Recent Trends in Iron and Steel Technology

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DURING the last decade, world annual ingot steel production has increased by about 150 million tons as shown in Fig. 1. Nine-tenths of the total pig iron produced forms an intermediate product for conversion into steel. Such post-war expansion has been actuated by the rapid growth of light and heavy engineering industries, increased demands of consumer goods and the universal desire to obtain higher standards of living. One-twentieth of the earth's crust consists of iron which should assure the supplies of this important metal as inexhaustible. This could be so if the production and processing techniques are under continuous transformation in relation to the nature of available resources.

Excellent and valuable survey reports are already available, published both by individual authors as also different organisations such as the United Nations who have brought out practically each year the publication "Advances in Steel Technology" and these publications contain a wealth of information and technical data. As such, little purpose will be served by re-surveying what has already been admirably covered. The attempt, therefore, would be to outline herein some specific observations of intrinsic interest and applicability.

The metallurgy of iron and steel is based on processes that have essentially remained unchanged in essence over the past century but have undergone spectacular alterations in the scale of operations and efficient utilisation of raw materials chiefly in the light of contemporary developments in engineering technology. Modern iron-making, although theoretically well established and scientifically well analysed, leaves much to be known, particularly in relation to gas-solid and gas-liquid interactions. It has only lately been established by British Iron and Steel Research Association by recent measurements made by Mr. E. W. Voice that it takes only 2–10 seconds for a gas molecule to pass from the tuyeres to the top of a modern blast furnace so that gas-solid and gas-liquid reaction must attain completion at enormous speeds. The entire chemistry of modern iron-making is most complex owing to interlocked equilibria and yet the resultant products, i.e. metal and slag, invariably emerge in chemical equilibrium with respect to metalloids whether it is in the modern Chinese one ton per day blast furnace or the four "Queen" furnaces that today stand at Appleby Fordingham or the latest and one of the most modern Tata's Blast Furnace of 28 ft. hearth diameter blown in a few months ago.

Each year brings in its quota of patents and suggestions for improvements in iron smelting; some chiefly relate to direct-reduction processes. The announcement by Sir Charles Goodeve to the British Association for Advancement of Science in the Bessemer Centenary year of the Cyclo-steel process indicates the progress made in the development of new methods of steel-making particularly against the background of a series of inventions designed to challenge the supremacy of the blast furnace-steel melting furnace combinations that still hold the stage today.

Iron-making

Chief improvements in the field of pig iron production relate to preparation of the charge which

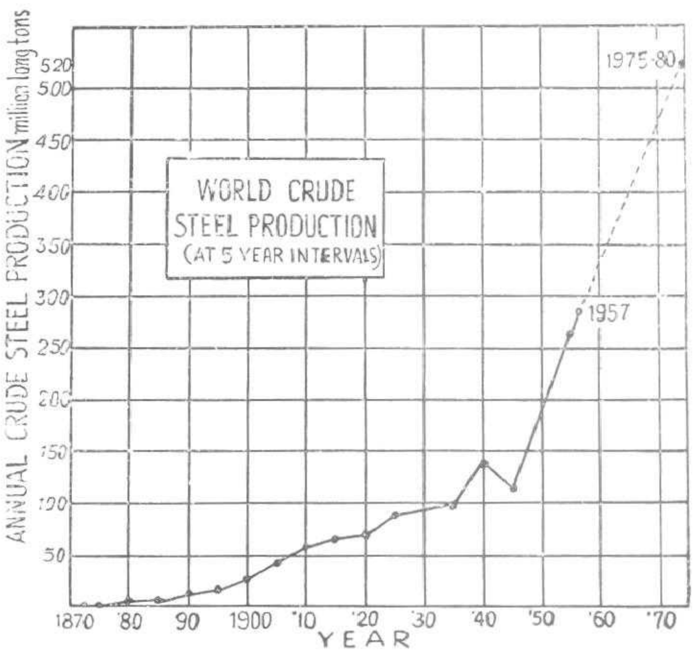

Fig. 1.
Graph of world steel production.

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consists of crushing, screening and size classification of the ores; concentration of low grade ores, pelletising and sintering. Proper size classification facilitates uniform descent of the charge, and promotes an equally uniform ascent of the rising gases, and thereby enables a uniform quality pig iron production and overall consistency in blast furnace operation. These points are important when considered in the context of increase in general of the size of the blast furnace. It has steadily increased since the last war. It is now considered that in the later forties, bigger furnaces usually comprised 14–16 ft. hearth diameter whereas by early sixties, iron will be produced in furnaces in the range of 26–28 ft. average diameter hearths. Most of us are already aware of the steadily increasing capacity of the furnaces. It has been recently claimed in Russia that they are installing a 5,000 tons per day blast furnace. Experience in operating blast furnaces in Russia and elsewhere suggests the practicability of designing furnaces to a maximum cubic capacity of 2,000 cubic metres to give a daily pig iron output of 5,000 tons. A recent report by "Gipromez", the Soviet State Planning Commission for Metallurgical Industry, suggests that a new operating technique must be developed, including not only careful ore-preparation, but also additions of the necessary proportion of fluxing material before charging or alternatively adding it prior to the sintering process. Division of the charge into sized fractions will be necessary, also the use of charging rate, operating temperature, blast heat, pressure and humidity[1].

The increase in the size of the furnaces in turn will necessitate the use of stronger coke to support the great burden weight. Lower consumption of coke per ton of iron made has been engaging the attention of many in different parts of the world. The problems of pelletising and sintering are engaging serious attention. When sintering fine ores, for example, benefits have been shown to accrue by pelletising the raw mix. Such pelletising products after sintering yield largely improved permeability. In England, studies are under way concerning the possibility of pelletising a part of the mix to act as "seeds" and thus avoiding the need to pelletise the entire mix. Remarkable work has also been done on sinter at the British Iron and Steel Research Association. According to Sir Charles Goodeve, it is now possible to increase the output from sinter plants very substantially as also to improve the sinter quality. In the sinter plants there is a layer of about 10–12 in. of powdered ores with some coke and water whilst air is sucked through the bottom. Water keeps the burden permeable in order to facilitate the passage of air. On ignition at the top, the flame burns through and converts the mixture into sinter. It has been shown by British Iron and Steel Research Association that two waves pass down the bed, one of which is heat transfer wave and the second, chemical combuston wave. If these two waves are kept in phase, high efficiency of the plant is achieved; if these two waves get out of phase the efficiency rapidly drops. The British Iron and Steel Research Association has shown that the control of these two waves is the principle underlying modern sinter plant practice[2]. In the U.K. the current research programme is also being extended to seeking better lining techniques of blast furnaces and acquiring information about the rate of wear of linings. In England, pellets of Cobalt 60 are being used at the plants of five organisations to assess the wear of stack and hearth linings.

U.S.S.R. blast furnace techniques[3]

The blast-furnace process is greatly affected by increased oxygen concentrations in the blast. The higher the oxygen content of the air blast, the greater are the changes in intensity of combustion, in the relative proportions and pressure of the gases and the zonal distribution of temperature, etc, Reduction in the quantity of nitrogen leads to smaller volumes of air blast. The chemical activity of the combustion process is intensified and the theoretical (and to a lesser extent, the actual) combustion temperature increases. The resulting rise in the temperature difference between gas and burden brings about a more intensive heat exchange in the lower levels of the furnace. A decrease in the evolved quantity of gases, their pressure, and increase in the intensity of heat-exchange in the lower levels contribute to a temperature reduction in the higher levels of the furnace; wherein the temperature difference between the ascending gases and descending burden falls. The higher temperature zones of the blast furnace are displaced vertically downwards towards the hearth (Fig. 2). The limit to which the blast may be enriched with oxygen is thus determined by the fall in temperature levels in upper portions of the shaft. The concentration of carbon monoxide in the gases increases as the nitrogen content of the blast decreases.

