## OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

## DISCLAIMER



## FAIR USE POLICY



## CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

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

United Nations Industrial Development Organization

Distribution
LIMITED

ID/WG.14/25
2 July 1968

ORIGINAL: ENGLISH

Second Interregional Symposium
on the Iron and Steel Industry

Moscow, USSR, 19 September – 9 October 1968

B-9-2

# THE IRSID CONTINUOUS STEELMAKING PROCESS 1/

by
P. Vayssiere, J. Rouanet, A. Berthet,
C. Roederer and B. Trentini
France



1/ The views and opinions expressed in this paper are those of the authors and do not necessarily reflect the views of the secretariat of UNIDO. The document is presented as submitted by the authors, without re-editing.

id. 68-2091

We regret that some of the pages in the microfiche copy of this report may not be up to the proper legibility standards, even though the best possible copy was used for preparing the master fiche.

**United Nations Industrial Development Organization**

Distr.
LIMITED

ID/WG.14/25 Summary*
2 July 1968

ORIGINAL: ENGLISH

Second Interregional Symposium
on the Iron and Steel Industry

Moscow, USSR, 19 September – 9 October 1968

B-9-2

# THE IRSID CONTINUOUS REFINING PROCESS 1/

by

P. Vayssiere, J. Rouanet, A. Berthet, C. Roederer and B. Trentini,

France

## SUMMARY

IRSID has devoted several years' research to the development of a continuous pig iron refining process. At present a 10-15 tons/hour pilot plant capable of treating various kinds of pig iron, ranging from haematitic pig iron to iron with a very high (1.8 per cent) phosphorus content, is already in operation, and an industrial-scale (30 tons/hour) plant is being installed in a steel works in Eastern France. This research has been carried out with the financial participation of the European Coal and Steel Community.

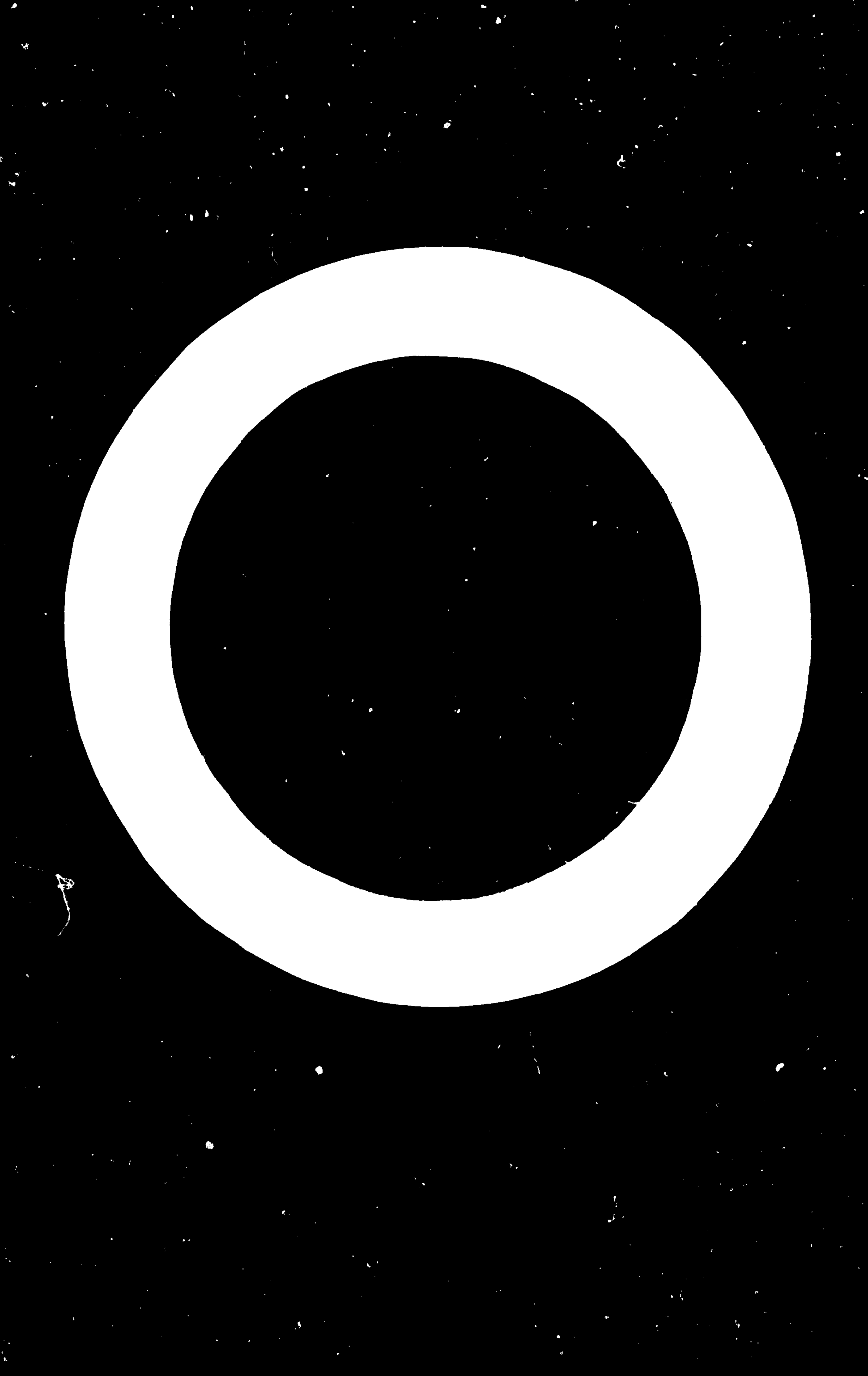
The authors describe the principle of the process, which is based on the formation of a complex metal-slag-gas phase in a converter. The converter is followed by vessels in which the slag can be separated from the metal and the steel can be brought to the desired degree of refinement. The refining also creates a "pump" effect which, by raising the level of the metal and the slag, makes it possible to construct a two-stage plant capable of internal recycling, which is particularly advantageous when processing pig iron with a high phosphorus content.

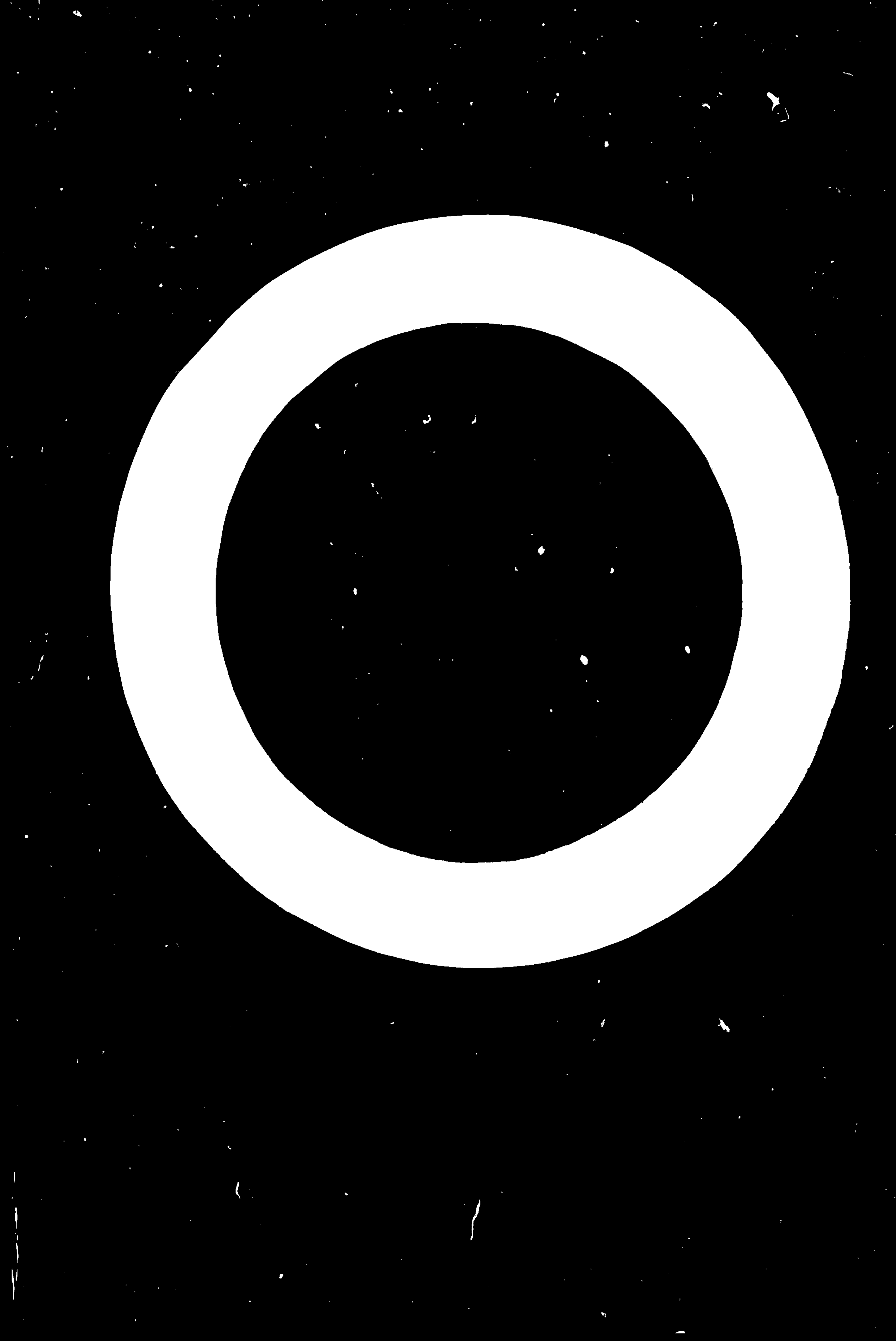
---

* This is a summary of the paper issued under the same title as ID/WG.14/25

1/ The views and opinions expressed in this paper are those of the authors and do not necessarily reflect the views of the secretariat of UNIDO. The document is presented as submitted by the author, without re-editing.

id.68-1924





The results discussed are of interest from several different points of view: on the one hand, there are the dynamic results concerning the adjustment of the degree of refinement and the automation in the course of the process; on the other hand, there are the results of an economic nature which permit a study of the profitability of the new process to be made. The results clearly establish even now that the investment costs per ton of iron produced will be greatly reduced, and that the use of continuous casting will be greatly facilitated.

