

L-D Oxygen Converter (I)

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EVER since steel has become the primary index of a nation's basic industrial prospect, tireless efforts are being made by the metallurgists all over the world in recent years to produce more and more steel by comparatively easier and cheaper methods. Whereas fundamental research workers are advancing slowly and steadily to study critically the various thermodynamical reactions involved in the refining of pig iron to steel, the process metallurgists are advancing at a very rapid speed to alter and increase the kinetics of steel-making reactions and hence to increase the throughput per unit time. Simultaneously, due to the wide range of application of steel in diverse fields, attention has been pressingly focussed on the quality of steel produced along with a faster rate of production. Due consideration, primarily on the quality and throughput, has practically revolutionised the up-to-date steel making processes fundamentally starting from the Bessemer process of steel making. This rapid evolution has lately innovated the use of high purity oxygen in the iron and steel production unit both for improvement in quality and for greater output. Basically of course there is nothing new in the use of oxygen for the refining of steel, a fact which was foreseen even 100 years ago by Henry Bessemer in addition to his original patent universally known as Bessemer process, namely, blowing of air inside the molten pig iron injected from the bottom of a vessel lined with refractory. Bessemer, as a matter of fact, attempted to use gaseous fluid carrying oxygen inside the molten metal by pumping air through a vertical pipe and actually his patent of 1856 claimed the use of oxygen in the refining of steel. Several other patents were also taken from 1900 to 1948 by William Kelly, Robert Mushet, Joshep Martin, F. W. Harbord, T. Twynam, O. Lellep, R. Durrer, E. V. Schwarth, H. Hellbrugge, T. E. Swess, H. Trenkler Herzog, etc. It is reported that the original initiative was started in 1939 by Karl Valerian Schwarz, an employee of Brassert Co. (German patent covering injection of O_2 into molten metal bath in 1945, which patent became British property afterwards), and by R. Durrer at Berlin. Further experiments were carried out in Germany, Switzerland and Austria and the ownership of L-D process is now vested in a consortium of interests, known as "Brassert Oxygen Technik A. G." with

headquarters at Zurich, covering various VOEST patents (23 in Austria, 114 in foreign countries) and DAMG patents (25 in Austria, 94 in foreign countries) and patents of the Brassert Group (20 in foreign countries). Since then the process has undergone many evolutions mainly in the method of injecting the gaseous fluid. Modern methods have been developed replacing the air by pure oxygen to improve the quality of steel avoiding nitrogen pick up and also to improve the production rate. Obviously these developments were possible due to the simultaneous development in the production of high purity tonnage oxygen on a commercial scale.

There are various methods of steel production, some of the commonly used being Open Hearth process, Basic Bessemer process (Thomas process), Duplex process (Acid Bessemer followed by basic Open Hearth) Electric process, Oxygen Steel-making processes (L-D, Rotor, Kaldo, etc.)

In this paper the various oxygen steel-making processes will be reviewed in the light of their chief advantages and disadvantages with regard to other processes with special reference to the possibilities of adopting oxygen steel-making under Indian conditions. Even with regard to oxygen steel-making processes, abundant literature is available on L-D, Rotor, Kaldo, O-V (Oxygen-steam), Oxygen-Carbon dioxide, Turbo-Hearth, MA (side blown) and Topenas converter processes. As the L-D process is finding more commercial application, attempts will be made to discuss the process in detail along with other oxygen steel making processes.

The oxidation reaction prevailing in various steel-making processes is normally affected by oxygen carrying element in various forms, namely, air or iron-ore, or by the use of oxygen alone. Unlike air, the main advantage of gaseous oxygen is the absence of nitrogen ballast, thus ensuring better and quick transfer of heat accompanied by a higher reaction temperature and an increased rate of reaction. Obviously the use of ore as an oxygen carrying agent, is being gradually replaced partly or wholly by gaseous oxygen because of the mobility of oxygen as well as the net saving in heat calorie, which would not only be needed to melt the ore but also will not introduce unwanted foreign material in the melt.

