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History of Basic Oxygen Steelmaking

 Basic oxygen steelmaking (BOS) is the process of making steel by blowing pure oxygen (O2) into a tank of liquid metal contained in a vessel known as a basic oxygen furnace (BOF)， LD converter， or simple converter.

The history of steelmaking began in the 19th century when Reaumur in France in 1772， Kelly in the United States in 1850 and Bessemer in England in 1856 discovered how to improve pig iron by controlling the carbon content of iron alloys to actually become steel. Reaumur， as a chemist， was driven by scientific curiosity， while Kerry and Bessemer， as engineers， were responding to the industrial revolution， including looms， steam engines， machines and railroads， which demanded larger quantities and better quality steel. This began the dialectic between science and technology when the basic concept of refining hot metal (pig iron) by means of carbon dioxide (C) in a liquid bath was invented.

This was a radical change from the gas-solid reaction in the shaft furnace (the predecessor of the blast furnace， where iron ore was reduced with charcoal)， or from the iron pit (forging and refining technology in the solid state)， a change that is not available in today's times.The second half of the 19th century was marked by an impressive intensity of innovation， which brought about a paradigm shift. The Bessemer converter， which appeared in 1856 to make steel， and the open hearth furnace， which melted scrap in addition to refining hot metal， were discovered only in 1865， nine years after the Bessemer converter， while the basic Thomas converter was discovered 12 years later， in 1877. The Thomas converter uses air to refine liquid metals.

The air-blown converter， invented by Bessemer in 1856， is considered the first modern steelmaking process. in 1877， the Thomas process， a modified Bessemer process， was developed to allow the treatment of liquid iron with high phosphorus. In the Thomas process， phosphorus (P) is oxidized in a so-called "back-blow" after most of the C has been removed from the melt pool. The open hearth process， also known as the Siemens-Martin (SM) process， was developed almost simultaneously with the Thomas process. The bright furnace process uses regenerative heat transfer to preheat the air used in the burner， which can generate enough heat to melt and refine solid scrap and hot metal in the reverberatory furnace. Around the 1950s， when basic oxygen steelmaking was on the horizon， steelmaking was primarily based on the open hearth process technology. Hot metal and scrap were loaded into large horizontal furnaces， and burners provided energy for scrap melting. Oxygen (O2) lances were used to increase the efficiency of the burners and to remove carbon and silicon (Si) from the hot metal. The open hearth process is an all-heat process， so external energy must be supplied to the furnace. For 200 to 250 tons of heat in liquid steel， a typical point-to-point time is 8 hours.

The next major innovation in steelmaking， immediately after the invention of electricity， was the electric arc furnace (EAF) steelmaking process. The electric arc furnace was introduced by Heroult around 1900 in the Alpine valley near the source of new energy sources， as long-distance power transmission was not feasible at that time. eaf technology was based on the development of an energy source that could replace coal and melt scrap steel in larger quantities than open hearths. the eaf steelmaking process is credited with initiating the circular economy.

The concept of BOS dates back to 1856， when Henry Bessemer patented a steelmaking process involving oxygen blowing to decarbonize the iron (British Patent No. 2207). At that time， there was no way to provide the amount of O2 needed for the process. Commercial quantities of oxygen were simply unavailable or too expensive， so Bessemer's invention remained on paper and was never used. steelmaking by blowing pure oxygen became practical in 1928 when the Lind company succeeded in developing a method for supplying pure oxygen in large quantities (the Lind-Fr?nkel process). Due to the success of the Lind-Fr?nkl process， oxygen also became so cheap that the two prerequisites for the introduction of the BOS process (a large supply as well as the availability of cheap oxygen) were both met.

In Europe and the USA， experiments with O2 were repeated. Among those who used high-purity oxygen was Otto Lellep， but his concept of "blowing oxygen vertically onto a liquid iron bath" proved to be unsuccessful. According to Hubert Hauttmann， he participated in Lellep's experiments at the Gutehoffnungshütte between 1936 and 1939， when he was employed by the company whose purpose was to convert iron by blowing pure oxygen through a nozzle at the bottom of the converter. The quality of the steel produced in this way was poor.

