

# L-D Oxygen Converter (II)

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THE growing acceptance of various oxygen steel making processes with their merits and demerits including theoretical aspects and metallurgical reactions involved has been thoroughly discussed in the first part of the paper by Sen, Nijhawan and Chatterjea. In this paper the economic consideration and cost comparison of L-D process with other conventional basic steel making processes, namely, the Open-Hearth and Thomas process as well as reasonings and justification of adopting L-D process in future steel expansion programme in India will be discussed.

The steel making situation in Asia and Europe is radically different from that prevailing in America. It is obvious that production methods are determined with due consideration to the availability of raw materials including fuels as well as existing market positions. In the U.S. scrap is available in large quantities and at competitive price while scrap is gradually becoming scarcer and dearer in Europe and the position is more critical in Asia. As such, more than 90% of the American steel is made in basic open hearth furnace. The U.K. is probably the next country in which about 85% steel is made in basic open hearth furnace whereas only 40% of the steel is made from O.H. and the remaining 60% by Basic Bessemer from high phosphorus pig iron in Europe, (43% in Germany, 61% in France, 85% in Belgium and Luxemburg). The high nitrogen steel produced in Basic Bessemer or even in Open Hearth tends to restrict its use to such products as bars, wires and small structural shapes and flat products such as strip and plates. Furthermore, fabrication processes requiring welding and cold forming as well as high ductility, have further restricted the use of nitrogen steel. About 50-60% of the steel produced is now reported to be required for the above purpose and recent trends are always on the higher side of its application. Thus the necessity of producing low nitrogen steel is becoming an absolute feature of the steel expansion programme of any country. L-D process produces very low nitrogen steel even lower than that produced by Open-Hearth process. In the normal conventional Basic Bessemer process, the nitrogen content of the steel is about 0.012% and in Open Hearth it is sometimes as low as 0.006%. Lately

there has been a good amount of research and investigational work on the improvement of Basic Bessemer practice to reduce the nitrogen content. Some of the investigations have yielded highly encouraging results and claims have been made to reduce the nitrogen content to the level of 0.005% to 0.006% by adopting certain modifications such as combination of air and oxygen blow, air for 8-10 minutes followed by pure oxygen for 2-3 minutes, mixing steam or carbon-dioxide with oxygen in the final blowing stage along with the addition of a small quantity of iron ore/scrap/millscale. Further improvements in efficient phosphorus removal have been claimed by adopting a technique of adding a new slag containing  $\text{Na}_2\text{CO}_3$  after interrupting the blow at the phosphorus level 0.06-0.08% and giving a second afterblow for a very short period.

With other modifications such as use of pyrometer in the tuyere box, a flame pyrometer for determining the end point by accounting the transmission rather than the emission characteristics of the flame as well as the opacity of the flame, use of ore as in HPN process in Germany at Duisburg-Hamborn, use of scale as in LPN process at Corby, England and oxygen steam or carbon dioxide during the afterblow period, claims have been made to reduce nitrogen content by more than 50%, i.e. to a level of about 0.004-0.006% by modified Thomas process. But the Thomas process has its tight limitations of requirement of high phosphorus (preferably more than 1.5%) and low silicon pig iron. Moreover, the quality of steel has not been reported to be very suitable for the fabrications of sheets, strips, plate, skelp, wire pipe, etc. The Basic Bessemer process could hardly be used in place of all-oxygen process for many reasons explained before for refining pig iron of wide composition, especially that containing high silicon, with medium or low phosphorus content. Moreover the cost of production is also high when compared with L-D process. In Thomas process the converter bottom has to be relined after 40-60 melts, the maintenance of the nozzle sometimes causes interruption in operation, after a certain amount of charges. Such interruptions are not experienced with L-D converter which permits higher time efficiency of the vessel. In practice a smaller number of top-blown converters are needed when compared with a Bessemer plant of the same capacity. For example, three top-blown converters can replace four Bessemer

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tion, resulting in a decreased capital cost. An L-D converter has got a much greater lining life allowing 200-300 melts. The nozzles last for several hundred melts. It is quite well known that the Open-Hearth process is the most widely used process and up till now open-hearth steels have to be used in practice for special fabrication purposes. But it is not always possible to process all kinds of pig iron directly by Open-Hearth process. For example, pig iron containing high silicon has to be processed through duplexing (Acid Bessemer followed by basic Open Hearth). The question of availability of cheap fuel and sufficient scrap is of paramount importance.

For any new investment, the choice of the method of production of steel will be governed by the following important factors:

1. Return on capital investment.
2. Rate of production per unit time (speed of production).
3. Availability of raw materials, namely, steel scrap, fuel and quality of pig iron to be treated.
4. Quality of the steel required for special fabrication purposes.

The most widely used open-hearth process of steel making is largely dependent on the supply of scrap or availability of return scrap on a reasonably cheaper price. The scrap prices are continuously going up and it is difficult for many countries to import sufficient quantities of scrap on economic prices and simultaneously if an undisturbed scrap supply has to be maintained to electric steel making furnaces, open-hearth furnaces in Continent and Asia has to be operated with reduced scrap charges raising the pig iron input sometimes as high as 80-85% of the total charges.

Obviously further expansion in open hearth furnaces for steel making in those countries will involve an increase in the production of pig iron, coke, etc. contributing to a higher cost of production, as well as

very high with an open-hearth furnace with a slow and low return of capital investment. For example, two 45-50 ton L-D vessels operating alternately on 30-35 minutes blowing cycles will produce about 100 tons of steel per hour which is 4-8 times the production rate of a modern 250-ton open-hearth furnace melting about 50% hot metal charge without oxygen enrichment. Thus attempts to equalise the high charging cost arising out of the scrap situation coupled with much lower installation costs and lower conversion costs, make a sound background for the adoption of the L-D process now getting wide favour in the Continent, Canada, Japan and even in the U.S.A. and the U.S.S.R. Many other considerations came later on in favour of the oxygen steel making process. Due to the wide field of application of steel in recent years, attention has been focussed on the production of low nitrogen steel. Reduction in nitrogen burden in the gaseous fluid not only improves the quality of steel but reduces the calorific energy of about 4 million B. T. U., the net fuel consumption required in the open-hearth process, down to 55-60 cu.m. oxygen which is equivalent to the cost of production of about 0.8 times kWh electric energy (unit per cu.m.) for the production of one metric ton of steel.

