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THE THEORY AND PRACTICE OF BOTTOM-BLOWING OXYGEN METALLURGY[1]

by

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SUMMARY

The paper describes the OBM oxygen bottom-blowing process. The essential advantages of the process are that the oxygen reacts with the metal in an ideal manner and lime can be blown simultaneously. The special tuyeres are protected from attack by simultaneous injection of gaseous or liquid hydrocarbons. The process is also being applied to other types of steelmaking furnace, such as the electric arc and open-hearth.

The paper begins with a description of the process. The number of tuyeres varies from 5 to 15, although it is believed that 10 is the maximum number that may be needed, even on the largest vessels. Bottom lives at Maxhütte have been as long as 300 heats, and it is believed that this figure could reach 400.

The section on the metallurgy of the process emphasizes the basic difference between bottom and top blowing. The iron oxide content of the slag is low, and only reaches 17% at the end of the refining period. Efficient dephosphorization is ensured by the intense bath agitation. Desulphurization is satisfactory, and the carbon content at the end of blowing is lower than that in the LD process. Nitrogen is brought down to as low as 10 ppm. Hydrogen contents are high, especially with high-phosphorus iron, but can be brought down by short inert-gas flushing treatments.

By comparison with the top-blown process, the iron oxide loss is only one-quarter, which means that there is less evolution of red fume. The iron oxide content of the slag is lower, giving 2½% greater yields. Scrap dissolution is more rapid. The simultaneous injection of oxygen and lime means that there is very little slopping. Some 20% more scrap can be processed. The height of plant needed is only two-thirds that of the LD process, which means that the OBM process can be inserted into existing melting shops based on open-hearth furnaces. Finally, there is a marked increase in productivity.

The process can produces steels with carbon contents ranging from 0.01% to 1% and above; calon contents lower than 0.15% are achieved by blowing down to 0.05% and recarburizing. Low-alloy and medium-alloy steels can be produced by converter or ladle additions. The paper reports on trials with a wide range of carbon steels; the results showed that those produced using the OBM process correspond in properties to the equivalent LD or open-hearth grades.

The OBM Process (Oxygen-Bottom-Maxhütte) which Eisenwerk-Gesellschaft Maximilianshütte mbH (MAXHÜTTE), in the Federal Republic of Germany, has developed for the production of steel up to its applicability on industrial-scale basis, is an oxygen bottom-blowing process.

While in top-blowing processes the agents required for refining operations are blown by means of lances on top of the melt, in the OBM process the oxygen is blown through tuyeres arranged in the converter bottom into the melt. Owing to the fact that the oxygen is blown through the metal bath to be refined, it can react with the melt in an ideal manner. In addition to this, it is feasible to inject the lime required for the metallurgical reactions as fine powder in conjunction with the oxygen, by which substantial phenomena in steel production are effected decisively and, in particular, an absolutely quiet course of blowing is obtained.

For the applicability of the process on large-scale basis, it has been of decisive inportance that, by surrounding the oxygen jet with a small quantity of gaseous or liquid hydrocarbons, protection of the tuyeres against rapid wear was obtained. Through this, an old wish, existing in steel production ever since the invention of the Bessemer process, became reality.

In the meantime, the principles of the process have been transferred also to other steel-refining vessels, for instance, open-hearth or electric furnaces, whereby similar positive results were obtained as at the application to converters.

The designation Q-BOP introduced in the United States of America makes it evident that in this process, like in the industrially widely adopted LD process, known in America as BOP process (Basic Oxygen

Process), pure oxygen is used as refining medium. The letter "Q" stands for "quiet, quick, quality" and emphasizes the advantages of the new oxygen bottom-blowing process in comparison with the oxygen top-blowing process, consisting in a more quiet blowing behaviour, a quicker refining, and a better quality.

Description of the Process

The OBM process involves arranging of appr. 5 - 15 tuyeres in the removable bottom, such number being dependent on the converter size, through which the oxygen and generally also the lime powder, as well as the hydrocarbon containing protective fluid surrounding the oxygen jet (fig. 1, schematic sketch), are introduced.

In large converters, a further decrease in number of tuyeres will probably be feasible. Even for converters of 200 tons capacity, 10 tuyeres should be sufficient.

Arrangement of tuyeres to which particular importance has to be attributed is chosen in such way that a most favourable blowing behaviour is achieved.

Sufficient protection of the tuyeres against burning-back is obtained already by a small amount of hydrocarbons corresponding to about 3 % of the amount of oxygen. Several hydrocarbon-containing media, such as propane, natural gas, or light fuel oil, may be used as protective fluid.

The life of the converter bottoms through which the oxygen is injected has increased considerably at MAXHÜTTE since the adoption of the OBM process and is on the average 300 heats at present. Considering a refractory lining life of the converter of about 500 heats, the bottom has still to be replaced only one time during one converter campaign. The time needed for replacing the bottom is approximately one shift.