During the Second World War， engineers such as C.V. Schwarz in Germany， John Myers in Belgium， Dürer Switzerland and Heinrich Heilbrügge in Germany presented their version of oxygen blowing， but only Dürer and Heilbrügge brought it to the level of mass production.

Carl Valerian Schwarz filed a patent application in 1939 for blowing oxygen into the melt pool at supersonic speed. But this method also "could not yet produce usable steel". Although the later Linz-Donawitz (LD) process had similarities to Schwarz's patent， its typical features were different (e.g. "central vertical blowing"). It must have been due to the outbreak of the Second World War that the technology described in the Schwarz patent did not initially lead to any practical applications. It was also at the end of the 1930s that Robert Durer in Switzerland started his own experiments.

After the war， Heinrich Hellbrügge and Robert Durrer (technical director of Roll'schen Eisenwerke) started further experiments at Roll'schen Eisenwerke in the Swiss town of Gerlafingen. A photo of the first top-blown oxygen converter in Gerlafingen is shown in Figure 1.

Fig. 1 Photo of the first top-blown oxygen converter in Gerlafingen

After the establishment of a technical partnership between Gerlafingen and V?EST on an industrial scale， it was Durrer who laid down the basic theoretical principles and suggested that V?EST blow oxygen from above in a separate vessel. On June 3， 1949， a series of experiments using a 2-ton experimental converter was started on the V?EST premises. After several initial setbacks for Linz's team， a breakthrough was made as early as June 25， 1949， when the pressure of the O2 was reduced and the tip of the blowgun was moved further away from the melt pool so that the O2 jet could not penetrate as far. With this breakthrough， the steel produced could be rolled into plates without any problems. the experimental department of V?EST examined the steel and was very positive about its observations. This was the moment when the LD converter steelmaking process was born. The experiments continued until several hundred 2-ton heats， after which they were transferred to a specially built 15-ton experimental converter， which was erected in the open air. The first batch was produced on October 2， 1949. This new grade of steel underwent continuous metallurgical and other tests.

The key element of this innovation was the movement of the liquid bath. Previously， it was thought that it was impossible to obtain sufficient bath movement without blowing O2 to greater depths. But this movement was achieved in a very satisfactory way by forming CO (carbon monoxide). The principle of "soft blowing" also promotes the formation of iron oxide， which in turn absorbs the oxidized impurities and forms slag. This contributes to the production of excellent new steel grades.

In addition to Roll'schen Eisenwerke and V?EST in Gerlafingen， Mannesmann AG and ?AMG (i.e. Donawitz) in Duisburg-Huckingen also expressed their interest in the O2-blowing process or at least in O2 metallurgy in general in May 1949. After a demonstration of the process in the Linz experiments， a precise division of labor was reached on June 17， 1949. v?EST would continue processing crude steel from Linz in a larger refining vessel， while Mannesmann would conduct oxygen blowing experiments on Thomas steel， Roll'schen Eisenwerke would study the use of O2 in an EAF， and ?AMG would conduct O2 tests in a low-axis pig iron furnace. The agreement required all those involved with O2 metallurgy to "refrain from making any statements and from passing on to anyone outside their own company any information about the details of O2 refining that had come to their attention or the conclusions they might have reached during the discussions in Linz on June 17， 1949.

On the basis of the agreement， it soon became apparent from Donowitz's experiments that the use of oxygen in the shaft furnace was worthless， and the company began to explore different methods. The process developed at Donowitz for the recovery of slag with high manganese content by oxygen blowing led to the realization that only oxygen blowing processes using pure oxygen should be considered in Donowitz's steel production expansion and rationalization program. After extensive investigations and successful development work on experimental units of 5 or 10 tons， in which oxygen was supplied from cylinders in series during the first tests， the company management decided to build a new steel mill， which would be ready for operation in two years. The Donowitz engineers initially named their process "SK"， the German initials for "oxygen converter". This terminology helped， to some extent， to distinguish the activities of ??EST from those of ?AMG.