Thus, a rise in the activity of the combustion processes increases the smelting intensity. Increasing concentrations of carbon monoxide following on oxygen concentrations in the gases intensify reduction reactions. Due to reduced volumes of top gases and a lowering of the temperature in the upper stack levels, there is a reduction in the sensible heat carried off by the evolved gases. In line with decreasing quantities of the nitrogen, the calorific power of the top gases, increases. Thus there should be expected an increase in the effectiveness of the blast furnace process both in respect of output and reduced coke consumption. However, in actual practice, it has been observed that the

[1] Iron and Coal Trades Rev., Nov. 1958, p. 1103.

[2] BHP Tech. Bulletin, Vol. 1, No, 2, Oct. 1957.

[3] Written communication from Academician I. P. Bardin, Vice-President of the U.S.S.R. Academy of Sciences.

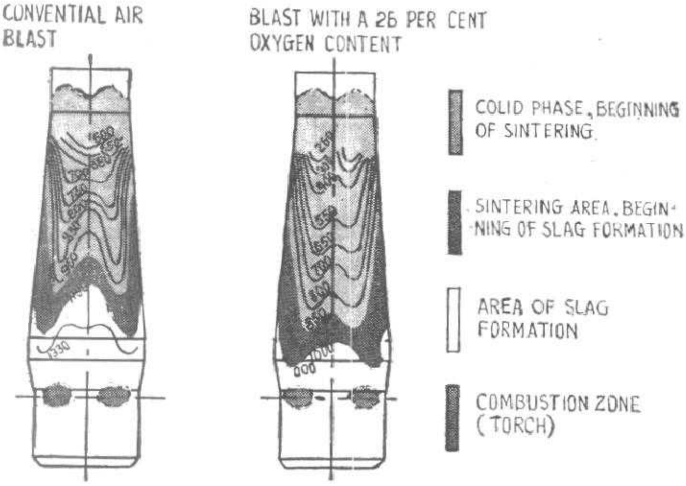

Fig. 2.
Isotherms and areas of phase transformations in the blast furnace (foundry iron melt).

possibilities of realising the intensifying properties of oxygen are not the same in the melting of different kinds of pig iron.

The melting of ferro-alloys in a blast furnace requires greater heat liberation in the hearth and bosh for direct reduction of oxides of silicon, manganese, and other elements which are more difficult to reduce than oxides of iron. When using normal air blast, the rate of heat utilisation of the gases is comparatively small, as a result there arises excess, unusable heat in the upper levels of the furnace. The gases leave the furnace at a temperature of 500 to 800°C. For this reason, the smelting of ferro-alloys entails increased fuel consumption. And the top temperature rises to a point that limits the possibility of normal furnace operation for the production of requisite quality ferro-alloys.

Blasts with higher oxygen concentration create more favourable thermochemical conditions for smelting ferro-alloys. Elevated temperatures and heat from gases in the lower levels of the furnace intensify the reduction reactions of silicon, manganese and other oxides with a simultaneous rise in the temperature of the upper levels. The blast furnace is then capable of smelting higher-quality ferro-alloys. Soviet experience shows that the use of ordinary poorly prepared stock and a blast containing 30 to 35 per cent oxygen increases the output of a blast furnace as follows:

> A 90 per cent increase in smelting ferro-manganese, a 50 per cent and more increase for ferro-silicon; coke consumption in both cases is cut by 15 to 16 per cent. The run is steady, the top gases are utilised normally, and can undergo the normal cleaning. However, producing open-hearth and foundry grade irons through the use of an oxygen-enriched blast proved to be a more difficult problem. Full scale smelting tests undertaken in the U.S.S.R. in a 330 cu. m. blast furnace using unprepared stock showed that increasing the oxygen content in the blast up to 23 to 24 per cent produced trouble in the furnace operation in the form of persistent hangings; slippings reached 80 in twenty four hours. Changes in the blast conditions, delivery of blast to the second (upper) row of tuyeres, alterations in the methods of burden charging and distribution, and a number of other measures did not result in any perceptible improvement in blast furnace operation. More effective were such measures as: changes in the furnace profile (cutting the height of inwall and bosh), increasing the proportion of screened ore and sinter (especially fluxed sinter) in the burden, and moistening the blast to 40 and 50 g. per cu. m. It was thereby possible to increase the oxygen content in the blast to 26 and 27 per cent when producing foundry pig iron, and 24 to 25 per cent when producing open-hearth pig iron with an increased furnace output of 16 to 20 per cent and 14 to 15 per cent respectively. In neither case was the coke rate reduced. The causes of burden hanging from increased oxygen content in the blast are not yet fully established. Some are inclined to explain it to be due to:

(*a*) reduction in the combustion zone volume, especially its depth, which impedes descent of the stock;

(*b*) increased pressure of gases on the burden from below; the volume of these gases increases with a rise in combustion temperature;

(*c*) intensification of gas movement along the walls;

(*d*) evaporation of silicon oxides (SiO, SiO_2) which on subsequent condensation close the passages between the lumps of stock thus reducing the gas-penetrability of the burden.

These effects are attributed to the rise in temperature in the combustion zone, to intensification of the heat exchange process therein and, as a consequence, the displacement of temperature zones and thermo-chemical processes (including reduction processes) into the lower levels of the furnace. For comparison, Fig. 2 shows the isotherms and areas of phase transformation in the smelting of foundry pig iron using ordinary blast and a 26 per cent oxygen-enriched blast. The lack of any coke economy in the case of an oxygen-enriched blast is explained by the same phenomenon of displacement of the temperature zones of the furnace downwards. A reduction in the area of indirect reduction of ferrous oxide to iron causes an additional consumption of fuel which compensates any economy obtained by greater concentration of the reducing medium, by raising the smelting intensity and reducing the sensible heat carried off by the gases.

Thus, further improvements in the blast-furnace process through the use of oxygen should develop in the direction of useful utilisation of the excess heat in the hearth of the furnace and by improving the heat state of the upper areas (of the shaft). This may be done by:

(*a*) injections of dissociated gases into the hearth,

(*b*) replacing raw limestone in the burden with burned lime (either directly or as a part of fluxed sinter),

(*c*) charging hot sinter into the furnace,

(*d*) improving the gas permeability of the stock through better preparation.

Dissociation in the hearth of the furnace of such substances as water vapour or carbon dioxide permits of reducing the temperature in the combustion zone and in transferring the heat to the upper-lying areas and in increasing the concentration of the reducing medium at the expense of the hydrogen or carbon monoxide that results. However, one cannot envisage any appreciable reduction in the coke rate. For more effective is the injection into the hearth of natural gas or coke gas.

Complete preparation of the burden (beneficiation, pelletising, blending) is necessary not only to establish steady blast furnace operation, increased output, an fuel economy, but also utilisation of the intensifying properties of oxygen.

The technique of blast furnace oxygen injection presents no difficulties. This is in marked contrast to steel making process. The oxygen is fed to the suction side of the turbo-blower; its content in the blast is regulated by the amount of oxygen supplied and is controlled by analyses of the blast in the pipeline near the furnace.

The Soviet experience in the use of oxygen in metallurgy not only permits further improvement in smelting an oxygen-enriched blast, but suggests the development of new methods. Proposals and elaborated methods of blowing iron with oxygen appeared in the U.S.S.R. as early as 1951–53 in connection with problems of pre-treatment of the hot metal, which simplifies its further conversion into steel. However, the matter has not been pushed to a practical test. In 1954 Japan published some data on the investigation of a similar process in a small blast furnace which data confirm the fundamental feasibility of the process. The conversion of pig iron in the hearth of a blast furnace cannot be aimed at obtaining finished steel. Under high temperature conditions and in the presence of carbon (for instance, the coke carbon) and basic slags, MnO will again be rapidly reduced, while the metal will be saturated with carbon. According to Japanese investigators, the content of manganese and carbon in the metal when it is blown with oxygen not only fails to decrease, it even shows a slight increase. An appreciable quantity of sulphur will also pass into the slag. With slag basicity CaO : $SiO_2=1{\cdot}5$, the Japanese investigators obtained a metal containing 0·01 per cent sulphur.