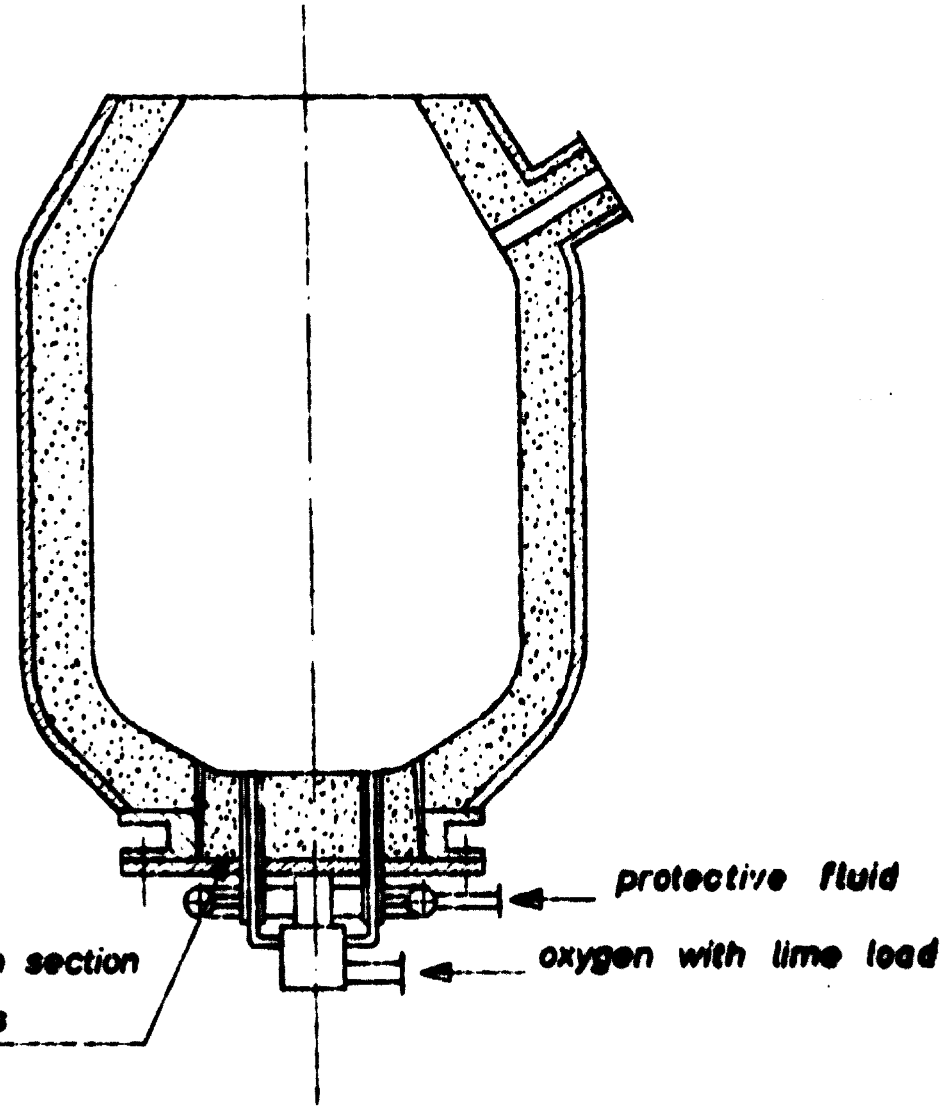


Fig. 1 OBM converter

Research work carried out recently at MAXHÜTTE resulted in achieving lifes of even more than 100 heats with several tuyere bottoms. Increase of bottom life to the duration of the refractory lining life of the converter jacket is expected before long, so that the one replacement of bottom still required at present during a converter campaign will equally become unnecessary.

Metallurgy of the OBM Process

Due to the way of feeding the oxygen, the metallurgy of the OBM Process is much different from that of the oxygen top-blowing processes.

During about 90 % of the total refining period, the iron-oxide content of the slag only runs up to about 5 % (fig. 2) and is also at the end of the refining with 17 % still relatively low.

In spite of such low content of iron oxide, a good dephosphorization is obtained as a result of the intense agitation of the bath leading to the equilibrium between bath and slag. The initial phosphorus content of the pig iron being 0.2 %, the average phosphorus content of the melt amounts to 0.006 % (fig. 3).

Special measures have to be taken for obtaining an advanced dephosphorization as required for catch-carbon heats. A certain way of injecting the lime powder in conjunction with the oxygen permits to arrive at an efficient dephosphorization also in the case of catch-carbon heats. With an initial phosphorus content in the pig iron of 0.200 %, a phosphorus content of 0.020 % is obtained by this means in the finished steel, the carbon content being simultaneously about 0.7 %. These results depend on the temperature. The indicated values apply to a temperature of 1620°C.

Desulphurization at the OBM Process is represented in fig. 4. The initial sulphur content in the pig iron being 0.040 %, a sulphur content of 0.020 % is obtained in the steel.