The average material balances for Open-Hearth, Basic Bessemer and L-D process can roughly be seen from the available data:

For one ton of ingot steel production the average material balance can be shown as follows:

The cost per ton of ingot steel produced from the above raw material balance will largely depend on local condition and market price, for example the price of scrap and pig iron of the composition needed for the purpose.

The comparative capital cost for a 1 m. ton annual capacity plant can be assessed from the prevailing data to be as follows:

2.3 : 1.5 : 1 for O.H. : B.B. : L.D. respectively. while comparative capital charges per ton of steel

	O. H. using iron of 0.3-0.4% P and 0.7-1% (max.) Si	B. B. (without oxygen) using iron of > 1.5% P and 0.7-1% (max.) Si	B.B. (30% oxygen) enrichment using iron of > 1.5% P and 0.7-1% (max.) Si	L-D using iron of 0.2% P and 0.7-1% (max.) Si
	In Tons	In Tons	In Tons	In Tons
Liquid iron	0.700-0.800	1.00-1.10	0.90-0.95	0.900-0.95
Steel scrap	0.250-0.260	0.110-0.120	0.220-0.240	0.190-0.20
Ore and scale	0.170-0.180	...	...	0.010
Limestone	0.080-0.085	...	...	0.030-0.035
Lime	...	0.155-0.165	0.155-0.165	0.070-0.075
Bauxite	...	...	...	0.002
Fuel oil	24.0-25.0 gal.	...	...	...
Flourspar	0.005	...	...	...
Burnt dolomite	0.025	...	...	...
Ferro-silicon (45%)	4-6 lb	...	...	...
Ferro-manganese (78%)	14-16 lb	19-22 lb	19-22 lb	19-22 lb
Oxygen	...	...	700-800 cft.	2,000-2,500 cft.
Compressed air	...	11-13,000 cft.	8-9,000 cft.	...
Labour (productive)	0.700-0.800 m.h.	0.40-0.55 m.h.	0.40-0.55 m.h.	0.40-0.55 m.h.

and a 1 m. ton annual output plant may be assessed as follows :

1.7 : 1.1 : 1.05 : 1 for O.H. : B.B. (without oxygen) : B.B. (with 25% oxygen) : L-D.

Though an extremely thorough calculation has not been made or is even difficult to make, it is claimed not only by "Voest" but by many other industrial concerns in Canada, U.S.A., etc. that the installation costs for an L-D steel plant compared with an Open-Hearth plant of the same capacity would require only 50-60% of the investments including the necessary oxygen plant. This has further been substantiated from the difference in value between calorific energy and electrical energy necessary for the production of oxygen as well as the difference in consumption of refractory. Usually an L-D plant requires only 5-6 kg. dolomite or magnesite per ton of steel as a total on refractories. Operation charges have also been claimed to be about 50-60% due to the reduced number of workers.

A thorough cost comparison is difficult but a general idea can be gained by comparing the cost of

- (a) O.H. using iron having 0.3-0.4% phosphorus with addition of scrap in quantities ranging from 25 to 60% of the charge.
- (b) O.H. using iron having 0.8-1.2% phosphorus with addition of scrap in quantities ranging from 25 to 60% of the charge.
- (c) B.B. using iron containing more than 1.5% phosphorus without any oxygen enrichment.
- (d) B.B. with oxygen enrichment, using iron containing more than 1.5% phosphorus.
- (e) Top-blown oxygen converter using iron of 0.25% phosphorus or more; the silicon content being within the range admissible for the respective processes.

There can be little doubt that the O.H. process will be the most economical provided economic scrap addition can always be made more than 50% of the charge and phosphorus and silicon content of the iron is reasonably low. With scrap additions less than 25% and iron having phosphorus higher than 1.5%, the B.B. might be slightly cheaper provided the silicon content is pretty low. With lower iron prices also, B.B. becomes somewhat more competitive. If the scrap prices are increased and simultaneously iron prices are reasonably steady the difference in costs between high-scrap burden open-hearth working and B.B. process becomes smaller.

The oxygen enriched Bessemer process might be profitable provided the scrap price is reasonably much lower than iron prices. The cost of open-hearth steel must be lower irrespective of iron and scrap prices when treating iron containing less than 0.4% phosphorus rather than 1.0-1.5% phosphorus. Here again the quality of steel produced will have to be taken into account, for example, to reduce the nitrogen content by the adoption of improvements by B.B. process using only 8-12% scrap, an additional quantity of about 1,400-1,600 cu.ft. of oxygen per ton is needed to reduce nitrogen content from 0.012 to 0.005%. In comparing the cost figure with open-hearth, consideration has to be given, of course, to

the fact that oxygen converters use a charge of 10% hot metal and 25% cold scrap or iron ore. Where the scrap position is slightly better and the metal composition is amenable to direct O.H. use and a 50%-50% charge can be consistently used in O.H., the adoption of L-D process will involve an overall increment of 25-50% in the establishment of blast furnaces, coke ovens including sintering and burden preparation plant; but when processing iron containing high silicon (1.5-2.5%) and medium phosphorus (0.3-0.4%) and scrap position is not favourable (say not more than 25-30% scrap is available for regular and constant use) the top-blown converter is likely to gain some more economic ground over open hearth as well as Basic Bessemer and definitely over two-stage Duplex process. Considering other oxygen steel making processes, namely, Rotor, Kaldo, O-V, Duel or Hybrid, Oxygen-Powder Lime, MA, Tropenas, Turbo hearth, Lime-packed tower, Buffer slag processes, etc. which are mostly designed to treat high phosphorus iron as well as to overcome certain shortcomings of L-D, namely, catching carbon on the way down, etc., the cost comparison and comparative economy are difficult to make. Of course it can easily be visualised that for treating at least medium phosphorus high silicon pig iron, these processes may not have any special additional advantage over L-D and is likely to be costlier due to many factors, one of them being definitely severe wearing of refractory lining.

