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CONTINUOUS STEEL-MAKING [1]

by

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United Kingdom

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

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Abstract

If a method of making steel which requires less expensive fuel, lower capital costs per ton of good steel made and less refractory costs can be developed, it will be possible to provide the 0.1 - 0.2 tons of steel per annum-capita needed to give everyone in the world a reasonable standard of living. The paper shows that such a process will inevitably be fullycontinuous, with flame melting of various proportions of scrap up to 100%, with oxidation of any metalloids by iron oxide fed into the slag, the heat and steam being provided by a stoichiometric fuel/oxygen lance. The main slag will flow in counterflow to the metal in a long narrow channel enlarged only where the lance is stirring the bath. The slag will be melted by a flame from a fuel/preheated air burner impinging on it after passing over the final zone where the last traces of slag float out of the steel.

I Steel making needs of the next 30 years

High strength substances, like steel, along with power supply are the two foundations of the material advancement of societies. Some countries already consume over half a ton of steel per head of the population per year and at least 0.1 and possibly 0.2 tons per year will be neceesary throughout the whole world to give everyone a reasonable standard of living.

Plastics may replace steel for many purposes but if the cost of making a ton of steel in terms of fuel, labour and plant can be steadily reduced as the world's output grows, then the intrinsic advantage of steel that it can be rolled into sheets, wires, plates or strips by the mile will cause it to retain its place in the new markets of the world.

The need for overall cheapness applies both to the highly developed countries which are already producing steel at a rate exceeding half a ton per head per year and to the less developed countries which will certainly develop their production many-fold in the next thirty years up to this kind of figure. It is fairly certain that the more highly developed countries will use their present plant until it is worn out but that some time in the future, less than 20 years from now, they will have to replace it by plant whose final production of steel is essentially and basically cheaper. On the other hand, the less developed countries present the ideal opportunity to develop a new and greatly improved steelmaking process as they are not saddled with the present generation of plant.

One can draw one other conclusion as far as the highly developed countries are concerned and this is that as they have already reached an equilibrium production of steel, the proportion of scrap steel which must be returned to the industry for remelting is bound to increase until it ultimately reaches a figure of the order of 70% or 80%. If this were not so, the developed countries would steadily be littered with rusting steel and the cost of ore would inevitably rise quite fast as the more accessible supplies were used up. As the less developed countries become industrialised, with large central steelworks, they too will use a steadily higher proportion of scrap.

This means that we have to find a way of making good quality steel from crap steel or cast iron with a high thermal efficiency using a cheap fuel (oil, natural gas or pulverised coal) and not coke or electricity which are and will remain expensive fuels because they are secondary fuels made by processing primary fuels in expensive plant (coke ovens and thermal power stations). It is likely that although nuclear electricity will become increasingly used and will become substantially cheaper than electricity made from the combustion of oil or coal, it will not become as cheap per unit of heat as the direct firing of oil or natural gas, at any rate until controlled nuclear fusion is developed. The development of nuclear fusion for large scale economic production of electricity is certainly twenty years away since the controlled production of power from nuclear fusion has not yet been achieved in the laboratory and the time lag between the first successful laboratory experiment and the successful power station is bound to be more than twenty years.

We can therefore summarise this section by saying that:-

1) The long term equilibrium needs of mankind are of the order of 0.1 to 0.2 tons of steel per annum per capita.

2) There is a great need for a substantially cheaper way of making good quality steel both in the developed countries and the under-developed countries.

3) This steel requires the use of cheap natural fuel, e.g. gas or oil or pulverised coal as the sole fuel for steelmaking and ore reduction.

4) The proportion of scrap will eventually rise to 70% or 80%.

II The Requirements for the New Steelmaking Process

The characteristics of a steelmaking process necessary to satisfy the needs in the next generation are the following:-

i) It must be possible to take as raw materials in one plant the Fe in proportions ranging from 20% scrap and 80% finely ground ore concentrate to the reverse percentages.

ii) The process must be fully continuous, completely automatically controlled and with no mechanical movement of ladles of liquid metal. A full list of reasons why it will be fully continuous is given in Appendix I.

iii) The process must be able to use oil, natural gas or crushed coal as the sole fuel for reducing the ore, melting the iron made from the ore and the scrap and refining and superheating the molten material.

iv) The overall capital cost of the plant for reduction, melting and refining, casting and rolling, the buildings to contain it, the necessary equipment and the material handling equipment must be

Figure 1

Diagram of the next generation of steelmaking processes

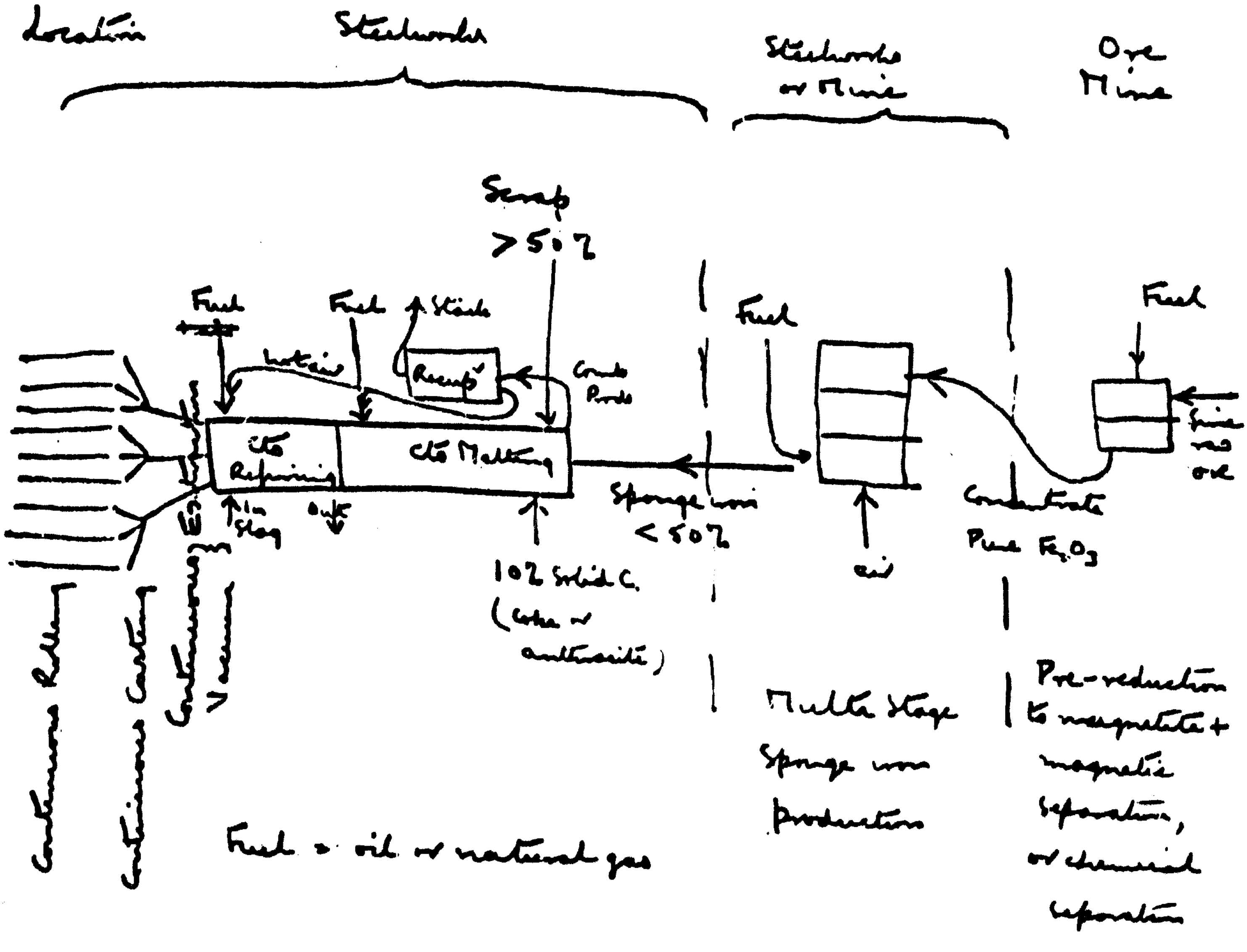
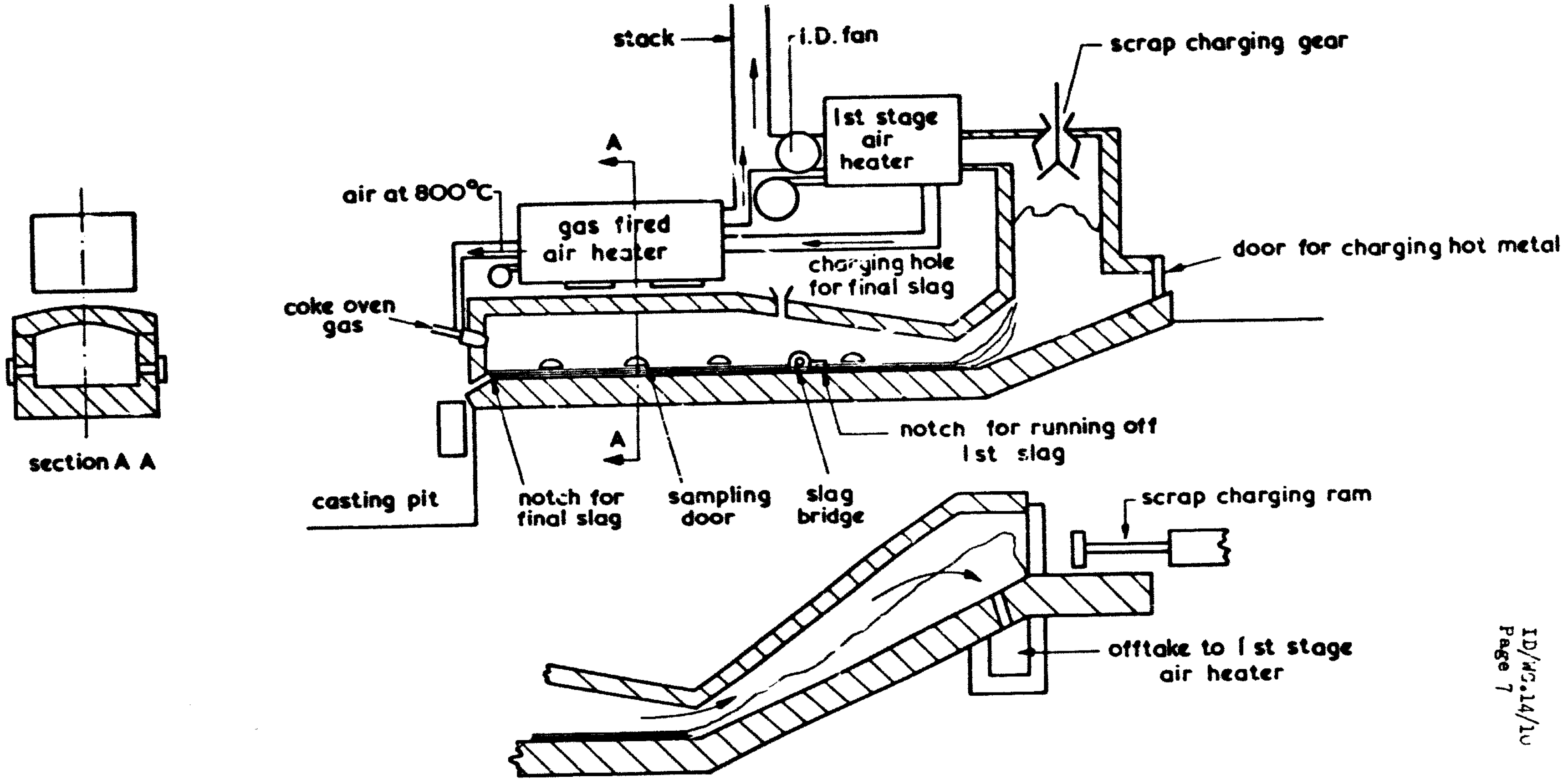