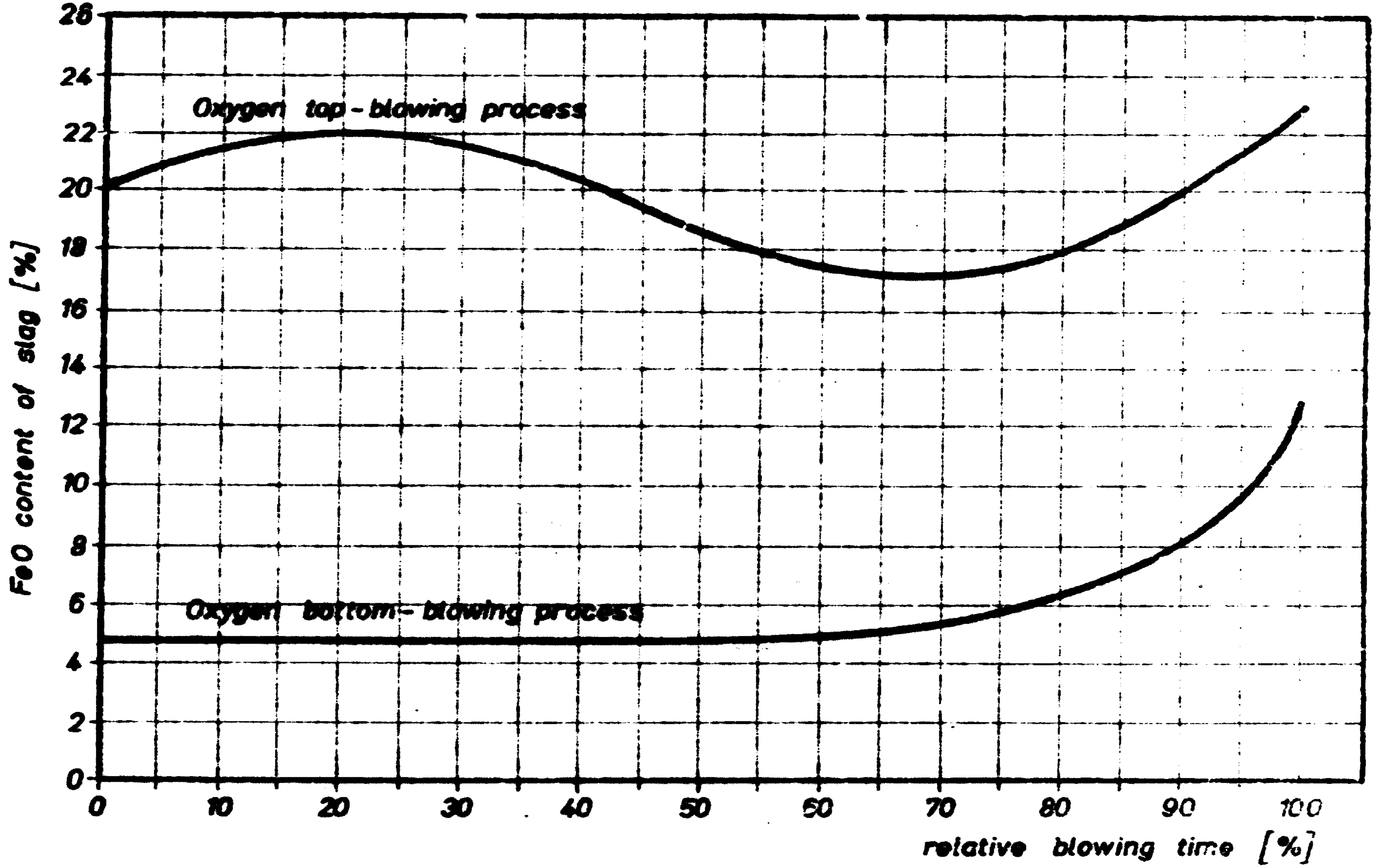
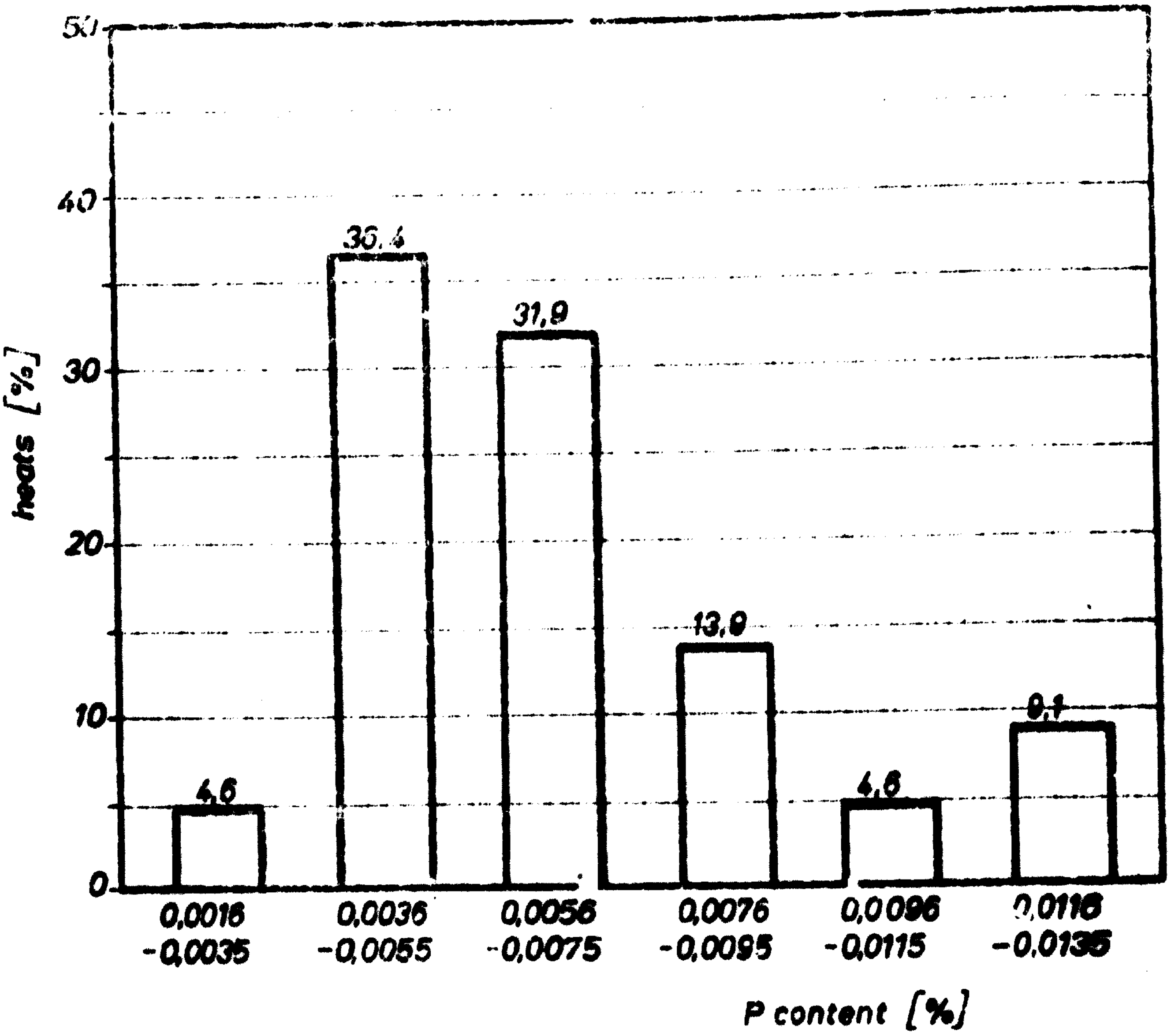


