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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

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Moscow, USSR, 19 September - 9 October 1968

B-5

MODERN TECHNOLOGY OF OXYGEN-BLOWING STEEL-MAKING PROCESSES [1]

by

Alfred Wegscheider
Austria

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MODERN TECHNOLOGY OF OXYGEN STEEL MAKING[1]

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SUMMARY

The paper deals with the oxygen-blowing processes for making steel as used in practice, in which exclusively technically pure oxygen refines different kinds of liquid pig iron.

The processes discussed are:

(1) The LD process and its varieties, such as LD-AC (OLP in France)
(2) The Kaldo process
(3) The Rotor process
(4) The tandem process
(5) The LD-Kaldo process

The LD process being the oxygen top blowing process most widely used of all, is treated on a wider scale. By way of an introduction, the first tests involving the LD process, its adoption by the industry and its further development are reported on. The development of the average vessel sizes and the erection of LD vessels in different countries between 1952 and 1967, and also the average vessel size in different countries of the world are shown and described in various pictures.

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* This is a summary of a paper issued under the same title as ID/WG.14/59

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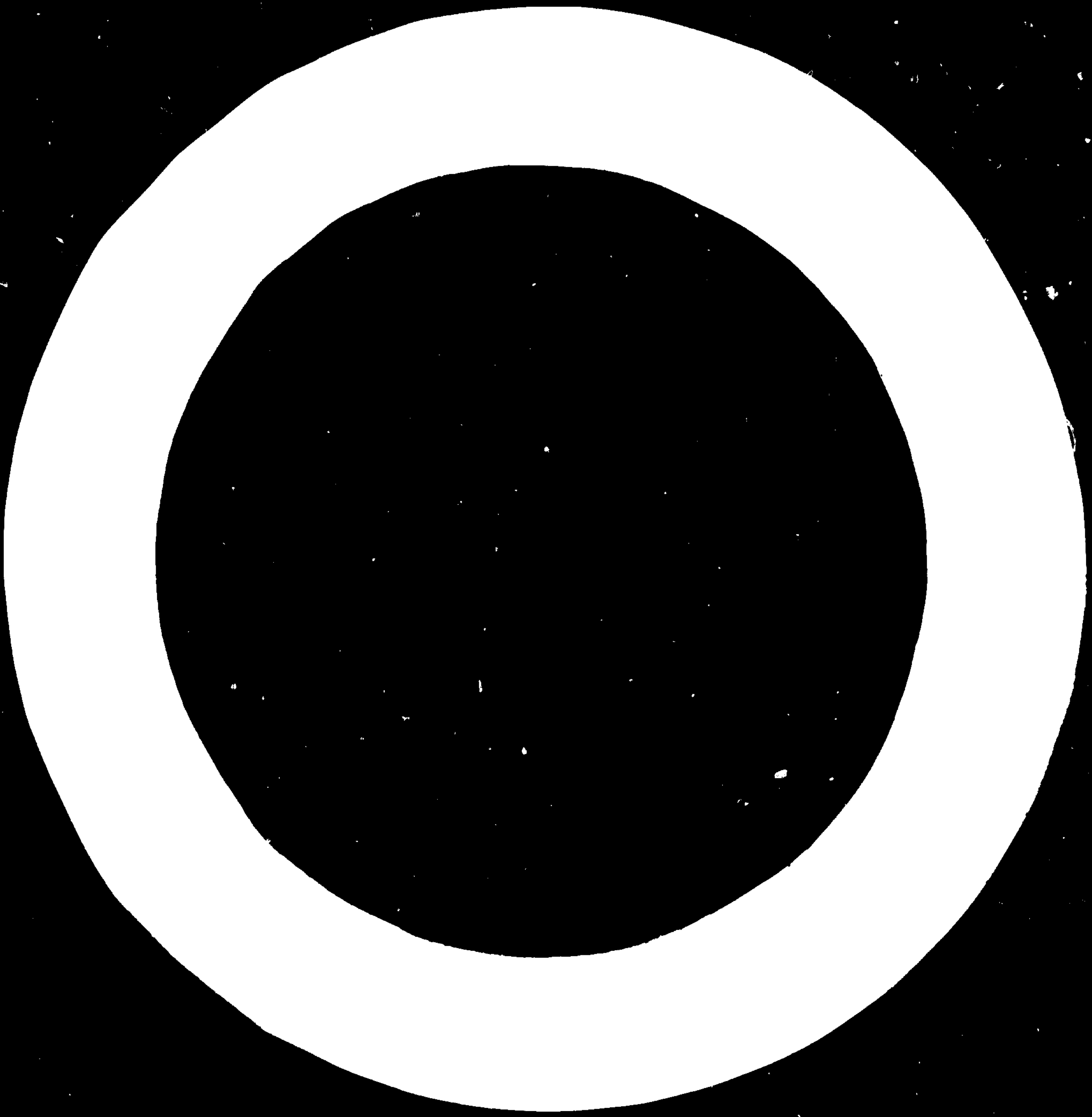


Furthermore, LD ingot steel production including the production of Kaldo-, Rotor- and Tandem steel plants is compared percentagewise with world ingot steel production between 1953 and 1967 including electric steel, Thomas steel and open-hearth steel.

Inasmuch as the amount of ingot steel produced by Kaldo, Rotor and Tandem steel plants constitutes only a small percentage of the total amount of ingot steel blown by the oxygen process, the LD steel process will be described as the process representative of all oxygen blowing processes in particular as far as its development during the past twenty years of its existence is concerned. The section on the development of the LD process deals with the production of mild steel, hard steel, unalloyed and also alloyed steels.

The other oxygen blowing processes are mentioned briefly as far as their methods are concerned, and are also shown in pictures.

In conclusion, the performance of the LD process corresponding to its most up-to-date stage of development including data on tonnage output per hour and tap-to-tap times of different vessel sizes, are compared with the tonnage per hour capacities of all other steel making processes. This comparison will clearly show the enormous superiority of the LD process as compared with all other steel making processes, a superiority which is based on its high productivity.

In accordance with this heading my report today is to deal with the steel-making processes using technically pure oxygen as a refining gas. As far as their sequence of adoption is concerned, the following oxygen-blowing steel-refining processes are being used in practice in the world today.

1. The LD-process and its varieties (LD-AC, OLP)
2. The Kaldo process
3. The Rotor process
4. The Tandem process
5. The LD-Kaldo process

Of the 5 processes mentioned above, the simple LD-process used for blowing basic pig iron containing less than 0,5% of phosphorus, was the first to be adopted by the iron and steel industry and to spread most rapidly in the whole industry.

If we include the years when the first tests were run in small units, we may say that the LD-process has been known for almost 20 years, and it will not be an exaggeration to state that, after the LD-process exceeded its 100-million-annual-tons mark of ingot steel in 1966, it will certainly continue its victorious march, remaining the predominant oxygen steel-making process for decades to come.

The Kaldo process was adopted by the industry on a considerably smaller scale.

The rotor process in its first modified form according to the Oberhausen, Germany, pattern, has practically been excluded from the field of steel-making processes. The first rotor plants to be built have been taken out of operation and some of them have even been dismounted. The design and the operation of rotor plants built in South-Africa a few years ago, have been modified by engineers of Messrs. Iscor during their operation to such an extent that it is no longer possible today to speak there of a simple rotor process as originally developed.