## Contents



## List of figures

The process of continuous steelmaking from pig iron follows logically on the progress achieved over the last quarter of a century in the field of steelmaking and, in particular, marks a new stage after the important development in discontinuous steelmaking processes using pure oxygen which appeared on the European scene approximately 15 years ago.

Several solutions have been proposed by various research groups. L'Institut de Recherches de la Sidérurgie Française (IRSID) has, over the last few years, broached the study of continuous steelmaking and has designed several entirely new types of apparatus. An extensive research program carried out with the financial assistance of the European Coal and Steel Community has materialized in the IRSID process of continuous steelmaking from pig iron of which the principle, the main results and the current stage of development are discussed in this paper.

The study project commenced in 1964 at the IRSID Research Center at Maizières-lès-Metz was carried out in several stages and 3 consecutive pilot plants have been constructed. The processing of hematite pig iron with low phosphorous content of 0.2 % was first tried out on a single stage unit, and the promising results obtained at the end of 1966 led us to the conclusion that research in this field was, for the time being, finished at pilot plant level. We then turned our attention to the more difficult problems of processing pig iron with a high phosphorous content (up to 1.8 %) as commonly used in Western Europe. The possibilities offered by the process were then utilized and clearly demonstrated on a two-stage installation. The results obtained from this extension of the process showed that the hopes which we had originally placed in this principles of processing were well founded. Operating tests using a two-stage unit for the processing of hematite pig iron were also commenced and the first results obtained were most promising.

At the present time, a semi-production plant with a slated output of 700 tons per day is being set up in a steelworks in the East of France and should start up operations in the second half of 1968.

# I. - PRINCIPLE OF THE PROCESS AND DESCRIPTION OF THE PLANT

The principle of the process is based on a considerable increase in the surface of the metal in the slag. To this end, a continuous complex phase of slag, metal and gas is created.

Using the principle, the actual process takes place in the first vessel, called a reactor, which is shown in fig. 1. This reactor is fed with a regular, known input of pig iron. A blowing lance feeds in oxygen and lime for making the slag and, if so wished, the cooling agents necessary for obtaining equilibrium in the heat balance. The cooling agents may be added in lump form, using chutes. The reactor is equipped with an outlet connected to a device for cooling and cleaning the gases which are treated without secondary combustion of CO with the ambiant air. An overflow aperture in the wall of the reactor, at a level higher than that of the pig iron inlet, provides for continuous draw-off of the slag-metal phase, this metal being the desired raw steel.

A second recipient, called a decanting vessel, is installed alongside the reactor and receives the slag-metal phase. This decanting vessel, which is chemically inert, or nearly so, particularly when refining low phosphorous pig iron, separates slag and metal and is equipped with an orifice for de-slagging and a siphon for extraction of the steel.

The reactor-decanting vessel assembly constitutes what we term a processing unit and, to complete the installation, a number of indispensible peripheral apparatus must, of course, be added.

This peripheral apparatus consists of the following :

- Firstly, a vessel for continuous collection of the raw steel and in which the usual additions are made for grading, such as ferro-manganese or various alloys and a deoxydizing agent or even a recarburizing agent. This vessel (termed "nuanceur") which, as previously stated, serves for collection and grading of the steel, is installed downstream of the decanting vessel. Its size will depend on the conditions of steel casting, i.e. continuous casting or conventional ingot mold casting. It is our opinion that, in a production plant, the "nuanceur" will be a temperature holding vessel and we have already carried out a number of tests along these lines ; the results of these tests are quite promising.

- Secondly, a device for regulating and monitoring the flow of pig iron which, in our opinion, is an essential factor. This part of the installation has given us full satisfaction at pilot plant scale and we are now at a stage where the flow of pig iron is controlled by a digital computer.

- Devices for regulating the flow of oxygen and the various solid materials in lump or powder form. Here again, we have reached the stage of computer control.

- An installation for cooling and cleaning the gases which, apart from solving the problems of atmospheric pollution, will enable us to solve those problems connected with continuous monitoring of the Carbon content of the bath using the continuous "carbometry" and "oxymetry" techniques which IRSID has developed for the discontinuous steelmaking processes using oxygen.

- A data logging installation feeding a digital computer which, using material and dynamic thermal balances, permits control of the steelmaking process and, consequently, the temperature and the grade of the steel produced. This part of the installation has only been partly studied for tests at the pilot steelmaking plant at Maizières-lès-Metz, but will be installed as soon as the production plant comes into operation.

This installation has, of course, to be connected with the various facilities to handle pig iron, additions, liquid steel and slag.

Figure 2 shows a picture of the single-stage installation as it has been built at Maizières-lès-Metz. This installation has enabled us to process pig iron inputs of between 6 to 18 tons per hour with an average flow of approximately 12 tons per hour. The actual steelmaking stage, as well as its immediate peripheral equipment mentioned earlier, can be seen on this drawing, namely the pig iron vessel and its flow-control system, the reactor with the gas outlet and the blowing lance, the decanting vessel with the de-slagging device and the siphon for conveying the steel to the grading vessel ("nuanceur") which is very small in size in this pilot plant and which provides for ingot mold casting.

The adaptation of the processing principle described previously to an installation of more than one stage (in practice 2 stages), offers a means of simultaneous execution of the processing phases in 2 different areas of the same installation, as compared with the conventional processes for treating the pig iron with oxygen where the various stages take place in sequence in the same vessel. The process is consequently particularly well adapted for the treatment of pig iron with high phosphorous content, i.e. 1.8 % P. In particular, it offers the possibility of exhaustion of the bath by the successive formation of dephosphorizing and also desulphurizing slags. In addition, it will be more efficient and more economic to run if it comprises a circuit for recirculation and slag-metal counter flow. By means of all these refinements the process may also be used for treating hematite pig iron where substancial improvements could be obtained.

In the IRSID process, the mechanism of steelmaking in a complex slag, metal and gas phase produces, by a swelling action, a pumping effect inside the reactor which raises the level of the materials and thus permits, by the mere force of gravity, a means of recirculation. In practice, the recirculation of the second slag takes place in the first decanting vessel which gives us a simple set-up and suitable kinetics for complementary dephosphorizing reaction with a limited loss of Carbon.

In fact, in this two-stages installation including recirculation of final slag, the decanting vessel is no more inactive and can be considered as a two-zones vessel : the first one where the recirculated iron-rich slag is reduced by the carbon contained in the intermediate metal coming from the first reactor, the second one is inactive and acts as slag-metal separator. Fig. 3 shows schematically the two-stage process, and fig. 4 a perspective drawing of the installation as it has been tried out in our pilot plant. The peripheral equipment mentioned earlier is identical, but is grouped around an assembly of 2 reactors and 2 decanting vessels.

## II. - EXPERIMENTAL RESULTS IN A SINGLE STAGE PLANT

Taking first of all the single stage plant, we shall describe an operation which is representative of the stage we had reached in December 1966 at the end of a test program using hematite pig iron. Then, we will made a rapid synthesis of the performance and operating results obtained after some 50 hours of processing.

The supply of pig iron to our pilot plant was not sufficient to enable us to carry out testing for a period of longer than 4 hours consecutively, although, as we shall see later when discussing the operating data, the results obtained led us to think that an uninterrupted operating time in the region of 150 hours, i.e. longer than 6 days, should be possible. In 1966 tests with hematite pig iron were carried out using a single lining and totalled 50 hours of operation within 31 individual tests. When examining the results, it is rather difficult to appreciate the influence (unfavorable in most cases) of the stop-start nature of the tests, such as thermal shocks in the refractory lining, lack of thermal equilibrium in the vessel, too short an adjustment period, etc.....

## 1°) Description of the processing operation of hematite pig iron in the single stage plant.

Figure 5 shows an operation lasting 4 hours using pig iron with the following chemical composition : C 4.0 %, Si 0.6 %, P 0.25 %, Mn 0.8 % ; 5 successive loads of pig iron were fed into the pig iron vessel and the variations in chemical composition of each of these feeds was approximately representative of those that one would usually find in production operation.

The figure shows the curves corresponding to the various constituents plotted against time ; the 4 upper curves show the continuous flow of input material, i.e. pig iron, gaseous oxygen, lime and cooling agents (prereduced pellets and ore). In this operation, the average pig iron flow was 160 kg per minute and the corresponding curve shows the satisfactory regularity which was obtained. After an initial period to obtain a thermal equilibrium, facilitated by intense preheating of the vessels, the flow of prereduced pellets was stabilized at approximately 45 kg per minute or, in other words, 280 kg per ton of pig iron which, taking into account the composition of these pellets, corresponded to a thermal equivalent of 300 kg of scrap.

The curves in the lower part of figure 5 show the characteristics of the steel and the slag in the decanting vessel :

- The average carbon content obtained was 0.061 %, for 80 % of the time, the carbon content was between 0.050 and 0.070 %. It should be remembered that we are dealing here with values corresponding to samples taken from the decanting vessel, i.e. before homogenization was achieved in the "nuanceur".

- The average phosphorous content was 0.018 % with a typical variation of 0.006 % in relation to this average. It should be noted here that the hematite pig iron does not have a very low phosphorous content, but is in the neighbourhood, on average, of 0.250 %. It can, also, be pointed out that the mean value of phosphorous content within the whole running time is not really representative of the degree of dephosphorization achieved ;

in fact, at the beginning of each operation, the dephosphorization is not so good as it is when steady conditions are reached. As an example for the test mentioned, the average value, during the last 150 minutes, is lower than 0.015 % P.

- The temperature of the steel which was monitored both on a continuous and a discontinuous basis remained within a narrow range throughout the operation ; the average value was 1610°C.

- The slag contained an average of 22.7 % iron in the case of the extra-mild grade steel produced.

These results call for two comments :

- Firstly, the operation we have just described displays a consistency in the composition of the steel in the decanting vessel and in its temperature which, in our opinion, is quite satisfactory. And this despite the fact that computer control was not used when these tests were carried out ; control was entirely manual and we feel that a marked improvement would be obtained using a computer-controlled process at production level.

- As previously mentioned, the values showed in figure 5 refer to raw steel flowing out of the decanting vessel. Consequently, we are dealing with "dynamic" results which do not represent exactly the average composition (nor the scatter) of the metal which one would have drawn off periodically from the "nuanceur" when tapping the steel.