Thus, by oxygen injection into the hearth of the blast furnace, it is possible to attain partial or practically complete elimination of silicon and a considerable part of the sulphur from the pig iron. The merits of the process are: the obtaining of pre-treated metal which facilitates its further conversion into steel; the complete utilisation of the heat of exothermic reactions in oxidising impurities; less loss of metal in the slag and flue dust; the possibility of using fuel with a higher sulphur content.

In Japanese experiments, the temperature of the pig iron rose 30 to 100°C while at the same time the top temperature fell approximately 50 per cent. The hearth temperature may be regulated by introducing dissociated gases such as steam, carbon dioxide, top stack gas or natural etc.

Successful application in open hearth and converter practice of the method of delivering oxygen into the liquid metal bath by means of telescopic water-cooled jetting probes led the Soviet metallurgists to believe that this method (suitably modified) may be used also for blowing oxygen into the hearth of the blast furnace. Fig. 3 is a rough sketch of this method. Thus, introduction of elements of the converter process into the hearths of blast furnaces may, in the future, lead to simplification of metallurgical processes and contribute to the working out of new technological and continuous-flow methods of producing steel.

For example, oxygen blowing of pig iron in the hearth of a blast furnace makes it possible to obtain desiliconised and desulphurised metal, whose further conversion into steel (at first, into the more common grades) may be accomplished in suitably designed units directly at the blast furnace (Fig. 4). The next and final step in such a scheme is steel production by means of the continuous and semi-continuous casting process. The future sees the entire metallurgical cycle concentrated near the blast furnace, on one side

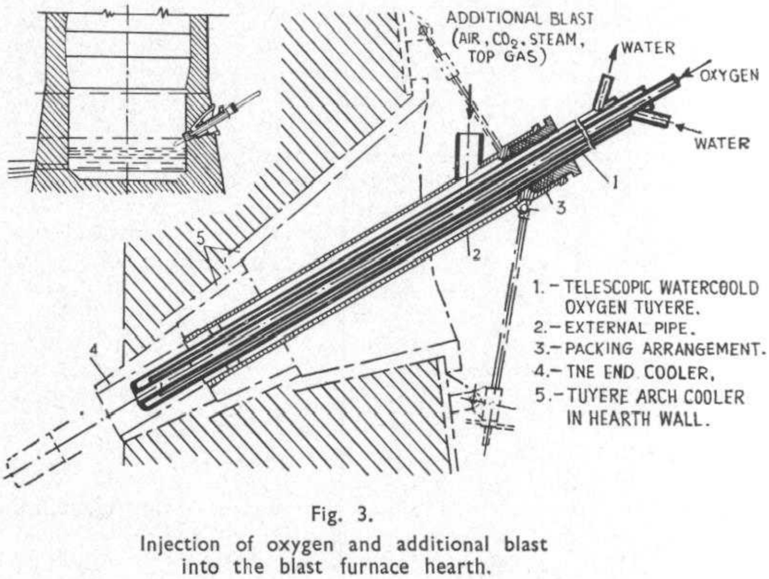

Fig. 3.
Injection of oxygen and additional blast into the blast furnace hearth.

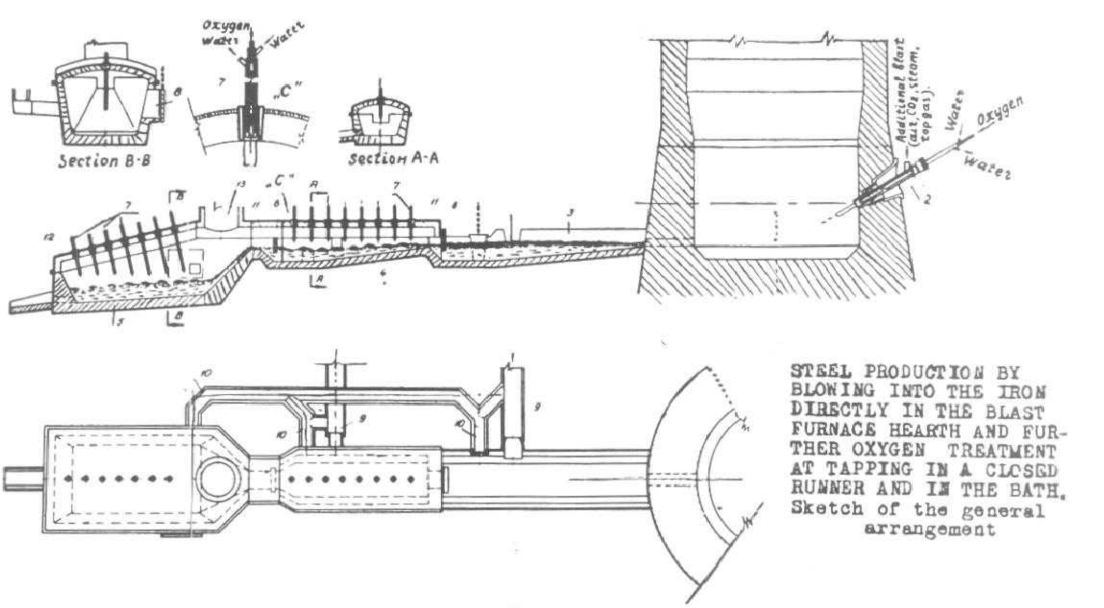

Fig. 4.

1. the blast furnace,
2. the water-cooled tuyere stock with the telescopic water-cooled oxygen nozzle and the arrangement for additional blast feeding,
3. the recurring runner for iron,
4. the runner for the hot metal oxygen treatment,
5. the bath for iron finishing (deoxydation, alloying),
6. the slag gate,
7. the telescopic water-cooled tuyere—the nozzles for gascous oxygen and ponedered materials (lime, etc.),
8. the door for addition charging,
9. the runners for surface slag overflow,
10. the runners for overflowing the remaining iron into the bath for finishing,
11. the runner cover,
12. the finishing bath cover,
13. the pipe for melting gascous by-product removal.

the ore, fuel and slag removal facilities and on the other the delivery of steel ingots. A scheme of this type will bring us closer to the continuous steel production methods.

Experiments in the blowing of pig iron in one ton ladles began in 1936 in the U.S.S.R. Iron from the cupola was blown with oxygen introduced through an iron lance. The lances immersed in the metal soon burned out. After several replacements of the lances, it was possible to obtain high-quality steel with a low content of sulphur and phosphorus. Castings made of this steel were very satisfactory. Some time later, during the war, the metal was blown in a side-blown converter. A graphite tuyere served to deliver the oxygen. Though the tuyeres rapidly burned out, one was enough for blowing of twenty melts. The melts were first made in an acid side-blown converter at plant in Hytishchi and later in more favourable conditions at the Dynamo Works and at the Kuznets Iron and Steel Works in bottom and side blown converters. The tuyeres used was similar in design to that intended for injection oxygen into the baths of open-hearth furnaces at Soviet Plants. It did not appear possible to work with pure oxygen in the case of bottom blowing, since practicable oxygen concentration in the blast could only reach 40 per cent. The problem was solved when the oxygen was delivered from above through a water-cooled tuyere. At present this method of blowing is used at two plants with an aggregate output of two million tons of steel per year. Steel produced by different methods utilising oxygen is not inferior to that produced by conventional methods. Drop forging properties and gas content (oxygen, hydrogen and nitrogen) are practically the same as those for ordinary smelting methods. There are likewise no changes in the tendency of the metal to mechanical ageing. The use of oxygen has not been found to affect the metal adversely in any way such as ferrite grain, size of structurally free cementite precipitations, composition and quantity of non-metallic inclusions.