L-D Process

The Linz-Donawitz process, commonly known as L-D

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process, has its origin of commercial production from "Vereinigte Osterreichische Eisen-und Stahlwerke Aktiengesellschaft" (VOEST), Linz, Austria. In Austria, the process was adopted for the regular production of steel from 1953 and 250,000 tons of finished steel was made in that very year. It is further reported that at present about 40% of the total steel is made by L-D process in Austria. High purity oxygen is usually jetted from above the molten metal by means of a water cooled nozzle (usually made of copper) in a converter type basic lined vessel. The motion of the nozzle is controlled by an electrically operated hoist. The position of the nozzle is indicated by a depth indicator. Nozzle dimensions which depend on the converter capacity as well as blowing time are usually adjusted to about 20-150 cm above the bath. The pressure of oxygen varies from 80-200 p.s.i. The temperature is recorded by immersion pyrometer. The blowing time varies between 18-22 minutes depending on the quality of the pig treated. It is very important that the nozzle tip should be placed exactly at the middle along the axis of the vessel in order to fulfil the conditions of continuous transfer of the chain of reactions throughout the mass of metal. Moreover, the continuous transfer of chain of the reactions demands particular geometrical proportion of the melting vessel. An adequate relation between the depth of the metal bath and the diameter and actual size of the reaction zone has been claimed to be an essential feature with the L-D converter to ensure sufficient effective space for the metallurgical reactions between the melt and the slag during the rotation as well as agitation of the bath within the time limit.

Metallurgical reactions

Referring to the metallurgical reactions involved during the operation of an L-D vessel, basically the reactions are oxidation of metalloids and their removal either as a gas or being slagged out through the addition agents. The slagging material is either lime stone or lime. In practice, scrap or millscale or high grade iron ore is also added along with lime or limestone. Much literature is available on the probable reactions prevailing in top blown oxygen steel-making process and it is worthwhile to discuss the reaction mechanism in some detail before going in for the practical trial results. As soon as oxygen strikes the surface of the metal bath an immediate formation of the iron oxide is ensured just on the surface and this iron oxide instantaneously reacts with lime, forming calciferite which then acts as a medium for the removal of the metalloids either slagging their oxides formed by gaseous oxygen directly, or oxidising the metalloids through excess iron oxide present and then slagging them down. It is most probable that in practice both the reactions occur simultaneously, the oxygen as it is, as well as the excess iron oxide present in the matrix both are responsible for oxidation of metalloids and reaction probably starts at the surface in the beginning, then rapidly progresses inside the bath rather than steady slag-metal interface reaction or reaction being

confined solely to the oxygen impingement zone. The major oxidation of course is initiated and effected by mobile oxygen. It is quite obvious that the slag should be of a highly oxidised nature as well as highly reactive and basic in character for rapid elimination of the metalloids. The jetting with oxygen is no doubt a highly intensive surface reaction but there is obviously a limit to this surface reaction which cannot continue without some sort of stirring or agitation throughout the whole mass, facilitating the movement of fresh unreacted metal surface onto the reaction zone of oxygen impingement. Fortunately this desired motion of the metal bath is generated through thermal diffusion and differences in specific weights of the just refined metal in the vicinity of the oxygen jet and that of the rest of the melt in which oxygen or oxygen carrying element has not yet penetrated. The former being greater in specific weight than the latter, has the tendency of sinking down while pushing the others up. Within a few minutes of the starting of oxygen blowing this movement becomes violent and more so when carbon starts boiling, with the necessary evolution of carbon monoxide gas bubbling throughout the mass. At that time slag-metal interface reactions are less predominant due to more irregular and violent movements and disturbed interface layer. Stopping is naturally expected during this violent motion when the slag has become sufficiently thick. The slag is also expected to be mixed up with shots of metal due to the violent irregular motion of the entire mass. The metalloid removals are likely to take the usual path of oxidation, namely, silicon-manganese, carbon, phosphorus and sulphur. Silicon and manganese are removed within the first few minutes of blowing in which the carbon blow is not so predominant. The next phase is naturally the carbon blow which becomes violent within a few minutes after the major portion of the silicon is blown out. Phosphorus removal should come after that. But for many reasons it is claimed that phosphorus is eliminated more or less simultaneously with carbon and this is claimed to be a special advantage of oxygen steel-making processes.

Though there is a small amount of sulphur removal, it is not yet clear how actually sulphur is removed except the contention that due to the abnormally high temperature developed some sulphur along with iron oxide and manganese oxide is likely to be volatilised out of the bath. Of course some sulphur is to be found in the slag, probably carried along with manganese. Theoretically of course better sulphur removal is expected in the use of gaseous oxygen because of the fact that the slag carries comparatively higher CaO and lower FeO % in it. Apart from other factors, as the desulphurisation power of a basic slag varies directly with the simple figure $\text{CaO} - (\text{SiO}_2 + \text{P}_2\text{O}_5)$, in normal steel-making processes sulphur removal becomes difficult due to the fact that CaO content of the slag is naturally forced down by the rising FeO content. During the Si-Mn blow, temperature shoots up very high, so much so that cooling down by the additions of

scrap or iron ore, or millscale is invariably necessary during the C-P blow. This is more so because of the fact that phosphorus removal has to be carried out at a comparatively lower temperature preferably in the region of 1,450°C.