Figure 6 gives the analysis which would have been obtained, concerning carbon and phosphorus in the following hypothesis : pouring each half hour the liquid metal contained in the "nuanceur" (considered as a mixing and storing vessel) in one ladle in view of ingot teeming.

## 2°) Results obtained concerning the characteristics of the liquid steel.

The results which we have just described will give you an idea of the consistency in the steel composition obtained and of the degree of purity achieved in the liquid steel. This purity is a result of the physico-chemical characteristics of the process and in particular of the slag-metal relationship. It would be out of place in this paper to go into a detailed description of the physico-chemical studies which have been, or could be carried out in the future, as for steelmaking in a conventional converter. There is a vast field of research to be explored in this connection. However, for the moment, we will confine ourselves to the discussion of two important factors :

- the oxygen content in the steel.

Figure 7 illustrates the carbon-oxygen relationship obtained in the decanting vessel as well as a number of plots corresponding to the "nuanceur" stage, for hematite pig iron. The graph also shows scatter zones obtained during LD processing and, as it can be observed, the plots which we obtained experimentally fall inside these scatter zones.

- nitrogen content in the steel.

The processes for nitrogen pick-up removal should be similar in the continuous steelmaking reactor to those which occur in a vertical lance converter. However, in the case of continuous steelmaking, air should be prevented from entering through the de-slagging hole which is located in the lower part of the unit. Consequently, the pressure should be regulated inside the reactor and the decanting vessel to obtain a slight over pressure of the gases inside the vessels. By this means, the nitrogen contents are of the same order as those in an LD converter.

## 3°) Description of the operating results.

The results were obtained on the pilot plant at Maizières-lès-Metz which, as said before, provides for average flows of 12 tons per hour. These results could be interesting for those who intend to know the main datas of this process in order to evaluate the possibility of applying it in any particular case. To date, the results have been promising as regards the iron yield, the heat balance and the wear of the refractory lining. It has not been possible to verify operational criteria such as reliability, in view of the interrupted pattern of tests on the pilot plant ; solutions to these problems can only be found through operation of the plant at production level.

### - Iron yield

Iron yield is defined as the ratio of the weight of liquid steel obtained (including that obtained at final emptying of the vessels) to the weight of iron fed into the system (iron content coming from the pig iron and the addition of various elements). Under our test conditions, and using hematite pig iron displaying the same average composition as that used in the operation illustrated in figure 5, the iron yield was 96 %. Among the various items of the iron balance which we have examined, the most characteristic are the metallic bead content in the slag and the emission of red fumes.

#### iron metallic beads

As regards the metallic bead content in the slag, and considering the importance of this item, a detailed study program has been carried out. It may be said that any process which does not master the technique of metal-slag separation cannot but produce a very poor metallic yield. We have examined the influence of these various factors on the separation process and have illustrated the importance of the retention time in the decanting vessel. Adapting the size of this unit enables the iron loss through metallic bead in the slag to be reduced practically to zero.

Through this adaptation, continuous and automatic de-slagging results in a definite gain in iron yield when compared with de-slagging in discontinuous converters.

- emission of red fumes

The feature of the IRSID continuous process, i.e. the permanent presence in the reactor of a swollen liquid slag pointed to a filter effect which was favorable to a significant reduction in losses through red fumes in comparison with LD converters. Measurements which were taken showed that this was indeed the case. Thus, after the initial transitory period, the losses in iron through red fumes did not exceed (under the operating conditions of the pilot plant), 2.4 kg of iron per ton of pig, to which must be added 0.5 kg of coarse dust particles deposited upstream of the dust collecter, which have been directly extracted by the exhaust gases.

To sum up, it can be seen that the continuous steelmaking process displays good iron yield characteristics which, at production level - using a suitable decanting vessel and controlling slag basicity, .... - should permit a yield higher than the 96 % obtained under the operating conditions at pilot plant level. Moreover, as you will be hearing later, a two-stage plant is likely to give a marked improvement in the metallic balance.

- Heat balance

The heat losses occasioned between two operations do, generally speaking, disfavour the discontinuous processes when compared with the continuous processes. The process developed by IRSID adds to this advantage the almost total absence of losses through radiation, as the apertures are very small.

Drawing up a dynamic thermal balance provides a means of appreciation of the thermal losses during permanent operation. Since the losses for a given unit are more or less independent of the flow of metal, the losses per ton of steel will vary inversally with the output. It is therefore important to know the flow possibilities of a given installation. In the case of the only reactor currently in operation, we have covered a range of flows from 1 to 3 (100 to 300 kg per minute) without being able to say that the maximum possible flow has been reached.

Taking the case of the Maizières plant, the heat balance shows that the losses are in the region of approximately 20.000 kcal/t of pig iron for an average flow of 12 t/hour. Under these conditions, we found an available thermal excess higher than 300 kg scrap equivalent for the hematite pig iron referred to in figure 5. Figure 8 gives the evolution of the cooling agent consumption (expressed in RTE i.e. quantity of scrap equivalent in kg charged pro each ton of pig iron) according to the blowing time : it can be seen that, although the apparatus was well preheated, steady conditions are only reached after a long time. For the pig iron flow of 160 kg/mn, the scrap equivalent consumption is at the level of 305 kg RTE/ton of pig iron. On the same installation, the value attained for a liquid pig iron flow of 300 kg/mn would be of 340 kg RTE/ton of pig iron. These results are always concerning the same hot metal analysis as for figure 5 and a hot metal temperature of 1360°C at the inlet of the reactor.

The quantity of cooling agents put into the plant will, of course, vary with their nature and, in each case, a heat balance and a material balance will permit determination of the corresponding quantities.

In view of the very principle of the process, its seems difficult to use any kind of scrap, and this drawback will be the same in every continuous refining process. We just have been able to use addition of very small size scraps : some tests have been conducted with processed scraps such as "prolerized" car bodies without troubles.

However, it must be emphasized that such a possibility does not solve the general problem of scrap utilization for two reasons :

- the very small dimensions of the vessel, in the IRSID continuous steelmaking process, does not allow the use of large scrap pieces,

- for any continuous process, control of feed rate of usual scrap, is clearly impossible. We think that this problem could be solved by integration of the continuous refining process with other suitable steelmaking facilities such as conventional melting units.

In the case of the developing countries where a medium size iron and steel plant is contemplated, one could associate :

- a continuous processing line including continuous steelmaking and continuous casting units, allowing the direct transformation of liquid pig iron into semi-products,

- a conventional arc melting furnace using recirculating scrap and allowing production of limited tonnages of different qualities steel ; this could be the first step towards production of high grade and special steel.

To date, we have used several types of cooling agents, outside prolerized scrap :

- Oxydized ore added either in powder form in the oxygen jet or in lump form (5-30 mm) fed in regularly on a conveyor belt.

- Reduced ore. This is a choice material for continuous steelmaking, particularly if the gangue content is low. On the other hand, contrary to utilizations such as the electric furnace, the degree of reduction is of less importance and it is certainly possible to find excellent optimization conditions between a direct reduction unit and a continuous steelmaking plant.

In our tests, utilization of prereduced pellets has been very satisfactory ; on the other hand, utilization of prereduced iron powder insufflated by a secondary lance raises questions about transportation gas : safety problems if oxygen is used and nitrogen level in steel if normal air is used.

It is also possible to give consideration to cooling agents of the same type as the reduced ores but which contain thermogenic elements such as carbon in order to increase the ratio of solid materials charged. The first approach in that way has been made during our tests by charging granulated pig iron and we have been able to charge 50 % of cold pig without troubles, this figure is probably not the final limit.

Before finishing with this question of heat balance, we should like to stress the advantages derived from recovery of the sensible heat and of the latent heat in the gases arising from the continuous steelmaking process. First of all, the recovery of gas with a high CO content is easy, since the reactor is a fixed installation and the operation is a continuous one. Secondly, it is also possible (and experience has proved this) to adjust the oxygen input so as to obtain a given secondary combustion of CO giving $CO_2$ inside the reactor (for example 30 % $CO_2$ and 70 % CO) which is compatible with the conditions of wear of the refractory lining. This is currently being studied in detail.

- <u>Lining life</u>

At the present time, the reactor-decanting vessel unit is constructed of ceramic-bonded magnesia brick impregnated with tar. The lime required for the continuous steelmaking process is magnesia-enriched and when blown through the lance, contains 8 % of MgO.

Under these conditions, as fig. 9 will show, the consumption of refractory material, calculated by the magnesia balance, was 2.3 kg/t of pig iron for the overall process and 1.4 kg/t of pig iron during periods of operation in a state of equilibrium (after the 45 initial minutes of blowing). Each time the plant is started up, as required by the test conditions, the consumption of refractory material increased due to the inevitable thermal shocks as well as to the imperatives of the initial transitory period (high levels of temperatures and slag FeO-content). The figure of 1.4 kg would therefore represent the consumption of refractory material for an operation of long duration and on the scale of the current pilot plant. However, this figure does not take in consideration the loss due to the remaining refractories at the end of each campaign, and the value which has to be retained for an economical evaluation must be somewhat higher.

The dimensional wear curves of the reactor, which also appear in figure 9, correspond to the two consumptions we have just mentioned :

- the round dots are related to the direct measurements made on the reactor between two successive operations ;
- within hypothesis concerning the wear profile, it is possible to correlate total refractory consumption (calculated by a MgO-balance) with a dimensional lining wear. Such an evaluation of the wear is plotted by the curve I on figure 9, which is in very good agreement with the experimental dots. This fact joined with the actual global weighing of bricks at the end of the campaign are good checks of the MgO balance we normally use.
- using the same evaluation based on the steady-state consumption (1.4 kg) instead of total consumption (2.3 kg), we get the curve II. This curve would represent the dimensional wear for an uninterrupted operation up to complete wear of the lining, in the case of our pilot plant running at 12 t/hr. This curve shows that with very usual lining thickness of 230 mm, the operating life of the reactor lining should be longer than one week.

It is most probable that the results concerning the refractory consumption would be better with larger size vessels than in our pilot installation. Moreover, considering that the reactor is a stationary and cheap vessel, we have designed it in order to be able to replace it quickly by another unit provided with new lining and, eventually, preheated ; so the productivity of the installation could be very high.

We never experienced any wear problem in the decanting unit ; the consumption figures quoted above (calculated by a MgO balance) includes, in fact, the lining wear of that vessel.