Many commercial L-D plants as well as Rotor and Kaldo plants exist in the Continent as well in Russia, Japan, United States, Canada, etc. The total number of units is likely to be about 40-50 ranging from 20 up to 80 tons capacity per heat. The estimated total production by the end of 1958 in Europe, the U.S.A., and the U.K. is about 7.8 million tons by L-D process and 2.3 million tons by other oxygen steel making processes.

The method of economic production of steel varies greatly from country to country and is dependent on various local conditions. For example, Basic Bessemer which is admirably suitable for processing high phosphorus pig iron in France, Belgium, etc. is not suitable for countries like the U.K. or the U.S.A. where the Open-Hearth process is widely used. The condition is further supplemented with regard to the scrap position, and availability of cheap fuel especially oil resources.

It has also been thoroughly emphasised that even with regard to the Open-Hearth process, any new installation must take care of the capital investment and quick return out of it. India's position can be easily reviewed if the following condition is observed :

- (i) Very little scrap is available for steel melting shop or otherwise constant supply or return of scrap available at reasonable price is irregular and low.
- (ii) Practically there are no resources of liquid fuel and gaseous fuel available is extremely limited.
- (iii) The pig iron produced from Indian raw materials contains medium phosphorus too

- (iv) The silicon content is quite high enough not to enable them for processing straightaway in Open-Hearth or in Basic-Bessemer.

The carbon and sulphur figures are not of any serious consequence accountable for their suitability to be processed by any of the conventional processes. Thus duplexing (Acid-Bessemer followed by Basic Open-Hearth) is the only process prevailing in India. Si and part of the carbon are removed in Acid-Bessemer and metal is charged in Basic Open-Hearth for removal of carbon, phosphorus, etc. Obviously duplexing is a slow process. It has been clearly stated that if Open-Hearth cannot use more than 50% cheap scrap continuously, then automatically the economics of the plant is reduced, more so if the silicon has to be removed prior to its entry into the Open-Hearth and if the phosphorus is not also low enough. Moreover, due to the shortage of cheap fuel and scrap, coupled with high silicon and medium phosphorus content pig iron and high capital investment, it cannot be agreed that full economical justice is being done to the production of steel by Duplex process alone. Naturally search for an alternative economic process has become imperative due to the high lights of improved commercial methods of recent origin.

The question has to be taken up right now, rather more earnestly, because of the well-known fact that India is going to step up her steel production manifold as rapidly as possible through the Second and Third Five Year Plans.

Not only the quantity but also the quality of steel will have to be improved in view of the fact that due to rapid industrialisation and the growth of the iron and steel industry there will be a tremendous amount of demand for steel used for such products as bars, wires, strip, plates, sheets, skelp and other fabrication processes requiring welding and cold working. Obviously low nitrogen rimming steel must be in great demand. Due to serious depletion of foreign exchange, due consideration will have to be given to avoid huge capital investment and low return out of it. Moreover the method must be a fool-proof one which should suit our raw-material and local conditions. One of the most promising methods may be adoption of top-blown L-D process. The advantages of L-D process have already been described in Part I of the paper. Now the possibility of refining Indian pig iron by top blown oxygen refining process will be discussed in detail.

The usual composition of Indian pig iron is :

Carbon	...	...	3.5	-4.0%
Silicon	...	...	1.5	-2.2%
Phosphorus	...	...	0.35	-0.4%
Manganese	...	...	0.7	-1.0%
Sulphur	...	...	0.035-0.04%	

From the theoretical point of view the metalloid removal with the application of gaseous oxygen is likely to follow the chain of oxidation reaction successively as silicon-manganese, carbon-phosphorus, and sulphur. But in practice the reaction kinetics are known to be

namely, lancing inside the bath with different bore size tube or jetting on the surface with subsonic, sonic and supersonic velocity nozzles. Removal of silicon is governed by many factors such as effective surface area with high metalloid concentration initially available for reaction to start and proceed further due to penetration of jet of oxygen in case of jetting over the surface as well as turbulence and violent irregular movement accompanied by slag metal contact due to lancing inside the bath. Just in the beginning of the blow there are possibilities of initial building up of iron oxide in the melt or the viscosity of iron getting slightly reduced as a result of which the silicon removal is likely to be slightly depressed just at the beginning; but desiliconisation increases tremendously and more or less instantaneously within few minutes and also ends quite sharply. Of course the efficiency of desiliconisation decreases with gradual decrease in silicon concentration in the melt and as such the amount of oxygen required per point (0.01%) removed, per ton of metal steadily increases. Removal of manganese is more or less similar in type of silicon. Carbon blow actually starts with higher melt temperature and appreciably with more vigour and intensity only when Si and Mn have been removed to a great extent. Once the carbon blow starts it proceeds rapidly. It is probable that during the process of refining at certain stages, the concentrations of Mn, C, P, etc. would develop a relation which is likely to be equivalent to a particular Si content. Many other factors, namely, surface tension and delay in boiling in the beginning also influence decarburisation. There is of course practically no difficulty in removing the silicon, manganese and carbon from Indian pig iron down to a concentration of about 0.02%.

Sulphur reduction is not very promising. About 20 to 30% of sulphur is reduced but similar results are not always obtained for all cases even more or less under the same working condition. But sulphur, as it is, is not a problem for Indian pig iron. The real problem lies with phosphorus as well as a combination of high silicon and medium phosphorus in Indian pig iron. The Indian pig iron usually contains 0.35-0.40% of phosphorus. The conventional L-D practices in Austria and Canada use pig iron containing less than 0.25% of phosphorus preferably much less. It has also been reported that the process becomes complicated and has not met with success in attempts to purify pig iron containing phosphorus more than 0.25%. Excessive slopping is a very common trouble met with in high phosphorus pig iron and this has been clearly experienced in our experiments too. Sometimes slopping throws (by splashing) away a good amount of foamy slag as a result of which some of the metal is also carried away as shots. All these troubles seriously hamper the running of the converter. Moreover, the conventional L-D process, as is now commercially practised, refines pig iron, the silicon content of which is lower than that of Indian pig iron.

in Indian pig iron (those in comparison with conventional L-D process), makes the process more complicated and difficult for smooth operation by adopting the usual L-D converter practice.