Fig. 2 FeO content of slag in oxygen top-blown and oxygen bottom-blown converters



pig iron: average P content 0,203 %

22 heats: average contents before tapping C < 0,05 %
P 0,0066 %

temperature: 1595 - 1620 °C

FeO (slag) 17 %

Fig. 3 Frequency distribution of P contents before tapping in OBM heats with low carbon content (USSC)

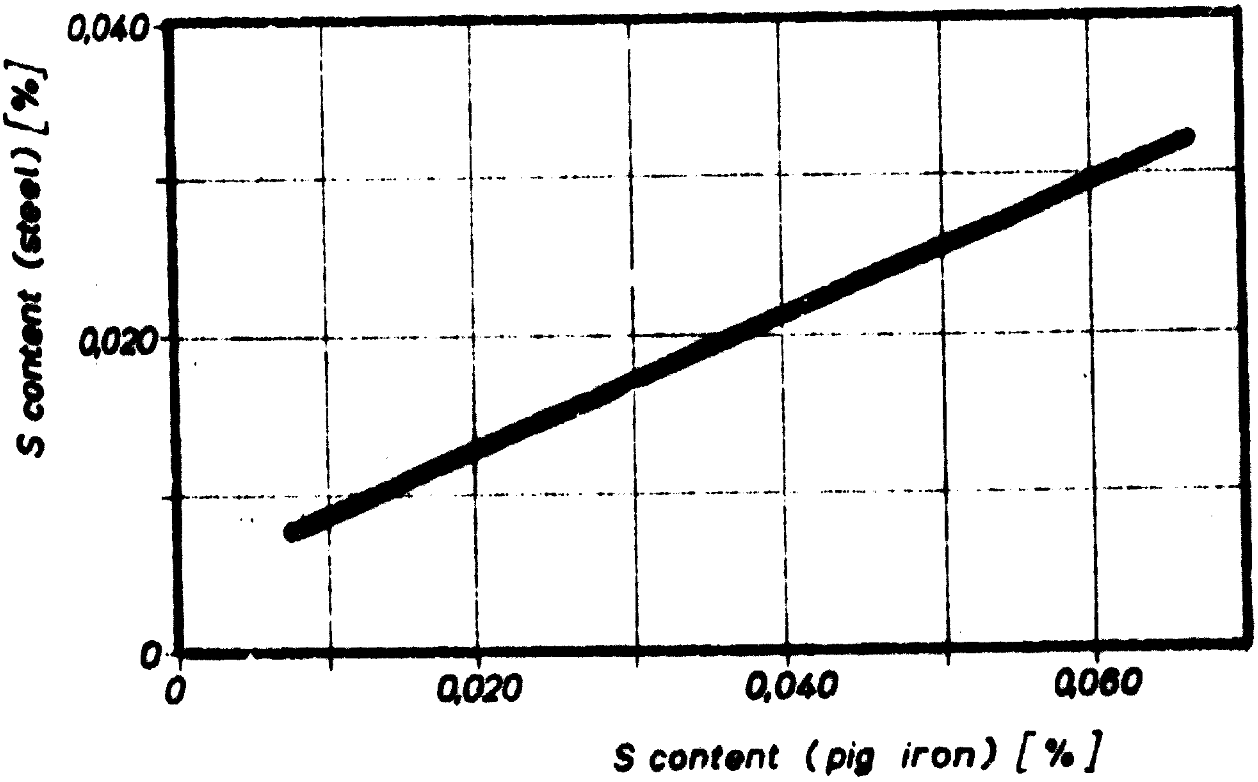


Fig. 4	S content in steel as function of S content in pig iron (USSC)	

In the refining of low-phosphorus pig iron, there are no problems in regard to hydrogen contents. Due to the carbon monoxide developed during refining, the hydrogen is for the most part again removed from the melt. Consequently, the average hydrogen contents both at high-carbon heats and at heats blown down to low carbon contents are about 3 ppm (fig. 5).

If required, even this hydrogen content can still be reduced considerably by a treatment with purging gas.

The carbon contents at the end of the blow are lower than in the LD process. With a slag containing 17 % iron oxide, the final carbon content is about 0.03 to 0.04 %. By purging the heat with an inert gas for about 1 min at a rate of 1.5 m^3/ton of steel, the carbon content is reduced to about 0.01 %. This is of specific importance for the production of electric sheet grades. However, also in view of the low-pearlitic or pearlite-free structural-steel grades, which constantly are gaining ground, the producti of heats with 0.01 % carbon in the converter is of interest, because it permits largely the addition of cheap carbon-containing ferro-manganese for adjusting the required contents of manganese without carbon contents exceeding 0.04 to 0.05 %.

The following might equally be of interest:

Unlike the oxygen top-blowing process, where the refining of high-phosphorus pig iron required special developments, unexpected problems were encountered when refining low-phosphorus pig iron by the oxygen bottom-blowing process.