Figure 2

Diagram of later proposal for a continuous counterflow steel melting furnace



substantially below that of the overall equipment of the present processes involving coke ovens, blast furnaces, Cowper stoves, molten iron carrying devices, oxygen blowing equipment, pouring equipment, fume removal equipment, casting bay, molten steel and ingot transport equipment, rolling mills, soaking pits and reheating furnaces, storage bins and bays and buildings to house all the equipment.

v) The process will certainly be linked to multi-strand continuous casting to cut out the cost of primary mills, soaking pits and reheating furnaces.

These requirements are shown diagrammatically in Fig.1.

III <u>Experiments already carried out on Continuous Steelmaking</u>

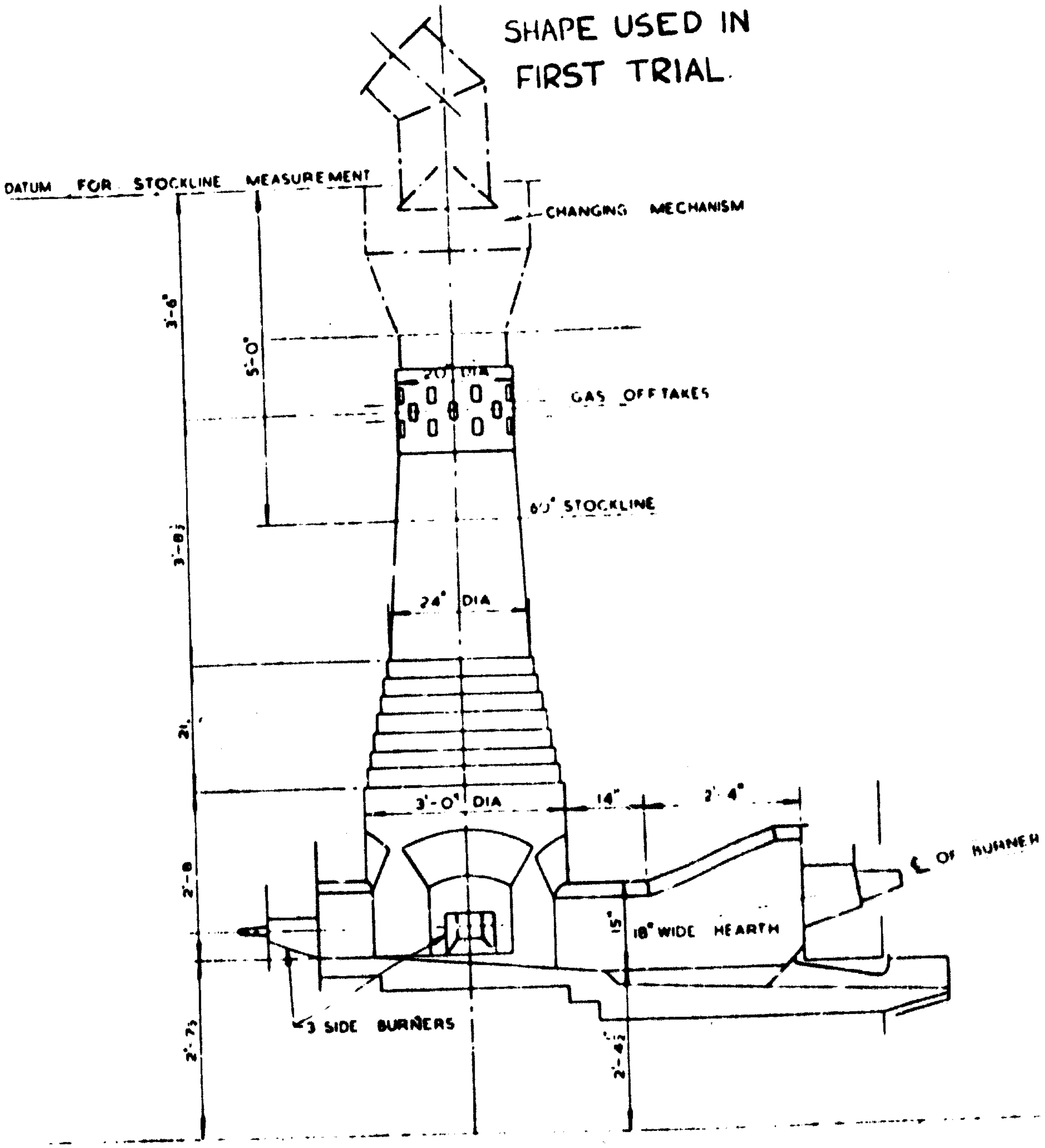
III 1. <u>Continuous scrapmelting</u>

In 1954 Thring (1) published a paper in the Journal of the Iron and Steel Institute in which he proposed the continuous counterflow flame steelmaking plant shown in Fig.2. In this there were two slags but the word counterflow referred to the heating gases in relation to the scrap being heated, melted and superheated.

There were two proposed methods of heat exchange for the solid material, in one it was charged down a shaft, the gases passing up through the shaft, in the other the scrap was charged on a platform immediately over the gas offtake by means of a ram and then passed under the combined action of gravity and the ram down a slope to the point where it was finally melted.

For four years experiments were conducted at Sheffield University in a co-operative research with Steel, Peach and Tozer and G.P. Wincotts of developing a scrapmelting furnace based on the shaft heating system (2). The furnace melted at a rate of about half a ton an hour using gas and air heated to 400°C; it melted continuously but was tapped every two hours. Various designs of the shaft, the first shown in Fig.3, were studied in continuous trials lasting up to a week using various proportions of cold scrap and cast iron. In almost all the furnaces there was no difficulty in melting charges of 100% pig iron but as the proportion of scrap was increased above 50% there were problems of oxidation and bridging.

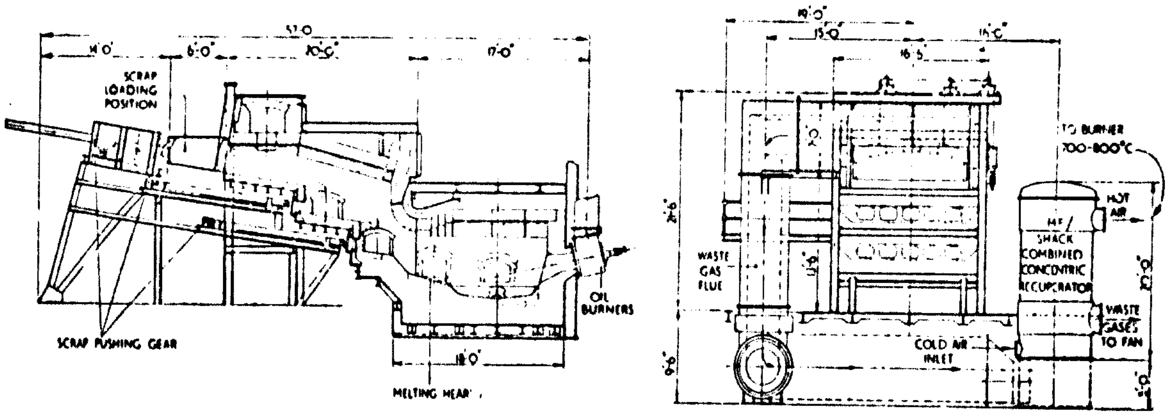
Figure 3
Shaft design



SHAPE 1. RUNS 1 AND 2 ACID HEARTH

Figure 4

10-ton/hr. one-way fired continuously charged scrap-melting furnace



The problems of bridging could be overcome by changing the design of the furnace, for example, having the hearths on both sides of the shaft instead of only one but it seemed likely that if one were melting 100% scrap one would always obtain too much oxidation if the gases passed through the pile of scrap in the region where the metal was hotter than a 1000°C and also therefore in the final melting region.
There would also be refractory problems in the region of the throat even on a large scale furnace. The most important conclusion, however, was that one could melt cast iron and scrap in this type of furnace with thermal efficiencies of over 50% expressed in terms of the enthalpy of the molten metal divided by the calorific value of all the fuel used.

