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OXYGEN STEELMAKING IN BOTTOM-BLOWN CONVERTERS[1]

by

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SUMMARY

At C.R.M., trials with a 200 kg pilot oxygen-converter, fitted with double tuyeres located in the bottom, started in 1968. The encouraging results which were obtained, led to the installation of a 21 t experimental converter at Forges de Thy-Marcinelle et Monceau, Belgium.

Intensive studies were carried out to solve all technological and metallurgical problems encountered with the conversion of low- and high-phosphorous hot metal.

One of the main features of the bottom-blowing technique is the fact that metal and slag are in equilibrium at turndown.

Another advantage of this process is the possibility of using the double tuyeres for final temperature and analysis adjustments in the converter before tapping.

Bottom wear is drastically reduced in comparison with the Basic Bessemer process.

Blowing times of 14 minutes are achieved.

As well with low- as with high-phosphorous hot metal, our results show the excellent metallurgical and technical possibilities of the new process, which allows a quick and quiet production of quality steels.

After this research it appeared that our technique was very similar to the OBM process developed by MAXIMILIANSHÜTTE. For this reason, C.R.M. pooled its results, patents, and know-how with Max-Hütte.

Considering the excellent results obtained on the 21 t pilot converter, the management of T.M.M. decided during the second half of 1971 to convert the entire Basic Bessemer shop to oxygen bottom blowing. The first OBM converter started operations on March 21,1972 and the fourth on May 26, 1972.

Already in June 1972, the production had increased from 700 t/shift (2100 t/day) in the Bessemer shop to 770 t per shift with OBM ; in September 815 t/shift were reached. By increasing progressively the charge weight up to 35 t per heat without changing the vessel size, an average of 905 t/shift was achieved in January 1973. This figure corresponds to an increase of production of 30 % compared to the output of the Basic Bessemer shop.

The converter bottoms fitted with seven tuyeres have an average lining life of 350 heats ; it is common practice to use only one bottom per converter lining. The total refractory consumption amounts to 5 kg dolomite per ton of steel.

The metallurgical results have confirmed the findings on the experimental converter.

The present paper reports the research work which has been carried out by Centre de Recherches Métallurgiques (C.R.M.) and Forges de Thy-Marcinelle et Monceau (T.M.M.) in the field of oxygen steelmaking in bottom-blown converters. As a result of this research, the four Basic Bessemer vessels of Monceau have been converted to the OBM process ; the start up and the performances of these steelworks are described.

INTRODUCTION

Almost all remaining Basic Bessemer Steelworks in Europe have now decided to adopt OBM process, which opens a new area to steelmaking in bottom-blown converters.

At C.R.M., trials with a 200 kg pilot oxygen-converter fitted with double tuyeres located in the converter bottom started in 1968. The encouraging results which were obtained led to the installation of a 21 t experimental converter at Forges de Thy-Marcinelle et Monceau, Belgium.

Intensive studies were carried out to solve all technological and metallurgical problems encountered with the conversion of low- and high-phosphorous hot metal. The first part of present paper reports the results of these trials.

It soon became evident that the technological solutions adopted by C.R.M. and T.M.M. were similar to those of Max-Hütte and for this reason, our results, patents, and know-how were pooled with the inventor of the OBM process.

During 1972, the entire Basic Bessemer steelworks of Monceau were converted to the OBM process. In the second part of our report, the start-up of this steelplant is described and the metallurgical results are discussed.

A diagrammatic section of the converter is shown in the Annex (page 31).

I. TRIALS ON A 21 T-EXPERIMENTAL CONVERTER.

I.1. Technology

In 1968, the Basic Bessemer shop of Monceau comprised four 21 t converters and one 17 t converter which was only used occasionally. For this reason, it was decided to convert the latter to oxygen bottom blowing and, in order to avoid production disturbances, its capacity was also increased to 21 t.

A working team was created between T.M.M., C.R.M., and several of its affiliated companies in order to design and build the main parts of the installation, i.e. :

- optimal design of the tuyeres to be located in the converter bottom ;
- choice of the number of tuyeres ;
- choice of the endothermic fluid (natural gas or propane have been used) ;
- distribution of the oxygen and the endothermic fluid to the different tuyeres and design of the circuits between the latter and the main oxygen and hydrocarbon ducts ;
- means for regulating the flow and the pressure of the different fluids : oxygen, endothermic fluid, and purging nitrogen ;
- devices ensuring a secure and fool-proof operation of the converter.

I.2. Operational results.

I.2.1. Bottom wear

From the beginning of our trials, it appeared that, thanks to the double tuyeres, the bottom life was considerably increased in comparison with the Basic Bessemer Process. On the 21 t converter, the bottom wear was controlled about every ten heats and figure 1 shows the evolution of the wear as a function of the number

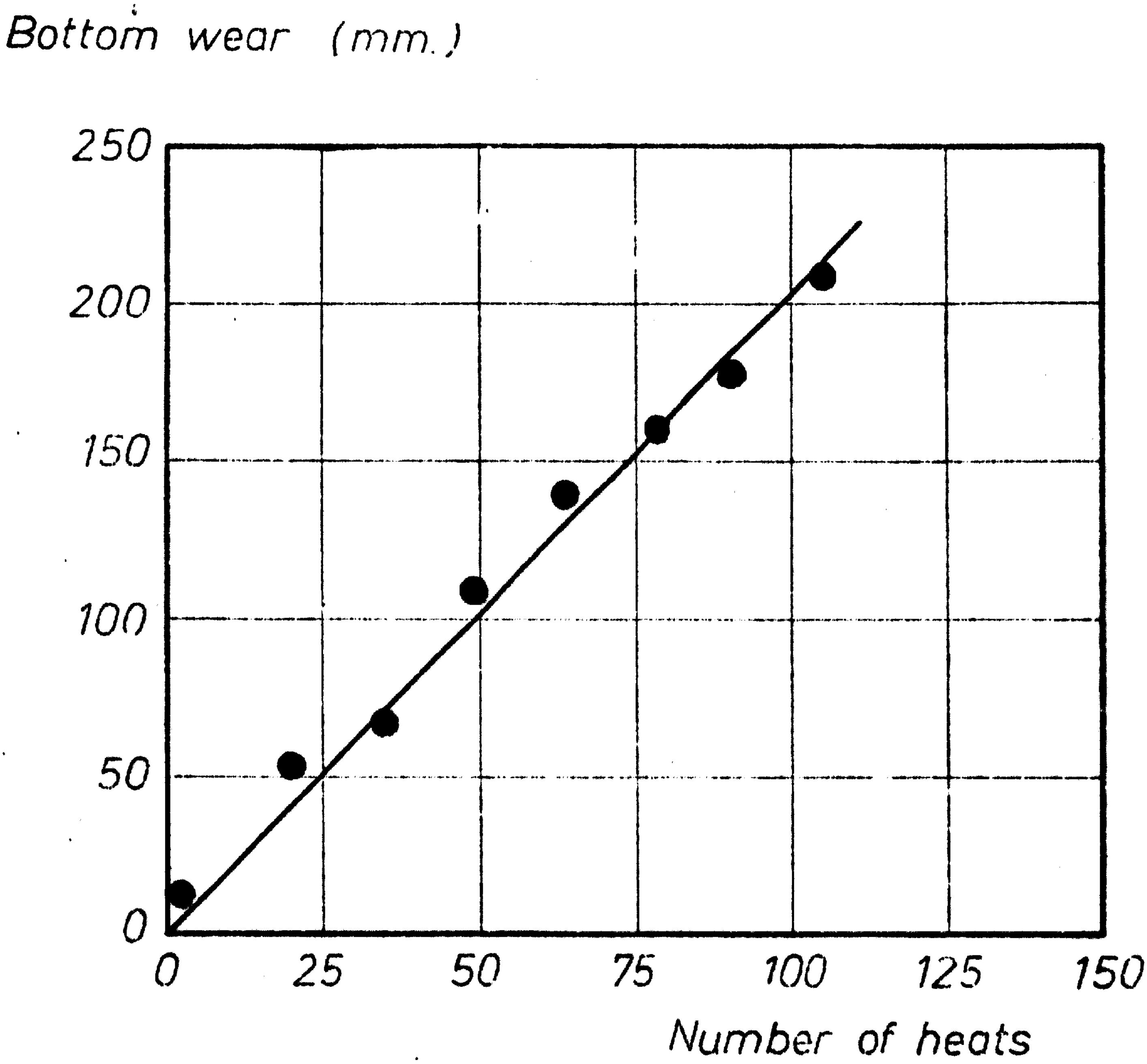

Fig. 1 - Bottom wear during a campaign

of blown heats ; it shows that the thickness of the dolomite bottom decreases by 2 to 2.5 mm per heat. This means that with a bottom of 1000 mm, it is possible to produce about 400 heats ; this is equivalent to the life of a dolomitic converter lining.

Figure 2 shows a view into the converter after a heat ; it may be seen that the wear is very regular all over the bottom.

I.2.2. Slopping, red fumes, skulls.