The manufacture of steel by the oxygen lance

Similarly, at the Cross Foundry and Engineering Company Limited[4] in U.K. some experiments have been done by oxygen lancing the steel held in a converter or container, say 30 to 40 cwt. of the metal derived from cupola furnace, oxygen was introduced at the rate of 100 cft. per minute at a pressure of 150 lb per sq. in. through the lance

[4] W.S. Williams, The British Steelmaker, Dec. 1957 p. 378.

of $\frac{3}{8}$ in. internal diameter. Following the normal procedure of making steel by the oxygen lance, oxygen is passed into 30/40 cwt. of the metal held in a container or converter into which it was poured from a cupola furnace. The oxygen is introduced at a rate of 100 cft. per minute at a pressure of 150 lb per sq. in. through a lance of $\frac{3}{8}$ in. internal diameter. Including stoppages for changing lances and for making various additions to the metal bath usual in steel making, steel with a carbon content of 0·2 to 0·3 per cent will be produced in about 20 minutes, when it will be found that the flow of oxygen has ceased. To make it possible for the blow to be continued beyond this point, the pressure of oxygen will have to be raised to about 170 lb per square inch if a carbon content of 0·06 per cent is desired. This will be reached in about 25 minutes from start of blow with a temperature of about 1,550°C when the oxygen flow will again stop. A further increase of pressure of oxygen to 175 per square inch will burn down the carbon content to about 0·03 per cent in a further five minutes of time, under the conditions before described. As an alternative to raising the pressure, the $\frac{3}{8}$ in. lance could be replaced by one of $\frac{1}{2}$ in. diameter the stoppage of the oxygen flow being observed in each case when the carbon content of the processed metal is down to 0·03 per cent.

Some further features of Soviet metallurgy of iron and steel

In the U.S.S.R. a ratio of blast furnace useful volume to daily production in tons is of 0·75; an output of 7·5 and more tons of steel per square metre of furnace hearth, and of 150 tons of rolled material per working hour by heavy section mills and rail and structural mills are no longer isolated records, but the indices reached by many units. Indeed if all the blast furnaces of the Soviet Union had operated with a ratio of blast furnace useful volume to daily production in tons of 0·68 (achieved at Magnitogorsk) this would have resulted in an additional production of 5 to 5·5 million tons of pig iron in 1954, with the same equipment.

Higher top gas pressures at the blast furnaces should be mentioned in the first place among the effective methods for accelerating the blast furnace production in U.S.S.R. At present high gas pressures of (0·5 to 0·7 atm.) have been introduced at many new furnaces. A considerable number of old furnaces with sufficient air-blowing facilities have also been equipped with higher top pressures. By the end of 1955, 71 per cent of all the pig iron in the U.S.S.R. were produced at furnaces with high top pressures. This method improved furnace operation: the productivity of furnaces is raised 3 to 6 per cent and the flue dust yield is cut by 25 to 30 per cent.

The number of furnaces operating at higher gas pressures will be further increased and the pressure of the gas will be raised to 1·5 atm. during the Sixth Five Year Plan period. The employment of powerful air blowers, with a capacity of 3,700 cu. m. per minute and more will make it possible to bring up the pressure to 1·7 atm.

Constant controlled humidity of the air blast based on the addition of steam to the blast is another effective method for intensifying the process in the furnace and consequently for improving the utilisation of equipment in the Soviet Union. The maintenance of constant moisture irrespective of the daily, monthly or seasonal fluctuations of air humidity, is accompanied by raising the temperature of the blast to 1,400 to 1,650°F. This increase productivity and cuts the consumption of coke. For example, the productivity of furnace at one of the works has been raised by 15 to 20 per cent and the coke rate lowered by 4 to 5 per cent. By the start of 1955 blast furnaces using a constant moisture blast produced 91 per cent of the total pig iron output in U.S.S.R.

The replacement of silica brick by chrome-magnesite refractories in the lining of the main open hearth roofs and the roofs of the vartical flues has made it possible to raise the temperature by 212 to 302°F in the working space of the furnace to intensify thereby the melting process, to improve the conditions for the intensive refining of the metal, obtain high casting temperatures, and increase the driving rate of the furnace consistent with increased service life of the steel furnaces. Chrome-magnesite thus helps to lengthen the campaign and to raise individual furnace productivity. Productivity at a number of works (such as Zaporozhastal) shows that furnace productivity is increased by 7·12 per cent and more by such means. However, the effectiveness of the chrome-magnesite roofs is not fully realised unless high durability of regenerators checker's refractories and inner lining of the furnace caisson are also ensured. It follows from this that the use of chrome-magnesite in the open hearth roofs must be accompanied by a respective reinforcement of the checkers and the caisson lining. Investigations in U.S.S.R. have shown that the regenerator checkers should be made of forsterite or high-alumina bricks, assuring their systematic blowing with compressed air during operation. The use of high-alumina refractories for the furnace caisson lining is being adopted in Russia.

Cold repairs of open hearth furnaces in Russia took recently 12 to 15 days in case of overhauls, 7 to 8 days for medium repairs, and 4 to 5 days for minor repairs. The times have been cut to 6 to 7 days, 3 to 4 days and 2 to 2·5 days respectively. At the Zaporzshstal works a similar furnace of 200 tons capacity is overhauled in 9·5 days. In open hearth production a transition is contemplated from the 400 ton to the 500 ton open hearth furnace.

Blast furnace operation

U.S.S.R. is highly advanced in the preparation of raw materials for the blast furnaces, such as iron ore beneficiation, iron sinter and higher blast temperatures, controlled humidity air blast, higher top pressures, etc. Russians have recognised that an essential condition for regular, high blast furnace output is to maintain constant all factors influencing characteristics of operation. Until recently in different parts of the U.S.S.R. the humidity of the wind was never a constant factor, and it varied considerably, from some tenths of gm. per cu. metre to 20 gm. per cu. m. and above, according to seasonal fluctuations and the locality. By injecting water vapour into the air blast the Russians have regulated the furnace operational efficiency. The dissociation of water vapour in the furnace requires a certain quantity of heat which can be supplied by higher blast temperatures. It has been claimed by the Russians that the production of the blast furnace increased with an increase in blast humidity, provided that the loss of heat due to the decomposition of the water vapour was compensated by increased blast temperature ; consistent with this provision and with an increase in the water vapour content of 10 gm. per cu. m. of air, the blast furnace production increased from 3·5 to 4·5 per cent and the coke rate decreased by as much as 1·5 per cent. The water injection of 10 gm. per cu. m. raises top temperatures to the order of 90°C but this does not exercise any unfavourable influence on the furnace's operations.

The normal average humidity of the wind of blast furnaces in the U.S.S.R. without any intentional humidification was previously about 7·5 gm. per cu. m. At present on blast furnaces with water vapour injection, the air blast is automatically maintained between 20 and 30 gm. per cu. m. depending on the stove capacity. This has been shown to result in increasing production by 7 per cent and decreasing the coke rate 2 per cent. Injections of steam to the air blast are made prior to the hot blast stove. The use of humidified blast does not increase production costs. The costs of humidification of air blast and increased volume of blast furnace gas necessary to heat the stoves are compensated by the lower coke rates and increased production rate besides uniformity in furnace operations and burden charges.

The influence of blast humidification on the hydrogen content of pig iron and steel *vis-a-vis* a tendency toward flaking, and on the mechanical characteristics of the metal has not been adverse in any way. No deleterious effects on the combustion zone at the tuyeres have been observed following humidification of air blast. The results show that furnaces can operate up to 30 gm. of water vapour per cu. m. of blast without experiencing any increase in the hydrogen content of pig iron. With steel produced from pig iron from humidified air blast furnaces, there is no noticeable tendency toward an increase of flaking in the case of rails and medium carbon steels. Thus the salient features of blast furnace operations in the U.S.S.R. are: high top pressure, high blast temperature, sinter (ordinary and self-fluxing), adequate blowing capacity, the emphasis on constancy of operating conditions and constant blast humidification of the order of 2·5 per cent by volume. The extent to which blast can be humidified without having to increase coke rate depends on the blast temperature attainable through adequate stove capacity in which direction also the Soviet Union has paid particular attention.

In the case of sinter, the average proportion of sinter in the blast furnace burden has risen to 54 per cent in 1955. By 1960 this proportion of sinter is expected to be over 80 per cent all of it self-fluxing. The objective is to confine the furnace charge to two components only : coke and fluxed sinter as far as possible. In general, iron production was increased by about 12 per cent and fuel consumption decreased by about 11 per cent with a sinter basicity of 1·25 in relation to the employment of unfluxed sinter. With a fluxed sinter basicity of only 0·6 the corresponding production increase was 3 to 5 per cent and decrease in fuel consumption 4 to 6·5 per cent. Great importance is above all attached in Soviet blast furnace practice to constancy and uniformity of operation. This is reflected in the Soviet urge to automate the operations and heavily instrument the variables. One leading impression gained in this short visit was elaborate instrumentation at all steps of metallurgical operations including separate instrument panels in blast furnace control rooms reserved for research and development work. The standard of maintenance of the plant was high particularly in relation to avoidance of wastages such as gas, steam or oil leaks.