In 1957, Professor Schack, who had applied a metallic recuperator to a 20 ton ore way fired open hearth furnace at Ruhrstahl A.G. before the war discussed this work with Sheffield University with a view to applying the counterflow scrap preheating process to cooling the waste gases of an open hearth furnace to a temperature at which he could pass them directly into a metallic recuperator. This temperature was to be not more than 1200°C and the recuperator was to produce preheated air for the main burner at some 750°C. In his earlier experiments (3) he had cooled the gases by means of a waste heat boiler but there were considerable problems in the fouling of the recuperator. While the Sheffield group believed that the most efficient way of exchanging the heat between the gases and the incoming scrap was the shaft system, they had not ovolved a completely satisfactory way of taking the melting scrap around the corner from the shaft into the molten path. It was therefore decided to complete the Schack furnace using the pusher principle, the second one given in the 1954 paper (Fig.2). Fig.4. shows a furnace which was built at Gebr. Benteler at Paderborn in Germany. This furnace was to melt continuously but not to be tapped every two hours with 16-20 tons of molten steel which was taken to an arc furnace for finishing and continuous casting. The furnace melted satisfactorily at 8 tons/hour with an overall thermal efficiency of 55%. The yield of molten steel was about 91%

which was considered to be satisfactory as the scrap was very dirty. The carbon could be controlled between 1.1% and 1.7% by charging anthracite with the scrap. The furnace was fired with heavy fuel oil with a sulphur content 2.5 - 4.0%, 2 cwt of lime was charged with 18 tons of scrap, the final sulphur of the metal was about 0.1% although this could be reduced. The waste gases were cooled to 950°C at the point of entry to the recuperator and 450°C at the exit from the recuperator. The recuperator was shot cleaned in the tubular section 5 - 8 minutes every hour. This furnace had one defect which would have to be overcome in future designs. This resulted from the fact that there were doors at the hearth level while the charging doors and side doors extended up to 10 metres higher. This meant that the buoyancy inside the furnace produces a very considerable sting out of waste gases at the upper doors if there was balanced pressure at the lower doors or conversely a very considerable air in leakage at the lower doors if there was balanced pressure at the higher ones. This would have to be overcome by reducing the number and size of the doors making them much more airtight and reducing the difference of level between the initial charging door and the final hearth level. It probably means that the principle of having three rams at different heights to move the charge on is not a satisfactory one.

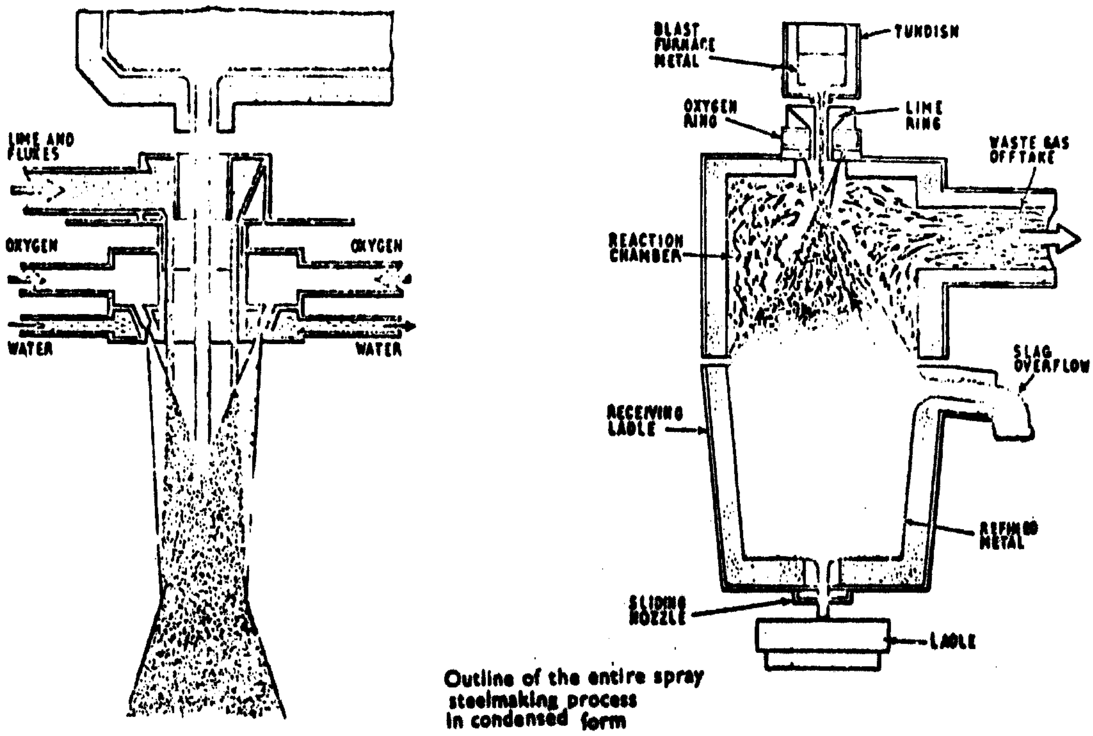
III 2. Continuous refining of molten iron using only oxygen

Fig.5. In this, the BISRA spray refining process is shown diagrammatically. The molten iron falls in a stream from a tun dish through two nozzles; through the first of these lime and flux are dropped as a continuous stream of powder while supersonic jets of oxygen enter through the second which is water cooled. These jets pick up the lime and fluxes and impinge at a small angle on a falling stream of iron. The refined metal falls into a receiving ladle with a nozzle at the base for metal flow into the casting equipment and a side spout for slag overflow. Nearly all the carbon monoxide produced is burnt with the oxygen to CO_2, the waste gases contain 1-2% carbon monoxide and 14 gr/ft^3 ($32gm/m^3$) of fume. The surplus heat can be absorbed by allowing the hot metal to melt up to 40% of cold scrap.

Figure 5

The BISRA spray refining process

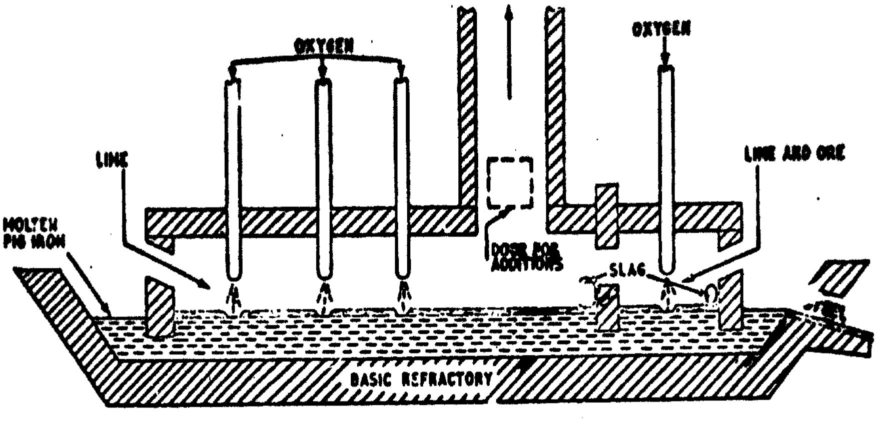
Showing how lime is injected into the falling cloud of iron droplets



Outline of the entire spray steelmaking process in condensed form

Figure 6a

Diagrammatic section through experimental continuous steelmaking furnace



The process is at present only used to empty one ladle of iron at a time.

IRSID have been working for a number of years on a continuous steel refining process at the scale of 11 tons/hr (6) in which the molten iron flows through a submerged tube into the bottom of a vessel which is continuously blown from the top with a watercooled oxygen lance as in the LD batch process; powdered lime and other slag forming materials are also fed in continuously. The reaction vessel may be regarded as a stirred reactor so that the slag and metal leaving have the same composition as that anywhere in the reactor except immediately at the points where the fresh material comes in. The slag forms and carries the refined metal out in the foam as liquid shot. It flows over a lip into another vessel where the metal separates out under gravity from the slag. This process is being further developed with a grant from the High Authority of the European Iron and Steel Community to bring it to a completely finished stage suitable for large scale industrial produdtion.

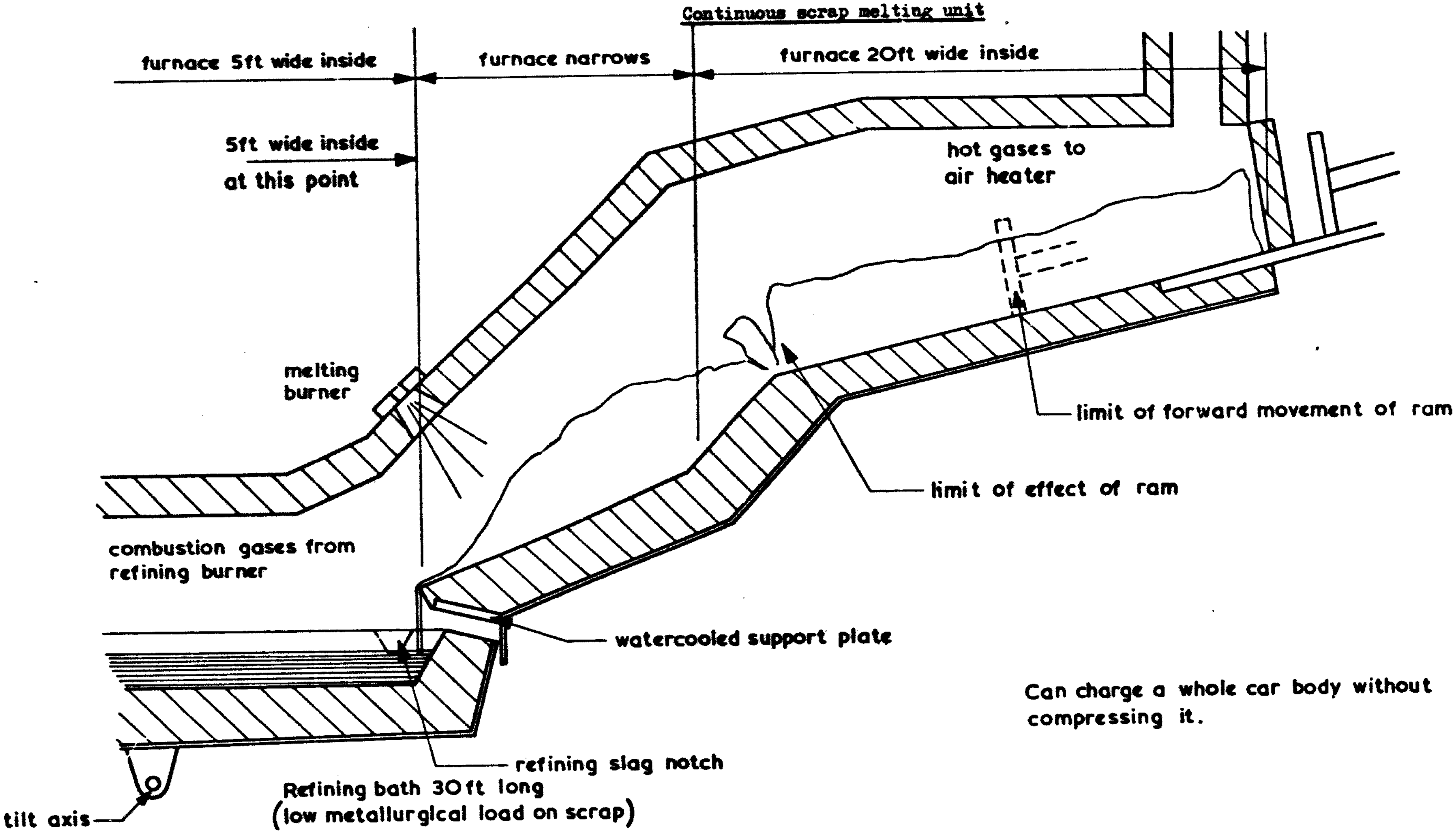
The CNRM (7) in Belgium have also worked on a modification of the LDAC process in which the lime and slag forming materials are fed in and removed continuously. This was mainly to eliminate the loss of production caused by having to stop the LDAC process to change the slag in the middle of blowing. The metal was however charged and discharged in the normal batchwise fashion.