With high-phosphorous hot metal and in spite of the increase of capacity from 17 to 21 t, slopping was drastically reduced in the OBM process compared to the Basic Bessemer Converters ; this reduction, due to a very soft blow, contributes to the improvement in iron yield which is observed in the OBM process.

At the beginning of our trials with low-phosphorous hot metal, problems were encountered with projections of a sticky slag. Thanks to the development of special slag-formation technique, this problem has been completely solved.

For equivalent bath heights in the Basic Bessemer and the OBM converters, the amount of red fumes is about the same for both processes. If, as in the case of Monceau, the OBM charge weight is increased in comparison with the Basic Bessemer process, a decrease of red fumes is observed.

It is well known that the availability of Basic Bessemer converters is reduced by the formation of skulls on the converter mouths which are difficult to remove. These skulls are generally inexistent with OBM converters ; with very low converter volumes ($<$0,5 m3/t steel), small skulls are formed which have only to be removed every 20 heats.

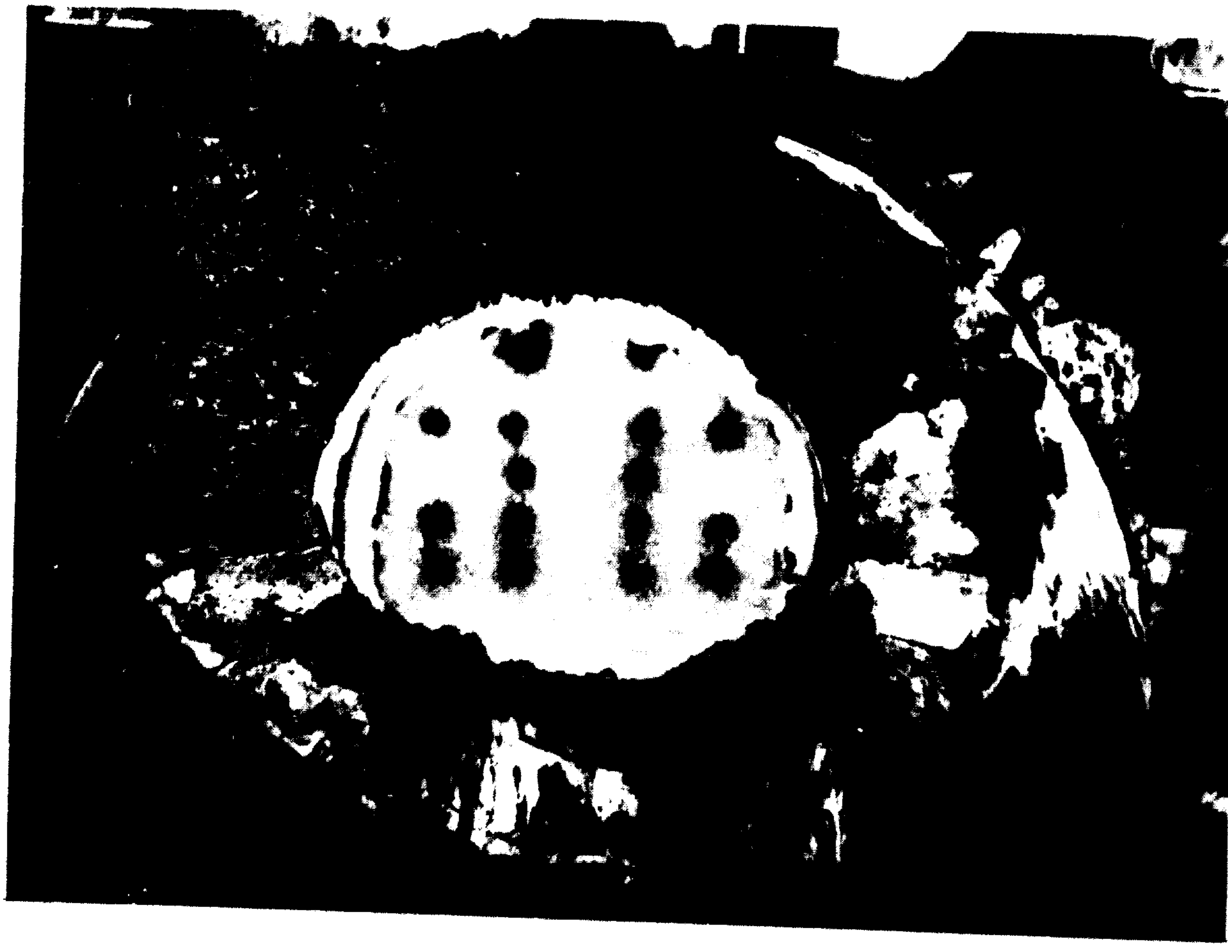

Fig. 2 - View into the converter
after a heat

I.2.3. Blowing time.

With low as well as with high-phosphorous hot metal, a blowing time of about [illegible] minutes [illegible] oxygen flow [illegible] and [illegible] per minute and ton of steel.

To guarantee these blowing times, the specific volume on a new lining should not fall below [illegible],6 m³/t.

I.2.4. Final adjustment

One of the advantages of bottom-blowing is the possibility of using the double tuyeres for final temperature and analysis adjustments in the converter before tapping.

During a short reblow of less than one minute, it is possible to perform different types of metallurgical work by

- varying the composition of the stirring gas (nitrogen, air, enriched air, or oxygen),
- eventually adding small amounts of slagging additions,
- eventually adding cooling or reheating elements.

I.3. Metallurgical results with high-phosphorous hot metal.

I.3.1. Metallic charge.

In the present chapter, we shall describe briefly the main results of our trials with 21 t heats on our pilot converter using high-phosphorous hot metal of the following average analysis and temperature :

C = 3,6 %	P = 1,6 %
Mn = 0,45 %	S = 0,054 %
Si = 0,3 %	T = 1216°C

As can be seen from these figures, the hot metal was cold, physically and chemically ; moreover a 21 t converter, operated on a pilot basis, does not permit the highest scrap rate. In spite of these limitations, we have realized the following metallic inputs :

Hot metal	:	840 kg/t steel
Scrap	:	250 kg/t steel

It is difficult to compare exactly these values with the top blowing processes converting high-phosphorous hot metal. Extrapolations which we have made indicate, however, that, thanks to the shorter blowing time and to the low iron evaporation of the OBM process, an increase in scrap input of 20 to 30 kg/t steel may be expected with this process.

Compared to the Basic Bessemer Converter with enriched air (34 %), an effective increase of 130 kg scrap/t steel has been experienced while the lime consumption was decreased by 20 kg per ton of steel.

I.3.2. Yields.

As well the iron as the metallic yield have been increased by about 1,5 - 2 % compared with the Basic Bessemer process :

$$\text{Iron yield} : \frac{\text{Liquid steel}}{\text{Fe (Hot metal + Scrap) + FeMn}} = 96\ \%$$

$$\text{Metallic yield} : \frac{\text{Liquid steel}}{\text{Hot metal + Scrap + FeMn}} = 92\ \%$$

I.3.3. Steel Analysis

a) With high-phosphorous hot metal, the phosphorus content at turndown is of prime importance. If equilibrium with the slag is reached, the lowest possible phosphorus contents are obtained.

Figure 3 shows that with the OBM process, this situation is effectively achieved. For all Fe contents, slag and metal are in equilibrium.

For Fe = 11 %, an average P content of 0,030 % is obtained while an iron content of 14 % permits an average phosphorus content of 0,020 %. This result, for high-P hot metal, is particularly favourable.

For rimming steel, rephosphorization in the ladle amounts to about 3.10^{-3} %, independently of the initial P content.

Rephosphorization may be reversed by using a small amount of a dephosphorizing slag in the ladle. The addition of 10 kg/t steel of a special flux (43 % lime, 13 % soda ash, 22 % fluorspar, 22 % mill scale) in the ladle yields an average dephosphorization of $3{,}2.10^{-3}$ % P in the ladle.

b) Compared to the Basic Bessemer Process, the OBM process decreases the sulfur content in the steel by 0,005 to 0,010 %

The following example illustrates the desulfurization observed with high-phosphorous hot metal (Lime 88 kg/t steel) :