The metallurgical reaction in the process of jetting oxygen can be better discussed by comparing it with different other ways of introducing oxygen. The oxygen can be introduced by means of subsonic, sonic and supersonic velocity jets and can be lanced with different bore diameter consumable mild steel tubes below the slag-metal interface. For example in jetting processes, during the first stage up to about 500 cft. of oxygen per ton, use of large bore nozzle is likely to give the highest total (C+Si+Mn) removal, and also desiliconising efficiency, probably as a result of the large surface area covered by the jet which is of more importance than the stirring action during the early stages when metalloid concentration is high. The total efficiency for subsonic, sonic or supersonic (venturi) velocity nozzle rises markedly throughout. The venturi nozzle gives the highest efficiencies of any method in the final stages of blowing when metalloid concentration is low. In lancing, the initial desiliconising efficiency is higher than either sonic or subsonic jetting. The governing factors determining the efficiencies of desiliconisation and the trend of further reactions depends on the effective area available due to penetration as well as on the depth of penetration which also causes turbulence. In the initial stages, of course, the controlling factor is governed by the effective area available due to penetration since high metalloid concentration is available at the surface. In the later stages turbulence is the predominant factor for allowing the metalloids to be brought into the reaction zone as quickly as possible. Large bore nozzles supplying oxygen with subsonic or sonic velocity are not likely to fulfil both the conditions and thus jetting with venturi nozzles would be likely to give the highest overall efficiencies for the removal of metalloids especially C, Si, Mn to their lowest concentrations. With subsonic velocity jetting, overall total efficiencies are expected to be lower. Lancing is likely to produce a combined effect and reaction is likely to be very rapid depending on the pressure of oxygen fed and adjustment of lancing tip inside the bath. The initial desiliconising efficiency appears to be higher than either sonic or subsonic jetting. Removal of phosphorus is governed by many factors. Unlike Basic Bessemer process, L-D process claims that phosphorus is removed along with carbon if not slightly ahead of carbon. Early removal of phosphorus may be governed by the following factors:

- (a) Very early formation of slag.
- (b) Slag being highly basic, thin and reactive in nature.
- (c) The oxygen potential of the slag being very high.
- (d) There being a thorough mixing of oxygen carrying slag with the metal, due to violent

as well as irregular movement of the whole mass of metal as well as the slag.

- (e) The reaction kinetics being altered through oxygen injection and other operational tactics.

In the conventional L-D process, it is difficult to reduce phosphorus and simultaneously catch carbon at a desired level for the production of low phosphorus carbon steel. Lately this problem has drawn the attention of many investigators and claims have also been forthcoming to achieve successful results. The thinking at certain quarters that top blown L-D process is more or less an improvement over the Thomas process of bottom blowing with air or even with oxygen enriched air, cannot be justified because of the reason that the reaction kinetics are different for the two processes. Active slag formation is much delayed in Thomas process and probably does not start before the carbon boil begins to an appreciable extent, whereas highly basic reactive slag is immediately formed in L-D process as soon as oxygen jetting is started. The iron oxide formed, being no longer subjected to survival of the action of silica, immediately reacts with lime, forming active calci-ferrite, which gradually takes up the metalloids. The rate of reaction in Thomas process is slow initially, increases to a maximum at the end of decarburisation resulting in a high oxygen content in the bath, while the rate of reaction of L-D process is more rapid during the early stages, reaches to a maximum after about 10 to 14 minutes, thereafter again decreases to a low value, thus having the effect of minimising the oxygen content of the bath. The phosphorus partition ratios in top blowing are tremendously greater than in bottom blowing at higher carbon concentration (>0.5%) of the bath.

A temperature of about 3,500-4,500°F is developed at the oxygen impingement point, but the average bath temperature seldom exceeds 1,550°C. From theoretical calculation, namely, % C × 94 + % Si × 176 + % P × 48 + % Mn × 57 + % iron oxide × 50, the theoretical temperature rise per point (.01%) can be calculated to be 1.3° for C, 3.1° for Si, 2.0° for P, 0.8° for Mn, 0.8° for S, 0.5° for Fe. With average pig iron composition the calculated theoretical temperature rise will then come to about 1,000°C. But in actual trial and practice the increase in temperature throughout the melt is hardly about 300°C.