Professor Schenk in Germany published in 1964 a paper (8) in which he pointed out the metallurgical advantages of a counterflow slag in continuous steelmaking and he is investigating the possibility of operating with such a continuous counterflow slag in an Oberhausen Rotor furnace and in a static furnace in which the steel is made to flow uphill by electro-magnetic means.

In the period 1960-63 H.K. Worner (9) carried out a series of experiments on a small pilot plant in Australia in the apparatus shown diagrammatically in Fig.6a. He poured molten iron from a cupola continuously in from one end of the furnace, it passed under three bridges to separate the slags and he used a number of oxygen lances to refine the metal. He operated at rates up to 4 tons/hour and showed

Figure 6b

Continuous scrap melting unit



Can charge a whole car body without compressing it.

that it was possible to produce steel continuously with contents of sulphur and phosphorous as low as those which can be obtained in the best arc furnace practice and that the carbon content of the steel could be controlled over a wide range.

The Fuji Iron and Steel Company (10) together with the Tokyo University described experiments of an annular continuous refining furnace in which the slag and metal were set in rotary motion at different speeds by arranging the oxygen nozzles tangentially. They made a large number of 5 ton heat with an average refining time of 27 minutes, but the process was not developed to the fully continuous stage since the iron is tapped intermittently.

III 3 Continuous refining of iron with flame

A number of experiments have been carried out on the 100 lb/hour scale by Sheffield University at English Steel Company in a narrow channel furnace 8 feet long. In this, slabs of cast iron were fed in at one end of the furnace where the combustion gases left and an oil/oxygen burner provided a very hot flame at the other end.

Various methods of feeding finely ground lime powder into the flame were tried and the resulting slag was tapped off at a hole close to the point where the molten iron flowed into the horizontal channel. Several hundred pounds of steel have been made in this furnace on a continuous basis from cast iron but the scale is so small that oxygen has to be used almost continuously at the taphole to keep it open and a flame has to be used to keep the slag running out. The use of oxygen at the taphole means that one does not know how much of the oxidation it has done but samples taken from points along the bath have shown that most of the carbon is taken out of the iron in the melting stage on the slope.

Although they have not yet been used for continuous processes the experiments (11) which have been done with watercooled burners in which light distillate oil and natural gas have been burnt with stoichiometric oxygen are very relevant to this problem. In the first place they have been used to replace the electrodes in arc furnaces and have shown that the use of a stoichiometric flame completely eliminates the fume which is obtained with oxygen blowing into the iron and that very high rates of heat transfer can be obtained with such systems together with complete combustion in a very small volume. Clearly once these burners are no longer used in any furnace designed for another form of heating but in a furnace designed to take full advantage of their possibilities and especially in a continuous furnace where they can be used for very accurate control of temperature and for the supply of heat for oxidation with Fe O (at the same time increasing the metallic Fe yield) they will be of much greater value.

III 4. Continuous casting and vacuum degassing

It is well known that continuous casting can reduce the capital cost and the running cost of the processes from liquid steel to the final rolled product. Continuous casting as at present practised is used to empty one ladle at a time. Much greater advantages will arise if it can be operated fully continuously, that is, with a number of continuous casting strands in parallel fed by a runner fully continuously from a continuous refining process.

In a recent paper Halliday (12) has suggested how continuous casting can be operated from continuous vacuum degassing.

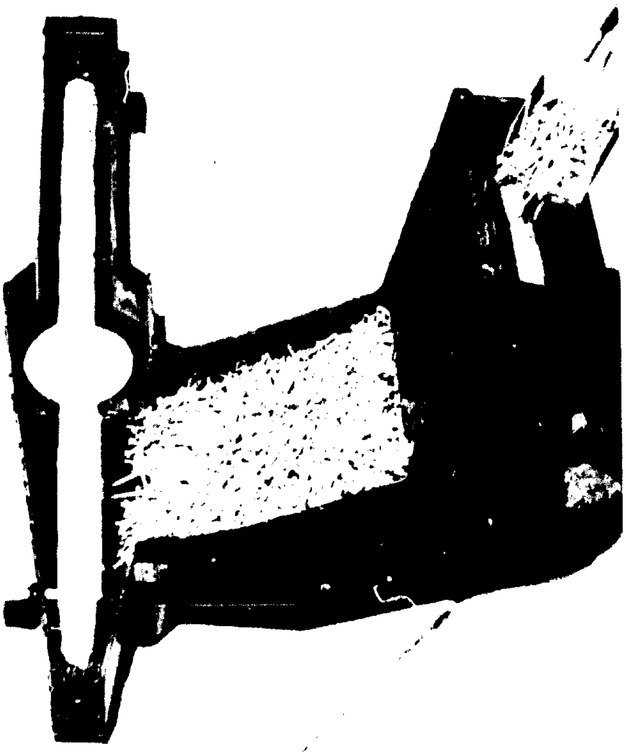
IV An attempt to predict the steel making process of the future

IV 1. Melting of scrap or sponge iron

The experiments discussed in Section 3 of this report have shown that it is perfectly feasible to heat scrap steel or sponge iron in a counter flow shaft with stoichiometric combustion gases provided the metal is not heated above a temperature of about 900°C. Above this temperature the heating must be by radiation from gases which do not pass through the material otherwise there is excessive oxidation and sticking together of the material so that it will no longer travel satisfactorily down a shaft (unless it is heated from both sides at the base). Iron containing three or four per cent carbon can be completely melted in such a shaft furnace which then becomes equivalent to a cupola fired with oil or gas at the base instead of using coke fed in with the charge.

It is of course possible to melt scrap in a blast furnace or cupola with coke but this requires large hard coke and gives a melting

Figure 7



thermal efficiency less than 20% because it makes a lot of carbon monoxide. It is therefore ruled out as the scrap melting process of the future. It follows that both the sponge iron and the scrap which will be the two sources of Fe to the steel melting and refining process of the future will necessarily be melted in one of the two types of furnace shown diagrammatically in Fig.2. In these processes there will be a flame at the refining end, whence the steel is continuously extracted by vacuum syphon. This flame will provide the necessary superheat for the molten metal and the heat to melt the refining slag and will consist of either the cheap liquid or gaseous fuel fired with superheated air from a metallic air heater through a burner in the end wall or the same fuel burnt with pure oxygen in a special burner which will also convey the slag forming materials and a reasonable proportion of finely ground iron oxide, some of which will be reduced to increase the metallic yield.

There will be a second burner impinging directly on the melting ferrous material so that the latter runs as a steady liquid stream in the refining slag in the bath. The cold ferrous material may be charged in by a ram as indicated in Fig.6b in which case the exit gases will be drawn off downwards by off-takes underneath the entry point or the material may be fed down through a shaft through which the gases are drawn in counterflow as indicated in Fig.7

IV 2. Refining

Molten blast furnace iron will be poured in at one end of a long narrow channel furnace (see fig 8 for design, fig 9 for diagram of flows and zones) a desulphurising slag will be fed in at point 3 (fig 8) and run co-current with the iron. The main oxidising slag will be fed in at point 2 and melted by the hot air oil burner flame impinging on it. The stoichiometric fuel/O_2 burner will provide the heat and stirring for the reaction

$$FeO + C \rightarrow Fe + Co$$

between the slag and the metal

IV 3. Casting

By having a series of six or more separate continuous vacuum degassing syphons (6) it is possible both to control the hold-up time