$S_{hot\ metal}$	:	0,040 %
Scrap	:	0,050 %
S_{Steel}	:	0,019 %

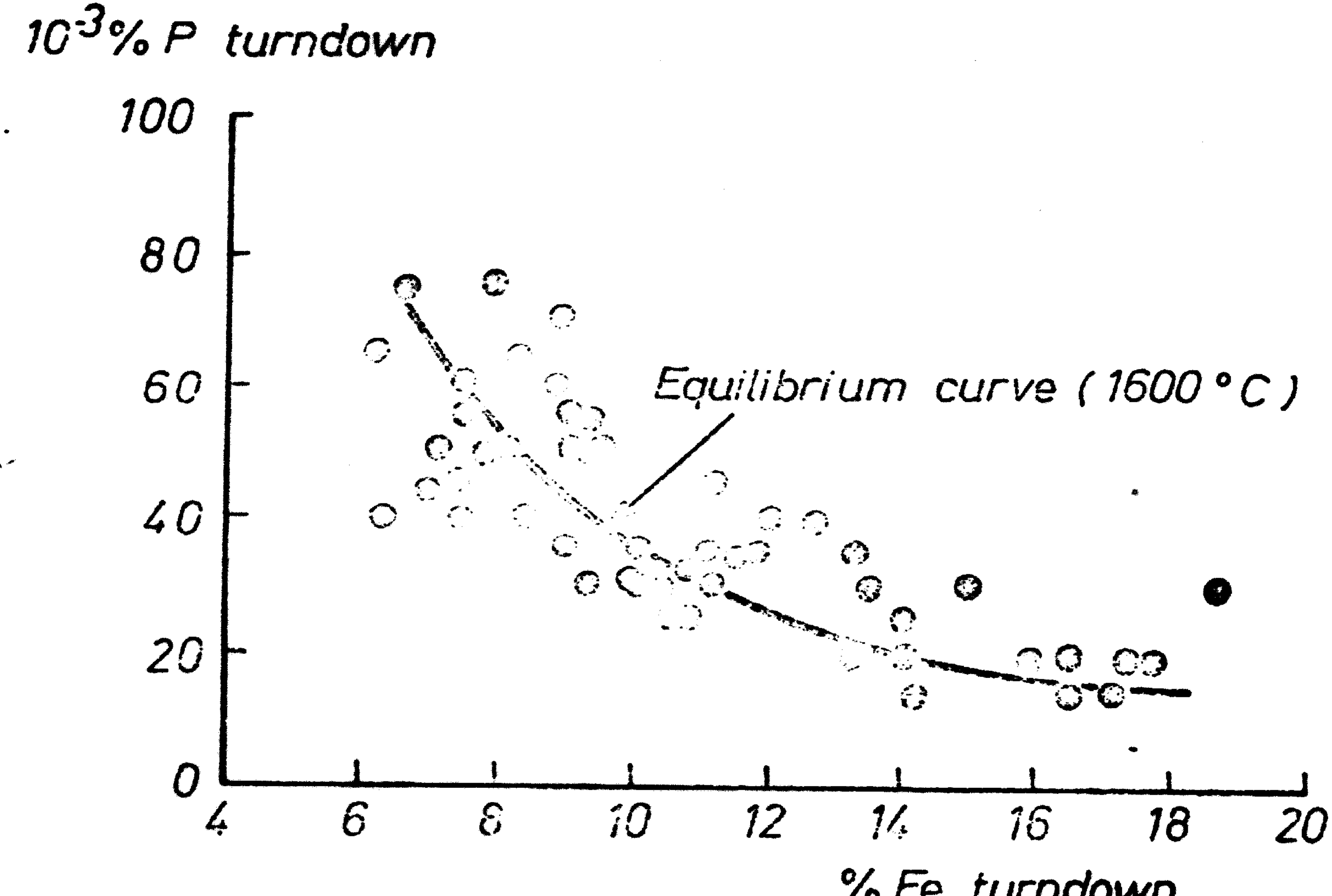
10-3% P turndown
100
80
60
40
20
0
4
6
8
10
12
14
16
18
20
% Fe turndown
Equilibrium curve (1600 °C)

Fig. 3.

c) The nitrogen content depends upon the endothermic fluid used in the tuyeres and upon the metallurgical practice :

- Dutch natural gas contains about 14 % nitrogen ; compared to propane, an increase in nitrogen of 0,0025 % in the steel will be observed.

- As in other conversion processes, the replacement of part of the scrap by a thermally equivalent quantity of ore results in a decrease of the nitrogen content at turndown.

The following table summarizes the results :

		Tapping $N (10^{-4} \%)$	Teeming $N (10^{-4} \%)$
Propane	scrap + 50 kg ore per ton of steel	15	21
Propane	100 % scrap	25	29
Natural gas	scrap + 50 kg ore per ton of steel	38	43
Natural gas	100 % scrap	50	56

The choice of the protecting fluid may thus be dictated by the type of steel which is produced. While propane or fuel-oil or natural gas without nitrogen are required, for instance for deep-drawing steels, it is possible for structural steels, to choose Dutch natural gas for oxygen shielding.

I.4. Metallurgical results with low-phosphorous hot metal.

I.4.1. Slag formation.

In the beginning of our trials with low-phosphorous hot metal, difficulties were encountered with slag-formation control.

By using hot metal from different origins, its analysis was varied in the following range :

C	:	3,60 - 4,50 %
Mn	:	0,45 - 1,00 %
Si	:	0,20 - 1,50 %
P	:	0,09 - 0,38 %
S	:	0,02 - 0,08 %

For all compositions, when using exclusively lumpy lime, slopping was encountered ; an increase of fluorspar was of no help.

By changing the way of lime addition, a completely quiet course of blowing was obtained.

I.4.2. Metallic charge and other consumptions.

Together with the variations of the hot metal analysis, a wide range of scrap rates has been covered ; the following mean inputs have been observed :

Hot metal (C : 4,30 % ; Si : 0,80 %)	:	830 kg/t steel
Scrap	:	260 kg/t steel
Lime	:	61 kg/t steel

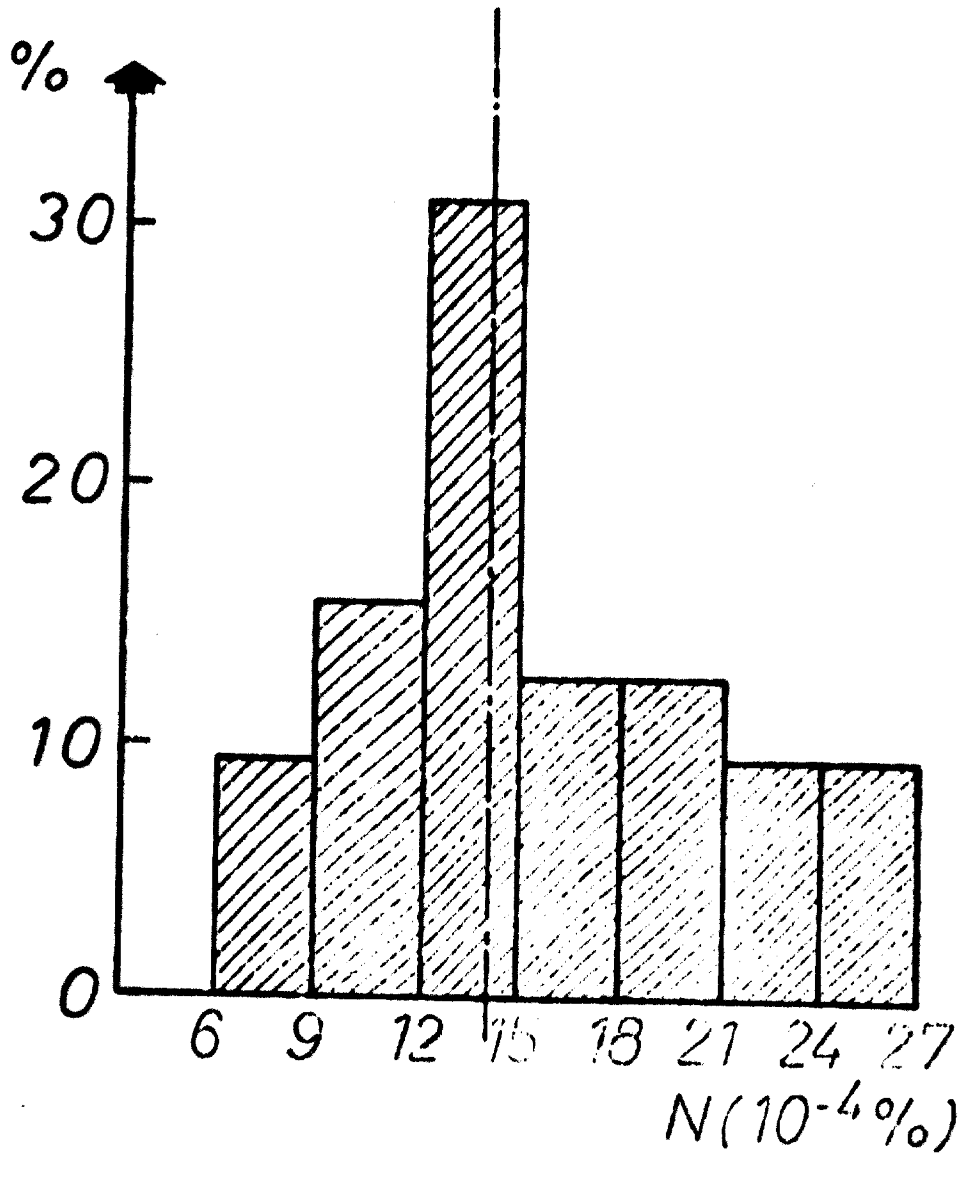

Fig. 4 - Nitrogen content at turndown (low-phosphorus hot metal)

The yields are similar to those observed with high-phosphorous hot metal.

I.4.3. Metallurgical results.

As far as the steel analysis is concerned, the results of our trials (21 t converter) may be summarized as follows :

With an average phosphorus content of 0,22 % in the hot metal, an average phosphorus content of 0.012 % was realized in the ingot.