Without simultaneous injection of lime powder, the blowing behaviour is so bad that it is hardly possible to finish refining of such heats. On the other hand, the simultaneous injection of lime powder in conjunction with oxygen results in a fully controlled and quiet blowing course.

By use of the OBM process, it is feasible to obtain, under favourable conditions (i.e. pig iron with low nitrogen content and ample cooling by ore addition), nitrogen contents of about 10 ppm. The possible effect of such low nitrogen contents on the production of unkilled deep-drawing steel and other cold-working steel grades will still have to be explored in future.

Now, some remarks as to the hydrogen contents in steel.

The use of the hydrocarbon-containing protective medium required in regard to tuyere life causes the delivery of certain amounts of hydrogen to the steel bath.

During refining of high-phosphorus pig iron, where subsequent to carbon oxidation the oxidation of phosphorus occurs, in which latter phase only a few gaseous reaction products develop, a considerable increase in hydrogen content appears.

At the end of refining phosphorous pig iron, an average hydrogen content of 8 ppm is found in the steel. Should this hydrogen content appear too high for certain steel grades, it can be reduced by a short purging with an inert gas, e.g. nitrogen. By injecting nitrogen in an amount of about 1 m^3/ton of steel, the hydrogen content can be decreased from 8 to about 3.5 ppm. This entails an increase of the nitrogen content by about 10 ppm.

In general, a reduction of the hydrogen content is not required for aluminium-killed steels. In case of unkilled steel grades, the elevated hydrogen content even exerts a favourable influence on the boiling behaviour.

In this connection, it might also be of interest that a hydrogen content of about 8 ppm permits to make Mn-Si-killed steels, with a silicon content of about 0.30 %, as hydrogen semi-killed steels. Thus, the structure of a semi-killed steel is obtained by the hydrogen, in which the subcutaneous blow-holes, probably due to the high diffusion velocity of the hydrogen, only commence at a larger distance from the surface than in the usual semi-killed steels.

carbon content (tapping) > 0,10 %
100 heats
average value (H_2) 3,1 ppm

carbon content (tapping) ≤ 0,10 %
35 heats
average value (H_2) 2,9 ppm

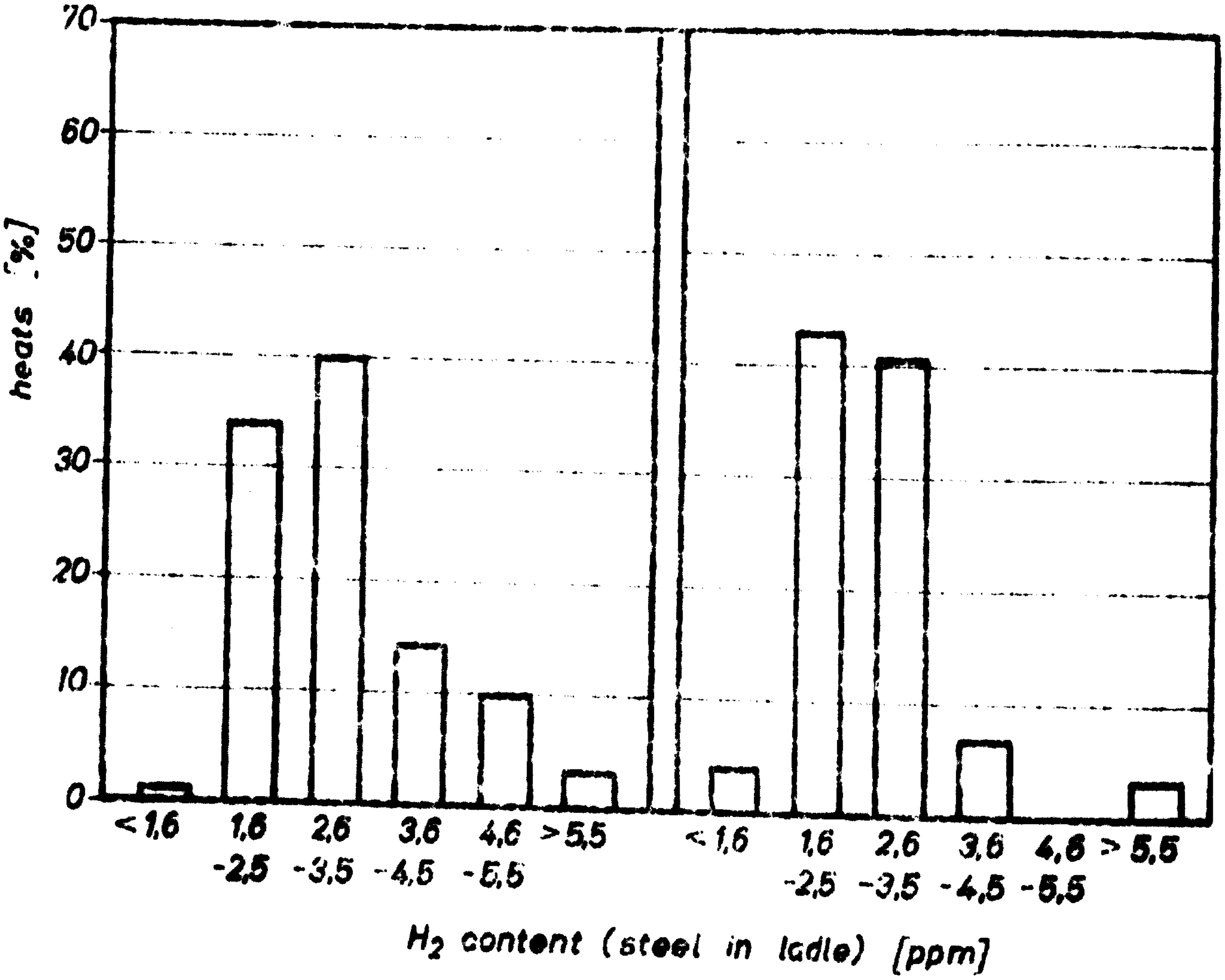


Fig. 5 Frequency distribution of H_2 contents in OBM heats (USSC)

In the oxygen bottom-blowing process, injection of lime powder was therefore not primarily required for metallurgical reasons, but due to the necessity to master the course of blowing by injecting lime powder and to arrive at extremely short refining times.