## III. - RESULTS OBTAINED WITH THE TWO-STACE PLANT

Over the past year a number of tests representing some 24 hours of continuous steelmaking have been carried out on a two-stage plant with recirculation of the second stage slag. This type of continuous steelmaking is perfectly adapted to pig iron with a high phosphorous content for which processing in conver - tional furnaces takes place in at least 2 phases. We have paid particular attention to the treatment of this type of pig iron produced in Western Europe, and the production plant which we are building will process particularly high-phosphorous pig iron.

Figure 10 illustrates the process of such an operation which, during our tests, lasted approximately 3 hours. The essential data curves, which are plotted as a function of time, illustrate composition and temperature of the metal in the two decanting vessels and the iron content of the slag coming out from the first decanting vessel.

The results which we shall now give correspond to the period commencing with the creation of an almost permanent operational regime (40 minutes after beginning of blowing) and terminating with the end of the operation at the 175th minute :

- For a carbon range between 0.060 % and 0.080 %, the average value obtained was 0.071 % ; for 90 % of the time, the carbon content remained between 0.090 % and 0.050 %. It should again be remembered in this connection that we are dealing with values corresponding to samples taken from the decanting vessel, that is to say before homogeneity was achieved in the grading vessel (or "nuanceur" as we call it).

- Mean value of phosphorus content is 0.016 % with a standard deviation of 0.005 % ; but from the 53td minute onwards, the phosphorous content remains below 0.020 % and, during the last 25 minutes, is lower than 0.009 %, which proves that in fact it is possible to achieve very low phosphorous contents even from high-phosphorous pig iron.

- The temperature in the first decanting vessel (in other words the de-slagging temperature) registered an average of 1629°C with a typical variation of 9°C.

- The evacuated slag contains, in average, 10.6 % Fe (as Fe-oxides) and 16 % $P_2O_5$. This figure is sufficient to use it as a fertilizer. In our case, it stays however on the low side because of the high Si content of pig iron (0.66 to 0.92 %). The average weight slagged-off is 250 kg/ton of pig iron, this high value is also related to the Si content of pig iron.

- In the second decanting vessel, the temperature showed an average of 1627°C with a typical variation of 5°C. This temperature becomes even more stable in the nuanceur ;

- The slag in the second reactor with an iron content of 29 % is recirculated to the first decanting vessel after the 40th minute ; the weight of recirculated slag is 74 kg per ton of pig iron. The difference in Fe content between the two slags illustrates the active part played by the first decanting vessel in the chemistry of the process.

As in the case of the one-stage process, full automation of the control will certainly improve results and, specially, consistent values of analysis and temperature of liquid steel ; all the remarks about the homogenizing effect of the "nuanceur" are still valid.

The results obtained are extremely promising for the processing of high-phosphorous pig iron. The operating figures attained at the pilot scale concerning iron yield, thermal balance and refractory consumption are extremely promising as shown below :

- <u>Iron yield</u>

In spite of the small number of tests conducted on high-phosphorous pig iron, which did not allow us to achieve optimization of operating procedure, and in spite of a too short decanting time, due to a too small decanting vessel, the average iron yield (with the same definition as before) has reached 95.7 %.

Theoretical calculations made, assuming more suitable and usual conditions (particularly, lower Si-content of pig iron) point to values in the range of 96.3 to 97.4 % according to residual content of P in steel.

- Thermal balance

In the following conditions :

- liquid pig iron flow rate : 12 tons/hour,
- liquid pig iron temperature at the first reactor inlet : 1310°C,
- average steel temperature : 1625°C,
- pig iron analysis as shown figure 10,

the asymptotic value of RTL (i.e. scrap equivalent) is 500 kg/ton of pig iron.

This large heat excess is essentially available in the first reactor and can be related to the high level of secondary combustion of CO into $CO_2$ which is, in average, 30 %.

- Refractory consumption

The two-stages installation is lined with magnesia bricks, ceramic-bonded and tar-impregnated ; the lime used contains 8 % MgO. The same methods, as before, are used to calculate the lining wear and the refractory consumption.

After 40 mn of blowing, where we are approaching a steady stage conditions, the refractory consumptions are :

- 2.18 kg per ton of pig iron in the first stage (reactor and decanting vessel),

- 0.69 kg per ton of pig iron in the second stage.

Between the second and the third hours of blowing, the limit values reached are, respectively, 1.8 and 0.45 kg/ton of pig iron.

In these conditions, the calculations about the dimensional wear of the lining shows that it is possible to anticipate a lining life of the first reactor (which is the critical part of the installation) of one week, even in using high-phosphorous pig iron.

These results have been mentioned here in order to demonstrate that the principle of a two-stage installation with recirculation of the second slag is perfectly valid. A few tests have shown that it was also applicable to hematite pig iron and, in this case, the estimated calculation point to promising operating values, particularly as regards the iron yield, and the refractory consumption, which are better than those related to high-phosphorous pig iron refining. Continuous two-stage steelmaking with recirculation of the second slag is, in our opinion, a possibility which should not be neglected in the future.

# CONCLUSIONS

During the two last years, research work has been strongly pushed to develop the IRSID continuous steelmaking process. At the end of the year 1966, we had accumulated sufficient results to evaluate the possibility of applying the process, with one stage operation, to low-phosphorous pig iron refining (P less than 0.3 %). The main technical characteristics, such as thermal balance, iron yield, refractory consumption, steel analysis have been ascertained ; in the same time, we began economical evaluation of this new process. As a first point, it can be said that the investment cost (i.e. cost per ton of steel produced) will be definitively lower than usual for conventional basic oxygen process ; this advantage will be specially marked when a small-scale or medium scale steelmaking plant is considered ; as an example, for a complete steelmaking plant of 1.500.000 tons per year, this gain has been evaluated around 25 % of total cost. We must mention further additional savings due to an easier possible link with a continuous casting plant.

In the case of developing countries, very simple continuous production lines from liquid pig iron to semi-products (billets or blooms) can be designed ; such designs have already been started in order to allow fast application to any request for a given project. In a medium scale iron and steel plant, such a line will ensure production of tonnage steel from "virgin" primary hot metal ; in the same time, electric arc furnace could ensure melting of recirculating scrap and production of small tonnages of special grades of steel.

During 1967, experience gained before has been applied to the development of a two-stage process, including recirculation of final slag, specially in view of continuous refining of high-phosphorous pig iron. From the results obtained so far at pilot scale, it can be assumed that the gain achieved in using the IRSID continuous steelmaking process, instead of a conventional oxygen process, will be still higher in the refining of high-phosphorous pig iron : as a matter of fact, the productivity of the process is not depending upon the pig iron analysis, contrarily to the conventional processes, and thus the conversion costs will not be affected by this analysis.

These results have been mentioned here in order to demonstrate that the principle of a two-stage installation with recirculation of the second slag is perfectly valid. A few tests have shown that it was also applicable to hematite pig iron and, in this case, the estimated calculation point to promising operating values, particularly as regards the iron yield, and the refractory consumption, which are better than those related to high-phosphorous pig iron refining. Continuous two-stage steelmaking with recirculation of the second slag is, in our opinion, a possibility which should not be neglected in the future.

# CONCLUSIONS

During the two last years, research work has been strongly pushed to develop the IRSID continuous steelmaking process. At the end of the year 1966, we had accumulated sufficient results to evaluate the possibility of applying the process, with one stage operation, to low-phosphorous pig iron refining (P less than 0.3 %). The main technical characteristics, such as thermal balance, iron yield, refractory consumption, steel analysis have been ascertained ; in the same time, we began economical evaluation of this new process. As a first point, it can be said that the investment cost (i.e. cost per ton of steel produced) will be definitively lower than usual for conventional basic oxygen process ; this advantage will be specially marked when a small-scale or medium scale steelmaking plant is considered ; as an example, for a complete steelmaking plant of 1.500.000 tons per year, this gain has been evaluated around 25 % of total cost. We must mention further additional savings due to an easier possible link with a continuous casting plant.

In the case of developing countries, very simple continuous production lines from liquid pig iron to semi-products (billets or blooms) can be designed ; such designs have already been started in order to allow fast application to any request for a given project. In a medium scale iron and steel plant, such a line will ensure production of tonnage steel from "virgin" primary hot metal ; in the same time, electric arc furnace could ensure melting of recirculating scrap and production of small tonnages of special grades of steel.

During 1967, experience gained before has been applied to the development of a two-stage process, including recirculation of final slag, specially in view of continuous refining of high-phosphorous pig iron. From the results obtained so far at pilot scale, it can be assumed that the gain achieved in using the IRSID continuous steelmaking process, instead of a conventional oxygen process, will be still higher in the refining of high-phosphorous pig iron : as a matter of fact, the productivity of the process is not depending upon the pig iron analysis, contrarily to the conventional processes, and thus the conversion costs will not be affected by this analysis.

The continuous steelmaking test carried out by IRSID over the last few years at pilot plant level have produced promising results which have motivated the construction of a semi-industrial plant, which will be running in at the middle of 1968. Designed for processing of high-phosphorous pig iron at the rate of 700 tons/day, it will allow to confirm and precise the fabrication costs, as well for the one stage as for two-stages process.

Tests conducted during the last months did show that the two-stage installation was also well adapted to processing low-phosphorous pig iron. Additional advantages concerning fabrication costs could be anticipated from such an application and technical results of the semi-industrial plant, which will be available at the end of 1968, will be interesting for all those who are confronted with development projects, whatever the type of iron ore is considered.