Figure 4 shows the distribution of the nitrogen content in steel at turndown. The average content is 0,0014 %,which may be considered excellent.

Figure 5 gives the sulfur content in the steel ingots as a function of the sulfur content in the hot metal. The improvement in comparison with the BOF process is probably due to a better gaseous desulphurization.

Figure 6 indicates that,also for pure oxygen bottom blowing, a carbon-oxygen relation is observed at turndown.

As far as hydrogen is concerned, it appears that a correct temperature at turndown,followed eventually by a short nitrogen reblow, brings the hydrogen level in the ladle in the range of 3,0 - 3,7 cc/100 g.

I.5. Steel quality.

With low- as well as with high-phosphorous hot metal, all examinations made until now have shown the quality of OBM steels to be equivalent to oxygen steel made from the same type of hot metal.

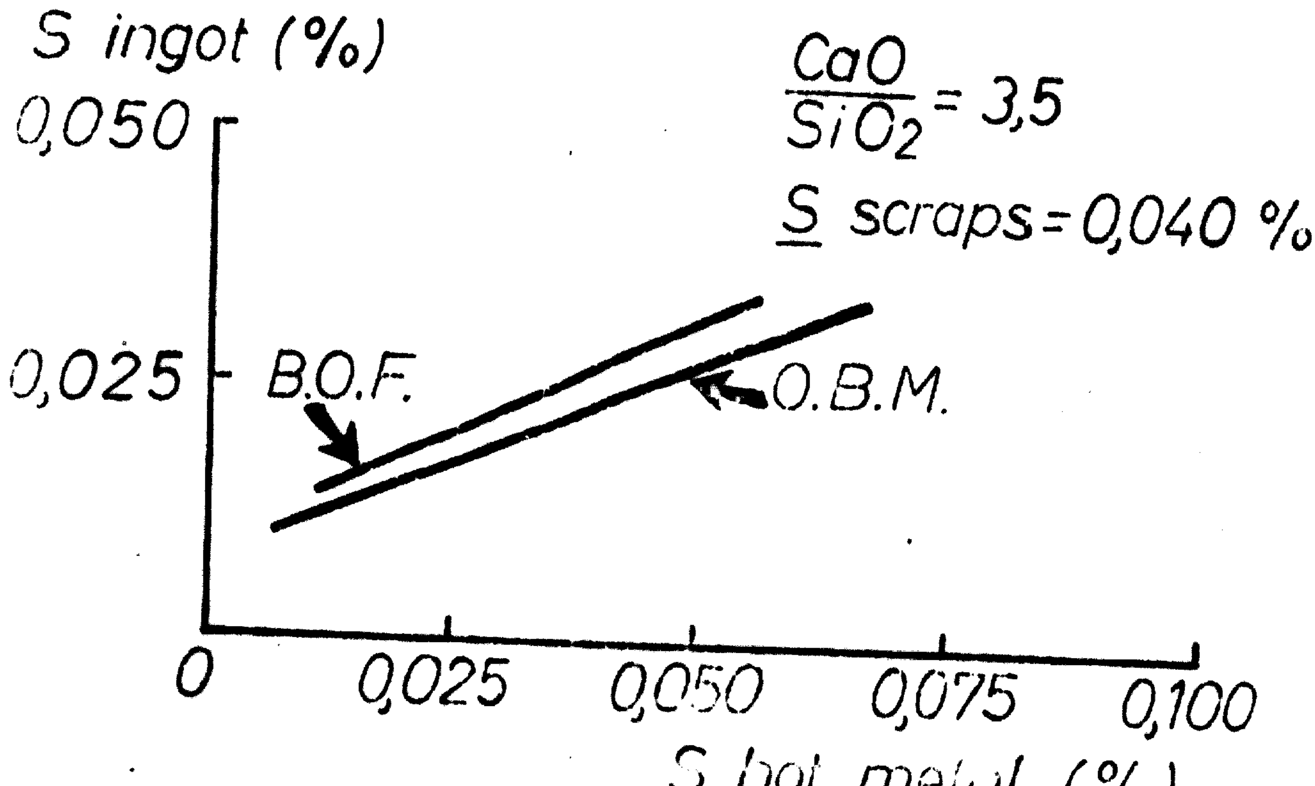

Fig. 5 - Sulfur content in steel (low-phosphorus hot metal)

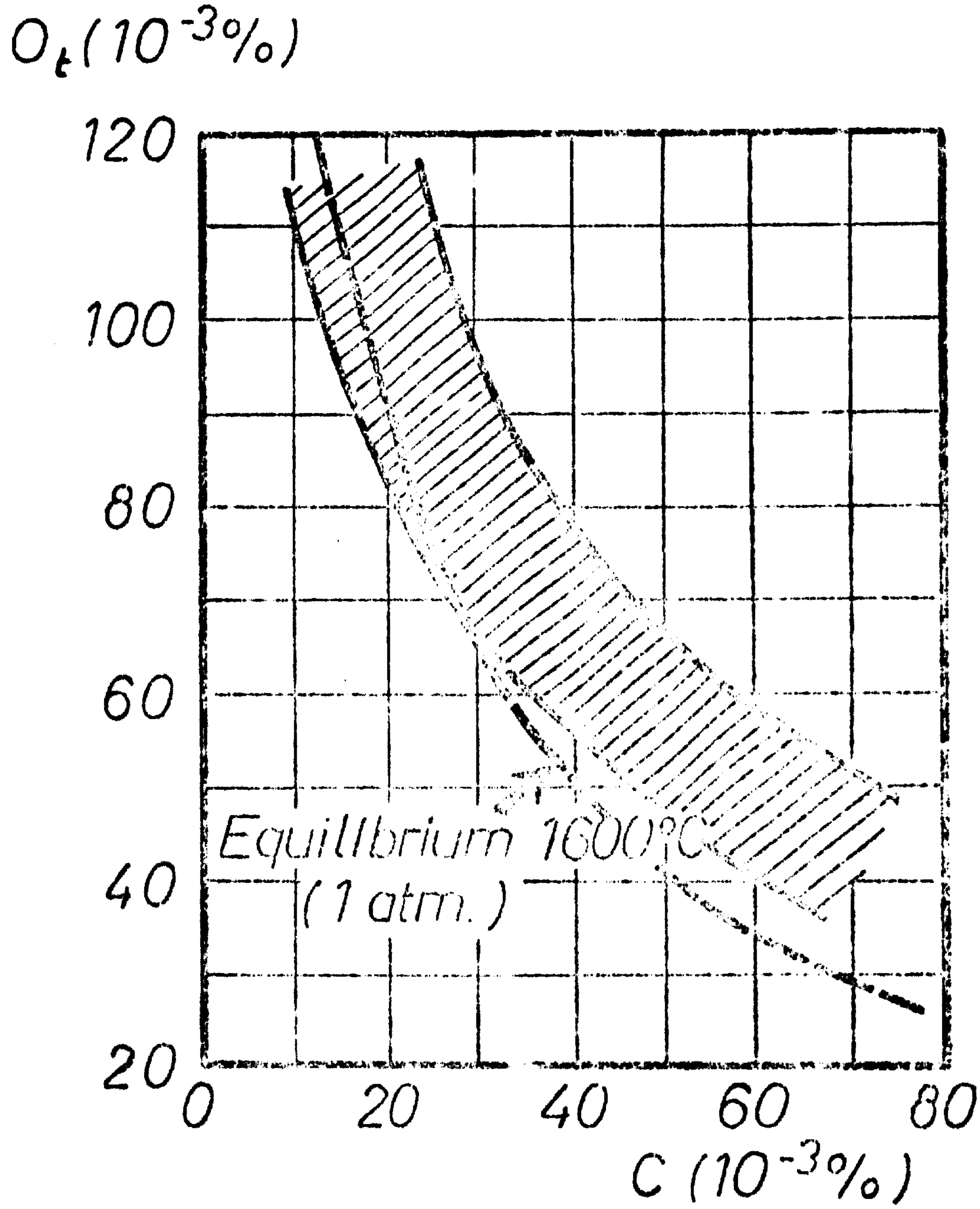

Fig. 6 - Carbon-oxygen ratio at turndown (low-phosphorus hot metal)

O_t = total oxygen analysed by neutron activation

II. START UP OF THE OBM STEELWORKS OF MONCEAU.

II.1. Modification of the Basic Bessemer shop.

Considering the excellent results obtained on the 21 t pilot converter, the management of T.M.M. decided during the second half of 1971, to convert the entire Basic Bessemer shop to oxygen bottom blowing.

To take advantage of all the possibilities of this process, the peripheral installations of the steelworks were modified in order to increase the charge weight from 21 t to 30 t or even 35 t, the vessel size remaining unchanged.

To achieve this goal, it was necessary :

- to strengthen the runways of the hot-metal charging cranes ;
- to install a new hot-metal charging crane ;
- to order a new teeming car as well as new ladles for 35 t of liquid steel ;
- to build the equipment for the flow and pressure regulations for the different fluids ;
- to design and realize an analog computer for charge calculation.