The up to date L-D process produces low-carbon rimming steel only. Commercial low-phosphorus carbon steel cannot be straightaway prepared without recarburising the finished products in L-D process and, as has been explained before, it is difficult to catch the carbon on way down and simultaneously reduce the phosphorus, a problem in which India is likely to be interested. The primary necessity for effective phosphorus removal is to have a highly reactive basic thin slag which must be formed quite early in the process of reaction. The temperature should be fairly low enough preferably about 1,450°C depending on the Si contents of the metal and slag. The relationship between iron content of slag and phosphorus of the steel indicates that lowering of phosphorus in metal can be achieved with increasing oxidising conditions of the slag. The removal of phosphorus is insignificant and probably does not begin in the true sense of metallurgical reaction before the removal of Si and Mn to a great extent. With lower silicon and manganese concentration it is most likely that phosphorus removal starts more or less simultaneously with carbon, provided the temperature is fairly low and the slag basicity and other conditions of slag are maintained to a congenial level. As usual the ratio of  $P_2O_5$  in slag to P in metal has the tendency of following, so to say, an arithmetical average result and P is likely to fall with increased slag basicity. Temperature has a very great effect in metalloid removal. While higher temperature favours desilicification, phosphorus removal can only be achieved at lower temperature. Particular relationship exists between Si content, temperature developed and phosphorus removal. With higher Si content, it is practically impossible to remove phosphorus above a temperature of 1,450°C even with suitable slag making additions. If the temperature is well controlled in the region of 1,450°C or less at Si content less than 0.5%, most of the slag making additions are likely to be utilised for phosphorus removal with comparatively less lining attached. Phosphorus removal is also directly proportional to slag basicity but inversely proportional to the Si content of the slag at least over the range of 20-30% or more of Si content. At Si content 0.5-1.0%, the melt temperature must be below 1,450°C while with the Si content less than 0.5%, phosphorus removal can be effected even at a temperature slightly higher than 1,400-1,450°C. Though phosphorus removal may begin over a range up to 0.8% Si irrespective of slag making material used, efficiency falls off rapidly with decreasing phosphorus content in the bath. Phosphorus removal is favoured by the addition of soda ash and a combination of soda ash and lime and iron ore may be very effective both for desilicification and desulphurisation as well as dephosphorisation. Soda ash even reduces the overall oxygen consumption

ash might be restricted in commercial scale practice due to its high price and other side effect on the lining. Limestone/iron ore/millscale mixture also favours early dephosphorisation and simultaneously preserves the carbon content to a higher level if proper slag making conditions can be maintained. Very highly encouraging and interesting results have been claimed recently for early removal of phosphorus preserving and simultaneously catching the carbon to the desired level by injecting powdered lime and fine iron ore along with oxygen. The use of oxygen-steam during the later part of the blow and adoption of buffer-slag technique and Rotor, Kaldo, Duel or Hybrid and similar processes also claim early removal of phosphorus simultaneously catching carbon on way down. In any case the theoretical aspects of removal of phosphorus before carbon arises out of the fact that the reaction kinetics are altered by the use of top blown oxygen.

National Metallurgical Laboratory has taken up studies on oxygen steel-making processes from Indian pig iron in order to study the following problems:

- (1) To refine the pig iron to steel removing the metalloids C, P, Si, etc. as low as possible.
- (2) To remove Si and P, simultaneously catching the carbon on way down to the desired level and also to produce low alloy steel.
- (3) To study the utility of Indian refractory material for their economic use in L-D converter.
- (4) To eliminate other operational difficulties.

A small converter vessel (Dimension and picture shown in Figs. 1 and 2) was designed and fabricated in the Laboratory. It has a concentric opening in a truncated cone top and fitted on caster-wheels for portability. The converter body can be tilted to any angle for the purpose of filling and pouring. The vessel has got the following dimensions:

Height of the cylindrical portion ...	400 mm.
Breadth of the cylindrical portion ...	300 mm.
Height of the conical portion ...	240 mm.
Diameter of the concentric opening at the mouth ...	150 mm.
Overall thickness of bottom lining ...	200 mm.
Side lining ...	150 mm.

The truncated cone top can be detached when required for lining. The bottom has been given a hemispherical shape during lining. For preliminary studies basic lining of magnesite bricks followed by magnesite ramming was applied. This is because of the fact that the converter has to be used only intermittently for which tar dolomite lining which is likely to absorb moisture during idle run may not be highly suitable. However future programme has been laid out for the application of Indian tar-dolomite lining. The vessel has been designed to treat up to 250 lb of molten metal per heat. At present, experiments are conducted without any hood or fume extraction arrangements and oxygen is fed from an oxygen cylinder through