On December 9， 1949， Heinrich Richter-Brohm， then managing director of ??EST， made a decision to build the first LD steel mill， not without risk. Shortly thereafter， after clarification of the issues concerning the production method for the harder steel grades， it was decided to build an LD plant in Donowitz as well. In 1950， the first patent for the process was filed.

In the annual research and quality assurance report for 1951， it was noted that "During the year under review， a great deal of research work was devoted to the LD steel grade， and a publication was issued. It is anticipated that this type of steel has great potential in terms of quality and will， in particular， permit the production of steels with high quality surfaces and good cold forming capabilities. This is particularly important for the production of sheet metal， where until now good cold formability (killed steel grades) has only been possible with the acceptance of certain surface defects. However， it was also possible to produce steels with a high yield strength by means of the oxygen refining process， which was very advantageous.

By 1951， the refining of hot metal with pure oxygen in the steelmaking process had become an innovative and operationally reliable process for the production of bulk quality steel in Linz. the first announcement of this new process was made at the conference of the Austrian Metallurgical Society "Steelmaking with Pure Oxygen" in Leoben in December 1951. At this meeting， Robert Durer stated that two metallurgical plants (Linz and Donowitz) had developed the concept of blowing high-purity oxygen into domestic hot metal into a viable industrial process， and congratulated them on this great success. With this announcement， Austria became the first country to produce steel from hot metal on an industrial scale by blowing pure oxygen. Figure 2 shows a cross section of the LD converter before and during oxygen blowing in a liquid metal bath.

Fig. 2 Cross-sectional view of the LD converter before and during oxygen blowing in a liquid metal bath

On November 27， 1952， the first converter was put into operation at the LD steel mill in Linz (Figure 3)， a milestone in the use of the oxygen blowing principle for steel production. on January 5， 1953， this first LD steel mill in the world was officially opened. By June 17， 1953， the first LD steel mill in Linz had produced 100，000 tons of LD steel， and by the beginning of December 1953， 250，000 tons of steel had been produced. A second LD steel mill was put into operation on May 22， 1953 at the ?sterreichisch-Alpine Montangesellschaft (?AMG) in Donowitz. The process has now been developed into a fully mature operation and exceeds all expectations in terms of the quality and economic viability of the steel it produces.

Fig. 3 Cross-section of converter 1 at V?EST's LD steel mill

The particularly favorable metallurgical conditions in this process produce O2-free crude steel and therefore do not require deoxidation. The steel is a low-gas， low-nitrogen (N2) steel， free of phosphorus (P)， sulfur (S) and unwanted accompanying elements. In terms of technical properties， especially cold formability， steel produced in LD converters is significantly better than steel produced in the open hearth process. the LD process is also capable of providing structural steel grades of excellent quality. Steels produced in LD converters have achieved excellent results in welded structures subjected to very severe loads. Wide strip coils produced in LD converters are being supplied in large quantities to cold rolling mills in Germany and abroad.

The abbreviation LD， commonly used today as Linz-Donawitz， was officially adopted in 1958. The name LD was chosen because V?EST in Linz and ?AMG in Donawitz had developed it to a mature level on an industrial scale.

In August 1954， Dominion Foundries & Steel， Ltd. of Canada became the first company outside Germany to operate an LD steel mill. It had two 60-ton converters. In the same year， McLouth Steel of the United States followed suit and started its LD steel plant with the help of Foster plant manager Rudolf Rinesch. in September 1956， the third company outside Germany to start operating LD was Société des Aciéries de Pompey of France， which had a 15-ton converter. in 1957， there were five LD plants in West Germany， Japan ， Brazil and the United States， five LD steel mills were in operation in 1958， five more in 1958， two in Rourkela， India， in 1959 and eight in 1960. in 1960， in the United States， Japan， Spain， Portugal， Italy (expansion of existing plants)， West Germany， Brazil， England， Scotland， Norway， Argentina， Australia (1961) and France， more of LD steel plants under construction， which had already been built prior to this.