Due to the high temperature in the reaction centre a certain amount of iron and manganese evaporates taking up excess oxygen bound up with them. Thus the iron and manganese oxide evaporate and condense to a reddish brown fume, which is a characteristic of this process. More than 90% of the solid particles contained in the fumes are iron oxide and the rest mainly MnO with small quantities of CaO and SiO₂, all being in a very fine state (<0.5 micron.). Usually about 25-35 lb of solid particles per ton of steel is formed. Efficient methods of catching these dusts up to about 70 to 75% have now been adopted in commercial plants. Data available from commercial plant practice

are produced from a 35-ton melt L-D converter. The gases which contain about 90% CO are evolved at a temperature of about 1,800°C.

Usually lime and small lumpy limestone are used for slag making. Depending on the Si, P and Mn content of the pig iron, about 50-70 kg. of slagging material is required per ton of steel produced. The slag quantity amounts to 120-150 kg. depending on the metalloid content, per ton of steel produced. The loss of iron carried in the slag amounts to about 2% per ton of steel. The amount of scrap or iron ore or millscale used as cooling agents amounts to about 20-30% of the charge. Very high thermal efficiency (70-75%) has been claimed in commercial practice.

The usual lining of an L-D converter consists of a permanent lining of magnesite bricks and wear lining of pressed tar-magnesitic dolomite bricks. Between these two linings, a back rammed layer of the same tar-dolomite material is placed in. Always a special grade of refractory material is used. The average durability of the wear lining has been claimed to be about 300 charges lasting for 10-15 days, which consumes about 5-6 kg. of dolomite. The durability of the oxygen jet is generally claimed to be unlimited and replacement can be done within a few minutes by a spare nozzle.

The oxygen requirements can be calculated theoretically from the following figures :

0.01% Si/ton	require	0.225 lb	O ₂	or	3.07 cft.	0.01%/ton
0.01% Mn/ton	"	0.0625 "	O ₂	or	0.784 "	do
0.01% C/ton	"	0.299 "	O ₂	or	3.59 "	do
0.01% P/ton	"	0.261 "	O ₂	or	3.48 "	do
0.01% S/ton	"	0.202 "	O ₂	or	2.69 "	do
0.01% Fe/ton	"	"	O ₂	or	0.77 "	do

Depending on the quality of the pig iron treated the average oxygen consumption per ton of steel produced is about 2,000 cft. or 57 normal cu.m. with an efficiency of about 95%. In commercial practice an additional amount of about 2-3 Nm³ is required for pre-heating the converter and the cleaning of the mouth, and in casting pit. So the average oxygen consumption per ton of steel is about 60 Nm³. A more reasonable figure for oxygen consumption can only be considered after taking into account both the phosphorus as well as silicon content of the pig iron. For example, oxygen consumption will be of the following nature with different phosphorus content of the pig iron with the normal silicon burden less than 1.5%.

Low P iron (0.3% P)	...	2,000-2,500 cft. O ₂ /ton
Med. P iron (1.0-1.5% P)	...	2,500-3,000 cft. O ₂ /ton
High P iron (1.5-2%)	...	3,000-3,500 cft. O ₂ /ton

Properties of L-D steel

The oxygen blown steel has a very low nitrogen content (<0.004%). Very good soft rimming steel is produced by L-D process even without the addition of deoxidisers. It is claimed that all grades of killed carbon steel and rimming steel as well as low alloy steel can be produced by L-D process. L-D

ship, plates and sheets. Tensile strength and yield point values very well correlate to chemical composition of L-D steel. Elongation, reduction of area and notch toughness values are claimed to be pretty high. Good resistivity to aging also can be obtained from soft L-D steel. In general the L-D steel is applicable from ordinary structural steels up to high tensile steels. It is also claimed from practical experiences that L-D steel is superior in quality in many respects to open hearth steel.