Figure 1

# THE IRSID CONTINUOUS STEELMAKING PROCESS

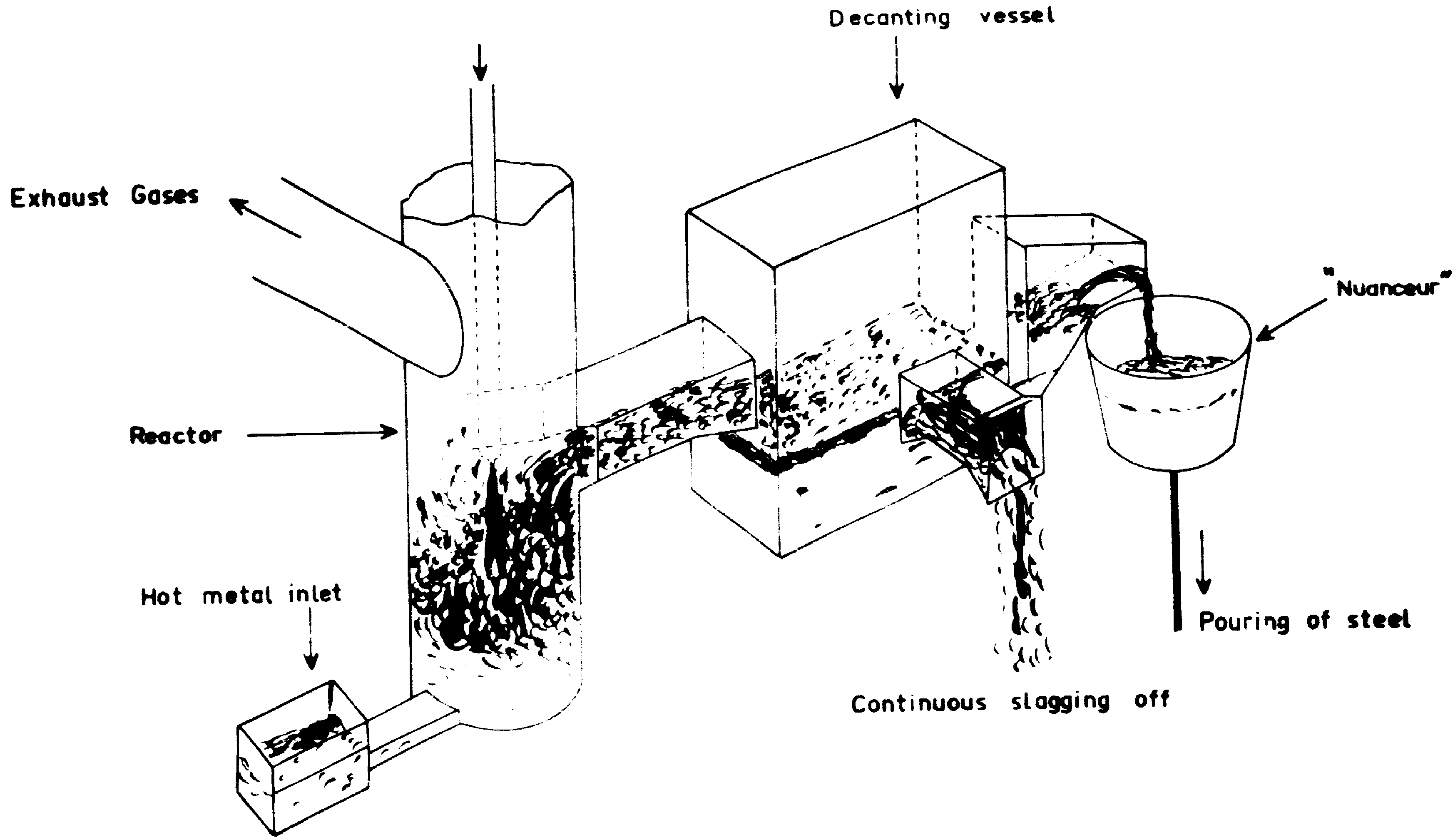


Figure 2

# IRSID CONTINUOUS STEELMAKING PROCESS
## ONE-STAGE INSTALLATION

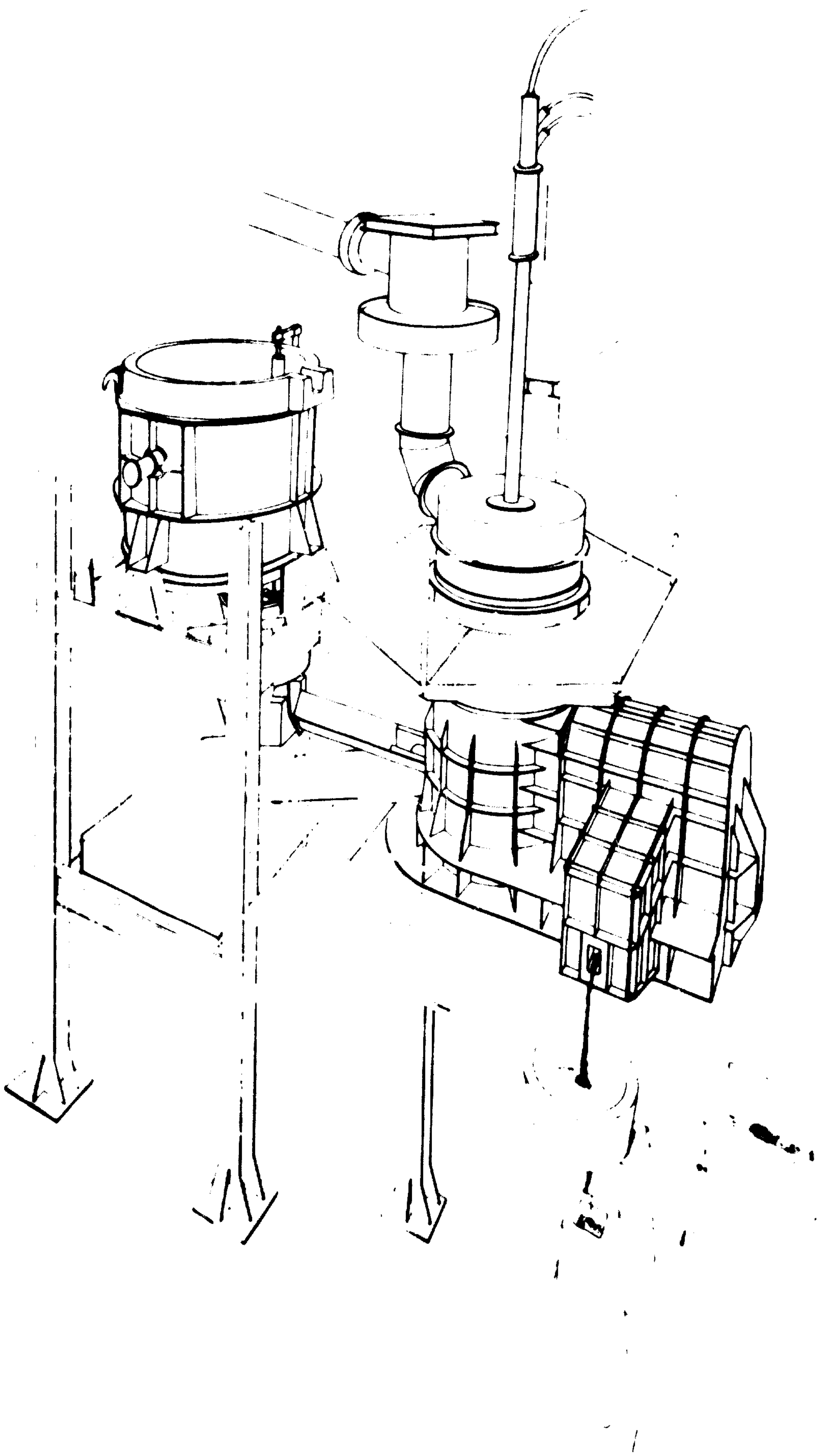


Figure 3

## TWO STAGE INSTALLATION WITH RECIRCULATING OF SECOND SLAG

## GENERAL LAYOUT

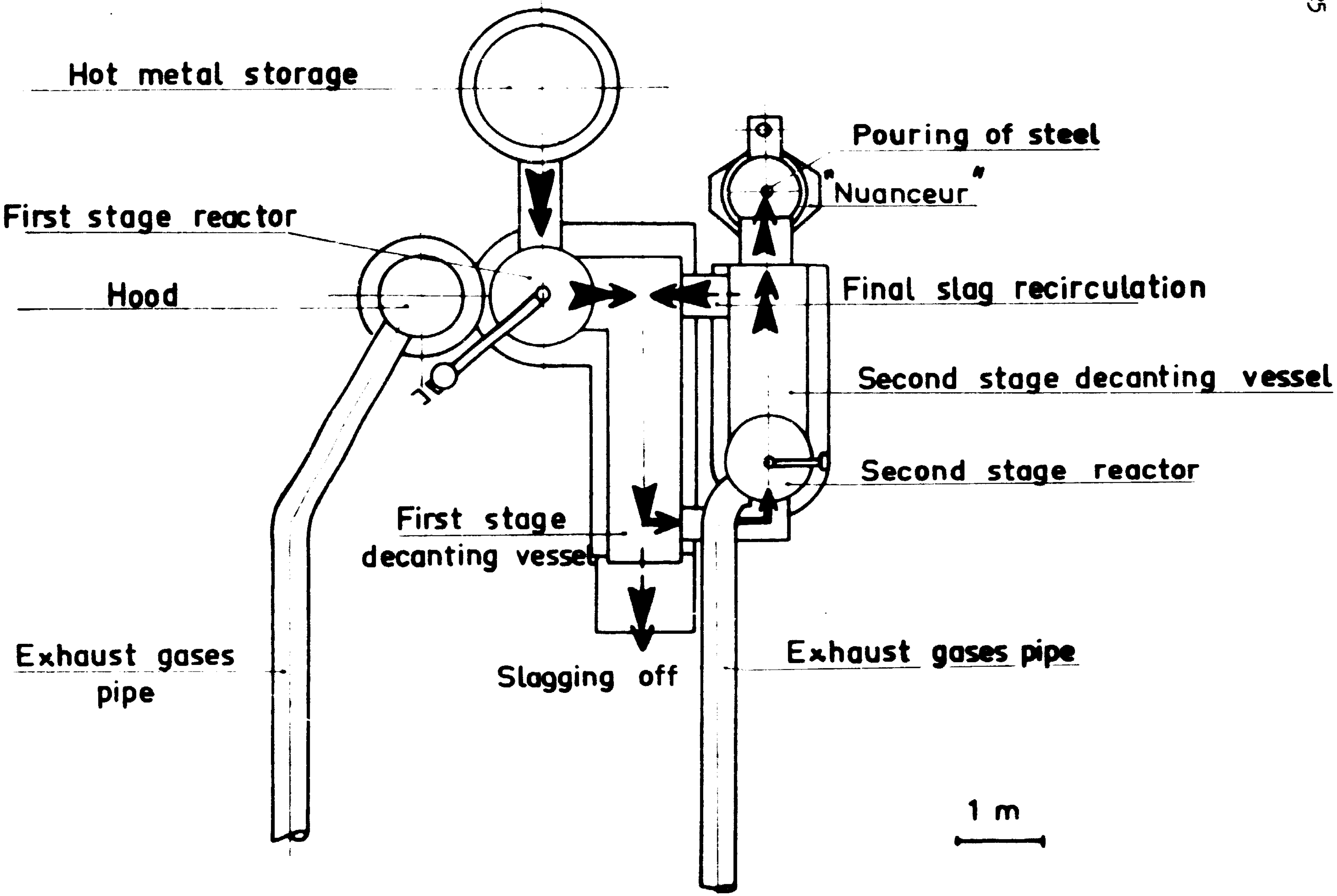


Figure 4