Figure 8

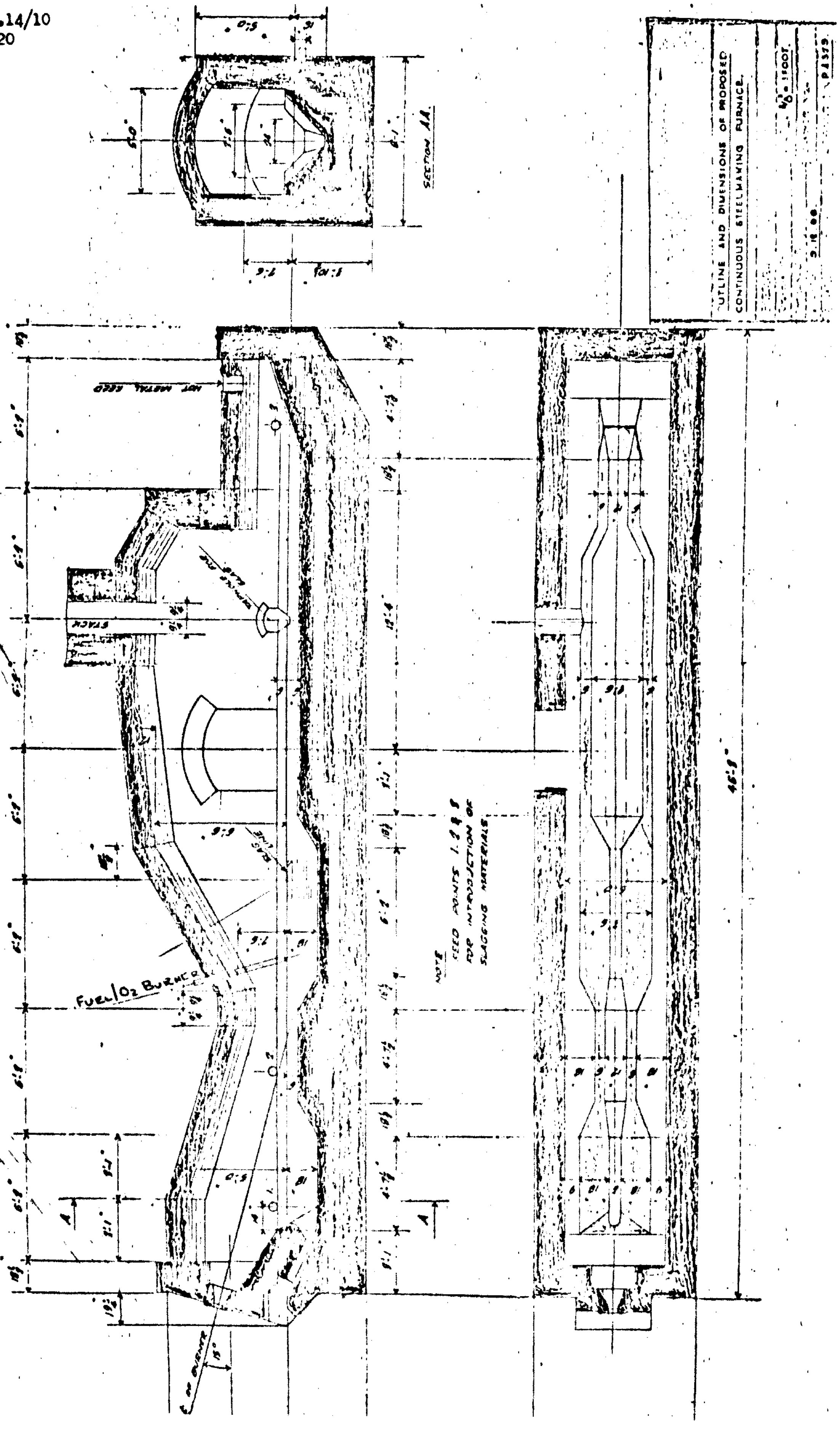
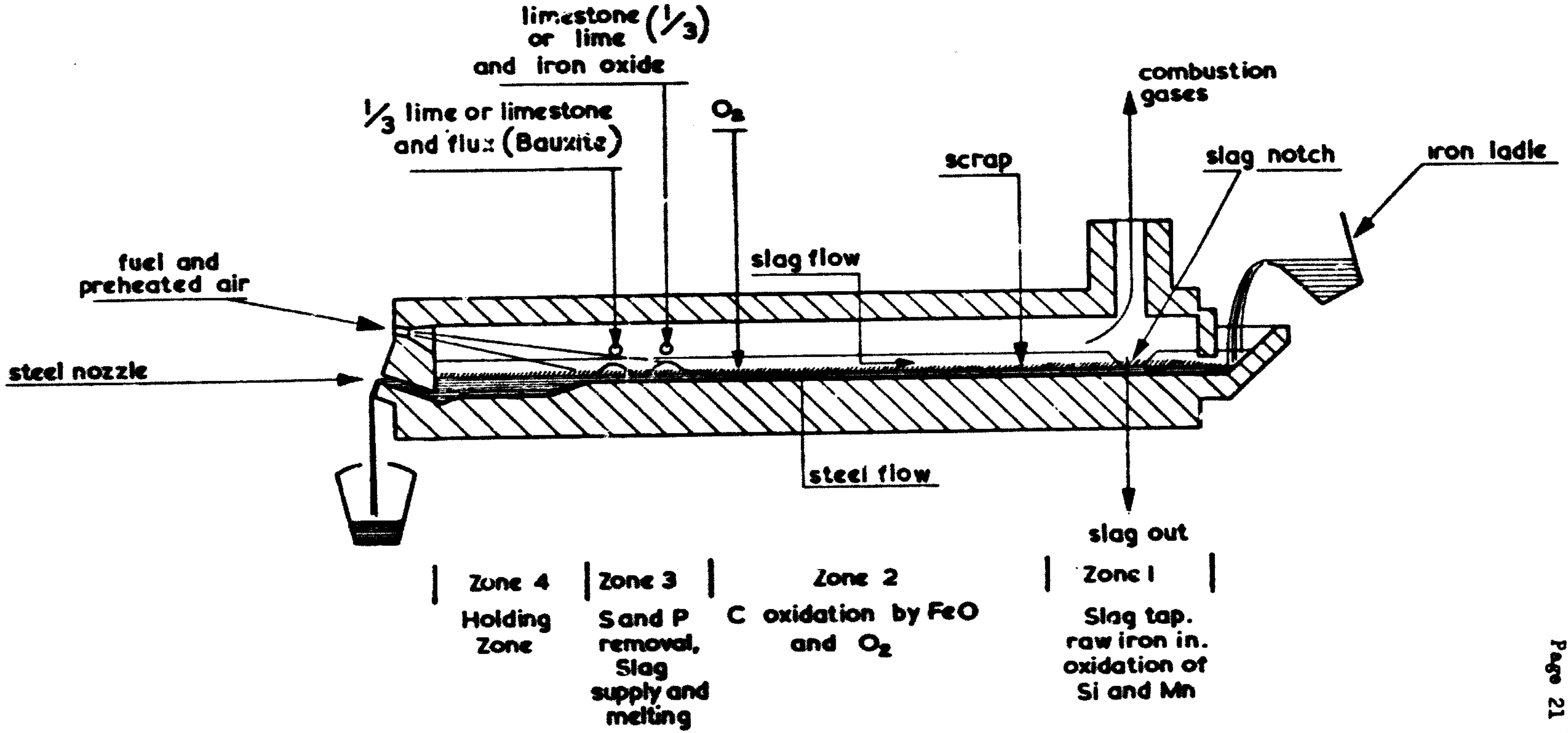

OUTLINE AND DIMENSIONS OF PROPOSED
CONTINUOUS STEELMAKING FURNACE.
P4379
SECTION AA
HOT METAL FEED
STACK
FUEL/O2 BURNER
NOTE
FEED POINTS 1.2.4 5
FOR INTRODUCTION OF
SLAGGING MATERIALS
46'-8"
15°

Figure 9

Diagram of continuous steel making process with fully counterflow refining slag



of the metal in the furnace for refining and to continue operation while a certain number of vacuum syphons or continuous casting apparatuses are out of action. Each of these vacuum extraction apparatuses can be raised or lowered a few inches separately and each one feeds a small number of continuous casting apparatuses spaced out so that all the continuously cast slabs or ingots run in parallel directions through the cooling and rolling stages.

Small scale experiments on continuous steelmelting and continuous refining are very restricted. Here the problem is maintaining the steady flow of liquid steel out of the apparatus. The work of melting 10 cwt/hr at Sheffield University was only possible because the bath was emptied during a period of a few minutes every 2-4 hours so that the metal was running out at a rate of the order of 20 tons/hr during the tapping period. In the work carried out by Sheffield University at English Steel at 100 pounds/hr the taphole had to be kept open by a continuous flame and this produced uncontrolled oxidation. It can be concluded from this that without auxiliary heating on the taphole the smallest experiment that can be done requires the steel to be running out continuously at a rate of at least 10 tons/hr. The only way to do experiments on the lab.scale on the effect of a counterflow slag fully continuously is by having some kilowatts of electric heating on the steel flowing in the throat of the taphole. This can be by (1) resistance heating by means of a current passed from an electrode under the bath from the molten steel and out through an electrode at the lip or (2) high frequency heating with a water-cooled coil outside this or (3) installing a carbon grain resistance heater beneath the taphole. These possibilities are being explored for the laboratory furnace which is being built in London.

On the other hand the 10 cwt/hr experiments at Sheffield showed that if one took adequate precautions with thermal insulation of the walls and insulating the preheated air pipe one could obtain thermal efficiency figures at least for a shaft type scrap melting kiln which were comparable with those obtained on an industrial scale (Paderborn furnace).

The scale-up law for continuous steelmelting and refining experiments should be that the mass throughput (tons/hr) should increase as the cube of the linear dimensions of the furnace. This is because the throughput of the process depends rather on the residence time of the metal in the furnace than upon the surface area of contact between the metal and slag. The system can be stirred sufficiently so that the reactions can be regarded as going on throughout the volume of the metal and slag rather than across the interfacial surface area. This means that one would go from a 10 hr plant to a 300 tons/hr plant with an increase in length of furnace, depth of metal and width of furnace of just over 3 times in each case so that if the 10 tons/hr furnace were 40' long the 300 ton/hr one would be about 120' long. Once the principle is established on the small scale pilot plant this is one of the systems that is easier to design and operate the larger the scale. However it is also true if one wants a small steel works in a region where plenty of scrap is available a plant of the size of 20 tons/hr would enable a complete economic steel works to be set up.