All these modifications were completed after about eight months ; the first OBM converter started operations on March 21, 1972 and the fourth on May 26, 1972 (1).

II.2. Production.

Figure 7 reflects the increase of production of the steelworks after the conversion from the Basic Bessemer to the OBM process. Already in June 1972, the production had increased from 700 t/shift (2100 t/day) in the Bessemer shop to 770 t per shift with OBM ; in September 815 t/shift were reached.

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(1) Meanwhile, agreements had been made between Max Hütte and C.R.M. in the field of pure oxygen bottom blowing.

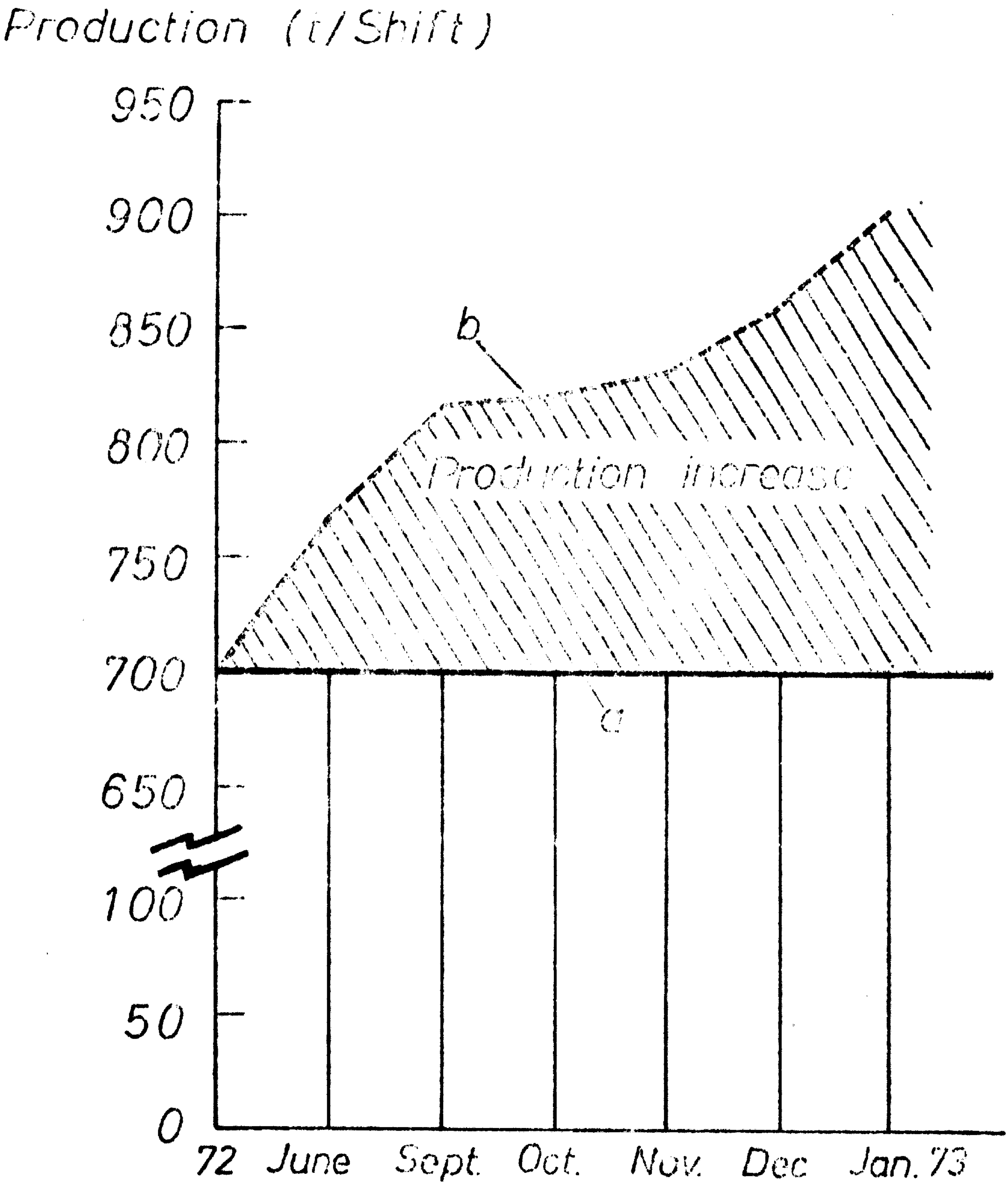


Fig. 7 - Evolution of steel production per shift : a = basic Bessemer, b = OBM

By increasing progressively the charge weight up to 35 t per heat, an average of 905 t/shift was achieved in January 1973. This figure corresponds to an increase of production of 30 % compared to the output of the Basic Bessemer shop.

At the present time, the bottlenecks of the steelworks are :

- the teeming car : the converters have to wait for about 3 minutes per charge for the teeming car ;
- the scrap charging facilities : the scrap consumption of the OBM process has doubled compared to the Basic Bessemer converters and the scrap crane and moulds are not adapted to the quantities to be charged.

If these bottlenecks could be suppressed the average daily production would be boosted to 3200 or 3400 t/day.

II.3. Technology

The converter bottoms fitted with seven tuyeres have an average lining life of 350 heats.

It is common practice to use only one bottom per converter lining. The latter is made of home-made dolomite bricks having an average thickness of 600 mm. The total dolomite consumption (lining and bottom) has decreased to about 5 kg/t which, with high-phosphorous hot metal, is excellent.

It is intended to use 450 mm magnesite bricks in part of the vessel instead of 600 mm dolomite bricks. This would allow a small increase of the free converter volume, which has now fallen below 0,5 m^3/t steel.

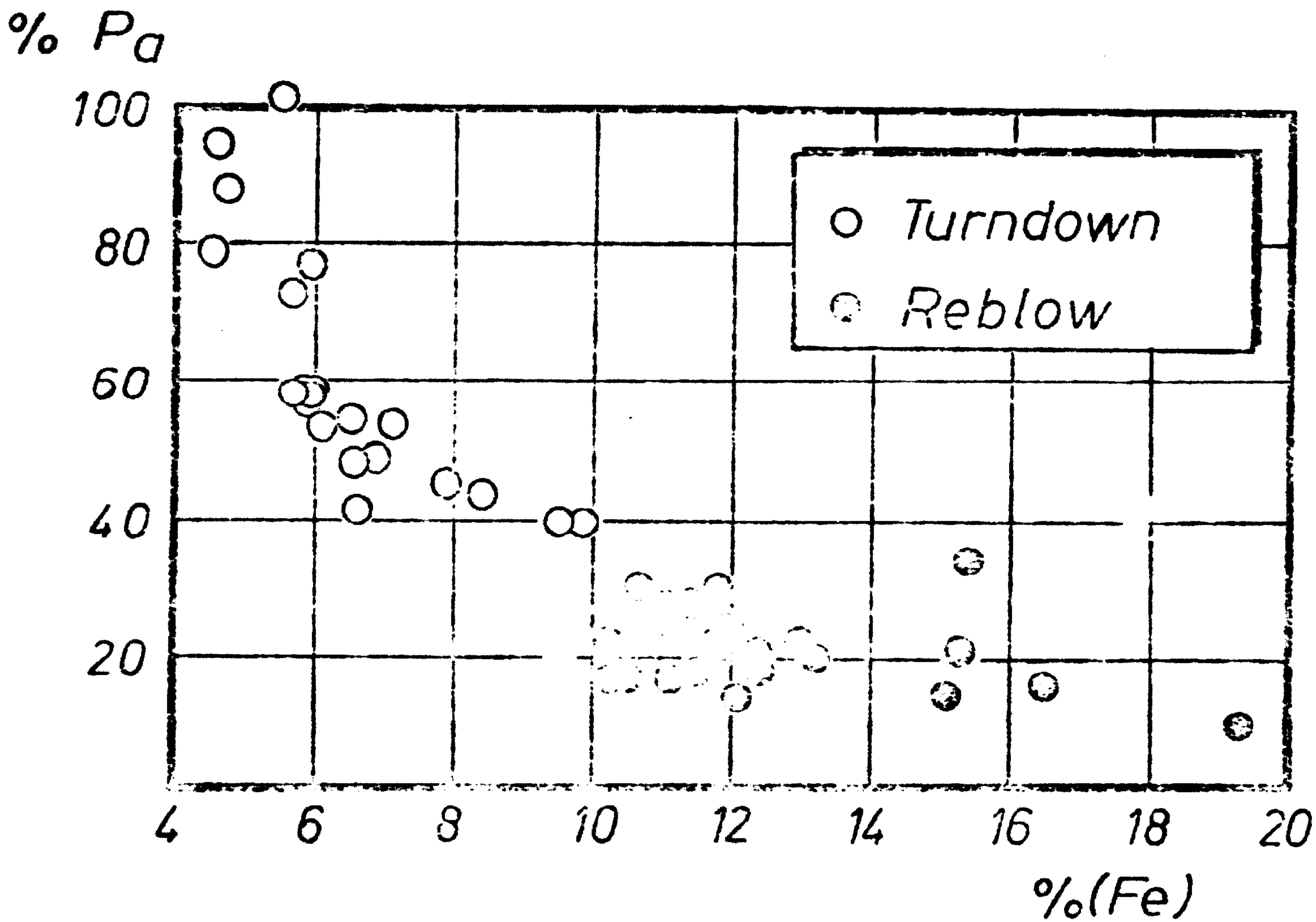


Fig. 8 – Relationship between the analysed phosphorus content in the steel and the iron content in the slag