# IRSID CONTINUOUS STEELMAKING PROCESS

## TWO STAGE INSTALLATION

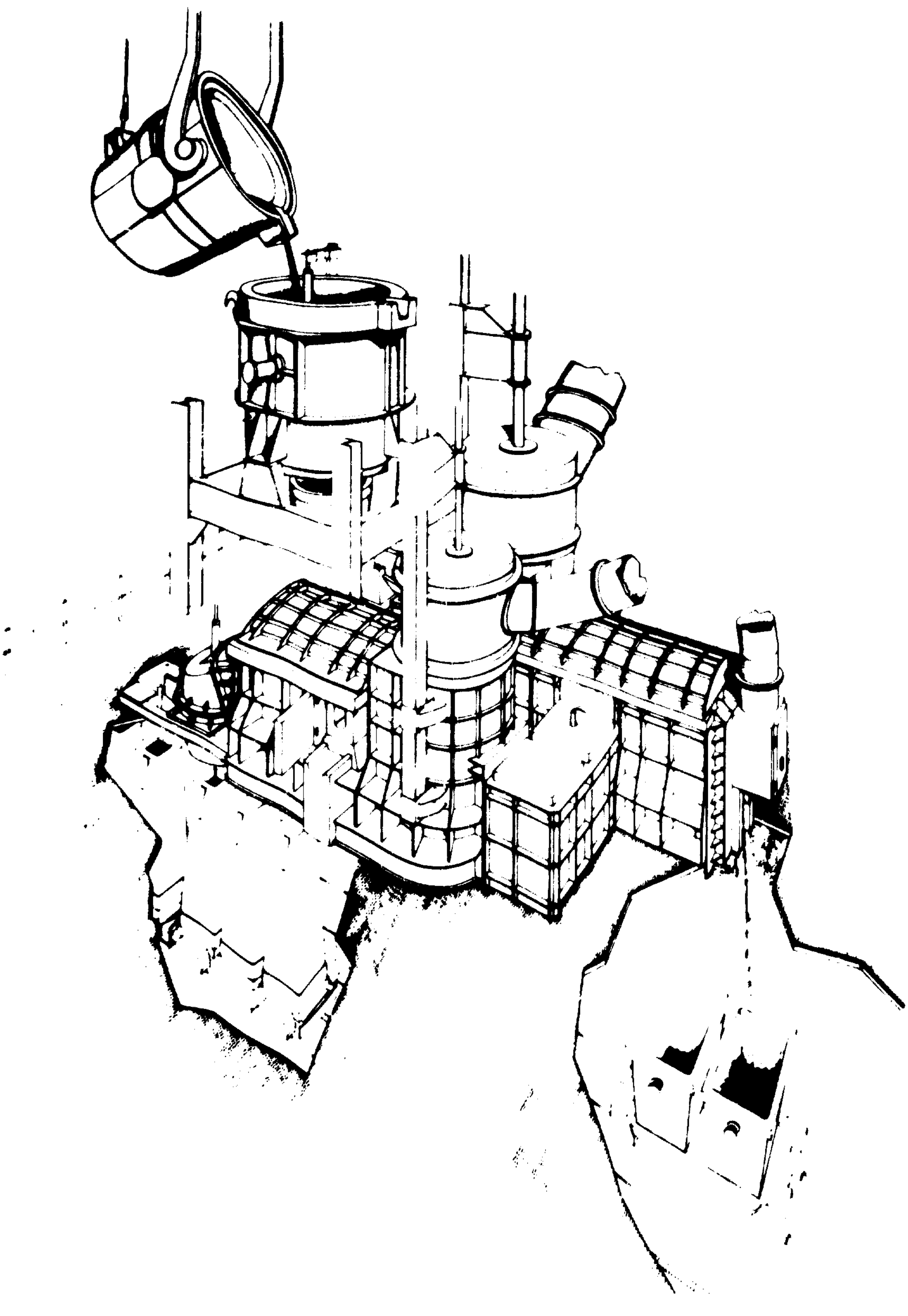


Figure 5

DESCRIPTION OF TEST 2163 (ONE STAGE)

COOLING AGENT: PREREDUCED PELLETS

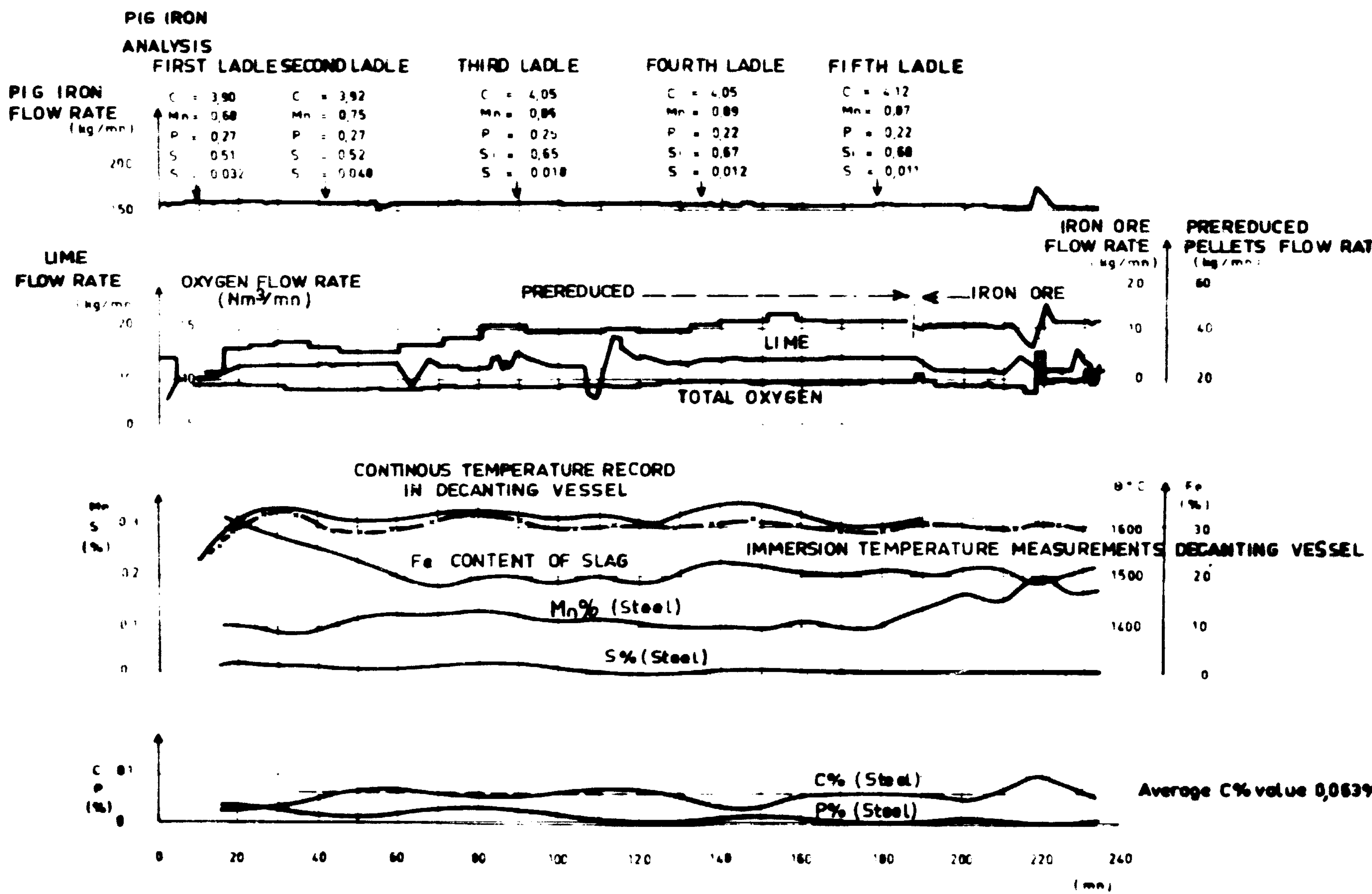


Figure 6

# STEEL ANALYSIS AT INGOT TEEMING

Hypothesis "nuanceur" capacity equal to one half of
The hourly production of steel
Calculation based on test 2163