Effect of moisture additions

The effects of moisture additions have also been thoroughly tried out in the U.S.A.[5] It has been shown that the use of moisture has probably had an effect on the size and extent of the combustion zones in front of the tuyeres. It is probable that the use of moisture in the blast tends to lengthen these combustion zones, whereas the use of either oxygen or high blast heat or both would tend to shorten the combustion zones with a sharpening up of the combustion process. The theory is that the lengthening and enlargement of the combustion zones in front of the tuyeres open up the trough-like space between the tuyeres and the deadman so that more annulus area is available for the upgoing gases, thereby creating less resistance to gas flow resulting in a smoother and faster working furnace. With oxygen enrichment, an increasing amount of moisture is necessary as more oxygen is introduced into the blast. Table I illustrates this practice based on hot blast temperature of

[5] J. H. Strassburger: Iron and Steel, 1958, V. 31, No. 11, p. 491.

1,100 to 1,150°F (593-621°C) :

TABLE I

Oxygen enrichment per cent	Moisture in grains per cft.
1·0	5
1·5	6
2·0	7
2·5	8
3·0	10
4·0	14

Blast temperature equivalent of various levels of steam

In order to use steam successfully it is necessary to know how much heat is being added or subtracted from the furnace when the amount of steam entering the furnace is changed[6].

Assuming that a furnace is blowing 75,000 cfm. of dry air at a blast temperature of 1,000°F the sensible heat in the blast would be :

$$75{,}000 \ \text{cfm} \times 1{,}000°\text{F} \times \frac{0{\cdot}0188 \ \text{Btu}}{\text{cft.} \times °\text{F}} \times 1{,}410{,}000 \ \text{Btu}$$

If 5 grains of moisture per cft. of blast is added and the volume of bosh gas produced remains constant, the following conditions exist :

Volume of dry air	...	74,003 cfm
Lb of moisture added per min	...	53·57
Sensible heat in dry air	...	

$$74{,}003 \ \text{cfm} \times 1{,}000°\text{F} \times \frac{0{\cdot}0188 \ \text{Btu}}{\text{cft.} \times °\text{F}} = 1{,}391{,}256 \ \text{Btu}$$

Sensible heat in moisture :

$$\frac{53{\cdot}57 \ \text{lb} \ H_2O}{\text{min}} \times 1{,}000°\text{F} \times \frac{0{\cdot}49 \ \text{Btu}}{\text{lb} \times °\text{F}} = 26{\cdot}249 \ \text{Btu}$$

Total sensible heat in blast ... 1,417,505 Btu.

In the case of using moisture in the blast, there is an additional loss of heat due to the endothermic reaction $C + H_2O \rightarrow CO + H_2 - 3{,}096$ Btu per lb

$$53{\cdot}57 \times 3{,}096 = 165{,}853 \ \text{Btu}.$$

Total sensible heat in blast less heat loss of steam reaction is 1,417,505−165,853=1,251,652 Btu.

Difference between dry air and equivalent dry air and moisture is 1,410,000−1,251,652=158,348 Btu.

Increase in sensible heat in blast required to counteract loss of heat due to the endothermic reaction is :

$$\frac{158{,}341}{141{,}750} \times 100°\text{F} = 112°\text{F}$$

Blast temperature equivalent per grain of steam is :

$$112\text{F} \div 5 = 22{\cdot}4°\text{F}$$

Table II shows the increase in blast temperature required for various levels of steam in the blast :

[6] Richard J. Wilson : Journal of Metals, April 1958, p, 268.

TABLE II

Blast Temperature Equivalents of Moisture.

Amount of moisture Gr per cft.	Blast temperature °F	Difference °F
0	1,000	...
5	1,112	+112
10	1,224	+224
15	1,336	+336
20	1,448	+448
25	1,560	+560
30	1,672	+672

The amount of moisture introducted to a blast furnace can be increased as long as the addition is compensated for by increased blast temperature. T. L. Joseph[7] showed how the sensible heat in the blast increases when additional moisture is injected into the furnace. This is shown in Table III. As the moisture content of the blast increases, the operator has a more direct control over the total heat input into the blast furnace process.

TABLE III

Effect of Moisture on the Sensible Heat in the Blast.

Moisture Gr per cft.	Sensible Heat in Blast, BTU	% of Total Heat input
0	1,888,500	24·4
5	2,179,850	28·3
10	2,459,200	31·9
20	3,033,900	39·4

The use of steam in the blast provides another control over flame temperature. A furnace beginning to become hot will invariably indicate this by starting to kick. A reduction in blast temperature results in lowering the flame temperature, thus reducing the volume of combustion products under conditions in the furnace, and the kicking will stop. A furnace that is cold or going cold will take higher blast temperature and operate smoothly. When the furnace starts to respond to the higher blast heat or higher flame temperature, the blast pressure will increase and, unless the blast temperature is reduced the furnace will start to kick. The same sequence of events occurs in the blast furnace where moisture is injected into the blast.

Steel production

Research in steel production has been mainly directed in Europe towards improving the quality of Thomas Steel. This is being done by the C.N.R.M. (Centre National de Recherches Metallurgiques) in collaboration with the I.R.S.I.A. (Institut de Recherches, Sciences Industrie Agriculture) and I.R.S.I.D. (Institut de Recherches de la Siderurgie) in France. Oxygen enriched converters have been

[7] T. L. Joseph : Blast Furnace Lecture, Inland Steel Co., December, 1957.

operated successfully in the Continent. In U.K. oxygen enrichment of side-blown converter has been successfully carried out at the Works of Messrs Catton and Co. Ltd., Leeds. At the Works of Stewarts and Lloyds, Corby (U.K.) in their Bessemer Plant, a careful technique of controlled additions of mill-scale during the converter blow, has been worked out which has roughly halved the average nitrogen and phosphorus contents of the converter steels compared with their earlier Bessemer blown heats, thereby putting them at par with normal quality open hearth steels. Concurrently, attention has been paid to evolve an improved Thomas steel by the use of oxygen-enrichment of the air-blast blown into the converter. This was first done in Germany at the Maxhutte Works, Bavaria. In view of the fact that a pure oxygen blast is deadly severe on converter tuyeres, attention has been directed on the Continent to the operation of converter supplied with mixed blasts of oxygen and other gas mixtures free of nitrogen such as O_2—CO_2 or O_2—super-heated steam or superheated steam and air. All such studies aim at the production of a low nitrogen Thomas Converter steel of improved quality, with nitrogen contents of below 0·004 per cent compared to normal Bessemer blown heats of over 0·008 per cent nitrogen contents. The differences in the quality of Thomas steels and those made by Siemen-Martin open-hearth method, are attributed to the higher nitrogen and phosphorus contents of the former in comparison with the latter. The higher nitrogen and phosphorus contents of Thomas steels induce in them a marked tendency towards work-hardening and strain-age-embrittlement—important factors in deep-drawing quality of steel. By using a blast of 1 part of oxygen (of 92 per cent purity) mixed with 2·5 parts of super-heated steam, a steel containing 0·003-0·004 per cent nitrogen can be obtained. The severe damage to the tuyeres of bottomblown converters inflicted by oxygen, restricts, however, the limit of oxygen in the air-blast to 25–30 per cent of the total volume blown in. The use of cold-steel scrap in oxygen-enriched blast converters has also been successful, although limited to certain percentages of the total charge. Sensible heat absorbed by the nitrogen and lost in an air-blown converter makes the melting of cold steel scrap in converters an almost impracticable proposition. A Bessemer shop equipped with vessels of 20–25 tons capacity operating on 30 per cent oxygen enrichment in the air-blast can be economically coupled with a "tonnage" oxygen plant of 100 tons per day capacity capable of producing medium quality oxygen at 1/10th of the normal cost of oxygen generation. This, however, would require in particular cases re-designing of the steel works to enable the handling of resulting larger steel outputs expeditiously.