OTHER OXYGEN STEEL MAKING PROCESSES

Rotor process

The process has been developed by Dr. Graef in Germany and small commercial units are in practice in Oberhausen, Germany. It is a long kiln, held more or less horizontally which revolves between 0.1 to 0.5 rpm. The rotor has a tilting arrangement to an angle of 10-15°. As usual, it is lined with a tar dolomite layer rammed over a permanent magnesite lining. There are two oxygen introducing arrangements, namely, the "primary" jet and "secondary" jet. Through the water-cooled primary jet oxygen is forced at 6 atmosphere inside the molten metal while the secondary nozzle placed above the molten bath serves the purpose of combusting all the CO into CO₂ by lancing oxygen at 3 atmosphere. The time of blowing is about 40-50 minutes and about 1½ to 2 hours are required to finish a heat. The advantages which have been claimed from the rotor process are mainly confined to its applicability in the refining of pig iron of varied phosphorus content even up to 2%. Unlike the stationary L-D converter, in Rotor process more surface area is likely to be available for the oxygen to react as well as more slag-metal reaction is ensured and it is claimed that the catching of carbon on the way down and simultaneous removal of phosphorus to a very low figure are remarkably achieved by this process. Dephosphorisation has been claimed to be completed at carbon content between 1-1.5%. About 1,000 kg. of iron ore per ton of raw steel can be added in this process so that the requirement of pig iron is also much less. Oxygen consumption is about 75 cu. m. of which 15-20 cu. m. of 95-99% pure oxygen is required for the primary nozzle and 60-65 cu. m. of 73% pure oxygen for the secondary nozzle. Slag volume amounts to about 4-5% of the weight of metal. Complete separation of metal from slag is difficult as the metal comes over with the slag and also it is liable to be contaminated with shots. High refractory wear and slow production rate are amongst certain difficulties which restrict the wide use of the process on a commercial scale.

Kaldo process

The process known as Kalling Domnarvet process

Domnarvet, Sweden through the pioneer work of Bo. Kalling. It is also a revolving kiln process and is composed of cylindrical crucible-converter type the bottom of which resembles a hemisphere. The cylindrical vessel which is placed in a tilting position at an angle of about 30° with the horizontal axis rotates at a speed of about 30 rpm. on its own central axis. Low pressure oxygen is introduced through water cooled nozzle above the surface of the molten metal in a slightly tangential way (about 15°). The centre line of the furnace and the centre line of the oxygen tube is about 5° . Here again the main advantages are more slag-metal reaction and greater surface area being exposed to oxygen reaction which have claimed successful treatment of high phosphorus pig iron and simultaneous catching of carbon on the way down with the removal of phosphorus to a very low figure e.g., about 0.025% phosphorus at 0.5% carbon. The Kaldo plant at Domnarvet, Sweden has been known to be equipped with arrangements of adding lime and iron ore continuously during the blow which are likely to decrease the present lengthy operating cycle. Blowing time is about 35-40 minutes using ordinary high phosphorus iron and cooling with ore. The time for tap to tap is about $1\frac{1}{2}$ hours to 2 hours. The slag volume amounts to about 4-5% of the weight of the metal. Complete separation of metal from slag is difficult as the metal comes over along with the slag and also it is liable to be contaminated with shots. Oxygen consumption amounts to 2,300-2,500 cft./ton of pig used. The amount of iron loss in gases is less than that of L-D process. Steel production amounts to 92%. Nitrogen content in the steel is claimed to be in the order of 0.002% only. Lining life amounts to only 50 heats and consumption of dolomite is about 45-50 lb/ton of steel. 13-15% lime is needed for slag making. The same difficulties of high refractory wear and slow production rate restrict the use of the process on a wide commercial scale.

Oxygen-steam process

The process commonly known as O.V. process is actually a modification of L-D process in which superheated steam is used along with oxygen in the same L-D type converter. The process claims advantages of easily controlling the final temperature and composition and can easily treat iron with 1.50-2.0% phosphorus. It also claims a much smaller amount of dust in the fumes. The usual proportion of O_2 and steam is 60% O_2 and 40% steam by weight. The O_2 -steam mixture is added usually after the carbon blow is over. The process is commercially adopted in Belgium as a modification to Thomas process. There were some attempts also in the use of oxygen- CO_2 mixture (50%+50% by vol.) in the final stage of blowing and in oxygen-blown rotating converter, but commercially it has not yet been adopted on

higher than that of L-D process.

There are other processes named after the design of the converter which, though cannot be termed wholly as oxygen steel making converters, are no doubt being still experimented upon rather on pilot plant scale with oxygen or oxygen enriched blast. Mention may be made of side blown converters:

- (i) MA process converter (submerged tuyers in Mannesmann).
- (ii) Turbo-hearth converters.
- (iii) (F.A. Tropenas converter in which blast is directed upon the surface from the side of the converter and the converter of concentric type and that with a detachable bottom).