The Tandem and above all the LD-Kaldo process belong to the most recent developments and are only beginning to prove their value.

The following picture is to show the revolutionising way in which the LD-process was adopted by the industry whenever new steel plants were to be built and when existing open-hearth furnaces were to be replaced.

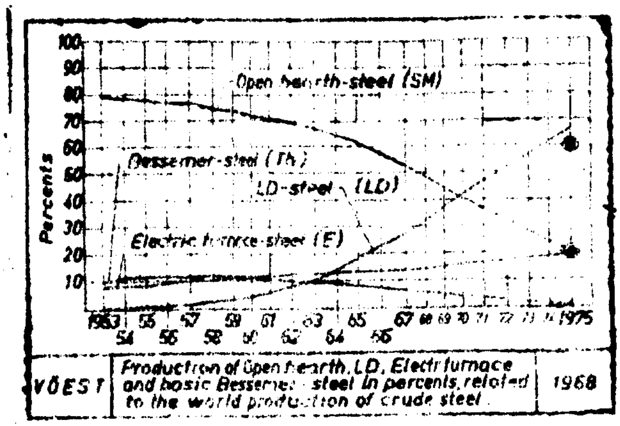


Fig. 1: Percentage of Open-Hearth-, LD-, Electric- and Thomas-steel of world ingot steel production 1953-67.

This picture clearly shows the increase in LD ingot steel production, the decrease in open-hearth production and also the remarkable increase in electric steel production.

The thin solid curve represents the percentage of ingot steel in world ingot steel production blown with technically pure oxygen, i.e. mostly LD-steel.

It was impossible to carry out a break-down into individual processes such as LD, Kaldo, Rotor or Tandem for the individual years, since the available statistical documentation contained only the ingot steel blown with technically pure oxygen. The consolidation of the LD, Kaldo and Tandem steel quantities in this figure, however, does not favour the LD-steel too much because the percentage of Kaldo-steel in world ingot steel production amounted to only 3% 1967, the one of rotor-steel to only about 0,5% and of Tandem-steel to only about 1%, that is at a time when world ingot steel production amounted to 135,9 Mio tons, all of which was produced by using technically pure oxygen. Therefore, in the following, all oxygen steelmaking processes are to be summarized under the name of LD-process.

The two curves in fig.1, that is Open-Hearth and LD ingot steel production as a percentage, clearly show how great the distance between the two processes still is today, in other words, how far steel production by the LD-process still lags behind steel production by the classical process, the open-hearth process.

Until 1958 the curve representing LD-steel practically runs at less than 2% of world steel production. It is not until 1959 that this curve begins to rise considerably in order to reach the quite remarkable height of 27,3% of world ingot steel production by the end of 1967. The area covered by the open-hearth process is still very large, although it constituted only about 52,5% in 1967. It may be assumed with certainty, however, that in the years to come, the LD-process will penetrate into the area of the open-hearth even more rapidly than it has been doing so far, and that its victorious march will not be completed until it has reached the borderline of the field, which in any case will continue to be reserved for the open-hearth.

If we were supposed to interpret the figure to give some indication for 1975 with regard to the percentage of world ingot steel production, we would say, I think, without making a great mistake, that in 1975 LD-steel will constitute 60%, electric-steel 20% and open-hearth-steel 20% of world ingot steel production. Since, however, this estimated percentage is already closely related to the amount of scrap available in the whole world, it will be more correct to give the following percentage: 50% LD, 20% E-steel, 30% open-hearth-steel.

In view of the predominant role played by the LD-process with its most recent type of operation in the field of the oxygen steel-making process, I am going to deal more in detail with the LD-process.

Let me discuss briefly the first LD-tests run in 1949, and, subsequently, the individual periods of development of the different types of LD-steel in their chronological sequence as far as they fit into this paper.

If we say that the LD-process has existed for the past 20 years, the pioniers who brought this process into being still remember the time of their test-work involving test vessels having a holding capacity of 2, 5, 10 and 15 tons.

The work was started in test plants whose construction was improvised and which were equipped as cheaply as possible.

A hot-metal ladle, on which a cone had been welded and which had been lined with basic material, was placed on a hot-metal transfer car. That was all the equipment available for the beginning of the tests.

In 1949-50 only one of the two test plants in Austria had a plant for the generation of 400 Nm^3/h of liquid oxygen. In the other plant the oxygen required to the tests had to be taken from oxygen bottles located in the vicinity of the blowing site. There was no electrically controlled lance equipment. The lance had to be moved by hand into the desired blowing position prior to and during the blowing.

In spite of all these difficulties, which had to be overcome during the tests, large-scale quality examination of the different types of steel obtained by refining with oxygen were carried out already after the first tests, and on the basis of the results obtained, the high quality of the steel blown was recognised.

The more favourable construction costs of LD-steel plants as compared with open-hearth-steel plants and the good properties of the steels made by this new process, which already at that time were equal or superior to the properties of open-hearth steel, together with a number of other favourable points paved the way for the LD-process.

In what manner then did the LD-process begin to prevail during the indiviual years?

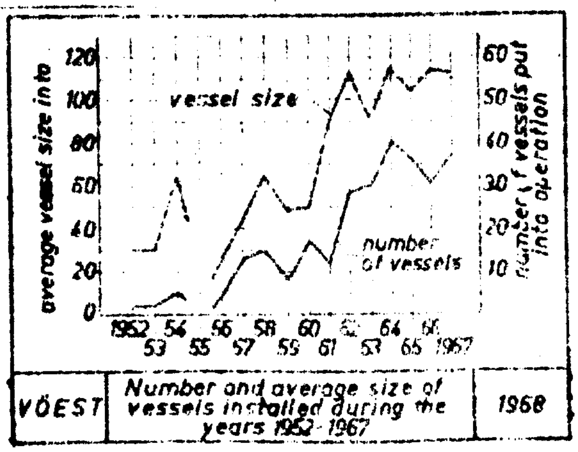


Fig.2: Number of vessels put into operation and avarage vessel size during 1952-57.

This figure contains all the LD-vessels operating according to the LD, LD-AC processes (called CLP-process in France). The thin curve unmistakably shows the trend towards a larger vessel size. In 1962 the limit of 100 tons was exceeded for the first time on an average. However, in 1963 the average size got below that limit, in 1964 it got beyond the 100 tons again in order to reach the average size of 115 or 113 tons in 1966 and 1967.

In the United States and in Soviet Russia a number of large plants will adopt the LD-process some time during the next few years. In these large steel-making plants with uniform steel-production programs connected with the largest possible weights of the ingots, the vessel units to be erected will be as large as possible. It can therefore be safely assumed that the curve in fig.2 will be strongly influenced so that it will run towards even larger vessel units above 115 tons on an average.

In what is shown in fig.2 (the broader solid curve) with regard to the average number of newly erected vessel sizes, it goes without saying that the time when the planning for the LD-steel plant to be erected was done, played an important part. In the countries where LD-steel plants were placed in operation comparatively early, i.e. as early as 1953-57 the planning of these steel plants was started, the same as today, 2 to 3 years earlier and owing to the precaution prevailing during the first years not permitting the safe use of vessels larger than 60 tons, the vessels built in those countries have a small holding capacity.