Technological innovations in upstream manufacturing processes， especially in refining and casting， are essential to achieve ever-increasing levels of quality in the steel required for various applications. Therefore， the BOS process has also been upgraded since the first LD converter was put into operation in Linz.

The original LD process consisted of blowing oxygen at the top of the molten iron through water-cooled nozzles of a vertical lance. In the 1960s， steelmakers began to investigate bottom-blowing converters and introduced inert gas blowing to agitate the liquid metal in the converter and remove P impurities.

In the early 1970s， there were further developments in BOS steelmaking with bottom-blowing of O2 by using hydrocarbon gas or fuel oil-protected spigots. with experience with both types of converters， a mixed top and bottom blowing vessel was developed. In the late 1970s， mixed blowing gas was introduced into the converters of the BOS process. Most of the converters used in the world today are of the combined type.

In top blowing converters， the lack of mixing in the metal bath creates chemical composition and temperature uniformity in the melt during the O2 blowing process. There is a relative dead zone directly below the injection cavity of the converter. The need to improve the top-blow converter steelmaking process led to the development of the co-blowing process. The first commercially accepted co-blowing practice was the LBE (Lance Bubbling Equilibrium) process developed by ARBE-IRSID. This process is more closely related to the BOF process as all oxygen is supplied from the top gun. The combined blowing aspect is achieved by a set of porous elements mounted at the bottom of the converter through which argon or nitrogen is blown. In the LBE process， nitrogen is typically used almost exclusively in the range of 3-11 N Cum/min for the majority of the blowing process. However， argon is used for stirring later in the blowdown when nitrogen absorption can be a problem. In addition， argon is used almost exclusively as an inert gas for post-blowing stirring， when the rate increases to 10-17 N Cum/min.

In the early days of the LD converter process， the top gas was completely burned at the converter mouth through an open hood and then cooled in the stack either indirectly with water or through an evaporative cooling system. At that time， about 300 kg of steam and 250 m3 of exhaust gas were generated per ton of crude steel.

Environmental issues were a serious challenge for the converter process when the industrialization was implemented in the 1950s. The fineness of the dust in the converter exhaust gas forced the suppliers of the process to develop new dust removal systems. 1 gram of converter dust has a visible surface area of between 300 and 500 square meters. In order to generally avoid the optical effects of "brown smoke"， dust has to be removed from the system to a level of less than 100 mg per cubic meter. For this purpose， both wet and dry dust removal systems are used. This challenge is increasingly becoming an opportunity for converter processes as environmental concerns increase. This opportunity contributes to the development of converter gas recovery systems that suppress combustion. Today， the economy and the environment require that the energy in converter gas and iron-bearing dust be captured and recovered efficiently.

In the early 1960s， processes were developed to recover the high calorific value gas from the top of the converter in order to use it as a gaseous fuel within the plant. This was achieved by pressurized combustion. The process equipment installed above the converter mouth has the function of cooling， cleaning and recovering the converter gas with the help of pressurized combustion. By suppressed combustion of the gas at the top of the converter， 70-100 m3 of converter gas with a calorific value range of 1600-2000 kcal/Nm3 per ton of crude steel can be recovered. In addition to the 80 kg/t of crude steel steam， steam can be made if an evaporative cooling system for the top gas is employed.

In the early days of converter steelmaking， brown smoke from the chimney indicated that the converter was working. Today， due to the existence of converter gas recovery and cleaning systems， converter operation can only be detected from the torch chimney.

Since 1977， several improvements in the design of the converter vessel itself， in refractory and refractory application practices， and in the design of the oxygen lance and furnace bottom nozzles have contributed significantly to increased steelmaking efficiency and reduced unit consumption of raw materials and refractory， all of which have helped to extend the life of the furnace to several thousand heats.

Today， converters have been scaled up and large converters with a capacity of 350 metric tons of iron are available. in 2014， out of a total global crude steel production of 169 million tons， the BOS process produced 129 million tons of crude steel， or 73.7% of the total global steel production.