IMPROVEMENT OVER DIFFERENT OXYGEN STEEL MAKING PROCESSES

The buffer slag process

This process has originated from the interesting variation in the relative ratios of carbon and phosphorus removal using a high pressure oxygen nozzle adjusted close to the slag surface and a low pressure nozzle adjusted just above the slag surface in usual L-D type stationary converter. With high pressure oxygen jet the rate of phosphorus removal is claimed to be about 0.07% per minute rising to 0.2% per minute only after all carbon is oxidised while the low pressure oxygen nozzle enables a phosphorus removal at a higher rate of about 0.2% per minute with the carbon content of the bath in the range of 3.6 to 1.2%. The special feature of the buffer slag process is the use of low pressure O_2 jet which, due to its impingement position, oxidises the FeO in the slag to Fe_2O_3 whereby the unreacted metalloid at the slag-metal interface are easily oxidised. After a short preblow direct contact between the mobile oxygen and the molten iron is avoided which facilitates the quick formation of a molten reactive lime-based slag. A highly oxidised slag is thus formed by this process which helps in the early removal of phosphorus quite efficiently.

The duel or hybrid converter process

This process is known to be operated partly by an air or oxygen-steam blast passing through the bottom tuyers and partly by means of a high pressure oxygen blast blown onto the surface of the molten bath through special high velocity nozzles suitably positioned into the converter walls.

The process thus involving simultaneous top and bottom blowing, has been developed in Germany for promoting early dephosphorisation and simultaneously catching carbon. The process may be described as a modification or combination of L-D and Thomas processes. The addition of bottom blast during the working of L-D provides the agitation necessary for the refining of high phosphorus charges, before the carbon blow is over.

A further step towards the possibility of extending the L-D process to refine medium or high phosphorus pig iron has been experimented upon by injecting powdered lime with or without iron ore and flourspar along with high purity oxygen in the usual L-D type converter. The results are claimed to be highly successful in eliminating phosphorus prior to carbon thus lending low phosphorus carbon steel. A suitable lime distributor allows the injection of powdered lime needed for refining and it is reported that pig iron of 1.8% P, requires 330 lb while that with 0.2% P requires about 150 lb of lime per ton. The lime powder is usually finer than 2 mm. The process has yet to be adopted on commercial scale plants but seems to be highly encouraging for treating medium or high phosphorus pig iron in basic lined converter.

There are many other recent studies concentrating mostly on the treatment of high phosphorus pig iron in basic lined converters. The addition of iron ore instead of steel scrap as a cooling agent has been found to give great change in the kinetics of refining reaction. Using cold scrap much of the phosphorus is found to remain in the bath until most of the carbon is oxidised out necessitating an after-blow to reduce phosphorus to the required level; whereas the addition of about 220-250 lb of low phosphorus iron ore (55-58% Fe) per ton (instead of steel scrap) reduces the bath temperature as well as increases the FeO content of the slag with the result that phosphorus is oxidised to be slagged out while carbon of the bath is still high (0.5-1.0%). The ore also supplies oxygen which is likely to reduce the oxygen gas consumption as well as the blowing time to a certain extent. The ore rapidly increases the FeO content of the slag which holds P₂O₅ strongly. Such additions of iron ore or mill-scale along with lime just after the silicon blow is over, are likely to yield low phosphorus carbon steel from medium or high phosphorus pig iron.

There are various other improvements which are aimed to standardise the process of operation thus trying to eliminate the uncertainty of some important factors like temperature control, oxygen flow-rate, slopping, etc., which are very important for successful commercial application. Mention may be made of the reports of research achievements on the following instrumentations:

1. Research on slopping by means of an entirely new type of flow meter, called "volume-debit-graph" in which the gas flow has been claimed to be automatically expressed in normal temperature, pressure and volume of gas blown since the beginning of the operation, which are rather more important than total time, and are true variables characterising the evolution of the refining. Further reports claim that the factors effecting slopping may be expressed as:

(i) Slopping decreases or disappears when the static depth of the bath is reduced.

ing period seems to be due to a swelling of the charge caused by a silicious primary slag with a high foaming power in the metal. It is gradually neutralised by lime. It is claimed that for a converter of a given shape and size it is possible to work out experimentally, using the volume-debit-graph, a pencil gas flow curve which will control slopping. For temperature control, radiation pyrometers have been experimentally employed by many investigators. Further advancements have been reported on the automatic control of the depth immersion of the lance and the control of discharge of oxygen by new devices for measurement of differential pressure and use of pouring hole provided in the converter wall. A British patent taken recently claims a method of determining the end point in the oxygen steel-making process by calibrating the oxygen lance equipment in such a way that for a given oxygen pressure, the flow of oxygen automatically ceases at a certain carbon value of the bath metal.