The experience gained subsequently by practical operation, however, soon did away with that precaution permitting a good operation only up to a vessel size of 60 tons. It is, therefore, easily comprehensible why countries building LD-steel plants after 1957, show average vessel sizes above that figure.

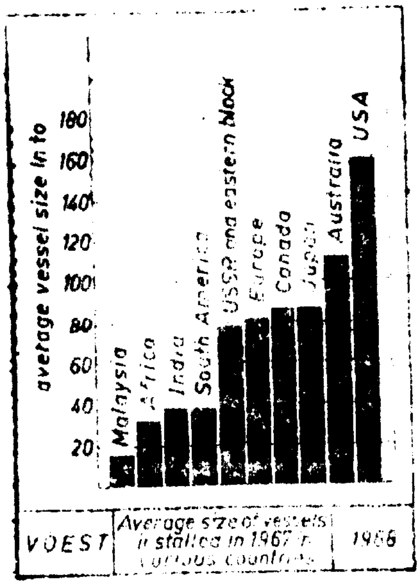


Fig.3: average vessel size in different countries during 1967.

Europe with its large number of highly industrialized countries, which adopted the LD-process at an early stage, has an average vessel size of only 81 tons as shown in fig.3. Australia's average size is 111 tons, Soviet Russia's together with the

Eastern countries is 79 tons, in the United States it is 159 tons, in Canada 86 tons, in Japan 86 tons, in South-America 38 tons, in India also 38 tons, in Africa 32 tons.

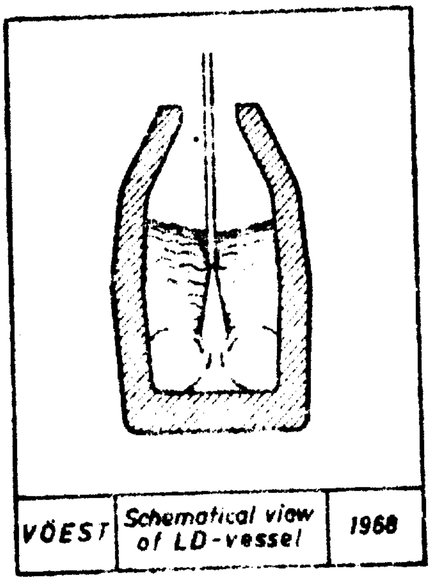


Fig. 4: The LD-process

This schematic sketch in Fig.4 shows the process at about the middle of the blowing time. You see the oxygen jet, the bath to be refined and the layer of slag on it. Various steps of the oxidation of iron occur, which in their turn together with the slag-forming material charged, form a slag of oxides, which during the further course of the process may be regarded as the carrier of the refining reactions owing to the violent mixing with the metal to be refined, which mixing is caused by the formation of CO.

The next section of this report is to deal with the most important facts relating to the conducting of the process as such, that is facts which were ascertained with regard to the various methods of processing different types of hot metal during the period under review.

In the course of the years a large amount of knowledge has been accumulated contributing to the further improvement of the LD-process when applied to pig iron low or high in phosphorus.

One of the most important conditions on which the process depends is the type of lance used and the nozzle head on the lance, respectively.

For this reason I want to say a few words about the development of the lance.

The one-hole nozzle has been partly replaced by multi-hole nozzles in recent times, both in the simple LD-process and the lime-dust process. The one-hole nozzle, particularly in the case of large vessel units, resulted in an unbearably violent operation with a lot of slopping whenever the operation was accelerated to achieve shorter blowing times, in other words, when larger amounts of oxygen were blown. Apart from a lower yield this type of operation also resulted in an increase of lost time on account of continuous clearing work caused by slag spilling into the space below the vessel. The idea of blowing fresh oxygen on to the bath, through a multi-hole nozzle with a smaller blowing power, was covered by patents already at the beginning of the introduction of the LD-process in 1950.

A number of years ago a variety of these multi-hole nozzles was used for the first time on an industrial scale in Japan when the OG-process was being adopted there. The nozzle proved satisfactory. Particularly in the case of vessels with a holding capacity of more than 100 tons, using OG equipment connected to the LD vessel, it was intended to find a way of blowing during a quiet and uniform operation, which would be free from slopping as far as possible. The multi-hole nozzle met this requirement and thus essentially contributed to the adoption of the OG-process and brought with it also the other minimum-gas processes.

The fundamental idea of achieving a quiet blowing process, however, was likewise very important for the LD-process, and this was the reason why subsequently also in vessels without the minimum-gas process, and today in vessels under 50 tons of holding capacity, two-hole nozzles or three-hole nozzles are used.

The possibility of blowing more oxygen into the process per unit of time by using a multi-hole lance, greatly reduced the blowing times, particularly in the case of vessels of more than 100 tons. Furthermore, the use of the multi-hole nozzle brought about a somewhat more favourable heat economy by burning more CO to CO_2 in the vessel itself, in which connection a larger amount of cooling scrap could be used for the process. Similarly, the life of the lining was better protected owing to the fact that the heat created in the upper part of the vessel by the one-hole lance operation was diminished. All these advantages held by the multi-hole nozzle completely ousted the one-hole nozzle in recent times, particularly in large vessels.

The multi-hole nozzle was developed last year even to such an extent that in large vessels 4-hole and 6-hole nozzles were used successfully in order to further decrease the blowing time. When using a one-hole nozzle in a still justifiable type of operation, the pure blowing time used to be from 35 - 37 min. in vessels with a holding capacity of 200 - 300 tons. Today, only a few years later, the blowing time is below 18 min. on an average, in the case of vessels with a holding capactiy of 200 - 250 tons if a multi-hole lance is used.

The originally established standards of blowing times for an operation involving a one-hole nozzle have been completely abandoned owing to the introduction of the multi-hole nozzle, which can be proved by examples taken from today's practice.

In the lime-dust process used for the blowing of Thomas iron, the multi-hole nozzle has also proved satisfactory in the case of large vessels, both in its normal design or in a special design having a finished surface in its interior, that is a chromium-plated, nickel-plated or copper-hardened surface.

Multi-hole nozzles for the lime-dust process are used with their individual nozzles being inclined to the middle axis or running parallel to the middle axis in a Laval-type design or also in a cylindrical design. A nozzle developed by Messrs. ARBED, Dudelange, Luxemburg, for the LD-AC process, called the ATR-lance, is of particular interest. It is a 2-jet oxygen nozzle with separate oxygen control, which, in addition to the main jet in the center of the nozzle head (Laval-type), has an outside nozzle-ring in the nozzle head which permits the secondary oxygen to enter obliquely into the main jet and rarefies the main jet depending on the pressure conditions prevailing at a particular moment. In other words, in the ATR-lance the secondary oxygen is blown through small nozzles mounted obliquely in the lance. Apart from the rarefaction the partly tangential effect on the main oxygen jet causes the latter to rotate too, in addition to being rarefied. The question as to what extent this rotation of the whole oxygen-blowing cone is of advantage for the development of the reactions or whether this rotation can cause an additional movement of the bath surface when the jet impinges upon it, cannot be answered here. This nozzle with the two oxygen jets enables, however, the blowing to be made harder or softer depending on what is required, by adjusting the flow and the pressure of the corresponding secondary oxygen accordingly. This possibility of adjustment has proved highly satisfactory when Thomas iron is blown, particularly during the first phase when the foaming period must be controlled and also at the end of the second phase when harder blowing is required, not only in the case of 20 ton-, 50 ton-, 70 ton-vessels, but also in the case of larger vessels holding 130 tons.