V. The continuous refining of molten blast furnace iron with counterflow slag and auxiliary flame heating

Existing blast furnaces will operate economically as sources of molten high carbon iron as long as the present generation of coke ovens is in working order. For the next 20 years therefore the developed countries will still have a major problem in making steel economically using a proportion varying between 30 and 40% of blast furnace molten iron, the remainder coming from scrap which will have to be melted, preferably in the same furnace as that in which the blast furnace iron is refined. Fig.8 shows the design for a pilot plant on the 10 tons/hr scale for such a furnace. This furnace is planned as a result of discussions of the use of a counterflow slag with many people especially Professor Elliot of M.I.T. and Dr. Howard Worner. Basically, it consists of a fixed furnace with an auxiliary heating flame of oil or natural gas plus preheated air at the steel tapping end. In the first experiments the steel would be withdrawn through a 'tea-pot' spout as shown, but later a continuous vacuum-syphon degassing apparatus would be used and the level of metal in the furnace adjusted by varying the level of the metal in the ladle into which the steel is being discharged by controlling the height of this ladle. This ladle would of course be replaced by the multi-strand continuous casting moulds in the large scale apparatus. The molten iron is poured in continuously at the other end of the furnace through a desulphurising slag which is also fed in continuously at this end. A small amount of reducing slag fed in immediately under the burner protects the metal in the steel withdrawal end while the main slag consisting of finely powdered lime or limestone together with a significant amount of iron oxide and a small amount of bauxite as flux is fed in close to a small high velocity burner distillate oil or natural gas with a stoichiometric fuel proportion in such a way that it causes violent agitation of the molten metal. All three slags are fed in continuously and discharged together at a slag notch placed immediately under the combustion products offtake near the end of the furnace where the iron enters, the scrap is charged in through a door in the side of the furnace about half-way between the oxygen fuel burner and the combustion gas off-take. The use of a fuel/oxygen lance means that no fume is made and that sufficient heat is available both to oxidise most of the carbon in the iron by means of the Fe O charged in (thus increasing the yield of metallic Fe per ton of metallic iron charged in) and also to melt a high proportion of scrap. Moreover, the proportion of scrap can be varied within a wide range by varying the amount of fuel/oxygen to this burner and fuel/air to the auxiliary burner at the hot end. The hold-up time of the slag in the furnace can be controlled by raising or lowering a watercooled notch at the end of the slag nozzle. This notch is covered with a layer of brittle frozen slag but the slag is kept molten in the top part of the notch by a sting out of flame gases which is withdrawn with a separate hood into the main existing hood.

Fig. 7 shows the proposal for a pilot plant for a continuous scrapmelting furnace based on the Paderborn experiments but designed to overcome the problems of air in-leakage due to having the doors at different heights. The furnace is also designed to enable the molten scrap to be continuously refined by a suitable counterflow slag in a narrow refining channel fed by the molten metal from the wide preheating and melting chamber. The latter must be wide to give sufficient surface area for the melting to be carried out by the gases from the main melting burners which impinge on the melting surface but do not penetrate through to cause excessive oxidation. The melting process is thus similar to that in an oil fired open hearth furnace melting a charge of pure scrap. The heating gases pass out through ports underneath water-cooled rails just inside the charging door. There are various possible devices equivalent to the double valve system of the blast furnace for charging the material without excessive leakage. One such is shown in the figure. This system ensures that the scrap is heated up to about 500°C by the gases passing through it giving a good rate of convective heat transfer, the other main feature of the system is that the action of the ram pushes the material as far as the point where the slope suddenly becomes much steeper. This is arranged to co-incide with the place where the scrap is just beginning to become sticky, that is at about 1000°C.

REFERENCES

1 M.W.Thring
The Future of Steelmelting
JISI April 1954 p.424

2 J.W.Eyre, C.Hulse, M.W.Thring
Steel Melting in a Pilot Plant Shaft Furnace
Indian Construction News, July 1960 p.119 also
Iron and Coal Dec.1 1961 p.1159

3 E.Hofmann and M.Paschke
Stahl u Eisen 1939 vol.59 p.417

4 Anon
Continuously Charged Recuperative One-Way Fired Steel Melting Furnace
Iron and Coal Dec. 8 1961 p.1244

5 Anon
Spray Steelmaking Proved in Practice
Iron and Steel Nov.1966 p.508

6 Rev.de Met. June 1965 p.605

7 P. Nilles, F.Muller, E. Denis
CNRM Oct.1964, CIT2 p.216 p.339

8 H. Schenck
Stahl u Eisen 84 March 12 1964

9 H.K. Worner Jof.Met.May 1962 p.375
J.Aust.Inst.Met.6 3 Aug.1961 p.167
Steel June 3 1963
Steel and Coal Aug.17 1962
Nature, July 7 1962 p.16
BHP Tech.Bull 6 1 Feb.1962

10 K. Kanamori
Application of Bessemizing as an Iron and Steelmaking Technique (Is Continuous Steelmaking a Dream of the Ferrous Metallurgist?)
Private Report

11 H. Lashley, H.Cowan
Development of Oxy-Fuel Burners in Electric Arc Steelmaking
Scottish Gas Board Rpt.Sept.1964
J.A.Grainger, J.G.Beeley and B.W.Bulmer
Assisted Melting Employing Oxy-Town Gas Burners
Ind. and Proc.Htg.Oct.1966
J.S.Lemkin, D.Smith and M.G. Sri Ram
J.Inst.F.Feb.1966 p.55

12 I.M.D. Halliday
Continuous Casting. The Outlook for Steel
Iron and Steel, Sept.1965 p.472

13 P. Rheinlander
Fuel and Power in the Iron and Steel Industry
Stahl u Eisen vol.85 1965 p.1659

APPENDIX I

The Advantages of Continuous Processes

The glass industry has been operating continuous melting processes at temperatures up to 1600°C (Pyrex production) for its tonnage production for nearly a hundred years. Artificial sapphire fused at 2080°C is being made continuously on a small scale. The petroleum and other heavy chemical industries have almost completely changed to fully continuous operation, the cement industry went over to continuous operation with the rotary kiln at the turn of the century and the refractory and ceramic industries are steadily moving over to continuous operation with tunnel and ring kilns. The blast furnace already works continuously except for the intermittent tapping and it could readily be adapted to fully continuous tapping since iron melting cupolas have already been successfully operated in Germany with continuous using a forehearth. It is very significant that no tonnage industry has ever wanted to return to batch processes once the continuous process has been established.

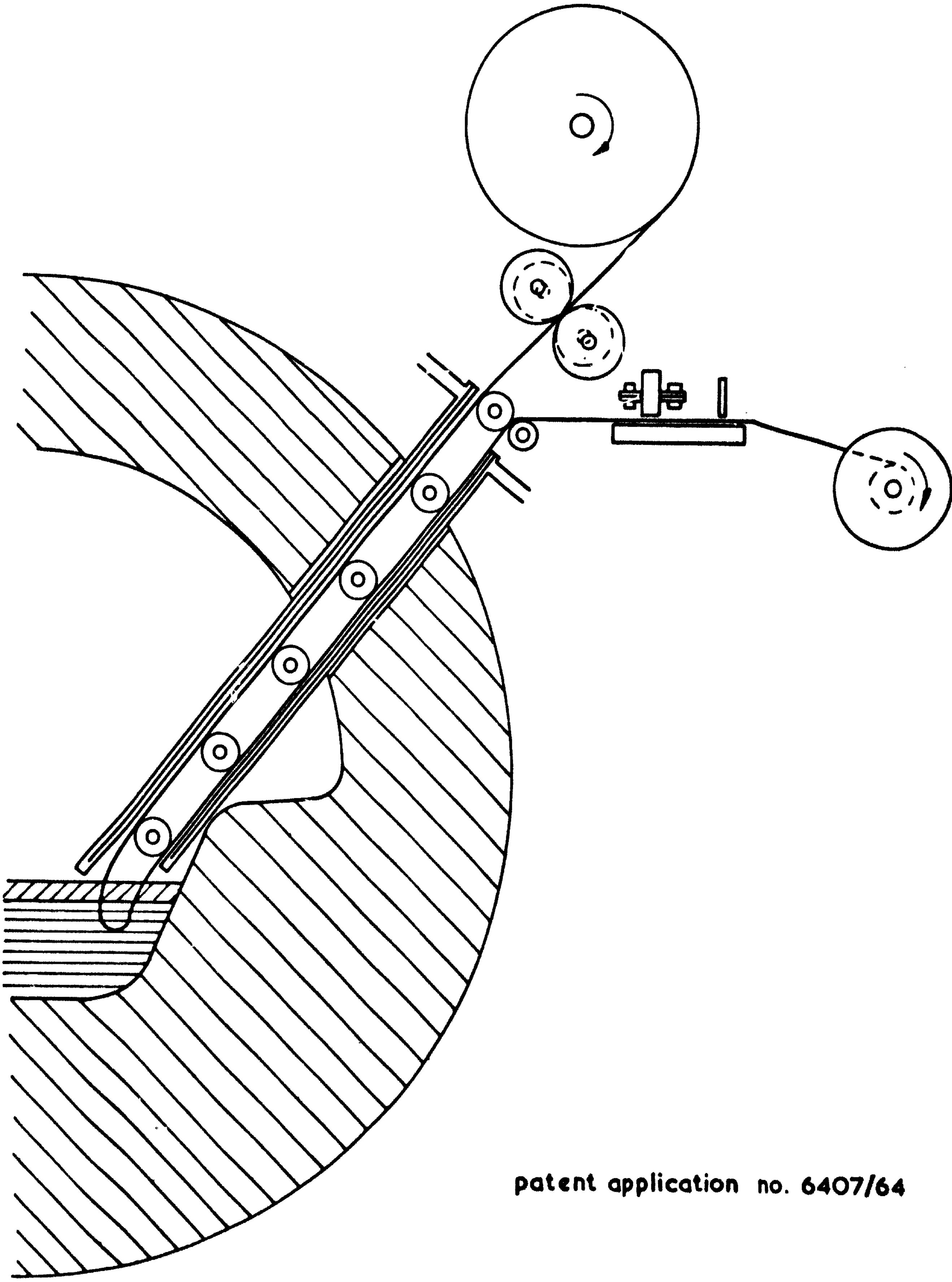
The main advantage of continuous processes as applied to the making of steel can be considered under five headings:

1. Automatic control of quality, composition and temperature

By developing fully continuous sampling of the metal before and after refining (see fig 10) and analysing these samples in a continuous vacuum spectroscope to give all the elements concerned, it is possible to control the quality, composition and temperature of the molten steel by means of a computer and to verify thatthis control is accurate. The computer would then control the process in terms of the quantity and composition of the slag feed materials, the amount of fuel and air and oxygen in the primary and secondary flames and the residence time of the metal in the bath, the supply rate of iron or sponge iron being maintained constant. This means firstly that one can obtain much more accurate control of the uniformity of the product; second that the product can be produced varying over the whole range of compositions and qualities of steels from the cheapest to the most expensive. Thirdly, it is possible to instruct the computer to change

Figure 10

Proposal for continuous steel sampling



patent application no. 6407/64

the composition of the metal at any time to make as little as 1/4 hrs production of a given steel instead of having to make one large batch of only one composition. For this change the flow of liquid steel through the vacuum syphons can be stopped until the continuoue casting moulds are empty while the conditions in the furnace are altered to make the new compoeition or if preferred there can simply be a sudden change in the composition of the metal coming continuously out of the casting moulds, juet ae oil of different compositions can be sent down a pipeline with minimal separation.