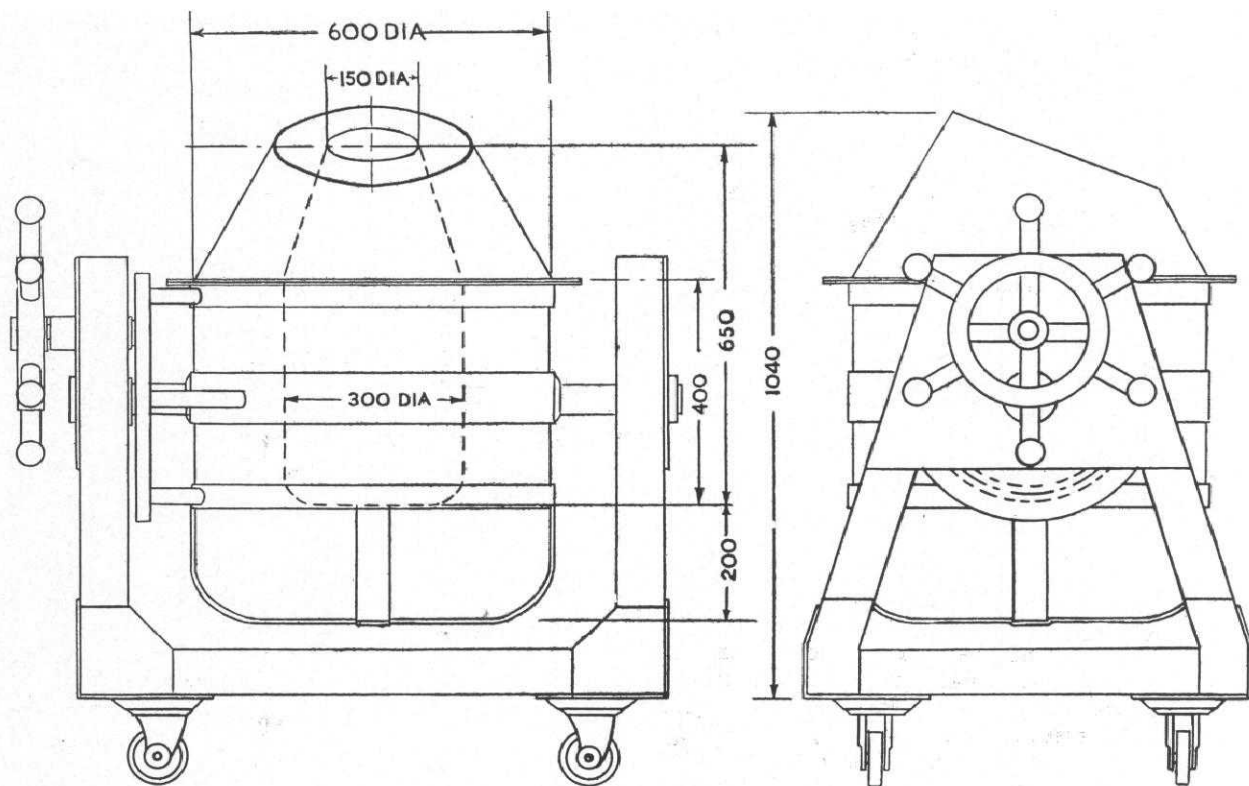


Fig. 1.  
Oxygen steel convertor (100 kg).

a high pressure oxygen hose and then through a non-returnable valve and an adapter which is connected to a 1/4" inside dia. consumable mild steel tube. The mild steel tube is fed vertically more or less on the centre of the bath, the tip dipping inside the bath as far as possible slightly below the slag-metal interface operated manually and by means of "feel". Oxygen volume and pressure are noted from the oxygen regulator attached to the cylinder itself as well as by a pressure gauge positioned on the hose closed to its connection to the lancing tube. The temperature of the feed metal and the final temperature are recorded at the time of experiment by means of optical pyrometer. The hot metal is manually carried by means of a ladle. The vessel is first heated by gas burner and then the hot metal is poured in it. Fluxing agent is added and lancing started. Time, oxygen pressure and oxygen flow-rate are simultaneously noted. From some preliminary experiments it was noted that continued lancing at a stress in a single slag operation not only increases the sloping more violently during the carbon blow period but phosphorus removal is not very encouraging even though carbon and other metalloids are reduced to a very low figure. While the concentration of C, Mn, and Si were reduced by about 90-99% the

the phosphorus could be reduced only up to 0.07%. A longer period of blowing oxygen after the drop of carbon flame was of no help resulting on the contrary sometimes in a chilling effect and over oxidation of metal. Different slag making additions also did not help much. Basicity was not found to improve much simply by the addition of more flux so long as the entire silicious portion remained within the slag. The process of operation has then been modified primarily with the object of removing the phosphorus more efficiently and also to catch carbon on way down simultaneously removing the other metalloids. The basic contention for adopting such modification was that the most important point in the removal of phosphorus is the control over the slag-making-conditions and temperature of the bath. A highly oxidised basic thin active slag formed in the early part of the experiment is the most important criterion for the rapid removal of phosphorus along with carbon or even ahead of carbon. So long as the slag remains highly silicious it is not always possible to increase the basicity simply by the addition of more lime or limestone. Moreover, the temperature of the bath goes very high during desilicisation and in the early part of decarburisation. The temperature has to be brought down by some means to