Although this type of lance, that is the ATR-lance, was first used only for the LD-AC process, that is for the blowing of Thomas iron where it is still being used, it could in my opinion likewise be used for the blowing of basic pig iron, because also in the one-slag process on the basis of what is known today, the possibility of adjusting the lance-work without changing the lance-height making the blowing harder or softer, would be highly desirable.

After blowing basic pig iron first, hot metal with a medium phosphorus content and finally regular Thomas iron was blown. Today any steel-maker knows, particularly any Thomas-steel-maker, that on condition that extremely low phosphorus contents, for example below 0,15%, are not required in the final analysis, the oxygen lime-dust process, i.e. the LD-AC process, which in France is called the OLP-process, is the cheapest and at the same time the most productive process to make steels with a low carbon content.

In the LD-AC-process lime dust is used, which is added to the process through the refining oxygen, which acts as a carrier in this case. In other words, lime dust and oxygen are sent under pressure to the working lance through tubes and metallic hoses.

A further development of the normal lime-dust lance is the telescopic lance, which has proved satisfactory in several cases after a solution was found to the delicate problems of packing.

The most important thing in the LD-AC-process and also in the simple two-slag LD-process using lumplime for the processing of high phosphorus hot metals, is the correct way of conducting the process during its first operational phase, i.e. during its first blowing period. During this phase the slag should be as foamy as possible. Owing to the improved reacting property of the slag with a high FeO-content, the foaming of the first slag permits dephosphorization to start earlier, i.e. prior to the combustion of carbon, which subsequently begins quite violently.

By using corresponding blowing methods the foaming of the slag can be achieved and controlled.

Since it is difficult to influence the behaviour of the slag by taking immediate action based on blowing technique, once the slag has begun to rise, other technical auxiliary means have been worked out, enabling the operator at the vessel to safely control the foaming slag to a very far extent.

The following methods have been used in practice successfully.

1. Observing the flame escaping above the vessel mouth for the control of the foaming slag by means of a photographic cell and by registration of the radiation intensity of the flame.
2. Measuring the stack temperatures in the stream of waste gases and registration of the same.

Using the current measurements of the stack temperature during the first blowing phase, it is possible to draw conclusions regarding the behaviour of the foam of the slag. A heat based on foamy-slag work is controlled by hand or also automatically by adjusting the lance and the oxygen flow on the basis of an impericallly established and drawn fixed curve. If the temperature curve is maintained as close as possible to the prescribed fixed curve the foaming of the slag will be good and can still be controlled.

3. Measuring the noise in the upper part of the vessel by means of special devices.

The devices are arranged outside the vessel in the area of the cone. On the basis of the blowing noise, which is amplified and registered, permitting direct conclusions regarding the foam degree of the slag, the heat can be conducted from the control-pulpit with a corresponding adjustment of the oxygen pressure and the lance position in such a way that there will be no slopping, but very well foaming slag.

4. Measuring the foaming slag rising in the interior of the vessel by means of water-cooled probes charged with electric current.

The use of this controlling equipment in a pilot plant enabled the height of the slag foam in the interior of the vessel to be measured unobjectionably. In other words, the first blowing phase was kept well under controll ensuring an operation without slopping. This cheap and simple method has not yet been used in practice, that is in an operation involving large vessels.

A number of countries have already shown interest in the LD-AC process also for blowing basic pig iron. In England and Japan, the LD-AC process is already being used for that purpose.

The LD-AC process, when used for blowing basic pig iron, also distinguishes itself by better dephosphorization and desulphurisation and by more favourable conditions for the life of the lining due to the fact that the slag is formed more rapidly.

For the lime-dust process the lime to be used must be crushed, ground and it must still be active when used. Besides, additional equipment, which is not required for normal LD-practice involving lump lime, must be installed for charging the lime dust in these processes. This additional equipment together with the lime preparation increases the conversion costs of the lime-dust processes as compared with the normal LD-process. This additional cost, however, is compensated to a large extent by the possibility of blowing Thomas iron into high-quality LD-steel with low phosphorus-, sulphur- and nitrogen contents.

Naturally, attempts have been made to eliminate as far as possible this additional cost caused by the construction of additional equipment in the lime-dust processes. In this connection the ring-nozzle for blowing Thomas iron was developed by Vöest, Linz, Austria, a few years ago. In the ring-nozzle the refining oxygen and the lime dust are charged separately. The lime dust is sent to the tip of the nozzle through a central tube, where it is mixed with the refining oxygen in the expanded portion of the nozzle-head, with the refining oxygen blowing out of a slot in the ring. The lime dust for the ring-nozzle can be sent to the upper head of a lance with air or also oxygen by a low or medium pressure station.

Extensive tests involving the ring-nozzle, have been carried out on a large operational basis and have shown that this very simple nozzle can be used for blowing Thomas iron.

Another method which proved successful in recharging dry dust obtained in the electric filter of the LD-process by using the Strico-process and in which the dust was returned to the process by means of a second lance separated from the oxygen-blowing lance, naturally also showed the possibility of charging lime dust instead of dry LD-dust to the process.

The way in which this two-lance operation worked, was reported as early as 1963 on the occasion of the Le Touquet-meeting, and, later on, several reports were filed on the further development of this method.

The lime-dust tests with a second lance were successful. The dust blown in was taken to the process a 100%, which means that no dust was lost to the waste gases escaping in the opposite direction.

This method according to the Strico-process, which is also called whirlwind system, for charging lime dust, is likewise a simple and cheap method. It has been developed by Messrs. ÖAMG, Austria, in cooperation with Messrs. Strico and has already been used on an industrial scale.

The attempt to find a solution to the problem of increasing the scrap charge in normal LD operation by the creation of additional heat, took many years of hard work. It is well known that the LD-process, when blowing different types of pig iron, uses certain cooling rates of scrap, ore or also limestone, whose amounts correspond to the chemical and physical heat of the hot metal to be blown.

At the beginning of these tests certain amounts of coke were used in order to supply additional heat to the process. The results, however, were hardly encouraging and not suited for application in practice, because the difficulties encountered in dissolving the coke charged caused the slag to foam, which interfered with the whole process particularly with good dephosphorization. In addition to that, the efficiency of coke consumption was so bad that there was no sense in continuing the tests on that basis.

The next step in the test series aiming at the possibility of melting larger amounts of scrap in the LD-process, was the use of special lances, which were to heat up the charge and simultaneously refine the bath with oxygen and oil or natural gas or coke-oven gas. Messrs. Vereinigte Österreichische Eisen- und Stahlwerke AG were the first to develop such a special lance called the heating and refining lance, which yielded quite remarkable results in practice. The lance acted as a heating or burning lance, on the one hand, and as a refining lance, on the other. Fuel was supplied until a few minutes prior to the end of the blowing period.

The test results showed that in order to increase the scrap charge by 10 % it was possible to use a heating and refining lance to heat up the scrap and the hot metal together in the vessel without interrupting the LD-process, maintaining a still justifiable heat efficiency for the heat brought to the process from the outside.