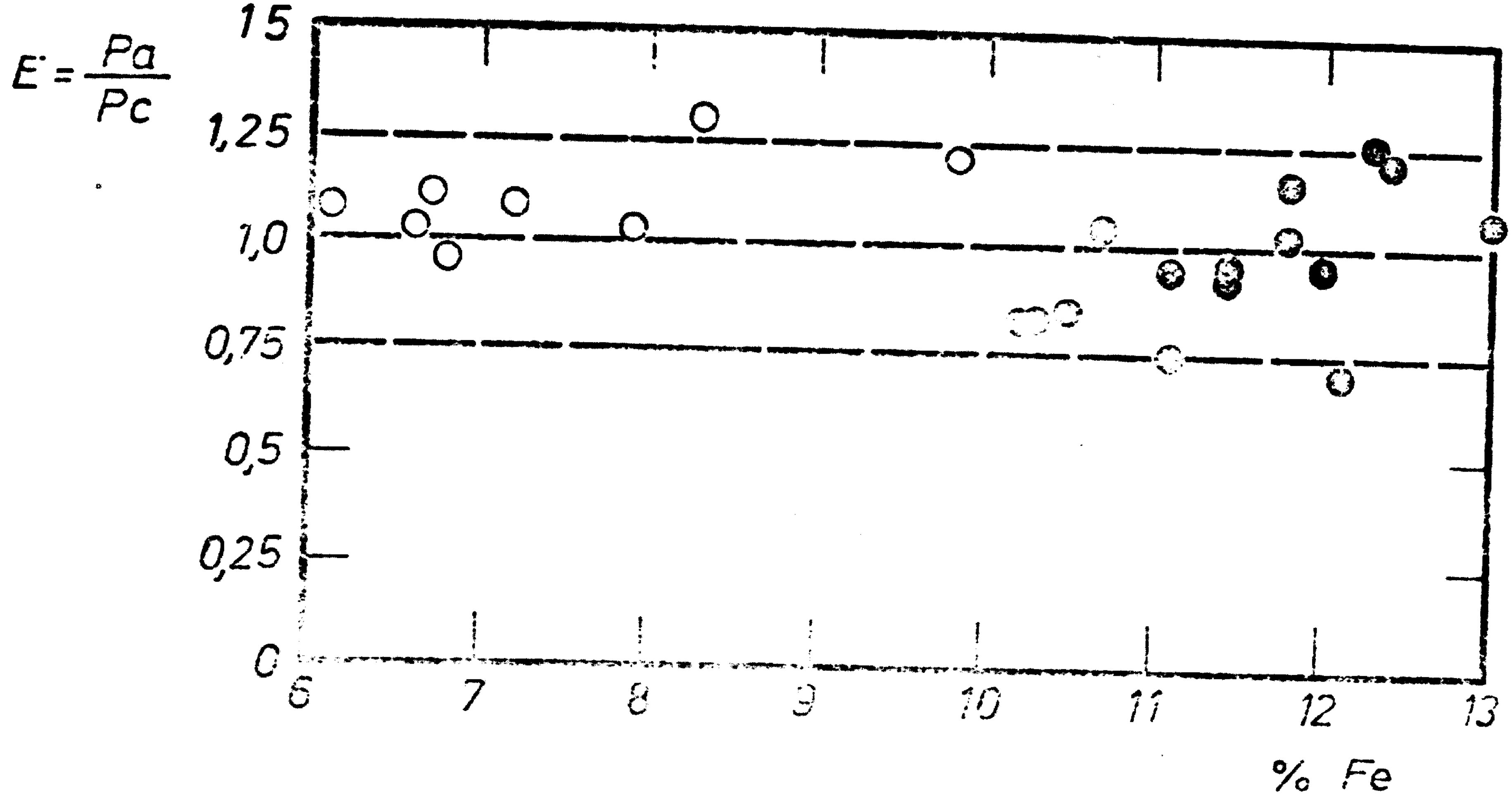


Fig. 9 - $E = P_a/P_c$ at turndown (○) and after reblow (●)

It has appeared that when light scrap has to be used and when high slag amounts are to be dealt with (silicon in hot metal over 0,5 %) it is useful, from a productivity standpoint, to have a free volume of 0,6 m3/t steel.

II.4. Metallurgical results.

The results achieved with high-phosphorous hot metal on the 21 t pilot-converter have been entirely confirmed on the four industrial converters .

For this reason, we shall discuss only a few metallurgical results which complete the picture given in chapter I.3. Most of the heats are turned down shortly before the end, and after deslagging are reblown for about 30 seconds before tapping.

Figure 8 gives the relation observed between the phosphorus content in the metal as a function of the iron content in the steel, at turndown and after the short reblow.

For a certain number of heats, the calculated phosphorus content (P_c) which is in equilibrium with the slag has been compared to the actual phosphorus content P_a. On figure 9, the ratio $E = P_c/P_a$ has been plotted as a function of the iron content in the slag. It appears that, on the average, slag and metal are in equilibrium ; it is well known that for top-blowing processes, E at turndown varies between 1,25 and 1,75. A desired P_a content is thus obtained with lower Fe contents in the OBM than in top-blowing processes and it is evident that this will have a favourable effect on the transformation costs per ton of steel.

Fig. 10 shows the increase in phosphorus content before tapping as a function of the bath temperature ; a similar relationship is observed at turndown.