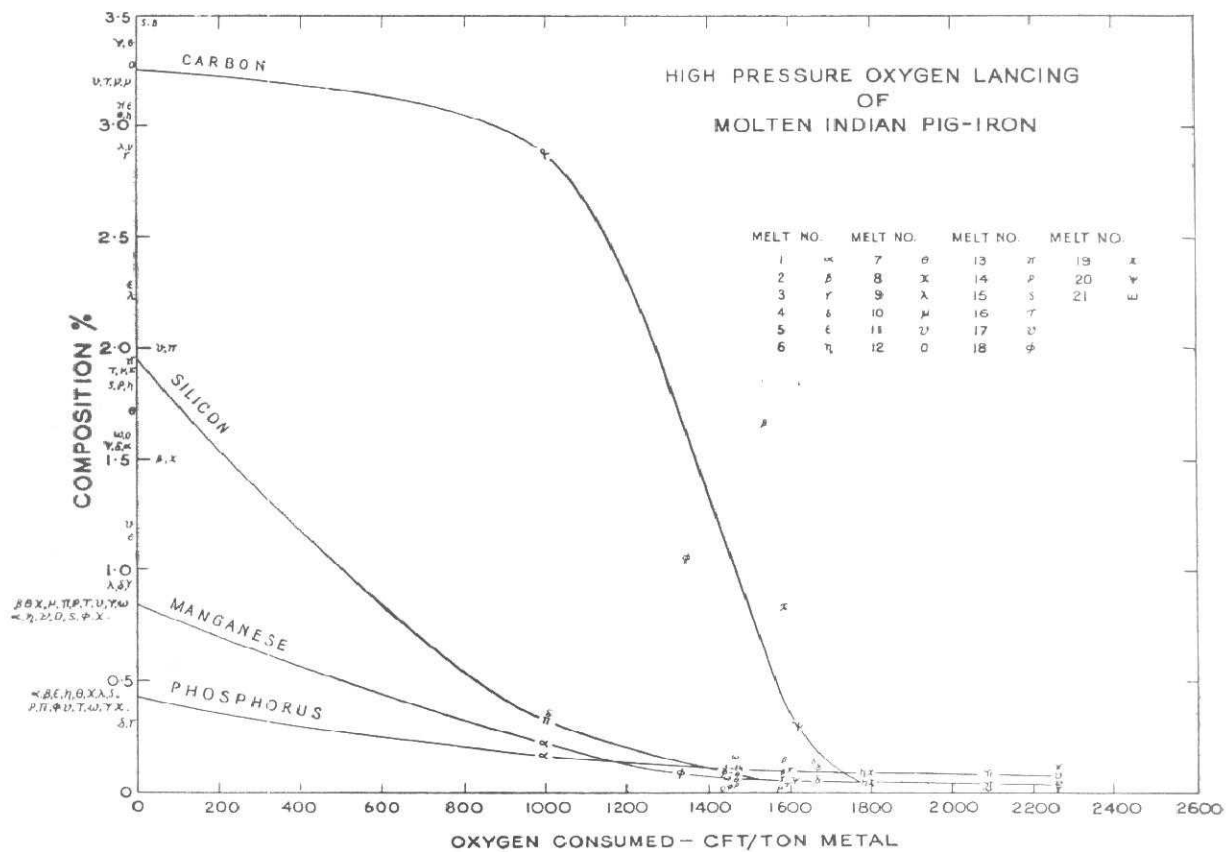


Fig. 2.

a region of 1,400°C. In order to reduce the temperature, and the slopping trouble and to get highly oxidised thin basic slag during the phosphorus removal period before carbon blow starts vigorously, the oxygen pressure, temperature control, regulation of oxygen impingement point, and slag making additions have to be carefully adjusted. Though these seem to be more or less operational technique, they are thoroughly based on theoretical reasoning. With the above contention and observation, a timely "double slagging" technique has been developed and finally adopted which gave very encouraging results with simultaneous temperature control by the addition of limestone/iron ore/millscale during the second stage of lancing after removing the silicious slag.

The hot metal is blown with oxygen, at the flow rate of 10-12 cft. per min. per cwt. metal, with added limestone or lime for about 3-5 min. somewhat with a higher oxygen pressure (120-150 lb. per sq. in.) the tip of the lance (oxygen outlet point) being well below the slag zone and inside the molten metal. Most of the Si is oxidised and taken up by the slag which has now become highly silicious in character

as well as viscous and thick. One lancing tube is consumed during this period. Oxygen blow is discontinued momentarily and major part of the silicious slag is removed. The temperature of the metal was about 1,500-1,600°C at that time. A fresh quantity of limestone/lime and iron-ore or millscale is then added and lancing continued for another 5-8 min. at a slightly lower oxygen pressure (70-100 lb/sq. in.). This gap period in the removal of slag and addition of limestone and iron-ore is utilised for changing the lancing tube. The time taken is hardly about 1 min. or less. Unlike the first stage of lancing the tip of the lancing tube during the second stage of lancing period is adjusted in such a way that it remains more or less very near to the slag-metal zone or just on the slag zone itself avoiding splashing of the slag as far as practicable. This is also further checked from the rate of consumption of lancing tube per min. The oxygen flow-rate for the second stage of lancing has been maintained at about 8-9 cft. per minute. In this way a fresh active highly basic slag is allowed to form and the temperature is also slightly lowered down, the slag being allowed to get highly

oxidized assisted by the arrangement of the oxygen tip position (impingement point), and oxygen pressure and volume, which then help in the removal of phosphorus in a very efficient way before vigorous carbon blow starts. Phosphorus removal being inversely proportional to the Si content of the slag there is likelihood of phosphorus being removed simultaneously by the slag during carbon blow if not some time ahead of carbon. Some of the results, as will be seen from the table (A, B, C & D), have been actually aimed at the removal of metalloids including phosphorus with simultaneous catching of carbon for the production of carbon steel without recarburising the final product. This was partly successful with timely "double-slugging" and addition of limestone/iron-ore/millscale and adjusting the temperature and oxygen impingement point more or less on the buffer slag zone (buffer-slag technique) as well as by adjusting optimum oxygen flow-rate. Moreover, due to the removal of silicious slag volume, and temperature being slightly low, slopping trouble is slightly minimised, though it could not be completely eliminated. The experiments were stopped as soon as the carbon flame drops or according to schedule time of lancing, no after-blow being necessary. Attempts to continue the blow for a very short period for any after-blow reaction of phosphorus after the carbon flame drops, was of no value and on the contrary in a few experiments this led to serious chilling effect and giving difficulty in pouring the metal from the vessel as well as leading to over oxidation of metal. Small ingots were produced from a few runs which gave the visual structure of rimming steel. With few experiments, the steel was deoxidised and killed with ferro-manganese and sometime with little aluminium shots. Physical tests were carried out with ingot sample (Table C) and some pieces could have been easily rolled to fine thin sheets. Primarily, experiments were started with the idea of maximum removal of metalloids with special reference to phosphorus. When encouraging results were obtained, few experiments were conducted to reduce phosphorus content sufficiently in the region of 0.05% simultaneously catching the carbon at the level of about 0.5-1%. (Ref. exp. No. 17-21 in Table B). Quite encouraging results were obtained by the adoption of timely double slugging and addition of limestone/iron-ore/millscale at the second stage of slugging after the elimination of most of the Si and silicious slag and through the adjustment of oxygen pressure, volume and oxygen impingement point. The metal recovery was about 85-90% and overall oxygen efficiency in most of the cases was more than 85%. Lining attack as it is, was practically negligible except in a few cases where the feeding of the lancing tube could not be properly controlled manually and the bottom lining of the vessel was attached to a particular central point due to too close an impingement of oxygen directly on the lining. Due to small scale experiments and difficulty in getting sufficient molten metal for charging the converter up to its full capacity, it was found that the entire refined metal could not sometimes be tapped from the vessel and

the vessel lining gradually develops a protective coating of metal after few experiments. Though this metal coating highly protects the lining and from further attack by silica, it will definitely lower the efficiency of basic lining in the removal of metalloids. However, the portion which is in direct contact with molten metal might be again melted away during the next trial, so that the overall effect of the protective coating was neutralised to a great extent. This is, of course, an operational difficulty and could possibly be very easily avoided by full capacity load molten metal and bigger capacity vessel. Sometimes difficulties have been observed in the complete separation of slag from metal. Shots of metal were very often entangled with slag and if the temperature is too high and there are vigorous bubbling and agitation, the slag has got a tendency to become more viscous during the end point and it was sometimes difficult to completely separate the blown metal from slag. This is more so with lancing inside the molten metal and might possibly be controlled reasonably with jetting arrangement. Because of the fact that only 100-150 lb of molten metal could have been treated in a 250 lb capacity vessel, preliminary experiments were conducted with a pretty high oxygen flow-rate to avoid chilling effect and to conduct the experiments fairly rapidly. The reaction was vigorous and carbon flame was seen to be dropped within 9-11 minutes. Overall consumption of oxygen was of course about 2,000 cft. per ton. From the results incorporated (Table A, B, C, D) it will be seen that complete refining is possible within 10-11 minutes by lancing with consumable tubes operated inside the molten metal, provided the oxygen flow-rate is maintained at about 10 cft. average per minute per cwt. metal approximately. The nitrogen content of the steel was found to be about 0.0035%. The conventional jetting process usually requires 18-22 min. blowing.