In order to increase the scrap charged by more than 10% the work involving the heating and refining lance must be devided into two work phases if a similarly favourable heat efficiency is to be obtained:

The scrap is heated up in the vessel to 800 - 1000°; after heating up the scrap the liquid hot metal is poured into the vessel, whereupon the slag-forming material is charged, and subsequently the heating and refining lance is brought into position for commencing the second work phase. By using this method it was possible to reach scrap charges amounting to abou 0% of the metallic charge together with the amounts of scrap corresponding to the chemical and physical heat of the hot meta

In attempting to further improve the heat efficiency in the operation involving liquid and gaseous burner lances, already known high-efficiency oxygen, oil or gas burners were used for heating up the scrap and the process, as mentioned above, was likewise devided into two parts. During the second part, after the hot metal had been poured into the vessel, the process was continued as a normal LD-process using a normal LD-lance without the addition of fuel.

These tests were carried out successfully also in large plants. The equipment on the vessel included the following:
On the lance carriage, which is laid out for a work lance and a stand-by lance, hangs the high-efficiency burner instead of the stand-by lance, and the second lance is the normal LD-lance. After heating up the scrap, the burning lance is removed; after pouring in the hot metal the oxygen-blowing lance, which has been prepared in the meantime, is brought into position without any delay being caused in the course of the operation. This two-phase

operation for increasing the amounts of scrap charged in the LD-process, has proved satisfactory in spite of the loss in performance connected with it as compared with the normal LD-process. This above all applies to plants in which there is sometimes a shortage of hot metal. It was possible in these cases to process larger amounts of scrap by the LD-process and to achieve in this manner a higher output of ingot steel.

A further step in the field of the increase of the scrap charge in the LD-process by the addition of additional heat carriers, was the use of CaC_2 as a slag-forming material in solid form replacing burnt lime either partially or completely.

After the first tests carried out in a small vessel plant at BHP, Australia, proved promising, large-scale tests were carried out i normal-operation plants.

Commercial carbide is expensive and anyone having to deal with this question will first think that owing to its high price carbi can hardly be used for metallurgical purposes on a large scale. If you go into details, however, and calculate the operating costs for carbide, basing your calculation on the ratio between the price of the hot metal and the price of the scrap, you will realize that in cases where the price of scrap is low the use of CaC_2 can really permit a still justifiable production of LD steel in spite of the high price of carbide.

It is interesting to note that the results obtained in practical operation by different steel plants showed that in the case of small vessel units, i.e. from 40 to 50 tons per kg of carbide, it was possible to charge by 10 to 12 kg of scrap more than usual. However, in the case of larger vessel units holding 150 to 200 tons, the amount of scrap could be increased only by 6 to 8 kg per kg of carbide. This difference in the efficiency of carbide consumption can be interpreted to mean that in the case of smaller vessels which, absolutely speaking, have a shorter bath diameter, the efficiency is higher for the solution of the carbide from the point of view of time, while in wider and larger vessels it is more difficult for the carbide pieces, spread over the whole large surface, to dissolve.

These results led to the idea to blow the carbide to be charged in the form of dust or of finest grain on to the central area of the surface of the bath where the highest temperature prevails during the process in order to achieve in this manner a more rapid dissolution and, thus, to prevent the slag from starting to foam.

In accordance with this idea of bringing carbide in the form of dust or finest grain into the process, tests were carried out in the plant of Messrs. ÖAMG, using the whirlwind process, which was already described in connection with the operation involving lime dust. The tests showed that it was correct to supply CaC_2 in its finest form to the LD-process, i.e. to the central part of the reaction area. In this manner it was possible to create the most favourable conditions for the dissolution of the carbide.

It was found that the use of carbide dust essentially improved the development of the process as compared with the operation involving lump carbide. It was possible to see a normal flame at the vessel mouth and there was no strongly foaming slag as when lump carbide was used. When carbide dust was used the formation of the slag began by 2 to 3 minutes earlier, which likewise was to be expected.

The fact that the use of carbide in its finest form instead of lump carbide permits a normal quiet operation of the slag with practically no foaming in the LD vessel, may be described as a success. It would therefore be an advantage to include equipment for the pneumatic dust supply according to the whirlwind system in the planning of any LD-steel plants in the future in order to permit the utilisation of these advantages in the operation. The use of dry LD dust permits a favourable reutilisation of the latter, the use of lime dust improves dephosphorization and desulphurization and the use of fine carbide permits an increase in the amount of scrap charged.

The great difficulty you run into when using carbide is its inclination to hydration. Carbide must be stored in airtight containers until it is used in the LD vessel, which in some plants causes difficulties.

Tests involving SiC to increase the amount of scrap charged in the LD vessel, on the other hand, have shown more favourable operational conditions. SiC can be stored in the open air without any danger and therefore has less problems when used in practical operation.

A number of improvements achieved in the course of the years in the field of the control of the LD-process should likewise be noted. The most important of them is the use of an optical method for observing the flame with simultaneous determining of the final point of soft steels. This method enabled the plants in which it was used to improve their yield by adhering more exactly to the blowing conditions at the end of the process, which is characteri by the fact that the FeO content in the slag remains practically the same. By the elimination of defects caused by overblowing soft heats, the quality of the steel produced was improved again.

A wide area is covered by the LD process in the production of high carbon and alloy steels. After the method, according to which the steel which had been blown down was recarburized in the ladle by the addition of carburizing agents if the C content was to be between 0,10 to 0,25%, the method of catching the heats in the case of steels with an even higher carbon content was developed on a large basis and is still being used today.

The reason why the method of catching the heats for higher carbon contents spread so rapidly, was the fact that it was very hard to hit the correct content by recarburizing the steels in the ladle. Today, however, carbon carriers are blown pneumatically through a tube into the ladle during the tapping according to the recarburizing method and, thus, it is possible to hit the carbon content of the heats quite safely.

On the other hand, the method of catching the heats still prevails in LD-steel plants when high-carbon steels are produced.

If the hot metal has a high Mn content remanganizing, which occurs during the last third of the blowing period, may be utilized when the catching method is applied. In the case of such a hot metal steels having a C content of 0,50 - 0,70% and a Mn content of 0,80 - 1,20% can be produced without any ferromanganese being added or with only a small amount of FeMn being added.

There are 3 points characterizing the catching of heats negatively They are the unsatisfactory P and S contents in the finished steel if the slag formation is not conducted exactly. Then the lower amount of scrap charged as compared with heats which are completely blown down in order to obtain the corresponding final temperature of the finished steel with a higher carbon content; and the third point concerns output, i.e. the productivity of the operation. The time required to get the rapid sample analysis from the laboratory, causes a loss of time with caught heats. The are plants equipped with most up-to-date spectrographs, which nevertheless have to wait for 6 to 12 minutes until they receive the teletyped analysis, i.e. the time that elapses between the taking of the sample and the receipt of the analysis in the control pulpit. This is too much time, it reduces the efficiency of the vessel and, besides, the finished heat lying at pouring temperature in the vessel unfavourably affects the sensitive lining.

In order to obtain a more favourable final analysis with regard to P and S, and to eliminate the loss of time as described above, the LD-steel plant of ÖAMG, Austria, developed a method which was indluded in their large production programme of high carbon steels.