2. Each part of the syetem is designed for one process only

In the conventional open hearth furnace, arc furnace or LD vessel the same vessel has to serve the various functions of charging of raw materials, scrap melting, slag formation, slag discharge, the various refining processees including the splasing due to oxygen lancing and containing the very high temperature final metal which is poured out. The hearth is at some times not covered, at others covered with solid metal, and at others with liquid metal at various temperatures. This means that the refractories above the metal level are subject to continual temperature variations and to variations in aerodynamic conditions and splashing so that their design has to be a compromise. Similarly, the material under the bath has to be suitable for very varying conditions and for resisting attack by slag as well as by molten metal. In a fully continuous process these problems can be completely eliminated. Each part of the refining and melting channel is designed to be the optimum for one stage of the process alone. One part is designed to house a flame, another part to hold the finishing reducing slag and the pool of quiescent metal before it is discharged. Another part has the feeding of the main oxidising slag and the flame preparation and melting of this slag. Another one houses the fuel oxygen burner which accelerates the oxidation reactions and this part can be designed so that any splashing which does occur does not reach the roof or side walls and the bath can be deeper again at this point. Another part is designed for the charging of scrap, another one for the discharge of the combustion gases and of the used slags and finally there is the part for the pouring in of the molten metal through a special slag or in the ultimate process with extended surface area for melting sponge iron and scrap in large quantities. This gives very long life between the shutdown of the furnace, probably two or three years, and hence very low maintenance costs.

3. The use of a flame

In the final steel plant where one will have to melt more than 60% of scrap or sponge iron then a flame for melting is quite essential. Even in the intermediate stage of a process providing molten steel continuously from 60-80% molten blast furnace iron, the use of the two flames, one with preheated air over the hot end of the furnace to superheat the metal, make up heat losses and melt and prepare the main slag gives a considerable number of advantages. Curiously enough, the first of these is that they reduce the fuel and oxygen costs. This is because the fuel in a straight oxygen blowing process is entirely the carbon, phosphorous, silicon, manganese and up to 1% of the Fe coming from the blast furnace. This means that all the heating reactions depend upon the use of extra coke in the blast furnace. This was shown clearly in a recent paper by Rheinlander (13) where in an analysis of the fuel costs he showed that the fuel fired open hearth furnace used considerably less fuel (in terms of calorific value and more difference in terms of cost) than the blast furnace/oxygen-blowing processes to make a ton of steel. Less oxygen will be used in the continuous process with flame heating because at least half the oxygen to combine with the carbon of the metal can come from Fe O melted in the main oxidising slag. This also increases the amount of steel produced per ton of blast furnace metal and this again reduces the coke used in the blast furnace per ton of steel made.

The second main advantage of the flame is that one can use a much wider range of raw materials, that is, going from 0% to more than 60% scrap and using light or heavy scrap and one can cope with variations over a fairly wide range in the temperature of the molten iron and its content of the heat producing elements, carbon, silicon, phosphorous and manganese. Finally, the flame and the burning of oxygen with fuel means the complete elimination of fume and a much less violent stirring action being necessary for the refining processes.

4. The advantages in the use of a counterflow slag

The metallurgical advantages of a counterflow slag are firstly that one uses less than half as much weight of slag to obtain the same degree of refining in a given steel because the slag leaving the furnace can have a very high concentration of the impurities since it leaves at a point where these impurities are at the maximum level near the incoming molten iron. Secondly one can produce an extremely clean steel of quality as good as that in the best arc furnace practice, that is the steel can be very low indeed in phosphorous and sulphur even if the iron is high in silicon. It can be very clean indeed in terms of refractory inclusions because of the steady flow conditions which enable expensive special materials to be used just at the critical points.

5. Cost of buildings and ancillary equipment will be considerably less

In any fair comparison the total capital cost of plant for proceeding from raw ore to rolled steel should ne compared for the same output assuming both plants were built at the same time on green field sites. Comparing first the continuous flame heated counterflow slag refining process with the batch type O_2 - blown refining process; the blast furnace, coke ovens and molten metal transfer equipment will all be about 25% less for a given output of finished steel because of the increased proportion of scrap that can be used directly in the continuous process and of the increased yield of steel due to the reduction of Fe O and elimination of fume. The equipment for pouring the molten iron continuously into the continuous refining furnace will simply involve a fixed crane and on the casting site there will be no crane at all so that the whole expense of the travelling transfer of molten steel in ladles which at present is required both with pit casting and with continuous casting will be completely eliminated. The refining furnace will probably cost about the same as an LD vessel because the refining furnace is longer but it does not require the complex tilting and rotating equipment of the steelmaking process that the continuous process will show its greatest advantages. (i) complex and expensive fume removal gear and waste heat boilers, at present required with the LD process will be replaced by a simple stack carrying clean combustion gases, (ii) the fuel oxygen burner will be a simple watercooled tube 3m.long in place of the 15m. or more length of the LD process lance and this in turn means that the roof of the building can be just above the crown of the furnace so that the whole furnace can be installed in a building with roof less than 15m. above ground level, (iii) when it is necessary to put a new crown on the furnace, which would be every two or three years, the whole crown can be removed in sections and replaced by new sections, (iv) the bath in contact with molten metal can be burnt in very hard by means of a flame and again because of the continuous conditions very little fettling will be required. Fettling can be done by emptying the furnace once a month probably by opening a special taphole on the lowest point for the purpose. (v) Finally, on the continuous casting side the capital cost can be minimised by having 12 or more strands fed from one furnace in parallel in such a way that any group can be taken off for repair by discontinuing the vacuum extraction from one box without interrupting the overall continuous operation.

When we come to the ultimate stage of using sponge iron the comparison of the sponge iron side of the process with the present Blast Furnace, Coke Oven, Cowper Stove assembly is so good that the new process will probably finish up with less than a quarter of the capital cost of the existing one. The melting furnace will not be very expensive because its main cost will be for the low temperature heating part with the extended surface area and this is equivalent to a continuous slab reheating furnace. The transferring of hot metal in ladles will also be completely eliminated the sponge iron will be conveyed continuously in a tube straight into the melting furnace.

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CONTINUOUS STEEL MAKING[1]

by

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SUMMARY

Some countries already consume over half a ton of steel per head of the population per year and at least 0.1 and possibly 0.2 tons per year will be necessary throughout the whole world to give everyone a reasonable standard of living.

It is fairly certain that the more highly developed countries will use their present plant until it is worn out but that some time in the future, less than 20 years from now, they will have to replace it by plant whose final production of steel is essentially and basically cheaper.

On the other hand, the less developed countries present an ideal opportunity to develop a new and greatly improved steelmaking process as they are not saddled with the present generation of plant.

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

One can draw one other conclusion as far as the highly developed countries are concerned and this is that as they have already reached an equilibrium production of steel, the proportion of scrap steel which must be returned to the industry for remelting is bound to increase until it ultimately reaches a figure of the order of 70 or 80 per cent.

The long term equilibrium needs of mankind are of the order of 0.1 to 0.2 tons of steel per annum per capita.

There is a great need for a substantially cheaper way of making good quality steel both in the developed countries and the under-developed countries.

This steel requires the use of cheap natural fuel, e.g. gas, oil or pulverized coal as the sole fuel for steelmaking and ore reduction.

The proportion of scrap will eventually rise to 70 or 80 per cent.

The requirements for the new steelmaking process

The characteristics of a steelmaking process necessary to satisfy these needs in the next generation are the following:

(i) It must be possible to take as raw materials in one plant the Fe in proportions ranging from 20 per cent scrap and 80 per cent finely ground ore concentrate to the reverse percentages.

(ii) The process must be fully continuous, completely automatically controlled and with no mechanical movement of ladles of liquid metal.

(iii) The process must be able to use oil, natural gas or crushed coal as the sole fuel for reducing the ore, melting the iron made from the ore and the scrap and refining and superheating the molten material.

(iv) The over-all capital cost of the plant for reduction, melting and refining, casting and rolling, the buildings to contain it, the necessary equipment and the material handling equipment must be substantially below that of the over-all equipment of the present processes involving coke-ovens, blast furnaces, Cowper stoves, molten iron-carrying devices, oxygen blowing equipment, pouring equipment, fume removal equipment, casting bay, molten steel and ingot transport equipment, rolling mills, soaking pits and reheating furnaces, storage bins and bays and buildings to house all the equipment.

(v) The process will certainly be linked to multi-strand continuous casting to cut out the cost of the primary mills, soaking pits and reheating furnaces.

Experiments already carried out on Continuous Steelmaking

Continuous scrapmelting

In 1954, Thring (1) published a paper in the Journal of the Iron and Steel Institute in which he proposed the continuous counterflow flame steelmaking plant. In this, there were two slags but the word counterflow referred to the heating gases in relation to the scrap being heated, melted and superheated.