The popularity and greater acceptance which oxygen steel-making processes are gaining in recent years can be easily seen from the reports of numerous 20-100 tons capacity L-D, Kaldo and Rotor plants set up in the Continent, U.S.A., U.S.S.R., Japan, Canada, etc.

1. Dominion Foundries and Steel Co. Ltd., Hamilton, Ontario, Canada.

Two L-D converters at

Dofasco 45-ton unit.

Two 80-ton units are added at Detroit (L. C. Louth Steel Co.).

Lining tar dolomite bricks with a backing of rammed tar dolomite.

Working volume ... 1,150 cft.

Average lining life ... 200-250 heats.

Charge-hot metal ... 1.3% Mn, 1.2% Si, 0.125% P, 0.025% S, 4.4% C.

Oxygen "on time" ... 22 minutes/heat

Oxygen consumption ... 1,850 cft./ton steel

Total tap to tap time ... 45-50 minutes

Consumption of dolomite 20 lb/ton of ingots

Waste gas ... about 110,000 cft./minute

Dust concentration ... about 0.223 gr/cft.

Oxygen plant ... 100 tons per day

Power consumption ... 400 kW per ton of oxygen

2. Linz and Donawitz in Austria.

Five L-D converters ... 35 tons unit

Annual capacity ... 250,000 tons

Lining tar dolomite

Average lining life ... 240-350 heats

Oxygen consumption ... 1,900 cft./ton

Refractory consumption 20-25 lb per ton of steel

quippa, ra.	
Two L-D converters ...	65 tons unit producing 54 tons per heat.
Annual capacity ...	750,000 tons
Lining ...	Permanent lining of magnesite bricks and an interior lining of pressed tar dolomite brick with a layer of rammed mixture of tar dolomite between the permanent and working linings.
Lining life ...	300-400 heats
Scrap addition ...	25-30%
Oxygen pressure ...	100-150 p.s.i.
Tap to tap time ...	37 minutes
Oxygen consumption ...	2,000 cft./ton

4. Barium Steel Corporation, Burlington Co. NJ
L-D converters for 800,000 tons annual capacity
5. Kaiser Steel Corporation, Fontana, Calif
Three L-D converters ... 65 tons unit
Annual capacity ... 1,400,000 tons
6. McLouth Steel Corporation Trinton Plant, Mich
Three L-D converters ... 40 tons unit
Annual capacity ... 238,000 tons
Another two L-D converters 80 tons unit have been recently added at Detroit.
7. An oxygen blown converter probably the first of its kind as commercial unit in Great Britain is reported to be soon in operation at Corby Works of Stewarts and Lloyds Ltd.
8. It is also reported that oxygen blowing arrangements are also being installed at Ebbw-Vale Works of Richard Thomas and Baldwin Ltd. (Oxygen-steam process is likely to be adopted).
9. The new Bessemer shops proposed for the Steel Co. of Wales Ltd., and for Consett Iron Co. Ltd., are reported to be making provision for oxygen blowing.
10. Messrs Bochumer Verein, Germany, have been reported to have set up an L-D plant.
11. One oxygen-blown converter at Societe Danker-
quise de Siderurgie, France
12. Esperance-Longdoz, Belgium, is reported to work with converter using oxygen-steam process—60% oxygen and 40% steam by weight
13. Certain Belgian works :
Converters using oxygen-carbon dioxide process
14. Acme Steel Co. at Riverdal, IU
Two L-D converters ... 50 tons unit
One 450,000 ingot
tons per annum
oxygen plant ... 110 tons/day
Annual capacity ... 450,000 ingot tons
15. Algoma Steel Co.,
Sault Ste Marie, Canada.
One ... 65 tons unit.

several countries including Russia, Japan, etc. Apart from this the other oxygen steel-making processes, especially Rotor and Kaldo, are meeting with great favour which can be observed from the following data :

1. One 80-ton Rotating Kaldo converter is being built at Oxelosund at a new steel plant on the central coast of Sweden. Two more vessels are also reported to be installed in due course.
Annual capacity—475,000 tons.
2. The Societe Lorraine de Laminge Continue (Sollac) has been known to be licensed to construct a 100-ton rotary converter adopting Stora-Kaldo process.
3. One 60-ton rotary steel-making converter at Hutten Werk, Oberhausen, Germany.
Overall length of the converter—48 ft.
Lining—tar dolomite layer rammed over a permanent magnesite lining.
Time of blowing—40-45 minutes
High as well as low phosphorus pig iron is used for refining. In addition to a 60-ton unit already in operation in Oberhausen another unit of 100 tons is under construction.
4. South African Iron and Steel Industrial Corporation have been reported to be planning to instal two rotary steel-making units (Rotor process) at its Vaderbihil Park and Pretoria Works at Burbach plant to increase ingot capacity by 600,000 tons annually.
Capacity of the rotar—100 ton/heat.
5. In Sweden the Kaldo or Stora process is in regular operation in 35 tons production units at Domnarvet.