50 % of the steels produced by that plant have a somewhat high carbon content. According to that method a certain amount of hot metal calculated on the basis of the carbon content to be achieved in the final analysis, is poured into the steel stream in the ladle during the tapping of the heat which has been blown down

to 0,08 to 0,10 % of carbon.

Special steel production in the LD vessel

During the first years when the LD vessel was adopted for the production of special steel, special steels with a total alloy content of 5 % were blown by it.

Inasmuch as the majority of the special steel plants are equipped with degassing plants for the treament of steel with special quality prescriptions, these plants were included in the various test series aimed at working out the entire technique for special-steel production in LD-steel plants.

The method of producing alloy steels is divided into 4 main groups.

1) The blowing of basic pig iron in the LD vessel with the slag being removed once or several times and the addition of alloys during the blowing process at certain intervals. After the tapping of the heat into the ladle, deoxidisers are added and slight alloy corrections are made. This is the old method as used in open-hearth furnaces.

2) The blowing of basic pig iron in the LD vessel with the slag being removed once or several times, the addition of alloys during the process and, subsequently, complete deoxidation of the steel in the vessel and the correction of the carbon content in the ladle during tapping.

3) The blowing of basic pig iron in the LD vessel with the slag being removed once or several times, the addition of alloys during the blowing and the transfer of the finished heat to the degassing plant, and after degassing final deoxidation of the steel.

The method mentioned under point 3) may be described as the method most widely used today, for it creates most favourable conditions from the point of view of quality. The subsequent vacuum-degassing method shortens the melting time in the vessel because the deoxidation (refining) period is transferred from the LD vessel to the pouring ladle and the vacuum plant.

4) The charging of medium-alloyed or high-alloyed liquid basic pig iron into the vessel.

The alloyed basic pig iron to be blown, should have a chemical composition not requiring the addition of solid alloys during the blowing process.

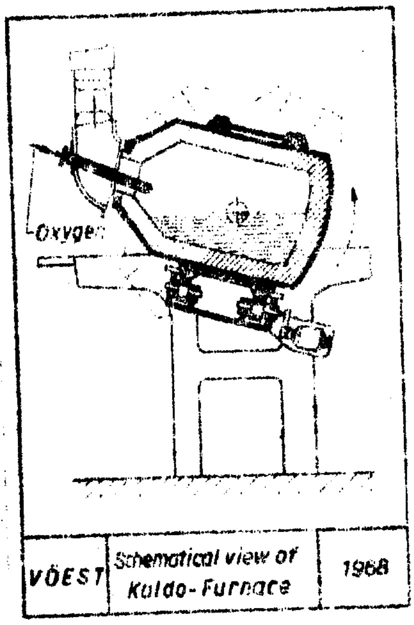
Taking into account the alloying elements contained in the charge of alloyed liquid pig iron, the heats are run in the LD vessel in a special way regarding slag formation.

The desulphurization of the alloyed hot metal is carried out prior to charging the hot metal into the LD vessel so that the slag work in the vessel does not have to accomplish any metallurgical tasks and the process is restricted exclusively to pure refining.

Inasmuch as the dephosphorization of an alloyed hot metal with a high Cr concentration is no longer possible from the metallurgical point of view, the charge for the unit producing the hot metal must be chosen in such a way that a correspondingly low P content will be obtained in the analysis.

The LD-process in connection with a vacuum plant has enabled the steelworker to produce even stainless steels of highly satisfactory quality by the LD-process.

The Kaldo process



VÖEST | Schematical view of Kaldo-Furnace | 1968

Fig. 5

The Kaldo process is characterized by the fact that the refining takes place in a slightly inclined rapidly rotating vessel.

The velocity of rotation is between 0 - 40 rpm.

The gaseous oxygen is blown across the bath by means of a water-cooled lance introduced into the vessel through an opening. The waste gases evolved during the process, which mainly consist of CO_2, go into the stack through the vessel mouth in the opposite direction. The schematic sketch in fig.5 shows the Kaldo rotor in its operating position, the lance position during the process and the stack receiving the waste gases.

The first plant of an industrial scale was put into operation in Sweden in 1956. This plant had been built for processing high-P hot metal.

In spite of its good performance and the results obtained quality-wise as compared with the open hearth, this process gained ground in practice rather slowly. By the end of 1957 a total of 10 Kaldo-plants were in operation in the whole world, of which 5 had been laid out with exchangeable vessels.

It goes without saying that the possibility of rotating the melting vessel holds advantage for the technique of the process. It is possible to control the iron content of the slag and the carbon drop by changing the distance of the lance and the speed of rotation of the vessel according to necessity.

After finishing the heat the final slag can easily be stiffened up in the melting vessel, particularly in the case of soft heats with a low carbon content, with a lime addition being made while the vessel is still rotating. The utilisation of this advantage ensures the lowest possible phosphorus contents, since any rephosphorization caused by slag getting into the ladle when the vessel is tipped, is excluded to a far extent. A further advantage of rotating steel and slag is the possibility of obtaining the required tapping temperature exactly.

The possibility of mixing the heat and the slag by rotating the vessel at the end of the process, results in a steel which, when poured into the ladle, has a far-reaching homogeneous composition.

Another highly remarkable feature of the Kaldo process is the possibility to burn the CO which evolves during the refining, to CO_2 in the rotor. 90 % of the CO evolving in the refining process is burnt to CO_2 in the rotor. The heat created by this combustion can be used for melting more scrap. The scrap in the Kaldo process constitutes 40 to 50 % of the metallic charge if Thomas iron is blown with 2 slags and a greater amount of slag. If basic pig iron is blown, the scrap charge may go up as high as 60 %. Any type of pig iron of course can be blown by the Kaldo process, although, originally, the Kaldo process was adopted in practice exclusively for blowing high-phosphorus hot metal.

This process may be cooled with cold pig, with scrap, but also with iron ore.

In the end, however, when judging the value of this process, the justified question arises why today, in spite of these favourable aspects, only 10 Kaldo plants are in operation. In contrast to that, a total of 115 LD-steel plants are operating in different countries of the world now.

In my opinion the most important reasons why the Kaldo process is being adopted in practice rather slowly, are the high maintainance costs of the rotating melting vessel, which is almost like a maschine, and the still unsolved problem of the refractory material best suited for it as well as its lower productivity in comparison with the LD-process.

The Rotor process

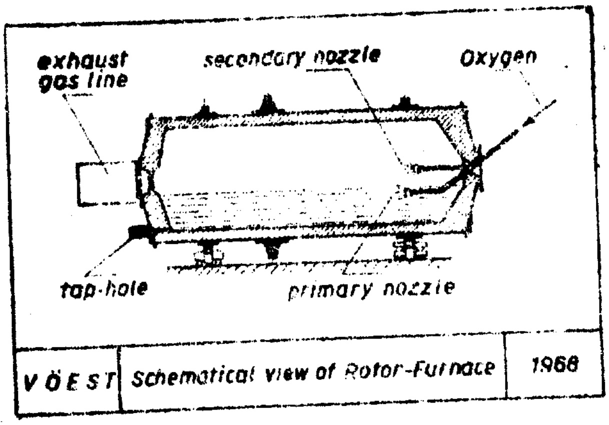


Fig. 6

Fig. 6 shows a schematic cross section of a rotor plant. You can see the tube-like vessel operating in a horizontal position.