Comparison with the Oxygen Top Blowing Processes

The advantages of the OBM process in comparison with the oxygen top-blowing processes are mainly as follows:

1. Unlike the oxygen top-blowing process, only about a quarter of the iron amount is evaporated; consequently, less red fume is developed

2. The iron oxide content of the slag, which in contrast with other steelmaking methods approaches the equilibrium with the metal bath, is substantially lower.

Due to the effects under 1. and 2., the yield is increased by about 2 1/2 % compared with the oxygen top-blowing processes, which means a decisive economic advantage of the OBM process.

3. The intense agitation of the bath caused by the introduction of the refining gas through the bottom leads to a more rapid dissolution of the scrap, whereby the total refining time in the converter is reduced to 10 min.

4. The simultaneous introduction of lime powder and oxygen permits to obtain a completely slopping-free refining which is far-reaching and independent of the pig-iron composition. Besides advantages relating to process control, also the design of the gas-cleaning equipment is affected thereby in a favourable way.

5. The amount of scrap to be processed at the OBM process is increase by about 20 %, compared with the oxygen top-blowing processes.

The reasons therefore are found in the lower iron evaporation corresponding in respect of oxygen consumption to the melting of 5 % scrap, the elimination of [illegible] shortening of [illegible] time; and the possibility to heat the converter during the charging operations by introducing through the tuyeres oxygen and hydrocarbon in the stoichiometric ratio.

Utilization of a special device permitting a partial reburning of the carbon monoxide directly above the bath may contribute to an increase of scrap rate.

6. New converter steel plants to be built according to the OBM process require only 2/3 of the construction height of oxygen top-blown steelworks, and can be erected more cheaply for this reason (fig. 6).

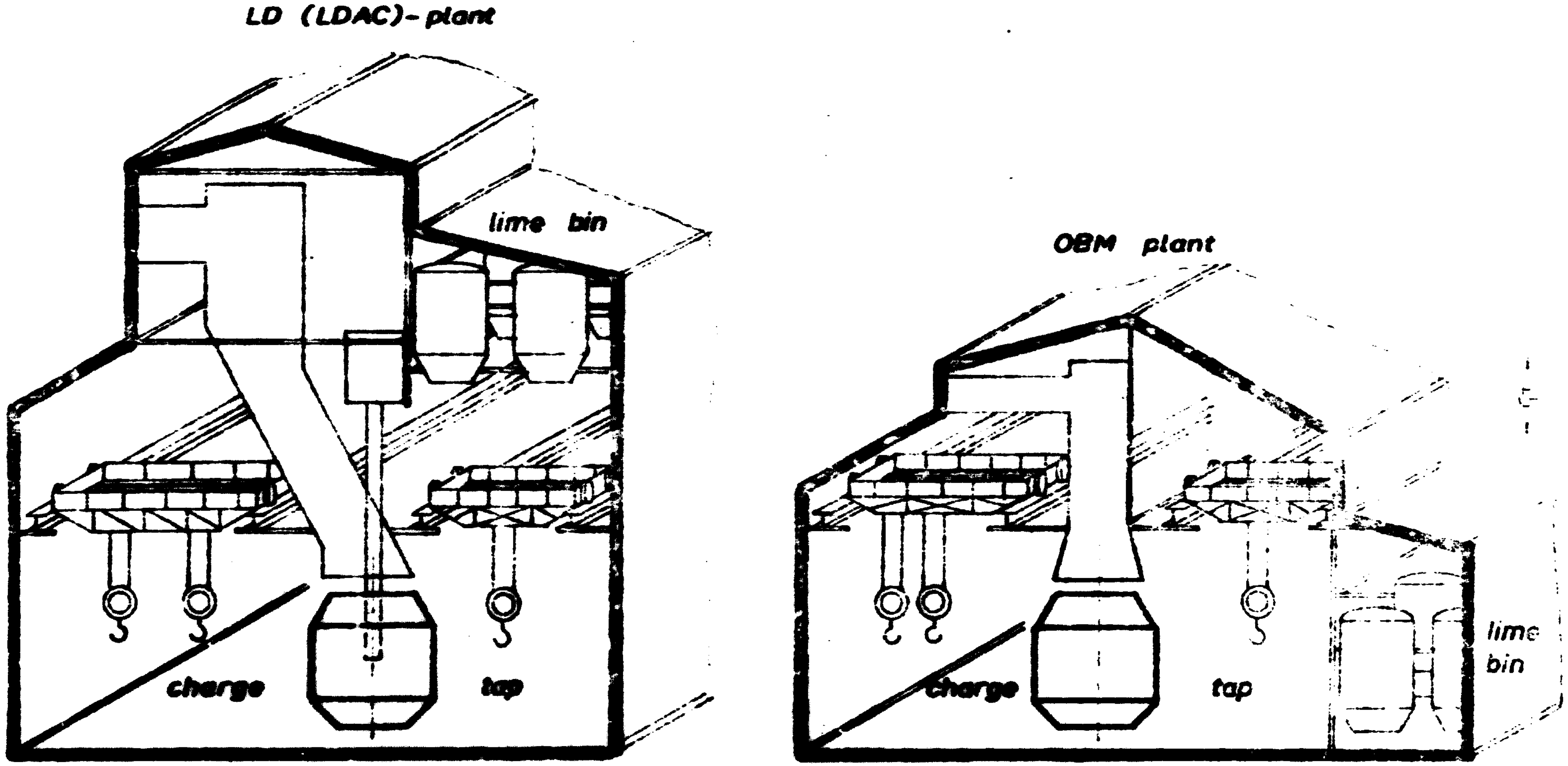
Due to the low construction height, OBM converters are particularly suitable to be installed in existing open-hearth steel plants. Compared to a conversion of open-hearth plants to the LD process, cost savings up to 50 % can be attained here.