Metal charge ...	...	3.5% C, 1.8-2.0% P, 0.2-0.3% Si
Time of oxygen lancing ...	...	35-40 minutes
Oxygen requirement ...	...	2,300-2,500 cft./- ton of pig used.
Steel yield ...	...	92%
Life of lining ...	...	about 50 heats
Consumption of lining ...	...	45 lb of dolomite/- ton of steel.

POSSIBILITIES OF REFINING INDIAN PIG IRON BY L-D PROCESS

Due to an ambitious scheme of stepping up the production of steel manifold during the Plan period the choice of a more advanced and economic process of steel-making has to be taken up right at the present moment keeping in view the tight foreign exchange position restricting high capital investment and the quality of pig iron (high silicon and medium phosphorus) available as well as the scrap position. Experiments have been started in National Metallurgical Laboratory hardly a year ago in a 250 lb per heat capacity basic

through consumable mild steel tube. Preliminary experiments on continued lancing with oxygen gave the following average results :

	Average composition of molten metal	Average composition of blown metal obtained
Carbon	... 3.5 -4.0%	0.03 -0.05%
Silicon	... 1.5 -2.0%	0.03 -0.05%
Manganese	... 0.7 -1.0%	0.02 -0.05%
Phosphorus	... 0.35 -0.4%	0.08 -0.1%
Sulphur	... 0.035-0.04%	0.022-0.03%

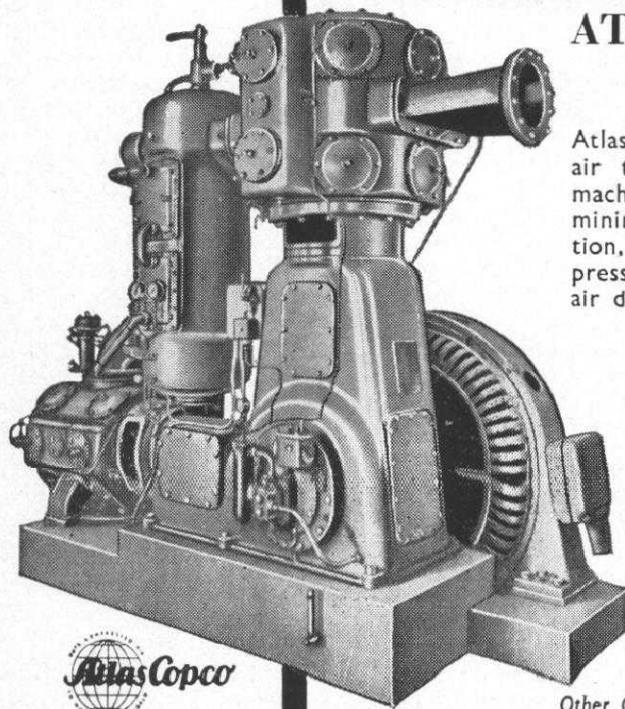
These results indicate the difficulty of refining the pig iron by a single stage operation. As such a "double slagging" technique has been adopted. By adopting the "double slagging" technique more than 95% of silicon, manganese and carbon and more than 80% phosphorus could have been removed.

Average composition of metal treated

Average composition of blown metal obtained

Carbon	... 3.5 -4.0%	less than 0.03%
Silicon	... 1.5 -2.0%	less than 0.02%
Manganese	... 0.7 -1.0%	less than 0.02%
Phosphorus	... 0.35 -0.4%	less than 0.04%
Sulphur	... 0.035-0.04%	less than 0.025%
Oxygen requirement was about	... 2,000 cft./ton	
Time of lancing varied from	... 9-11 mi	
Oxygen was lanced at a pressure of	... 80-150 lb/sq. in.	
Slag making material and other additions	... Limestone/lime, iron-ore./millscale	
Rate of oxygen introduction	... about 10 cft. per min. per cwt metal	

Results are quite encouraging and convincing for laying the possibilities of refining Indian pig iron to steel of desired composition. Future programme for studying the process on a bigger scale in about 1-3 ton vessel with water cooled jetting nozzle with Indian dolomite as lining material is being planned.



VTC-29

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