Though the Rotor, Kaldo, O-V and other modified processes claim to treat high range phosphorus content iron and to catch carbon on way down, recent experiments in the Continent over L-D process are very encouraging and lay the possibility of treating a wide range of phosphorus containing iron specially those falling in the region of 0.2-0.6% P, provided certain modifications are adopted in L-D converter. The problem of refractory is not so severe with L-D process in comparison with Rotor and Kaldo processes. Moreover the reaction is much faster and takes less time of refining than any other process. Injection of powdered lime along with oxygen and incorporation of steam during the later part of blowing may solve some of the shortcomings of L-D process to treat at least medium phosphorus iron and to reduce slopping trouble and fume evolution.

Though the present experiments have been conducted in a small converter and correlations are necessary with a commercial type bigger converter, as well as that with jetting nozzle, the results are quite encouraging. Further working details are being studied along with the following improvements undertaken



for mechanising the operation :

- (1) Automatic feeding of the lancing tube at the optimum consumption rate per minute.
- (2) Automatic recording of oxygen flow-rate and pressure.
- (3) Recording of bath temperature during successive stages of the blow.
- (4) Fume extraction hood.
- (5) Refractory coated nozzles as well as water cooled nozzles for jetting oxygen at supersonic velocity.
- (6) Other instrumentations.
- (7) Studies on the applicability of Indian refractory material especially Indian dolomite as lining material.

With all these mechanical arrangements a comprehensive study is under way on a bigger scale in an about 3-ton converter with a jetting nozzle to find out all the optimum conditions including operational technique to process Indian pig iron to steel of desired composition including carbon steel.

In the mean-time a good amount of interest has been expressed by a very large number of small foundry industries to adopt oxygen steel-making process on cottage industry scale in India.

There are many other small scale foundries spread out in the different parts of the country who have their own cupola and are interested in making steel castings. It may be possible to run small scale steel-making units using a converter blown with oxygen from the top and fed with hot metal from a cold or hot blast cupola. For a medium size production unit, say of 100 tons per day, two 3-ton oxygen converters working alternately with 35-40 min. maximum overall tap to tap time can easily refine 100 tons of steel per day, which is a suitable medium production unit for a small foundry. Two hot-blast cupolas can easily supply the hot metal at the rate of 4.5 tons/hr. working continuously on the usual 3 shifts a day basis. These combined cupola/L-D installations are likely to be less expensive units when compared with the electric furnace with its accessories. If required even 100% heavy scrap can be melted in these cupolas provided 20-30 lb of high grade ferro-silicon per ton of metal are added. The ultimate composition of the cupola metal thus obtained may be adjusted to about 0.7-1% Si and 2.3% carbon and 0.1-0.2% phosphorus, 0.030 to 0.040% sulphur and 0.8 to 1% manganese which will consume about 2,000 cft. of oxygen for conversion to steel. With hot-blast cupola having a normal metal: coke ratio of 7:1, the consumption of a good variety of bed coke would be about 30 lb per ton metal per day. The total metal loss including 4-5% in cupola and the maximum blowing loss of about 5-8% in the converter would also be counted. Cost figure can roughly be calculated from the material balance :

Hot-blast cupola/L-D converter under a high percentage of heavy scrap melting condition in the

cupola for one ton of liquid steel production.

Raw materials	Amount
Steel scrap to cupola	... 0.8-0.9 ton
Ferro-silicon	... 20-25 lb
Limestone	... 0.015-0.017 lb
Coke for bed	... 0.01 ton
Coke for melting	... 0.120 ton
Scrap/iron ore/millscale addition to converter	... 0.25-0.30 ton
Oxygen	... 1,800-2,000 cft.
Other additions	... 20-22 lb

Under Indian conditions the iron: bed coke ratio might be about 5-6/1 and overall coke consumption might be slightly over 300 lb. Part of the scrap or a good amount of it can be easily replaced by cold pig iron in the cupola. There is even the possibility of adding alloying elements during the final stage of blowing in the converter for the production of low alloy steel.

In adopting oxygen steel making processes consideration has to be given to the cost of tonnage oxygen. Though the cost of oxygen gas production is difficult to assess, it is from that, the cost of production of oxygen is mostly dependent on the cost of electric power. Generally for a 50 ton/day plant a 1,800 h.p. motor is used for production purposes only; this will consume about 1,200 kWh and thus power unit comes to about 23-25 maximum unit per 1,000 cft., for production purpose only. Including compression etc. the maximum unit required for 1,000 cft. is likely to be about 30-35. With a 12 tons per day small unit, a motor of about 825 h.p. is used which running on about 85-90% load will consume about 550 kWh and the overall unit including compression etc. will be 40-45 (max) per 1,000 cft. The probable cost of production only (factory production cost only) with such a small unit under Indian conditions is likely to be about Rs. 7-8 per 1,000 cft. including depreciation (10% annual) and factory overhead expenses but excluding building, salary, etc. The approximate factory production cost of tonnage oxygen for a plant capacity of 1.5 million cft. per day or over 60 tons/day is likely to be about 6-7 rupees per thousand cft. and that of a 3 million cft. per day or 100 tons/day plant required for a half a million tons steel refining plant per annum will be about 4-6 rupees per thousand cft. with an annual depreciation including plant and installations cost of about 10 per cent per annum. So the cost of oxygen per ton of steel might be 12-15 rupees for a steel plant size of 0.25 million tons and 8-12 rupees for a steel plant size of 0.5 million tons per annum on the basis of factory production. Though the capital investment of the oxygen plant may be heavy in the first instance and depreciation is sometimes very high, the return is quick and the life of the plant is quite long.