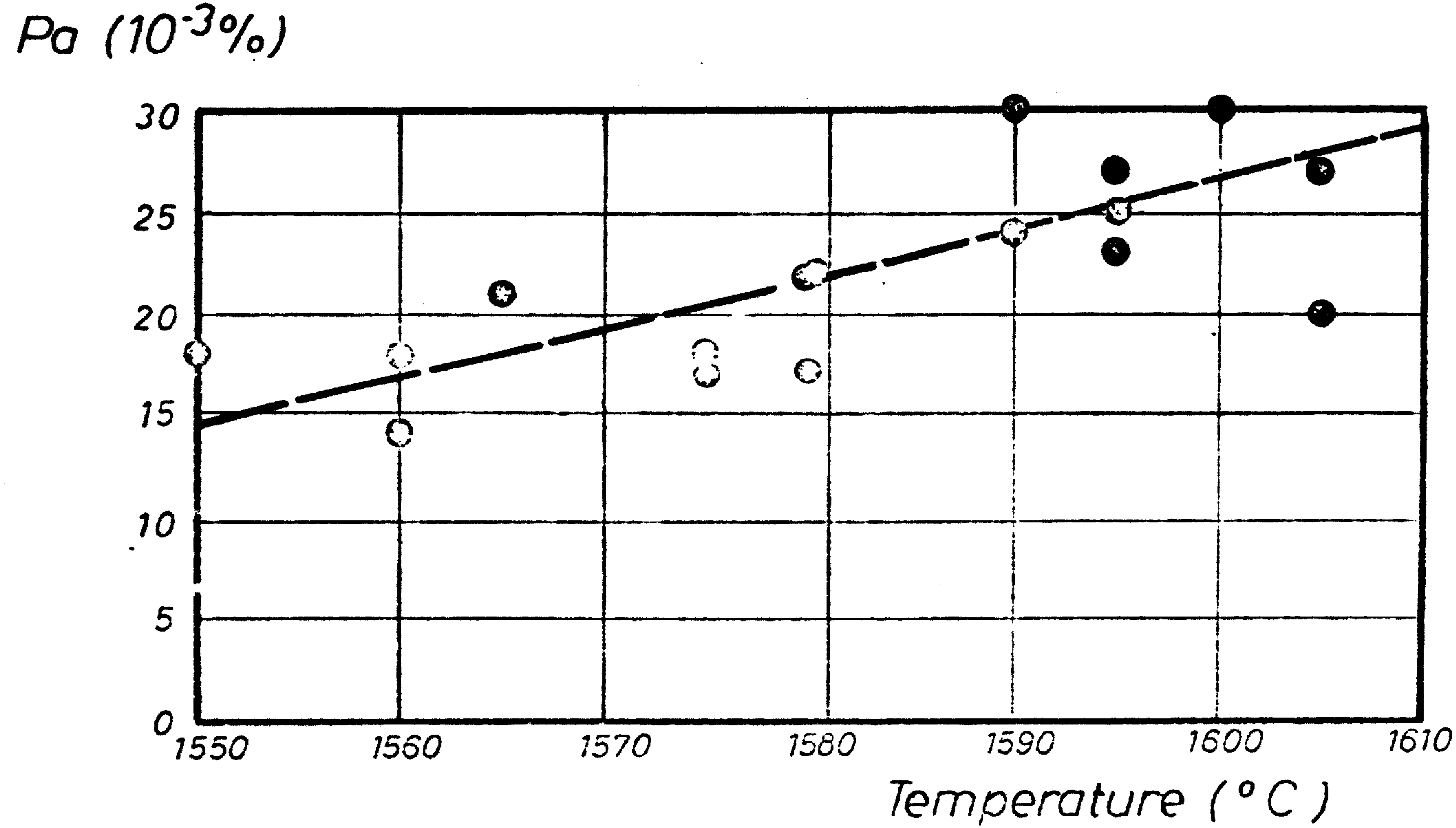


Fig. 10 - Phosphorus content before tapping as a function of bath temperature

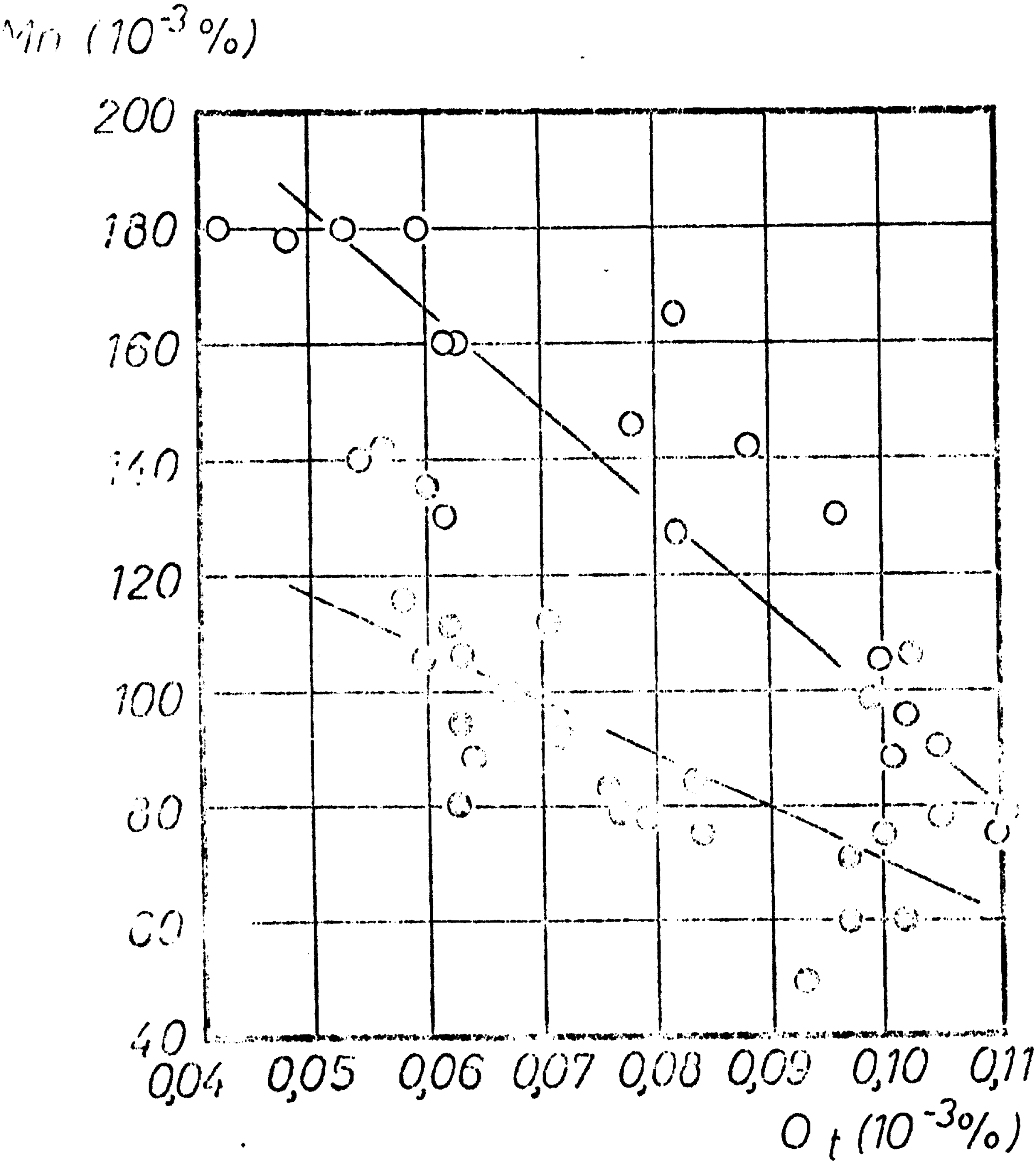


Fig. 11 - **Manganese-oxygen ratio at turndown (o) and after reblow (●)**

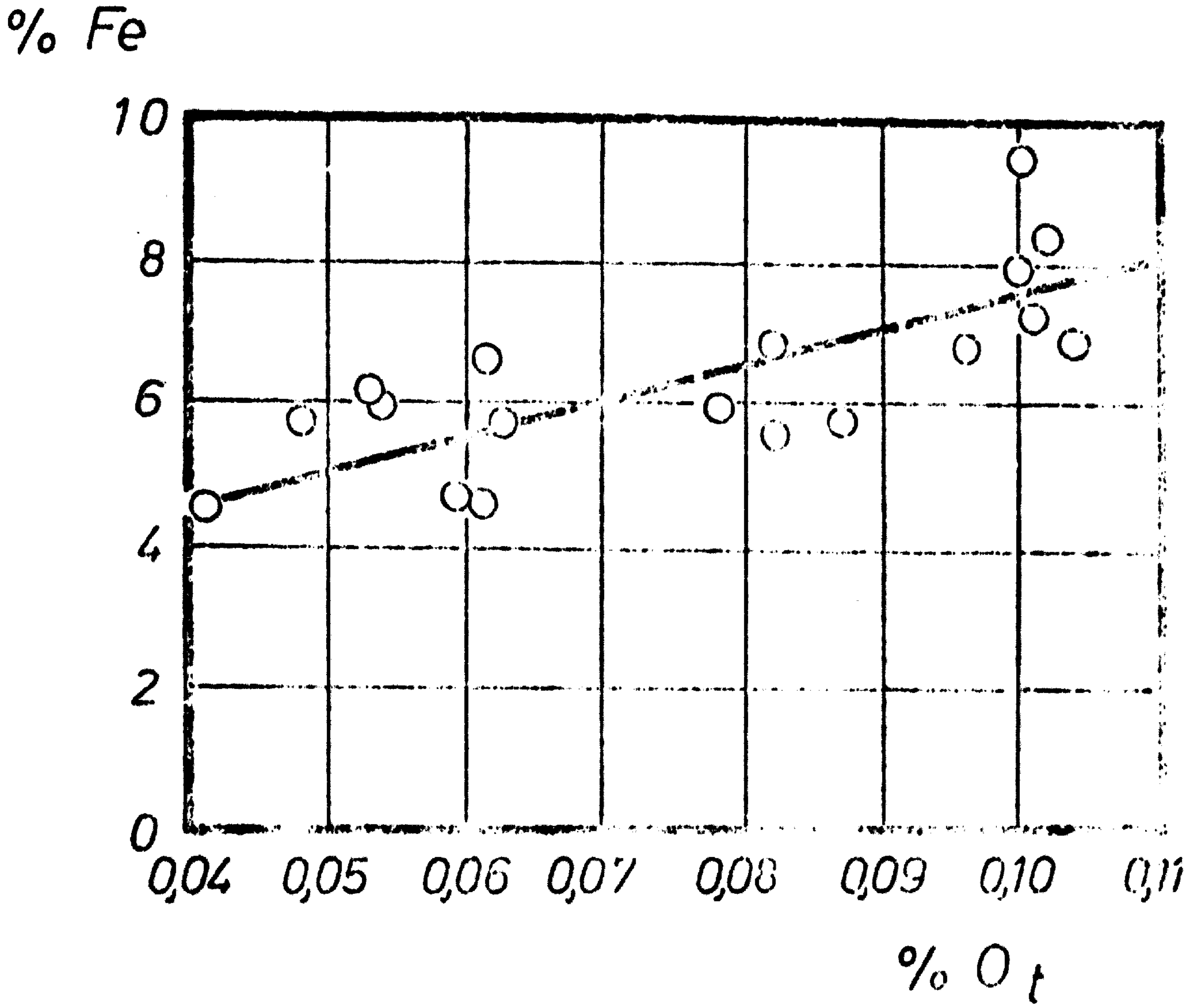


Fig. 12 - Relationship between the iron content of the slag and the oxygen content of the steel at turndown

On figure 11, we have plotted the manganese content at turndown and after the short reblow, as a function of the total oxygen content of the bath, determined by neutron activation. In both cases, a good correlation is observed. Figure 12 indicates a satisfactory relationship between the iron content in the slag and the total oxygen content of the steel at turndown.

The results reported on figures 8 to 12 indicate that a rapid determination of the oxygen activity of the bath, and of its temperature, offers excellent control possibilities.

At turndown, the iron content of the slag (Fig. 12), and thus the phosphorus content (Fig. 8), may be estimated almost instantaneously with a satisfactory precision, if the bath oxygen content and the temperature are known.