You can also see the primary-oxygen lance working as an immersed lance and the secondary lance which sends the oxygen across the bath.

The development work for the rotor process as adopted in practice subsequently, originally started at Oberhausen, Germany, and was based on the use of additional oxygen for steel-making in general as tried out in that plant many years ago.

In 1952 it was attempted for the first time to refine hot metal in practice in a 20-ton melting vessel equipped with an oil burner and on which instead of that oil burner an oxygen lance had been mounted. The tests aimed at refining hot metal in this manner yielded encouraging results and in the course of the subsequent tests a vessel of similar design, which, however, could be rotated, was placed in the pouring area of the blast furnace. This rotating vessel had the lance equipment for the supply of oxygen on its open side and its tap hole on the opposite side.

In the rotor process proper, which developed from these preliminary tests, the oxygen is supplied in two separate jets. There is a primary oxygen jet and a secondary oxygen jet. The flow and the pressure of the two jets can be adjusted separately. The primary oxygen is blown below the bath surface by means of a water-cooled lance at the entry side of the rotor. This oxygen, which is blown in at high speed, oxidises and moves the bath.

The secondary oxygen is used for burning the CO which evolves during refining, and is therefore blown in above the surface.

The waste gases evolving during the process are sucked off into the stack at the opposite side. The rotor is, as its name implies, a vessel which rotates during the course of process. The number of revolutions per minute, however, is only in the area of 0,1 - 0,5.

Any type of pig iron can be processed by the rotor process. If basic pig iron is used, the process is run with one slag; if

Thomas iron is used, it is run with two or several slags. In this case too, the final slag is used for the next heat.

In spite of the fact that after the first tests and the first operating plants the opinion prevailed that this process would be widely adopted in practice, this did not happen. The rotor plants in Germany, the country of origin of this process, have been shut down and part of them have even been dismounted.

In my opinion there are several reasons why this process was not adopted on a large scale. They were the difficulties regarding lining life, long tap-to-tap times, i.e. an essentially lower productivity than in other oxygen-refining processes, difficulties in melting technique encountered in large plants, such as the conduct of the slag and uniform temperature control of the heat as well as higher capital investment for a rotor plant as compared with other oxygen-steel-making facilities.

The Tandem furnace

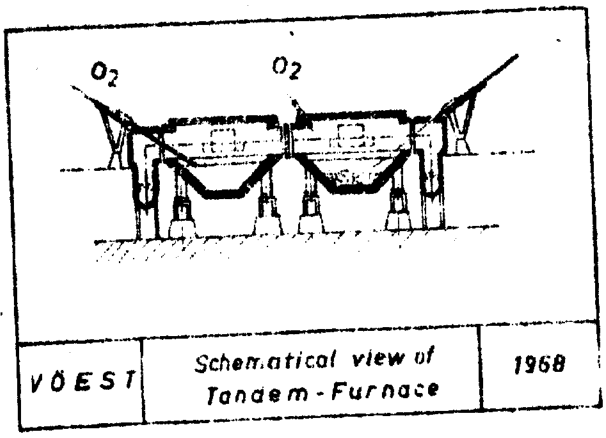


Fig. 7

When pig iron is refined with oxygen the heat produced by the oxidation and the slagging of the impurities is somewhat greater than the combustion heat together with the sensible heat of the CO, which evolves during the refining. The Kaldo process and also the rotor process are based partly on this knowledge and both processes utilize the heat produced by the combustion of CO in the interior of the melting vessel.

After the development of the Kaldo and the rotor process it was attempted to find a new way to use the heat originating from CO combustion advantageously in practice. On the basis of experience gained in rotor operation Messrs. Iscor, South-Africa, developed the Tandem process.

In the Tandem process the refining and the CO combustion brought about by oxygen, takes place in two separate melting vessels located close to each other. The same as in the case of the Iscor rotor process, the refining oxygen is blown deep into the bath at supersonic speed. The lance is located immediately above the bath.

Picture 7 is a schematic representation of the Tandem plant. While the refining is done in one furnace, the cold charge is heated up for the next heat in the furnace next to it.

The refining phase covers about 50 % of the time of a heat with the other 50 % being the heating-up work. In other words, the hearth vessels operate interchangeably as refining furnaces and as preheating furnaces. According to the most recent stage of the development of this technique the pure blowing time for a 120-ton heat is 45 minutes in this process. About 16 - 20 heats per day can be blown in such a Tandem furnace plant. As far as perfomance is concerned, also this process lags behind the LD-process.

The great advantage held by the Tandem furnace is the fact that such facilities can be installed in existing open-hearth plants at lowest cost and that after such installation a remarkable increase in performance can be achieved as compared with the open-hearth plant.

The space required by a 100 - 120-ton Tandem plant is not larger than the space for a 160 - 180-ton open-hearth-furnace plant.

In this connection, however, it should be pointed out that it is possible to install also LD vessels in existing open-hearth-furnace plants. Plants of this kind have already been erected in different countries and thus prove that such installation is possible without extending the height of the existing steel-plant building.

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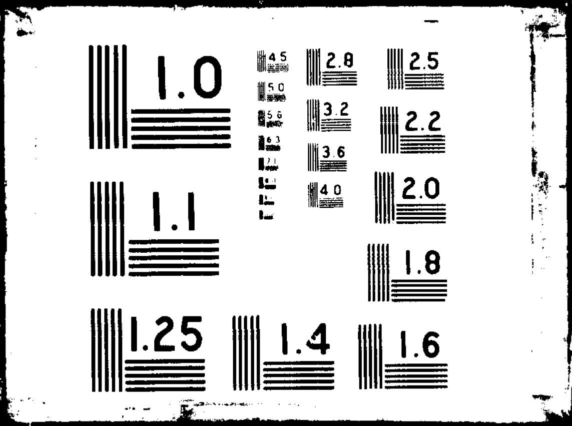


The LD-Kaldo process

The most recent development in the field of the oxygen-steel-making processes is the LD-Kaldo process, which has likewise been developed for blowing Thomas iron, i.e. iron with a high P content.

About 13 years after the adoption of the LD-process by the steel industry and 9 years after the start-up of the first Kaldo plant in the world, Messrs. Cockerill-Ougrée, Belgium, decided to develop a process which would combine the advantage of the two processes. i.e. LD and Kaldo.

In the Marchienne plant of that company an LD-Kaldo plant with a nominal capacity of 35 tons was erected and put into operation in 1965.

As its name implies, the LD-Kaldo process is a combination process which for any length of time can be run just like an LD-process, i.e. with the vessel in upright position not rotating, or like the Kaldo process with the vessel in inclined position rotating around its longitudinal axis.

From the time of start-up until today they have produced by this combination process at Marchienne several hundred thousand tons of ingot steel of different grades, soft and high carbon, rimmed and killed, unalloyed and also alloyed. From the point of view of quality the results were absolutely satisfactory in all steel grades blown.