7. Due to the short blowing periods and the completely slopping-free blowing behaviour, a considerable increase in production can also be achieved in case of large-space converters in comparison with LD steel plants.

Apart from the benefit of the higher yield, this fact might be a strong incitement to convert already existing LD steelworks to the OBM process.

Decarburization and Temperature Control

Owing to the fact that refining times at the OBM process are very short, the possibilities of that process can fully be exhausted only in case that decisions and charge calculations are made rapidly. This control should therefore be accomplished by use of an appropriate process model and a process computer.



LD (LDAC)- plant

OBM plant

Fig. 6 height comparison between LD and OBM plants

An already developed thermochemical process model offers the possibility to predict the charges of hot metal, scrap, lime, and oxygen required to achieve the aim values for the final carbon content and the temperature at the turndown of the converter.

This model incorporates the thermochemical data available for the known metallurgical charges. On account of the inputs in respect of heat size, carbon content,and temperature aimed at,including hot-metal composition and temperature,the process computer determines the required charging quantities of hot metal, scrap, lime,and oxygen. In the same way the quantities of mold iron, pig-iron, calcium carbide, silicon carbide, ferro-silicon, aluminium, gravel, limestone,and other variables can be computed.

By use of such control system, the reblowing required for adjusting the final carbon content and temperature can extensively be restricted and the tap-to-tap time be reduced in general.

Steel Grades and Product Quality

The OBM Process permits the production of quality steels over a wide range of composition,extending in the case of carbon contents from 0.01 % to more than 1 % C.

Steels with less than 0.15 % carbon are made by blowing down to about 0.05 % carbon or lower, and then recarburizing as needed to obtain the desired carbon content. Steels with higher carbon contents are made as catch-carbon heats, that is, stopping the oxygen blow when the carbon content is slightly below the desired value.

Final contents of manganese are slightly higher than in the LD process. Hence, the metallurgical conditions at the end of the refining period are ideal for the production of unalloyed and alloyed quality steel grades.

Low-and medium-alloy steel are made by converter or ladle additions.

Due to the feasibility of injecting simultaneously finely divided solid materials, e.g. burnt lime, in conjunction with oxygen of high purity degree, an excellent control of the metallurgical reactions is possible.

Although the quality and properties of the products independent of steelmaking processes should be identical, this is frequently not the case in practice. Therefore it is interesting to compare steels of similar compositions and similar teeming techniques produced according to different processes.

To demonstrate the wide range of applicability of the OBM Process, heats produced in a 30-tons converter were teemed into ingot molds and conventionally processed at various works.

Included in this comparison investigations were:

rimmed and mechanically capped low-carbon steels processed to hot-rolled and cold-rolled flat products;

mechanically capped low-carbon steels cold-rolled into double-reduced body stock for the manufacture of cans as well as processed to tinplate of moderate drawability, stock for deep drawing tinplate, and other tin-mill products.

Some of the tin-mill products were also subjected to "Type K" processing, which is designed to enhance the corrosion resistance of the tinplate.

To determine the quality of OBM steels for plate application, structural-grade steels (carbon-manganese steels and low-alloy higher-strength steels) were produced.

Furthermore, rail steels with high carbon contents were rolled into standard railroad rails with meter-weights of 58-66 kg/m.

The products from these experimental heats were tested to determine their conformance to customer specifications; furthermore, they were also subjected to special evaluations and studies.

All test results showed that the properties of the products made from OBM steels at least corresponded to the characteristics of products made from steels produced in open-hearth furnaces or LD converters.

Existing Applications

After the conversion of MAXHÜTTE's Thomas steel plant to the OBM Process, eight steelworks in the Western European territory were granted use licenses to convert their Thomas converters to the OBM Process. The actual production of such works according to the OBM Process together with the production of MAXHÜTTE runs up to 7 million tons of steel per annum (fig. 7).

Figs. 8 and 9 represent a blowing OBM converter at MAXHÜTTE as well as a part of the control room of the steel-works.

Subsequently to preliminary experiments regarding the refining of low-phosphorus pig iron executed at MAXHÜTTE in a 5-ton experimental converter, the results of which were verified at several 30-tons heats, US Steel Corporation has investigated, in a 40-ton LD converter which was converted to the OBM Process, the applicability of the OBM Process to many different products. In this connection, new knowledge on the refining of low-phosphorus pig iron - for instance, the making of catch-carbon heats - was obtained in addition.