In the Siemen-Martin open-hearth process for the production particularly of low carbon steels, the use of oxygen will probably find a permanent application. Oxygen in the open-hearth furnace can be introduced by the so-called oxygen nozzle into the bath or/and by oxygen enriched air under the gas producers and in front of furnace chambers or even at furnace ends. Under favourable conditions, the collective results of providing additional oxygen for the gas producers and in the combustion air and of introducing oxygen directly into the bath, have raised the production by 50% particularly of low-carbon steels. As an aid to quick melting an oxygen-enriched flame is utilised. This process is ideal for 100% cold scrap charges which will absorb the surplus heat without damaging the furnace roof. However, charges comprising large amounts of mixer metal will not derive much benefit from the use of oxygen enriched flames. The introduction of oxygen to the bath by lancing accelerates carbon removal and refining of the bath. This oxygen replaces that of the ore and mill-scale. The turbulence caused by the oxygen nozzle—introduced, ensures better mixing of the slag and metal and helps to speed up carbon and phosphorus removal besides reduction in final nitrogen content of the steel.

Chemical considerations

In a general investigation of the physical chemistry of iron and steel-making processes. Oelsen[8] gives some attention to gases in steel. He quotes Naeser's observations regarding the absorption, by molten iron, of nitrogen from a mixture of gases ; if the nitrogen is mixed with an oxidising gas, e.g. oxygen or carbon dioxide, no nitrogen is absorbed by the metal, but in the presence of a reducing gas, e.g. carbon monoxide or hydrogen, the nitrogen is rapidly absorbed. In order, therefore, to obtain Bessemer steel of minimum nitrogen content, the blast should still be oxidising when it leaves the metal.

The improvements recently achieved at Corby in basic Bessemer steel quality are described by Dickie[9]. The aim was to produce basic Bessemer steel more free from the tendency to work-hardening and strain-age embrittlement, which arises principally from the high phosphorus and nitrogen contents. The problem, then, was to reduce the contents of these two elements in basic Bessemer steel. The phosphorus content was at first reduced by a double blowing process. After blowing in the normal manner, the slag was removed and more lime added prior to a second short blow of half a minute duration. In this way phosphorus was reduced to 0·025 per cent, instead of the normal value of 0·050–0·055 per cent in Bessemer steel, but there was no improvement in the nitrogen content. Dickie has discussed various methods by which nitrogen may be removed from Bessemer steel or fixed in an innocuous condition by suitable additions. However, prevention of absorption of nitrogen was considered preferable to any of the other alternatives, and to this end, the factors affecting nitrogen absorption were studied. It was established that the amount of nitrogen

8 Oelson, W : Kainser-Wilhelm-Institut fur Eisenforschung, Report 481 (abridged), Stahl u. Eisen 1948, 68, May 20, 175.

9 Dickie : H. A. J. Iron and Steel Inst. 1948, 159, Aug. 360.

absorbed was related to (*a*) partial pressure of nitrogen: (*b*) the time of contact; (*c*) the surface area of contact between gas and metal and (*d*) the coefficient of diffusion.

Beneficial decrease in pressure and time of contact may be effected concurrently by decreasing the bath depth. A decrease in the partial pressure of nitrogen in contact with the charge is effected by additions of iron oxide; oxygen-enrichment of the blast would be similarly beneficial. Somewhat paradoxically, the the addition of oxide (mill-scale is most suitable) slows down the rate at which the iron content of the slag increases, so that after blowing to the normal 0·05 per cent phosphorus, the bath is not sufficiently oxidising to promote a good rimming action. The blow must, therefore, be continued for a short time to give the necessary state of oxidation, during which time the phosphorus content falls to about 0·03 per cent. There is practically no nitrogen pick-up at this stage and the finished steel, as well as being low in phosphorus, has a low nitrogen content of the order of 0·008 to 0·010 per cent. The new procedure gives steel of greatly improved physical and chemical properties.

Refining of phosphoric irons

A process for the refining of phosphoric irons by means of pure oxygen and powdered lime developed by Institut de Recherches de la Siderurgie (IRSID) is discussed in a paper by B. Trentini and M. Allard[10]. It combines methods already employed for the desulphurisation of irons by powdered lime, the treatment of very silicious irons in the converter and the thermal control of converter operations; with the well known method of using a cooled oxygen jet in contact with liquid bath, particularly of iron, so as to oxidise and remove certain elements, with or without the production of slag. The IRSID process, designed to convert phosphoric irons into steels of varying carbon content, was first investigated on a scale of some hundreds of kilos, and then on a 3-tonne scale in a small dolomite-lined converter, the results of the second series of tests[11] being as follows:

(*a*) Irons of compositions within the following limits:

C	...	...	3·0 – 3·9%
Si	...	...	0·15 – 1%
S	...	...	0·008 – 0·120%
P	...	...	1·7 – 2·0%
Mn	...	...	0·3 – 0·7%

(*b*) Lime, alternatively coke-burnt with a sulphur content of 0·12 per cent: or gas-burnt, with a sulphur content of 0·07 per cent, in either case being pulverised by a hammer-crusher of Gondard type, and passed through a sieve of 1 mm mesh.

(*c*) Oxygen of 99·5 per cent purity, supplied at a pressure of 15 kg. per square centimetre.

(*d*) Swedish iron ore containing at least 57 per cent of iron, with some 2 per cent of lime and 10 per cent of silica, being charged either at the beginning of the process, as a powder passed through a sieve of 1 mm mesh, and in quantity varying with the composition of the iron; or during the course of the process, in the form of small pieces not over 20 mm in size.

The oxygen jet is situated vertically above the bath, being supported by a pivoted bracket permitting precise regulation of the height, and cooled by the circulation of air of the order of 20 cubic metres per hour. The oxygen contains a suspension of powdered lime, which can be precisely varied as required, and is used in a concentration varying with the composition of the iron and the stage of the process which has been reached.

In operation, after the iron has been poured into the converter, the requisite amount of iron ore is added, depending on the composition of the iron, and the temperature of the bath is measured by means of an immersion pyrometer. The converter is set upright, and the oxygen-lime jet is turned on. The first phase lasts some 12 to 15 minutes, during which about two-thirds of the oxygen, and the whole of the lime required for refining, have been used—the concentration of lime in the oxygen varying with the silicon content of the iron charged. Refining proceeds quietly without frothing or overflowing of the slag, in spite of the short distance between the bath and the lower rim of the spout. At the end of this first phase, the bath contains some 1 to 1·5 per cent of carbon and only 0·2 to 0·4 per cent of phosphorus. The temperature is some 1,600°C, the liquid slag, containing some 5 per cent of iron and more than 20 per cent of P_2O_5, being then largely removed. Before raising the converter for the second phase, a quantity of iron ore, depending on the bath temperature shown by the immersion pyrometer, is added for cooling purposes. The second phase lasts about 10 minutes, and can finally result in the production of dead-mild steel. When using a 3-tonne converter, there is no time to send a sample of metal to the laboratory and wait for the analysis to be made, so as to know how much oxygen is still required. One has thus to rely on the fuel of the flame to determine when the correct carbon content has been reached. Because of the removal of a large quantity of P_2O_5 with the first phase slag, a final phosphorus content of less than 0·025 per cent is readily obtained, in spite of the final temperature being higher than usual. The nitrogen content of the steel so treated is consistently very low, of the order of 0·001 per cent whatever the final temperature may be, this extending from 1,580 to 1,700°C for extra mild steel. It is thus possible to obtain values for the indices, $P + 5\,N$ and $P + 10\,N$, of below 0·025 and 0·030 respectively; such as have been impossible to obtain hitherto by the normal refining methods. The mechanical qualities of hot-rolled test bars from a 2·6-tonne ingot of

10 Revue de Metallurgie, 1958, vol. 55, p. 67.

11 The Engineer, June 27, 1958, p. 968.

composition: C 0·06 per cent; S 0·025 per cent; P 0·013 per cent; Mn 0·35 per cent, N_2 0·001 per cent are shown in Table IV.