The essential features of the LD-Kaldo process are the following: The vessel in which the process is run, is designed in accordance with the measurements applying to an LD vessel. It can be rotated around its longitudinal axis in an inclined position for any length of time both during and after the completion of the heat. This feature ensures optimum dephosphorization and desulphurization. If Thomas iron is used with the intention of obtaining lowest phosphorus contents in the steel, the LD-Kaldo vessel is operated according to the two-slag system. The changing of the operation from LD to Kaldo or vice versa, can be carriedout with very little loss of time. Another advantage apart from the flexibility of the process in addition to the improved metallurgical conditions prevailing during the course of the process, is the fact that the heat economy in the vessel can be controlled by the operator to a far extent. The possibility of adjusting the heat economy, i.e. the possibility of adding more or less scrap for cooling the process, results in a favourable operation from the point of view of cost because the operation can be adapted to the particular situation of the market with regard to scrap.

The possibility of rotating the LD-Kaldo vessel also enables the processing of Thomas iron to be regulated exactly with regard to carbon combustion, particularly during the second phase so that caught heats with high carbon contents can be produced with the greatest exactness.

The possibility of rotating the vessel, i.e. the fact that the same as in the case of the Kaldo rotor the vessel can be rotated even after the completion of the process, is advantageous for the steel worker because by taking appropriate measures while rotating the vessel for a short time after the completion of the blowing process and, if necessary, by adding a certain amount of lime, he can achieve the desired final temperature without difficulty.

The possibility of mixing the slag and the steel after the completion of the blowing process improves the homogeneousness of the bath, which is of importance for the production of alloyed steels and also for steels which undergo continuous casting.

As previously stated the LD-Kaldo process at Marchienne was intended to be used for the blowing of Thomas iron at the time when the first such plant was being planned. The operation of that plant, however, soon showed that the advantage held by this process, which resulted from the design permitting rotation of the LD-Kaldo vessel, might also become of interest for the one-slag LD-process in the future.

The work on an industrial scale showed that Thomas iron can be blown also with one slag if in the case of soft steels, final phosphorus contents of 0,020 - 0,022 % are required.

Owing to the fact that in the LD-Kaldo process the slag can be treated better in the vessel after the blowing, for example by better stiffening up the slag, it is easier to hit the desired values of the analysis in this process. By excluding subsequent reactions in the ladle, manganese losses or undesirable rephosphorization can be avoided.

Thomas steel grades which nowadays are very hard or even impossible to sell because of their high phosphorus and nitrogen contents, can be produced with one slag in the LD-Kaldo vessel simply and cheaply with lower phosphorus and nitrogen contents.

The LD-Kaldo process is operated without lime dust, screened lime in grain sizes from 15 to 25 mm is used as slag-forming material.

In comparison with the lime-dust process this may be regarded as an advantage.

The life of the vessel lining in this process is good. On an average, 400 heats have already been achieved.

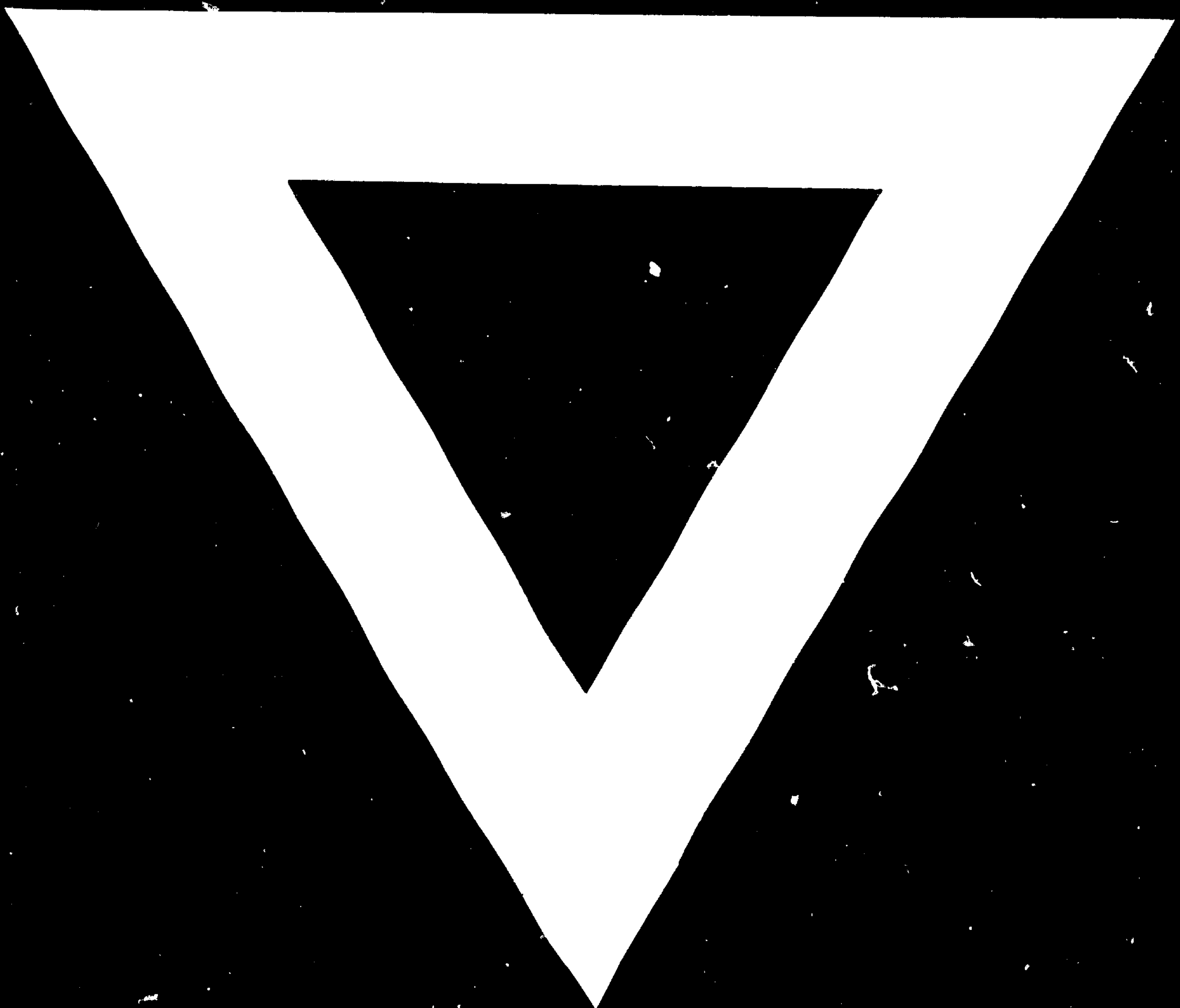
Steel workers still hold widely differing opinions regarding the LD-Kaldo process today. Some say that for the blowing of Thomas iron, the LD-Kaldo process should be preferred to the simple Kaldo process, while others say that for working Thomas iron you need neither the Kaldo nor the new LD-Kaldo process, since all requirements with regard to performance and quality can be met by the LD-AC lime-dust process. There are still others who say that, since the vessel size for the LD-Kaldo vessel is limited, they could imagine a large steel plant on LD-AC or on LD basis having an additional 40-80-ton Kaldo plant for the production of special and alloyed steels.

It is also the opinion of this group of people that all special steel plants where nowadays high-quality steel is produced by the

LD-process, should produce these steels by the LD-Kaldo process.

It is still too early to say definitely whether the use of the LD-Kaldo process for blowing basic pig iron with a low phosphorus content would be a good idea since no test results are available yet.

I hope that my report has given you sufficient information about the modern oxygen-steel-making processes and thank you very much for your kind attention.



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