Fig. 7

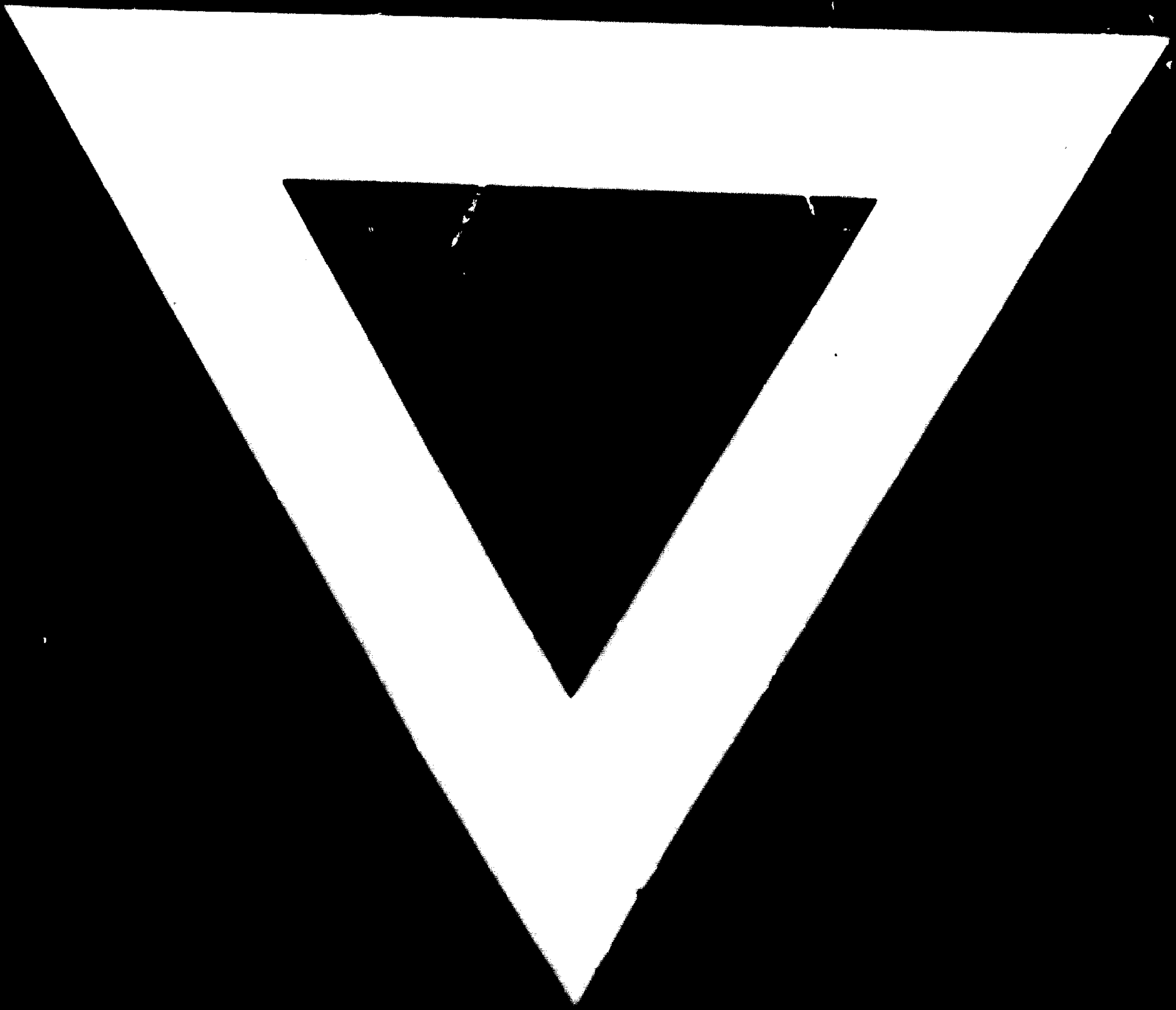
OBM converters in operation and projected

Country	Company	Location	Commissioning	Size of Vessel
Germany	Eisenwerk-Gesellschaft Maximilianshütte mbH	Sulzbach-Rosenberg	April 1968	30
			June 1969	30
			August 1969	30
			November 1969	30
			December 1969	30
			Januar 1970	30
Germany	Röchling'sche Eisen- und Stahlwerke GmbH	Völklingen	May 1969	40
France	Société des Aciéries et Tréfileries de Neuves-Maisons	Chatillon	August 1969	30
			August 1970	30
			October 1970	30
			February 1971	30
			October 1972	25
France	Union Sidérurgique du Nord et de L'est de la France (USINOR)	Valenciennes	June 1970	70
			August 1970	70
			October 1970	70
		Longwy	September 1970	40
			October 1970	40
Luxembourg	Minière & Métallurgique de Rodange	Rodange	June 1970	30
			October 1970	30
Belgium	Cockerill-Ougrée-Providence	Marchiennes	September 1971	30
			March 1972	30
U.S.A.	US Steel Corporation	South Chicago	September 1971	40
Belgium	Forges de Thy-Marcinelle et Monceau	Monceau	March 1972	30
			April 1972	30
			May 1972 2x	30
France	Cockerill	Rehon	March 1973	25
			June 1973	25
U.S.A.	US Steel Corporation	Gary	February 1973	200 3x
		Fairfield	August 1973	200 2x
Sweden	Surahammar Bruks	Surahammar	June 1974	35

Based on the results achieved at such experiments, US Steel Corporation decided to replace ten 350-ton open-hearth furnaces by two 220-ton OBM converters at Fairfield, and to convert to the OBM Process an LD steel plant (three 200-ton converters with an annual capacity of 5.5 million tons of steel) under construction at Gary, even before that plant was put into operation.

Alone at Fairfield and Gary, US Steel Corporation will produce within about one year already 25 % of its total steel production according to the OBM Process.

In Europe, the first new OBM steel works is under construction at Surahammar in Sweden. Commissioning is expected to take place in 1974.



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