For four years experiments were conducted at Sheffield University in a co-operative research with Steel, Peach and Tozer and G. P. Wincotts of developing a scrapmelting furnace based on the shaft heating system (2). The furnace melted at a rate of about half a ton an hour using gas and air heated to 400°C it melted continuously but was tapped every two hours.

A furnace was designed and built by Professor Schack at Gebr. Benteler at Paderborn in Germany. This furnace was to melt continuously but to be tapped every two hours with 16-20 tons of molten steel which was taken to an arc furnace for finishing and continuous casting. The furnace melted satisfactorily at 8 tons/hour with an over-all thermal efficiency of 55 per cent.

Continuous refining of molten iron using only oxygen

In the BISRA spray refining process, the molten iron falls in a stream from a tun dish through two nozzles; through the first of these, lime and flux are dropped as a continuous stream of powder while supersonic jets of oxygen enter through the second, which is water-cooled. These jets pick up the lime and fluxes and impinge at a small angle on a falling stream of iron. The refined metal falls into a receiving ladle with a nozzle at the base for metal flow into the casting equipment and a side spout for slag overflow. Nearly all the carbon monoxide produced is burnt with the oxygen to CO_2, the waste gases contain 1-2% carbon monoxide and 14 gr/ft^3 (32 gm/m^3) of fume. The surplus heat can be absorbed by allowing the hot metal to melt up to 40 per cent of cold scrap. The process is at present only used to empty one ladle of iron at a time.

In the period 1960-68 H. K. Worner (9) has carried out a series of experiments on several pilot plants in Australia. He poured molten iron from a cupola continuously in from one end of the furnace, it passed under three bridges to separate the slags and he used a number of oxygen lances to refine the metal. He operated at rates up to 4 tons/hour and showed that it was possible to produce steel continuously with contents of sulphur and phosphorus as low as those which can be obtained in the best arc furnace practice and that the carbon content of the steel could be controlled over a wide range. In later furnaces (9a) he has dispensed with internal slag baffles altogether and has provided a slag settling chamber. 0.004% P and S from more than average hot metal and has a completely counterflow slag throughout the whole length of the converting branch.

The Fuji Iron and Steel Company (10) together with the Tokyo University, described experiments of an annular continuous refining furnace in which the slag and metal were set in rotary motion at different speeds by arranging the oxygen nozzles tangentially. They made a large number of five ton heat with an average refining time of 27 minutes, but the process was not developed to the fully continuous stage since the iron is tapped intermittently.

Continuous refining of iron with a flame

A number of experiments have been carried out on the 100 lb/hour scale by Sheffield University at English Steel Company in a narrow channel furnace eight feet long. In this, slabs of cast iron were fed in at one end of the furnace where the combustion gases left and an oil/oxygen burner provided a very hot flame at the other end.

An attempt to predict the steel-making process of the future

Melting of scrap or sponge iron

The experiments discussed in Section 3 of the Paper have shown that it is perfectly feasible to heat scrap steel or sponge iron in a counter flow shaft with stoichiometric combustion gases provided the metal is not heated above a temperature of about 900°C. Above this temperature the heating must be by radiation from gases which do not pass through the material, otherwise there is excessive oxidation and sticking together of the material so that it will no longer travel satisfactorily down a shaft (unless it is heated from both sides at the base).

Iron containing three or four per cent carbon can be completely melted in such a shaft furnace which then becomes equivalent to a cupola fired with oil or gas at the base instead of using coke fed in with the charge.

It is of course possible to melt scrap in a blast furnace or cupola with coke but this requires large hard coke and gives a melting thermal efficiency less than 20 per cent because it makes a lot of carbon monoxide. It is therefore ruled out as the scrap melting process of the future. It follows that both the sponge iron and the scrap which will be the two sources of Fe to the steel melting and refining process of the future will necessarily be melted in one of the two types of furnace shown diagrammatically in Fig.2 of the Paper. In these processes there will be a flame at the refining end, whence the steel is continuously extracted by vacuum syphon. This flame will provide the necessary superheat for the molten metal and the heat to melt the refining slag and will consist of either the cheap liquid or gaseous fuel fired with superheated air from a metallic air heater through a burner in the end wall or the same fuel burnt with pure oxygen in a special burner which will also convey the slag forming materials and a reasonable proportion of finely ground iron oxide, some of which will be reduced to increase the metallic yield.

There will be a second burner impinging directly on the melting ferrous material so that the latter runs as a steady liquid stream in the refining slag in the bath. The cold ferrous material may be charged in by a ram in which case the exit gases will be drawn off downwards by off-takes underneath the entry point or the material may be fed down through a shaft through which the gases are drawn in counterflow.

Refining

Molten blast furnace iron will be poured in at one end of a long narrow channel furnace; a desulphurising slag will be fed in at point 3 in Fig. 8 of the Paper and run co-current with the iron. The main oxidising slag will be fed in at point 2 and melted by the hot air oil burner flame impinging on it. The stoichiometric fuel/O_2 burner will provide the heat and stirring for the reaction

$$FeO + C \rightarrow Fe + Co$$

between the slag and the metal.

Casting

By having a series of six or more separate continuous vacuum de-gassing syphons, it is possible both to control the hold-up time of the metal in the furnace for refining and to continue operation while a certain number of vacuum syphons or continuous casting apparatuses are out of action. Each of these vacuum extraction apparatuses can be raised or lowered a few inches separately and each one feeds a small number of continuous casting apparatuses spaced out so that all the continuously cast slabs or ingots run in parallel directions through the cooling and rolling stages.

The scale-up law for continuous steelmelting and refining experiments should be that the mass throughput (tons/hour) should increase as the cube of the linear dimensions of the furnace. This is because the throughput of the process depends rather on the residence time of the metal in the furnace than upon the surface area of contact between the metal and slag. The system can be stirred sufficiently so that the reactions can be regarded as going on throughout the volume of the metal and slag rather than across the interfacial surface area.

A pilot plant on the ten tons/hour scale for a furnace to make steel continuously from molten iron consists of a fixed furnace with an auxiliary heating flame of oil or natural gas plus preheated air at the steel tapping end. In the first experiments the steel would be withdrawn through a "tea-pot" spout as shown but later a continuous vacuum-syphon de-gassing apparatus would be used and the level of the metal in the furnace adjusted by varying the level of the metal in the ladle into which the steel is being discharged by controlling the height of this ladle. This ladle would of course be replaced by the multi-strand continuous casting moulds in the large scale apparatus. The molten iron is poured in continuously at the other end of the furnace through a desulphurising slag which is also fed in continuously at this end. A small amount of reducing slag fed in immediately under the burner protects the metal in the steel withdrawal end while the main slag consisting of finely powdered lime or limestone together with a significant amount of iron oxide and a small amount of bauxite as flux is fed in close to a small high velocity burner distillate oil or natural gas with a stoichiometric fuel proportion in such a way that it causes violent agitation of the molten metal. All three slags are fed in continuously and discharged together at a slag notch placed immediately under the combustion products offtake near the end of the furnace where the iron enters, the scrap is charged in through a door in the side of the furnace about half-way between the oxygen fuel burner and the combustion gas offtake. The use of a fuel/oxygen lance means that no fume is made and that sufficient heat is available both to oxidise most of the carbon in the iron by means of the FeO charged in (thus increasing the yield of metallic Fe per ton of metallic iron charged in) and also to melt a high proportion of scrap. Moreover the proportion of scrap can be varied within a wide range by varying the amount of fuel/oxygen to this burner and fuel/air to the auxiliary burner at the hot end. The hold-up time of the slag in the furnace can be controlled by raising or lowering a watercooled notch at the end of the slag nozzle. This notch is covered with a layer of brittle frozen slag but the slag is kept molten in the top part of the notch by a sting out of flame gases which is withdrawn with a separate hood into the main existing hood.

The Advantages of Continuous Processes

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2. Each part of the system is designed for one process only

In the conventional open hearth furnace, arc furnace or LD vessel, the same vessel has to serve the various functions of charging of raw materials, scrap melting, slag formation, slag discharge, the various refining processes including the splashing due to oxygen lancing and containing the very high temperature final metal which is poured out. The hearth is at some times not covered, at others covered with solid metal, and at others with liquid metal at various temperatures. This means that the refractories above the metal level are subject to continual temperature variations and to variations in aerodynamic conditions and splashing so that their design has to be a compromise. Similarly, the material under the bath has to be suitable for very varying conditions and for resisting attack by slag as well as by molten metal. In a fully continuous process, these problems can be completely eliminated.

3. The use of a flame

In the final steel plant where one will have to melt more than 60 per cent of scrap or sponge iron then a flame for melting is quite essential. Even in the intermediate stage of a process providing molten steel continuously from 60-80 per cent molten blast furnace iron, the use of the two flames, one with preheated air over the hot end of the furnace to superheat the metal, make up heat losses and melt and prepare the main slag gives a considerable number of advantages. They reduce the fuel and oxygen costs. This is because the fuel in a straight oxygen blowing process is entirely the carbon, phosphorous, silicon, manganese and up to one per cent of the Fe coming from the blast furnace. This means that all the heating reactions depend upon the use of extra coke in the blast furnace. Less oxygen will be used in the continuous process with flame heating because at least half the oxygen to combine with the carbon of the metal can come from Fe 0 melted in the main oxidising slag. This also increases the amount of steel produced per ton of blast furnace metal and this again reduces the coke used in the blast furnace per ton of steel made.

The second main advantage of the flame is that one can use a much wider range of raw materials, that is, going from 0% to more than 60% scrap and using light or heavy scrap and one can cope with variations over a fairly wide range in the temperature of the molten iron and its content of the heat producing elements, carbon, silicon, phosphorous and manganese. Finally, the flame and the burning of the oxygen with fuel means the complete elimination of fume and a much less violent stirring action being necessary for the refining processes.

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5. Cost of buildings and ancillary equipment will be considerably less because of the simplicity of the continuous steel-making process as compared to present conventional processes.

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