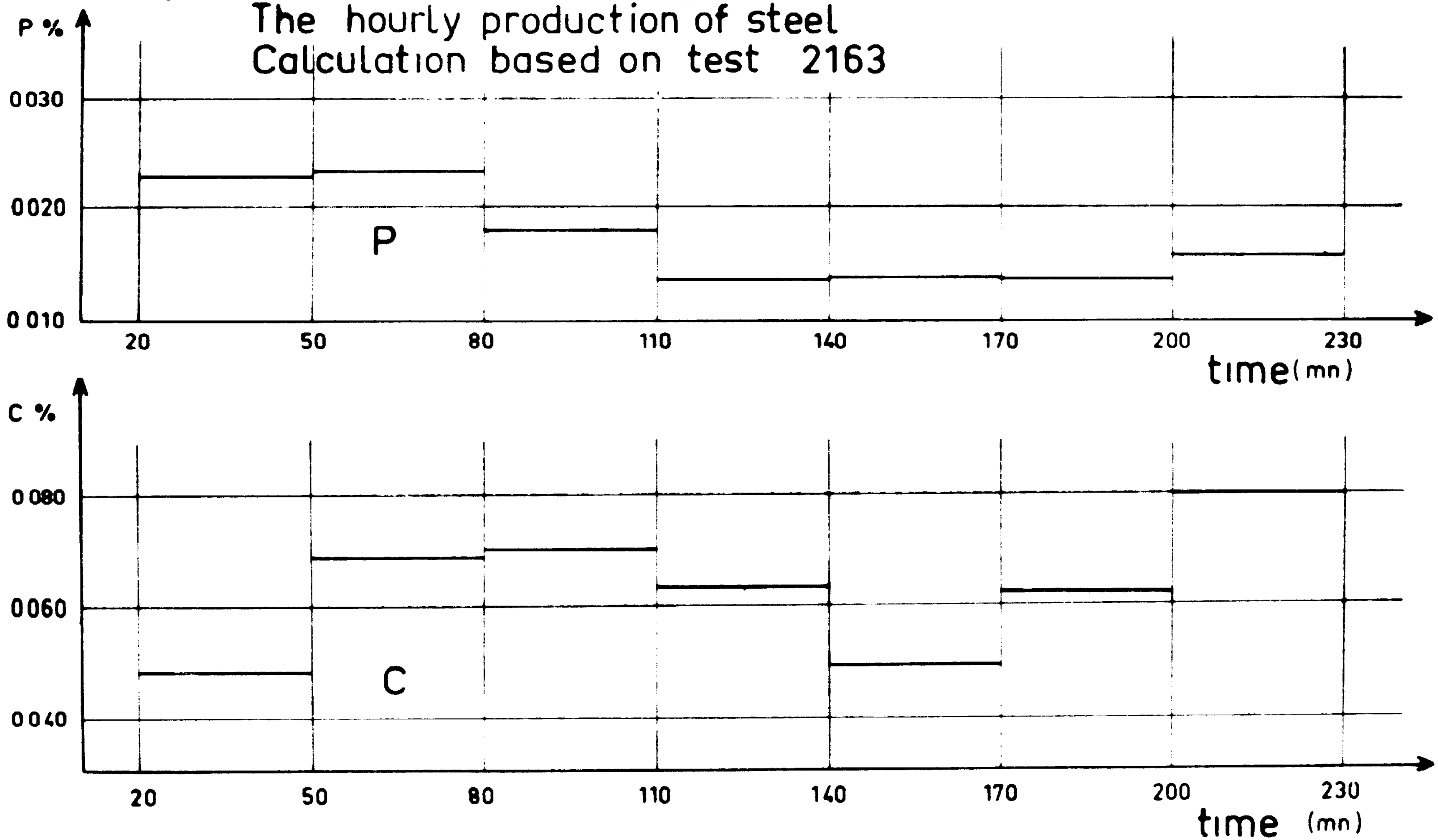


Figure 7

OXYGEN-CARBON CORRELATION IN STEEL

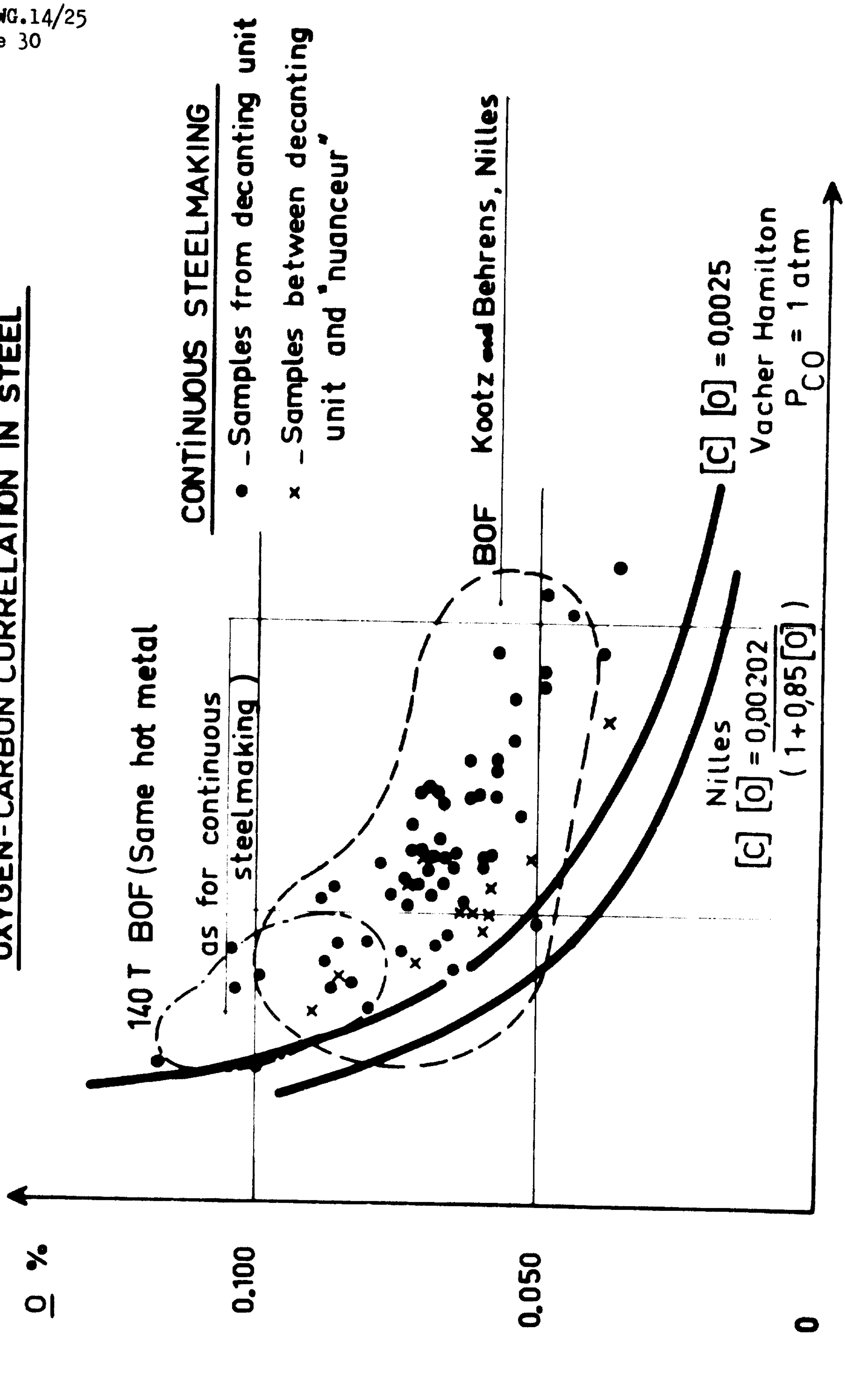


Figure 8

EVOLUTION OF COOLING AGENT CONSUMPTION (EXPRESSED AS R.T.E, i.e Kg SCRAP EQUIVALENT PER TON HOT METAL)

ONE STAGE OPERATION - HOT METAL FLOW RATE 160 Kg/mn

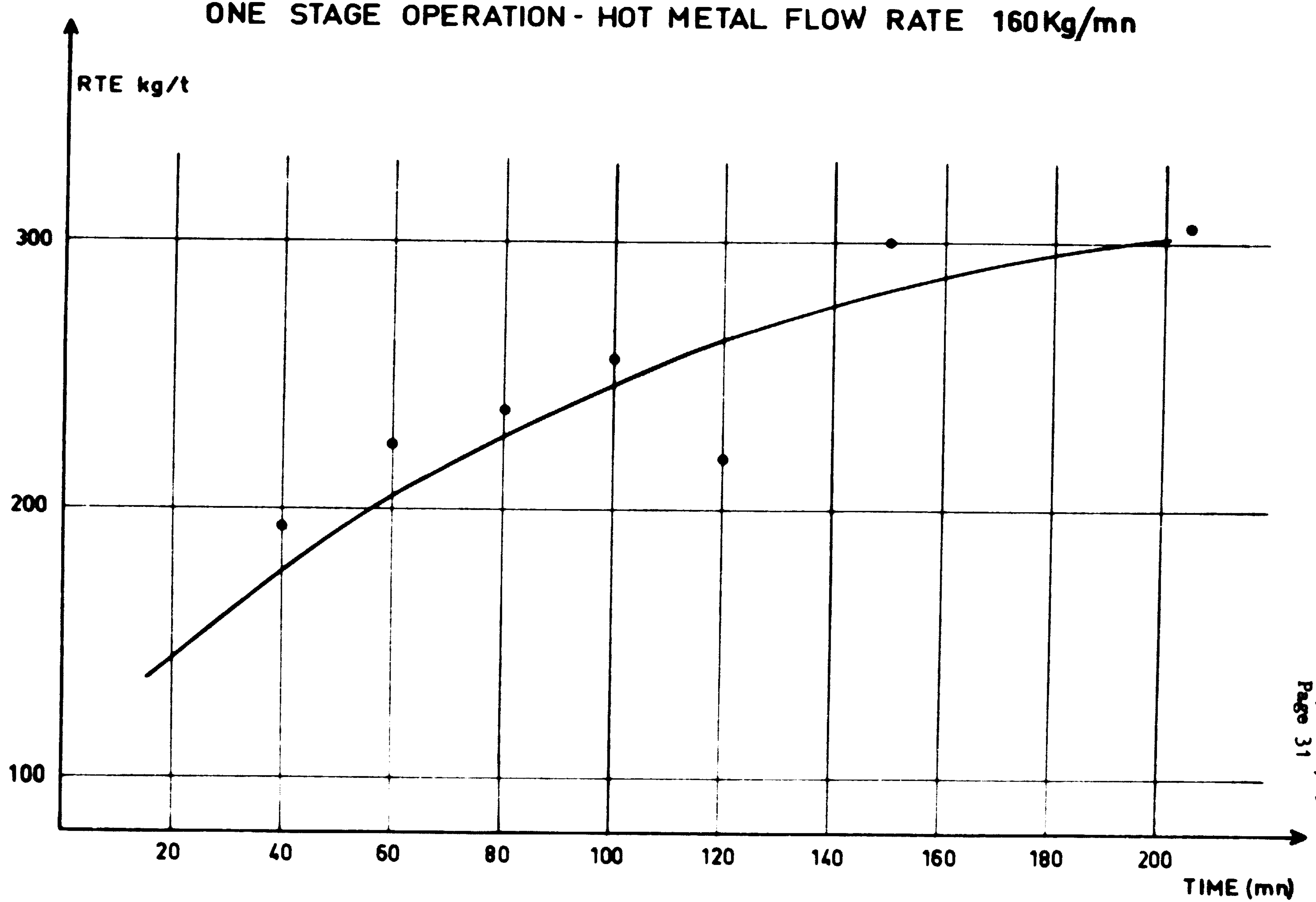
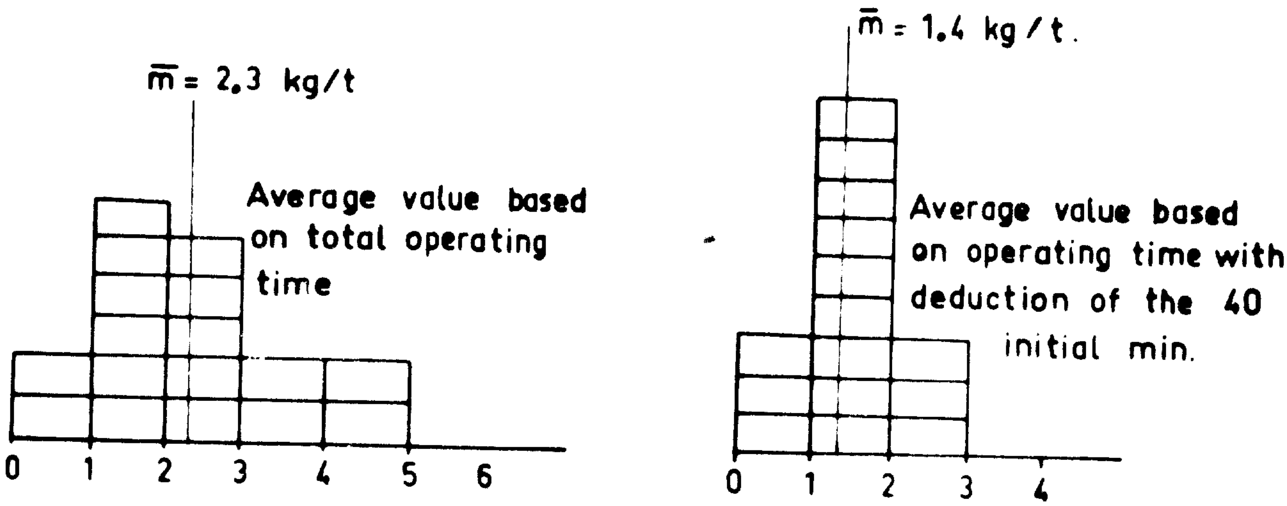