TABLE IV

Mechanical qualities

Position		Yield point tons per sq. inch	Tensile strength tons per sq. inch	Elongation per cent
Bottom of ingot: (4·1 per cent crop)				
Surface	...	16·75	21·72	41·3
Centre	...	16·62	21·72	41·0
Middle of ingot:				
Surface	...	16·69	22·29	40·4
Centre	...	17·42	23·18	42·1
Top of ingot: (23·5 per cent crop)				
Surface	...	17·77	22·48	42·1
Centre	...	17·89	23·50	40·1

These mechanical qualities are equivalent to those of open-hearth steel of deep-drawing quality.

Conversion of iron using pure oxygen: development of OCP process

It is feasible to convert pig iron to low nitrogen steel using a blast of pure oxygen which carries with it a suspension of powdered lime to ensure early formation of a basic slag. In his contribution to the International Meeting at Liege on June 18, 1958, P. Metz[12] describes how this technique has been introduced experimentally on full size (28-ton) converters at the works of ARBED—Dudelange (Luxembourg) in what has been named the OCP (Oxygen-Chaux-Pulverisee) process. According to this author, the results already obtained from industrial trials with the OCP process may be summarised as follows:

1. Higher metal yield, about 90 per cent.
2. High consumption of scrap, 215 kg per ton steel (21·5 per cent).
3. Low oxygen consumption, 54 to 58 cu. m/ton iron and low lime consumption, 93 kg/ton steel (9·3 per cent).
4. Great speed of refining, 35 to 45 sec./ton steel in 26-ton converter.
5. Easy dephosphorisation with a high final carbon.
6. Considerable desulphurisation, 60 per cent.
7. Easy making of steel with very low S and P.
8. N_2 content is dependent on purity of refining oxygen; with 96·5 per cent purity oxygen, average nitrogen content is 0·0044 per cent; with 99·5 per cent pure oxygen, it is less than 0·003 per cent.

It should also be pointed out that consumption of dolomite refractories is equal to, if not lower than, normal Thomas practice. It follows that the process is very economical and allows of very high quality steels being made. Finally, for steel makers who wish to eliminate P during decarburisation or in other words to finish the heat on a given carbon content as in the open hearth, the OCP process is of great interest since it can easily be fitted into a standard Thomas steel-making plant.

Conversion of high-phosphorus iron

The L-D process, originally confined to the conversion of iron with not more than 0·3 per cent phosphorus, can be extended to convert irons containing from 0·5 to 1·5 per cent phosphorus if a double-slag method of operation is adopted[13]. The second slag formed can be reused as a first slag on the next heat and in order to tap metal cleanly from under this slag, a special taphole is incorporated in the vessel.

The buffer-slag process

The successful development of the L-D process has shown that conversion of pig iron to steel by the overhead oxygen jet using a stationary converter is feasible provided that the phosphorus content of the iron does not exceed about 0·2 per cent. Meanwhile, developments such as the "Rotor" a., "Kaldo" process have shown that by the use of a revolving kiln-type vessel it is possible to convert higher phosphorus metal. H. Kosmider, H. Neuhaus and H. Schenck have developed what they call a a "buffer-slag process"[14] characterised by the fact that the oxygen, instead of being jetted into the the metal, is made to flood the atmosphere above the bath, thus only coming into contact with the slag. Agitation of the metal must be kept to a minimum if the desired early dephosphorisation is to be successfully achieved. In the buffer-slag oxidation method, refining is conducted indirectly through the slag blanket. In this the method resembles the open-hearth process, since after the fluid, lime slag has been formed, the oxygen blast no longer touches the bath surface. With this method, the start of phosphorus elimination can be satisfactorily advanced, with relatively short blowing times. The nitrogen content of the steel is in a great measure independent of the purity of the oxygen used. Indirect oxidation by blowing oxygen into the slag is also effective in removing sulphur and prevents the appearance of brown smoke. The buffer-slag oxidation method is suitable for basic Bessemer pig, intermediate pig and open-hearth pig, for direct steel-making or the production of an intermediate metal (master alloy) with a phosphorus content below 0·1 per cent and a carbon content over 1 per cent.

In England, the open-hearth furnace is the main steel-making unit today and the main emphasis at

[12] P. Metz—Iron and Coal Trades Review, Oct. 17, 1958, p. 931.

[13] H. Trenkler—Iron and Coal Trades Review, Aug. 29, 1958, p. 501.

[14] Iron and Coal Trades Review, Nov. 22, 1957, p. 1191.

present is on the improvement of regenerator efficiency and increasing the life and output of open-hearth furnaces especially those being converted to oil firing.

Furnace size is an important factor in relation not only to open-hearth furnace but to Bessemer converters and electric furnaces as well. Most of the new open-hearth furnaces will be over 150 tons capacity for cold metal and 225 tons for hot metal, compared with the position in 1956 when of the 372 open-hearth furnaces then operating, 133 were of only 60 tons capacity or less. New Bessemer plants are to be of 40 to 50 tons capacity compared with the 25-ton units now in use, while several electric furnaces will be in the 60 to 80-ton range, compared with the more usual 20-ton furnace of today.

Of the new steel-making processes now at varying stages of development, oxygen is finding increasing applications in conventional steel-making processes after the arrival of tonnage oxygen plant. A comparatively recent development is the introduction of oxygen through the roof of the open-hearth furnace for carbon removal from the bath, a technique for which has been developed with considerable success. Another development is that of using oxygen as an aid to combustion. Both these oxygen applications in the open-hearth can be expected to become more general as tonnage oxygen becomes available at all steel-making centres. Much has been written about the L-D process of oxygen steel-making and extensive literature and data exist on the subject. The L-D process is in commercial use in Austria and in North America but may have only limited possibilities in the U.K. in view of the position that it requires iron of low phosphorus content. Two other processes employing oxygen, the German Rotor process and the Swedish Kaldo process, both depend on the use of a rotating container, and since they can be employed with phosphoric iron, they may have future applications in Britain.

I would also not deal with continuous casting in this paper, as the subject will be discussed elsewhere, apart from pointing out that Russia probably leads the world in continuous casting technique. Two plants for research and development on continuous casting are now in operation by the British Iron and Steel Research Association. The larger of the two plants will cast ingots up to 22 ft. long and has been used with considerable success for many different steels. The other plant has been in operation since September, 1957 and has produced 4 in. square ingots of plain carbon steel to the maximum length of 11 ft.

Production of sponge iron

The M. W. Kellogg Company of New York has recently developed a new process for the production of sponge iron from iron ore using hydrocarbons[15]. Hojalata Y. Lamina S.A. with the engineering assistance of the M. W. Kellogg Co. developed this new process for the production of sponge iron from iron ore with natural gas, and it has been proved technically and economically sound in a plant at Monterrey, engineered by Kellogg and owned and operated by Fierro Esponja, S.A. which has been producing 300 tons of sponge iron per day for several months.

Plans are already under way to set up a plant to produce 500 tons of sponge iron per day embodying several design improvements to increase the thermal efficiency of the process. The reducing gas, produced in a Kellogg high pressured steam reforming furnace, contains 85 per cent hydrogen and carbon monoxide and is sulphur free.

Requiring a much smaller capital investment than that naturally associated with the steel industry the new plant can be built economically on a much smaller scale than conventional steel plants so that a nation with large supplies of iron ore but a limited amount of coal or limestone will find it valuable for their industrial development. It will be also of interest to small producers of speciality steels who rely on purchased scrap and pig iron from other producers. It is felt that this subject would be more adequately covered by Mr. H. A. Havemann who will be presenting a paper on the subject at this symposium.

The low shaft blast furnace

The low shaft furnace has been designed for producing pig iron not only from ore fines but also by using coal which is non-coking. As all know, an experimental low shaft furnace was erected at Ougree by an international body, with the participation of different European countries. The first campaign of the low shaft furnace began on the 13th May, 1953, and ended with the following results :

"It is possible to produce in the low shaft furnace from poor raw materials a basic pig iron but owing to its rather low silicon content, this is difficult to achieve.

