. The furnace then has to make 600 heats for the refractory cost to be the same as that at 400 heats. The argument is therefore that the repair schedule is in order as the refractory material cost per ton of steel produced remains the same. However, a five-day repair every 400 heats as opposed to a three-day repair every 400 heats combined with a five-day repair after a further 200 heats results in a yearly gain in production of 3 000 tons, i.e. R90 000 at say R30 per ton. For six furnaces this means R540 000 per year.

It is perhaps clear why furnace scheduling, furnace repair policy, increased rates of production as well as gunning practice are becoming more and more the subject of cost analysis. An additional clerk at R5 000 per year or a computer analysis system is well worth while if the analysis leads to information whereby decisions can be made that will result in a saving of R540 000 per year. A mere statement of record production or increased production per clock hour is worthless unless the increased or decreased cost of the achievement is also given. Curve D of Figure 7 illustrates what happens if a more costly refractory is used in that at a unit life of 300 heats the furnace has to make 100 additional heats with the more expensive refractory to break even. At a unit life of 720 heats the additional number of heats to break even on refractory cost is 380 heats. The relationships between cost, properties and life of refractory materials are becoming increasingly important.

ELECTRIC FURNACES

The inability of LD units, relative to open-hearth furnaces, to consume scrap has resulted in a steady increase in volume of steel made in electric furnaces. The ultra high power concept has reduced the overall refractory costs where this concept has been applied and correctly controlled. Arc length and proper electrode alignment are particularly important factors especially during the refining period when the walls are unprotected by scrap and become exposed to very high temperatures. The control of power consumption to achieve melt down and the length of the arc is critical for refractory life, and computers are used to regulate and calculate the power input. Again, basicity of the slag, the rate at which high basicities are achieved, the FeO content of the slag as well as temperature, determine the life achieved.

The refractories used are determined by the metallurgical conditions and in general the hearth and slagline are constructed with high quality periclase with a tendency to pitch-impregnate these bricks. The walls are direct-bonded magnesia-chrome followed by chrome-magnesia higher up and under severe conditions fused cast magnesia-chrome in critical areas. The roofs are mainly fired or phosphate bonded high alumina with a tendency to use direct bonded magnesia-chrome in critical areas. If the instability of all basic magnesia-chrome roofs can be overcome then these roofs will most probably be used if economical results cannot be achieved with high alumina. Promising results have been obtained at Republic Steel[20] with low silica magnesia-chrome, and the stability appears to be a function of the strength at high temperatures after lime has been taken up. Again special cements are[11] developed to accommodate stresses developed as a result of knuckle loading. Phosphate bonding of high alumina and also magnesia-chrome is increasing and it is claimed that phosphate-bonded magnesia-chrome is as good as a direct-bonded magnesia-chrome in open-hearth furnaces where conditions are not as reducing as in electric furnaces.[21] This difference in atmosphere perhaps also explains why a pitch-impregnated periclase stood two to three inches proud of a similar quality not impregnated after 45 heats in an electric furnace trial.[22]

Once again the trend is to try to protect the refractory as far as economically possible, either through scrap preheating, and/or soft blowing of lime to obtain high basicity slags[23] and lower lime consumption, and/or the injection of millscale to take the place of oxygen blowing[24] to produce a carbon boil without emission of the brown fume associated with oxygen injection. It is claimed that the oxide injection can lower operating costs by up to R1.80 per ton of steel. Scrap preheating up to 650–700°C[25,26] in the scrap charging bucket saves up to R1.50 per ton of steel and 50–58 kWh/ton as well as 20 minutes in heat time. A further protection of the refractory is obtained by the continuous feeding of iron pellets around the electrodes towards the end of the melt-down period of the scrap.

STEEL CASTING LADLES

Slag constitution, slag volume and temperature of the metal and slag as well as holding time all materially affect the lives obtained in ladles. Normally bloating ladle bricks (25–35% Al_2O_3) were used but in order to achieve better lives bricks containing higher alumina have been used. The results are not very encouraging as although increased lives have been obtained these increases were not compatible with the increase in cost. With 50 per cent Al_2O_3 bricks the break-even point is 23.4 heats whereas 19.2 heats were obtained, and with 70 per cent Al_2O_3 the break-even point is 33.2 heats and 18.5 heats were obtained.[27] This small increase is ascribed to the fact that, as the lining wears, the slag picks up Al_2O_3 and becomes more fluid and consequently more aggressive. Pick-up of SiO_2 on the other hand increases the viscosity of the slag and decreases the rate of wear. More and more steelmakers are going over to sand slinging of ladles as an increase of 20 per cent in life is expected. The main advantages of sand slinging of ladles are, however, a reduced cost of the refractory but principally the ease and speed of installation as well as a substantial saving in the number of bricklayers employed. The clay content of the sand is critical and is varied with the steel tapping temperature.

VACUUM DEGASSING

The refractory used is the fused grain rebonded magnesia-chrome as the slag present is relatively acid due to wear of the ladle refractory. Slag volume should be a minimum and the main problem is joint erosion. The effect of method of brick construction is extremely interesting as whereas lives of 800 heats are regarded as good in Europe and Japan lives of up to 2 200 heats are achieved in the U.S.A. The bricks used are similar chemically and physically but there is a marked difference in brick construction. The refractories used in the nozzle are mainly fused grain rebonded brick plus an outer section of fine grained high alumina castable.

CONTINUOUS CASTING

Tundish life appears to be a universal problem as a result of joint erosion and skulling. The bricks used vary from bloating ladle to high-alumina with varying designs of tundishes but as yet there is no real solution to the problem. The best solution to the problem of tundishes appears to be that of Brown and Harry[28] at the Aliquippa Works of Jones and Laughlin, in controlling the atmosphere above the metal in the tundishes together with as small a temperature drop from ladle to mould as is possible. A somewhat disturbing fact of continuous casting is that the refractory material cost is not necessarily less than that of conventional casting and finishing of steel.

REHEATING FURNACES

As a result of trade union problems and a manpower shortage the move is more and more towards the use of plastic refractory materials (either siliceous or high alumina) and castables in soaking pits and reheating furnaces. Fused cast alumina or alumina-silica-zircon is used in critical areas of hearths and there is a trend to use more siliceous plastics as a result of the substantially lower cost of these materials in comparison with that of high alumina.

To conclude, I hope that it has become clear that refractory materials cannot be viewed in isolation, but that there is an interrelationship between refractory material properties and the environment in which these materials are used, with the nature of the environment often determining the life obtained to a much greater extent than the properties of the refractory materials.

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