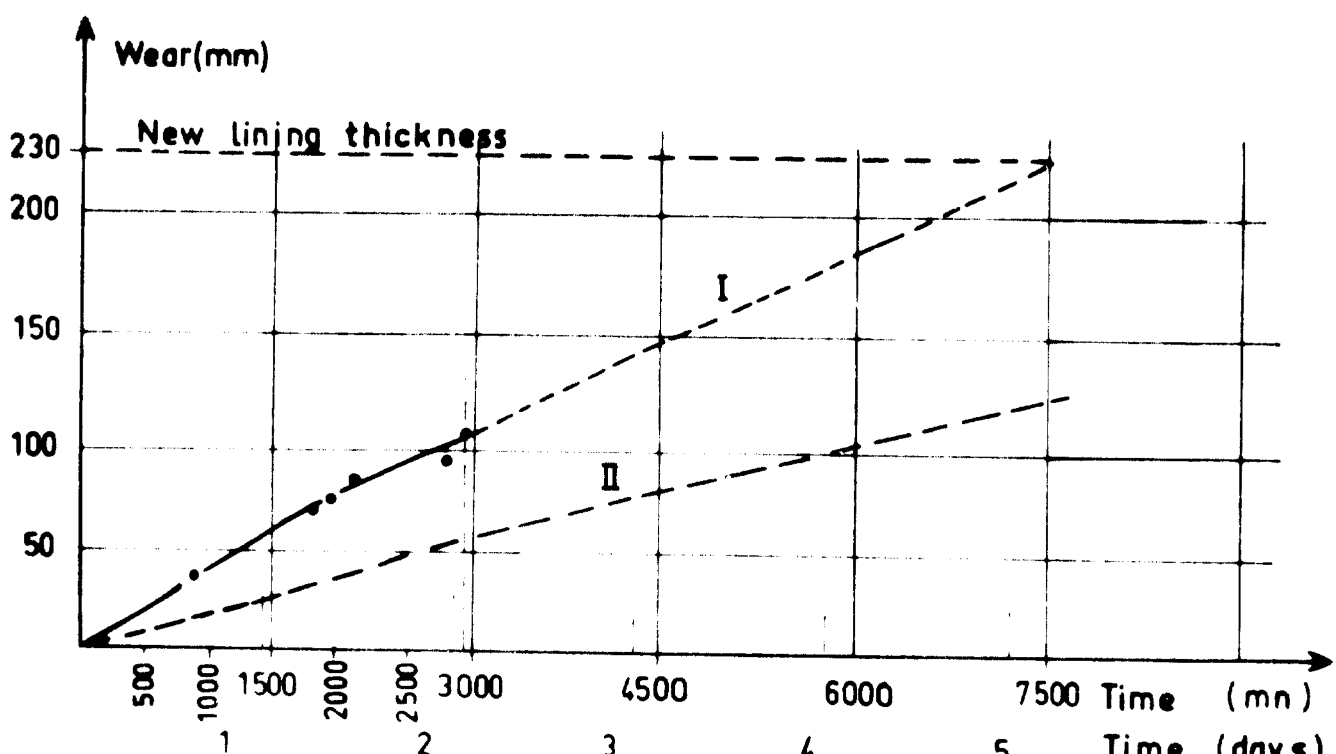
Figure 9

## ONE STAGE OPERATION REFRACTORY CONSUMPTION (Kg/t hot metal)




## DIMENSIONAL WEAR OF REACTOR

Hot metal flow rate 160 Kg/mn



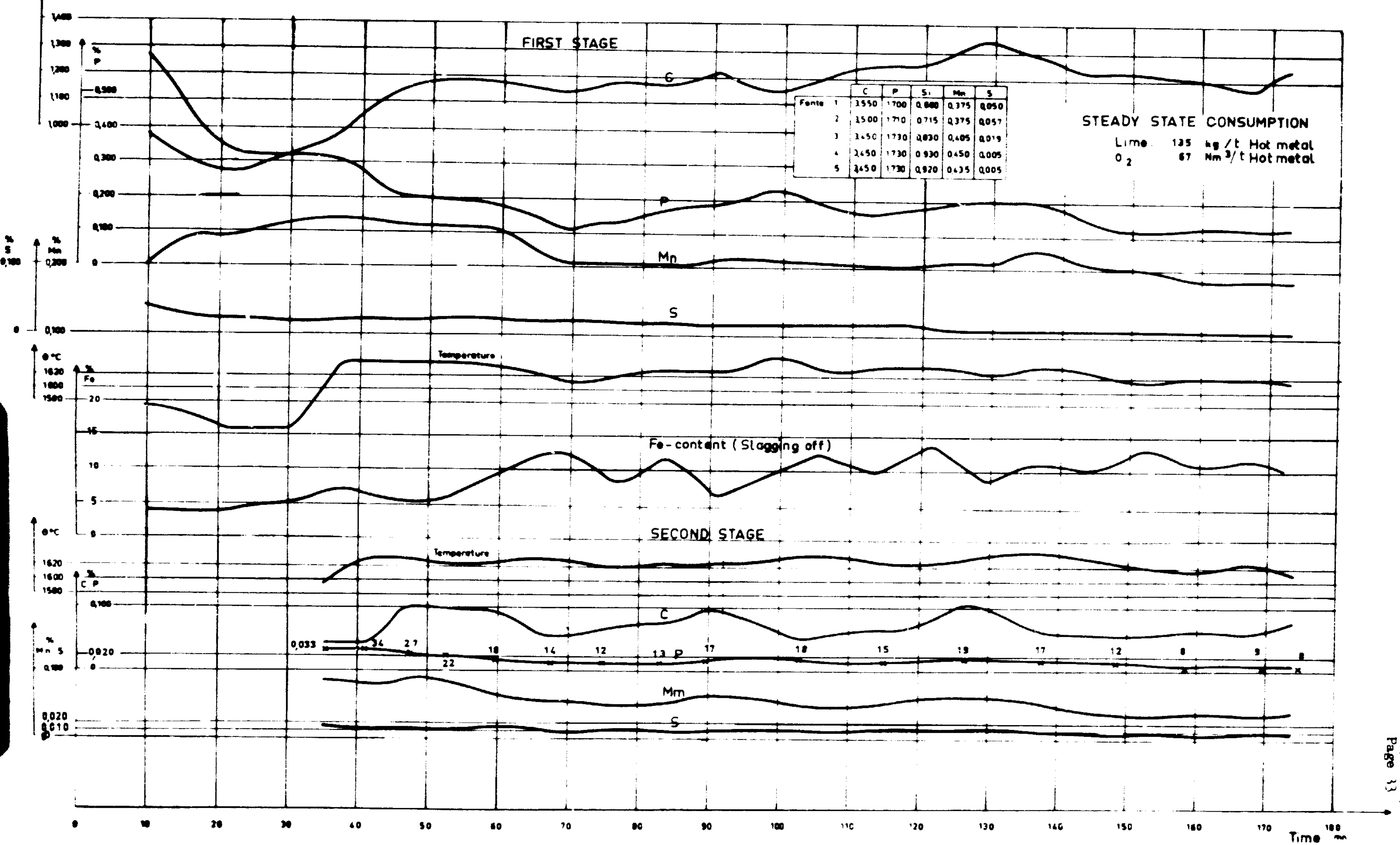

I - Theoretical wear for a refractory consumption of 2,8 Kg/t hot metal

II - " " " " " " " " 1,4 Kg/t " "

• - Direct measurement of reactor dimension

**Figure 10**

TWO STAGE PROCESS RESULTS OF TEST 2418




| Fonte | C | P | Si | Mn | S |
|---|---|---|---|---|---|
| 1 | 3,550 | 1,700 | 0,880 | 0,375 | 0,050 |
| 2 | 3,500 | 1,710 | 0,715 | 0,375 | 0,057 |
| 3 | 3,450 | 1,730 | 0,830 | 0,405 | 0,019 |
| 4 | 3,450 | 1,730 | 0,930 | 0,450 | 0,005 |
| 5 | 3,450 | 1,730 | 0,920 | 0,435 | 0,005 |

74.10.15