If a short corrective reblow is necessary, these indications serve to calculate rapidly the additions and the blowing conditions which will bring the heat to the desired temperature and to the required slag and metal compositions.

The ladle additions may then be calculated from a new oxygen activity measurement which, as figure 11 has shown, allows also the determination of the manganese content of the bath ; it must be noted that before tapping all heats have a carbon content of 0,020 ± 0,005 % (fig. 13).

A large campaign based on these considerations is now under way at Monceau with the Celox oxygen activity cell which has been developed by C.R.M. and Electronite.

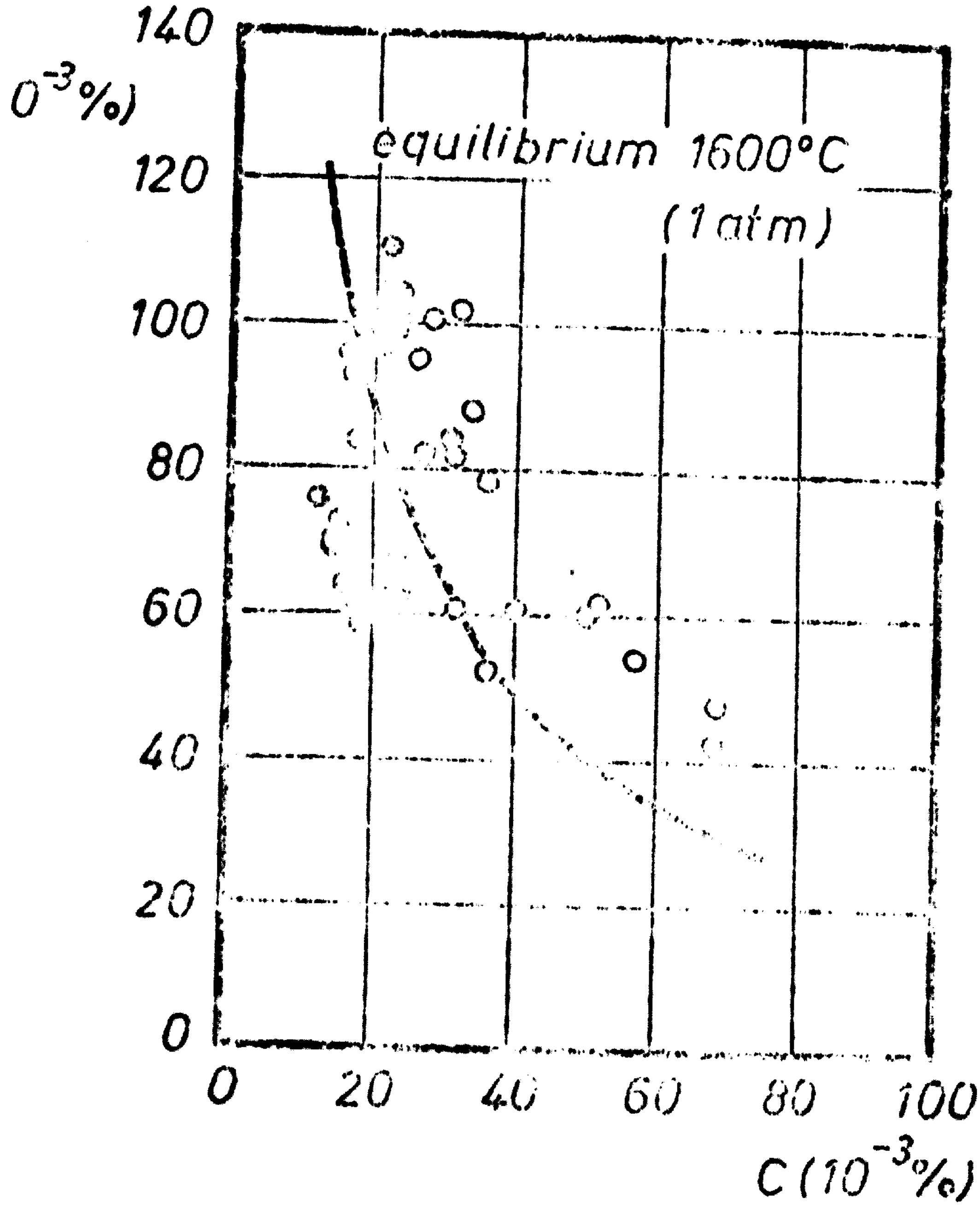


Fig. 13 - Carbon-oxygen ratio at turndown (o) and after reblow (●)

Conclusions

In the present paper, the research work carried out by Centre de Recherches Métallurgiques and Forges de Thy-Marcinelle et Monceau in the field of oxygen bottom blowing has been reported.

The results with high- and low-phosphorous hot metal show the excellent possibilities of the new process, which allows a quick and quiet conversion of hot metal into quality steels.

In the second part of the paper, the start-up of the steelworks of Monceau is described. This Basic Bessemer shop has been converted to OBM and its productivity has thus been increased by more than 30 %.

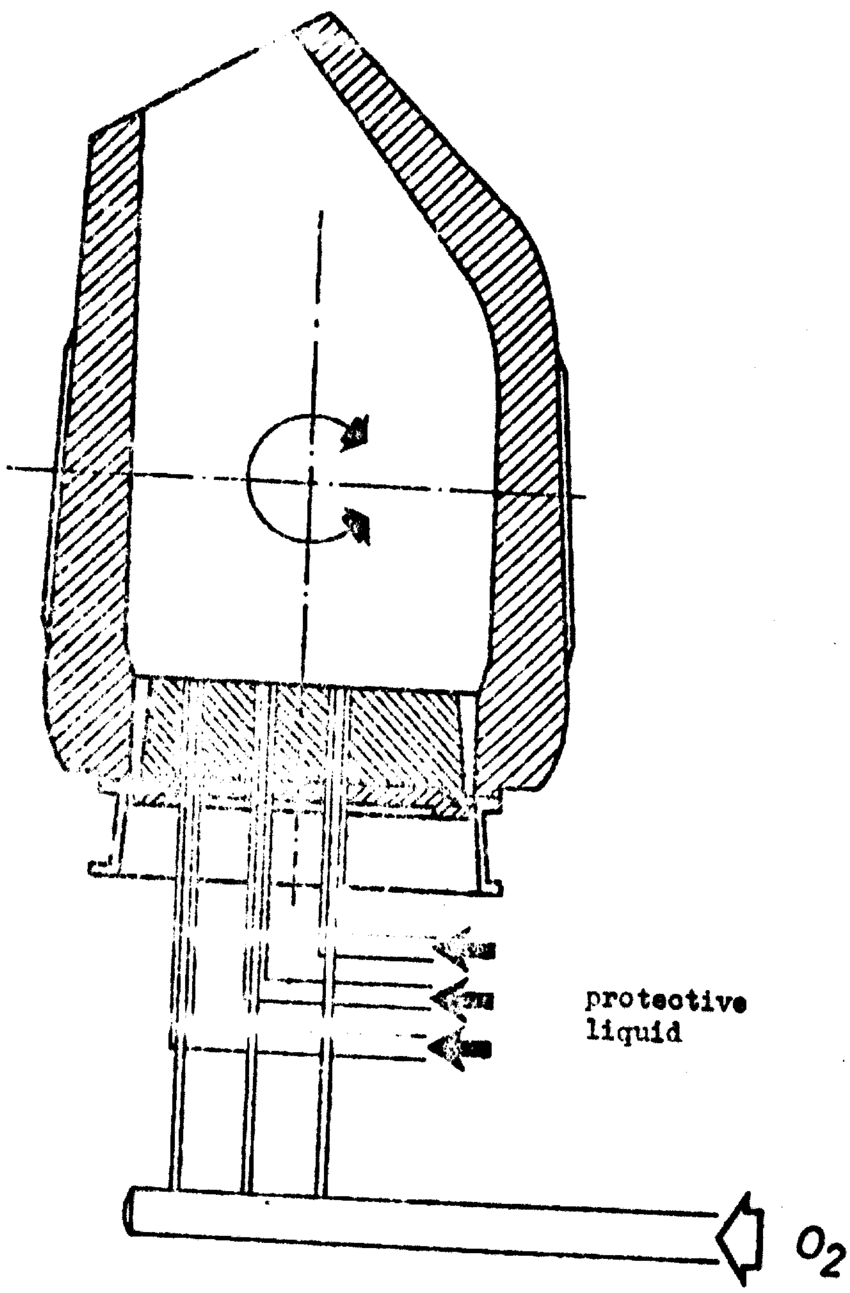
The metallurgical results correspond entirely to the findings on the experimental converter. In particular, slag and metal are shown to be in equilibrium ; at turndown or before tapping, a fast measurement of the oxygen activity of the bath allows a rapid determination of corrective additions in the converter and of the deoxidizing additions in the ladle.

Acknowledgments

The authors wish to thank the managements of T.M.M., C.R.M., and Max Hütte for the permission to publish the present paper. They are indebted to numerous collaborators ; they want to stress more particularly the participations of Messrs JACOBS, RICHARD, DAUBY, and COURARD.

A N N E X

Diagrammatic section of OBM converter



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