The L-D process though not independent of scrap has the further advantage of using ore as a replacement of scrap. 25-30% of scrap or iron-ore or millscale or a mixture of the above can be successfully used depending on the availability of the scrap,

So far as the position of scrap is concerned the process very well suits Indian conditions. In the near future a sufficient amount of hydro-electric power may be available at a reasonable rate to justify the setting up of moderately large tonnage oxygen plant.

Results of some preliminary studies have been given (Table A, B, C, and D). Though the studies are not comprehensive enough to dictate finally the suitability of the process to fit local conditions, the results are quite convincing and encouraging to eliminate a certain amount of doubt and confusion about the suitability of refining Indian high-silicon medium phosphorus pig iron to high grade steel. By the adoption of a timely "double-slugging" technique coupled with limestone/iron ore/millscale addition as cooling agents in the opportune moment combined with oxygen powder lime injection if necessary, and buffer slag oxygen impingement technique with suitable adjustment of operational technique with proper instrumentations, it can very well be recommended that top blown oxygen processes will lend themselves to refining Indian pig iron to steel of desired grade including carbon steel.

There are other important applications of top-blown oxygen steel making processes which can very well be utilised under Indian conditions of making steel. For example, the Duplex process which is at present the only process of making steel in India can be improved by first desiliconising the

pig iron in L-D converter or even in open ladle by top-blown high pressure oxygen (preferably by lancing) and then processing the metal in basic open-hearth furnace. It can further be suggested that the Acid Bessemer converter is obsolete and can easily be replaced by top-blown L-D type converter for desiliconisation or even by open ladle desiliconisation by high purity oxygen lancing followed by open-hearth practice as and when needed. This is likely to reduce the cost of production as well as to improve the quality of the low nitrogen steel thus produced. For the installation of any new future steel producing unit, the measures suggested above may be considered for keeping in view the quality of pig iron available for refining to steel.

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## DISCUSSIONS

*Mr. J. A. Charles, British Oxygen Research and Development Ltd., U.K.:* It is good to see that there is a great measure of agreement between our work and that of the N.M.L. From the results I give in Fig. 4 of my paper, an Indian-type iron of 1.5% silicon, i.e., within the range quoted as being used in Mr. Sen's work, is dephosphorised down to about 0.06% phosphorus using a single slag only, whilst the carbon content is still above 1%. I should have thought, it should have been possible to achieve this or even lower phosphorus levels in the final steel by maintaining basicity without recourse to a double slag treatment as found necessary by Mr. Sen. Is it possible that this is the result of oxygen introduction only just beneath the metal surface, as is described as being the practice during the second part of the double slag technique? Blowing at low velocities at the metal slag interface is good from the point of view of the rapid formation of a fluid slag but is not the

best way to obtain the lowest phosphorus contents once the slag is formed. The high local temperatures and melt stratification which result are against it. At this stage the maximum mixing of the bath and slag is required either by deep lancing using a protected lance or by high velocity jetting.

*Mr. B. L. Sen (Author):* I agree with Mr. Charles that depth of penetration and surface area available are important factors, and I have made mention of them in my paper. I would further clarify that in the single slag operation, we have carried out the experiments with the lancing tube well below the metal bath, the initial pressure of oxygen was increased from 100 psi to 160 psi and there was a lot of agitation as well as depth and surface available leading to mixing of the slag with the metal; but we could not reach any satisfactory P removal. One of the reasons might probably be the high Si content of Indian pig iron which produces voluminous highly silicious slag. Mr. Charles

might be referring to refining of a low Si content iron say, about 1% or at 1.2% maximum, but we started with a Si level of about 2% usually available with Indian iron and with all the silicious slag remaining inside the bath and the matrix, it was really very difficult to go below 0.07% P unless part of the silicious slag was removed and fresh active highly basic slag allowed to form in spite of the fact that in the single slag operation we had the lance tube impingement point quite within the matrix and operated at a pressure of about 160 psi.

*Mr. A. A. Parish, Broken Hill Proprietary Ltd., Australia:* Will the author comment on the economics of oxygen steel making processes?

*Mr. B. L. Sen (Author):* Comparison of costs has been given in my paper: the particular figure of two 40-ton L-D vessels operating alternately producing 4 to 8 times of steel as compared with 250 tons open hearth furnace without oxygen enrichment was actually taken from existing L-D furnace practices in Canada and other places, where it was worked out on the basis of their L-D operations over a period of 2½ years. I would however like to emphasise on the point that we are also interested in having a steel much lower in nitrogen than that produced in the open hearth furnace. With the present rate of increase in steel production this low N steel will be essential in certain products required in deep drawing, small structural straps, etc., and it appears that the oxygen steel making processes will definitely have some advantages over the open hearth processes.

*Dr. K. Wada, Director Yawata Steel Works, Japan:* The authors have given an elaborate account of the various steel making processes and I thought it would not be out of place for me to say here a few words on the present position of the L-D process in Japan. Experimental work was carried out at the Yawata Works between 1954-56 in a 5-ton converter and from the study of 1330 heats that were made it was decided to adopt the L-D process. Two 50-ton L-D converters were put in regular operation in September 1957 and are at present producing 45,000 to 50,000 tons of steel per month without serious difficulties.

The elimination of the red fumes given off during the blow is one of the most important problems. Our converters are equipped with a waste heat boiler which yields 320 kg of steam, from the heat recovered, per ton of steel. A dust collector also recovers the dust which is contained to the extent of 50 mg/mm<sup>3</sup> in the waste gas. P content being controlled in the pig iron we have not experienced any difficulty regarding dephosphorisation. N<sub>2</sub> content in the ladle is of 0.002% and the quality of steel obtained is quite satisfactory. Using 85% molten pig iron and blowing with O<sub>2</sub> of 99.6% purity, steel is tapped at intervals of 30 minutes.

The experiments carried out at the Yawata Works have contributed a great deal towards the establishment of the L-D process in Japan and it is expected that 1/4 of the Japanese steel ingots will be obtained from L-D converters by 1962.



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