"This basic pig iron can be produced from materials which cannot be used in the blast furnace, either because their grain size is too small, or because their composition is not suitable.

"The results obtained in these campaigns represent a very important step towards the final aim and cannot but encourage the promoters of the scheme to persevere in the work in which they are engaged."

Briquetted charge

The other main approach to the development of a successful low shaft process is based on intimate mixing of the components of the charge with the object of encouraging more rapid heat transfer and reduction so that a long period of heating and reaction is unnecessary and the tall shaft avoided. Some attempts have been based on the production of an "ore-coke" in which coal is carbonised together with fine ore or other iron-bearing material, the product being generally

[15] Iron and Coal Trades Rev., Oct. 10, 1958, p. 858.

weak if more than a small amount of ore is used. This principle is expanded in the Weber[16] process, in which it is proposed that ore, coal and flux are finely ground, mixed together with a binder, and compressed into briquettes which are first carbonised in a retort at a temperature of 700 to 800°C and then fed along with lump ore to a low shaft furnace using an oxygenated blast. A simpler modification, however, is the Humboldt process, for which a pilot-scale plant has been in operation at Cologne[17]. In this, ore-coal-flux briquettes are fed without prior treatment as the entire charge to a low shaft furnace working with a normal blast, the coal being carbonised in the upper part of the furnace itself. Results so far obtained show a satisfactory product but a high fuel consumption (about 2 tons of coal per ton of pig iron) although it is claimed that this figure is influenced by out-of-scale effects with the small furnace used (1 metre square hearth) and consumption would be very much better in a full-size unit. It has been suggested that evolution of gases in the carbonising of the coal helps in the reduction of the ore, but it is doubtful if the extent of this is very great, as the speed of reaction is low at the temperatures at which these gases are released.

It is difficult to visualise how the conditions of the process affect the course of reactions, but the intimate mixing of the ore and carbon probably encourages direct reduction without a corresponding increase in case of indirect reduction higher in the furnace. The carbon monoxide in the gas still needs to diffuse into the briquettes to effect reduction in just the same way as in the case of ordinary lump ores.

Tests so far show a poor $CO : CO_2$ ratio in the top gases as compared with good standard blast furnace practice. Difficulties with the process include the necessity to crush all the charge below about $\frac{1}{8}$ in the cost of binder (usually coal-tar pitch), and the mechanical difficulty of briquetting a very large continuous throughput if the process were used on a commercial scale. It is necessary, too, to incorporate a plant to collect the by-products from the destructive distillation of the coal and to make suitable use of the top gas, which has a considerably higher calorific value than normal (150 to 170 B.Th.U./cft.). It is expected that briquetted charge experiments will be tried in the Liege Low Shaft Furnace and, as in the case of work on oxygenated blast, the results will be of much interest to countries short of good coking coal.

Humbolt low shaft furnace

Jaeger[18] gives an account of experimental work carried out in Germany on smelting fine ores with non-coking coals in a low shaft furnace. The raw materials are introduced in the form of briquettes made from finely ground ore, coal and fluxes. Pilot trials showed a low shaft furnace (17 ft.) to be suitable. Pre-coking occurs in the top of the stack, normal reduction near the middle and fusion in the hearth. The initial coking action gives a strong briquette in which all materials are in intimate contact, so that both heat transfer and reduction are facilitated. It was found that a suitable temperature-gradient could be maintained without addition of oxygen to the blast. The exit gases are hotter than those from a normal blast furnace, and, because of the coal volatiles, have a high C.V. (about 150 B.Th.U./cft.). After the gases have passed through a dust catcher, tar is condensed and is subsequently used for bonding the briquettes. Satisfactory process-control is effected by adjustment of blast volume and temperature or of the ratio of ore to fuel and because of the low throughput time ($1\frac{1}{2}$–2 hr.) hearth response is rapid. Output per unit volume is about $2\frac{1}{2}$ times greater than the best results recorded by Tigerschiold[19] at Domnarvet. A large unit constructed in 1949 at Humboldt used hot blast, the recuperator being fired from the furnace gas. Iron and slag compositions were on the average: C—3·3 per cent, Si—2·8 per cent, Mn—0·2 to 1·8 per cent, S—0·03 per cent and CaO—44·3 per cent, SiO_2—29·3 per cent, Al_2O_3—18·5 per cent, MgO—2·4 per cent, S—2·5 per cent. The process is considered to be economically feasible; the capital cost is relatively low for an equivalent blast furnace output, blast requirements are smaller and coking plant is eliminated; moreover, sulphur removal is particularly good.

General observations

Under-developed countries like India have a special interest in studying alternative technological processes in connection with iron and steel making. Certain areas which have resources for economical production of steel for domestic markets are likely to find that the development of the iron and steel industry will promote their economic development. The regional expansion of the steel industry on the most economical basis will be promoted by trade in steel products among the countries concerned. In this context, several alternative processes can be considered such as the Krupp-Renn process, Wiberg-Soderfors process, Swedish iron process, etc.

The outstanding low-temperature methods in commercial operation are the ceramic, or brickyard, process and Wiberg continuous shaft process, both in use in Sweden and the Krupp-Renn process, which has been used in Germany, Japan and Czechoslovakia, and which employs a large rotary kiln in which the ore is mixed with, and reduced by, pulverised coke, anthracite dust or other fuel.

16 Lameck, P.—Iron and Coal Trades Rev., 156, 1948, p. 1173.

17 Anon—Post-war work in Germany, ibid, 161, 1950, p. 833.

18 Jaeger, F. (1950): Stahl. u. Eisen, Dusseldorf 70, 71.

19 Tigerschiold—Amer. Inst. Min, Metall. Engrs., Blast Furnace, Coke Oven Raw Materials Proceedings.

Many other low-temperature processes in the experimental stage continue to be the subject of considerable study in a number of countries. The Japanese used the sponge iron method to produce raw material for large-scale, centrally located refining and rolling mill operations. This type of industrial organisation may be useful if there are a number of local iron ore deposits which can be exploited through small sponge iron plants, and if the overall demand for steel products is large enough to support a modern rolling mill, as for example, in China or in Mexico.

A ceramic or brickyard process, the Hoganas process, invented by Sieurin, has been in regular operation since 1911 in Sweden. In recent years, much work has been done in Canada and the United States towards the further development of this type of process. It is also reported that a small Mexican steel company has decided to install a brickyard sponge iron plant. Under this method, fine ore is charged into containers with fine dust; the containers are heated in a furnace, of the type frequently used for burning bricks, where the ore is reduced. Labour requirements for this process are relatively high. Where an extremely rich and pure iron is used, as in Sweden, the product may be used as melting stock for high-quality steel. Recent developments in the iron and steel industry in China have been given in a separate paper before the symposium but Figs. 5 and 6 will illustrate what is still being done in a primitive way there for direct reduction of iron ore.

Lubatti process for smelting iron-ore fines

A development in using electric furnaces for solving the problem of processing iron ore fines is being investigated in conjunction with the Lubatti electric furnace in Italy[20]. The process is carried out in a furnace consisting essentially of flat hearth with a refractory lining and one tap-hole each for metal and slag. The top of the hearth is entirely open, the furnace itself having no roof. Further, it requires neither tilting mechanism as in the case of conventional arc furnaces nor any rotating mechanism as is used in various other methods of ore reduction. The greater part of the furnace space is taken up by molten slag, which is heated by means of ball-shaped graphite electrodes dipping into the melt. These electrodes are fitted to water-cooled electrode holders at the sides of the furnace, thus permitting free movement both horizontally and vertically.

The burden, consisting of fine ore, is fed continuously by a conveyor on to the surface of the liquid slag in such a way that a layer of 6 to 8 in. thick floats on the surface of the slag. The

[20] From an article on "Recent Advances in Steel Technology" prepared by the Industry Division, Economic Commission for Europe and published by the European office of the United Nations, Geneva.

Fig. 5.
Direct reduction of iron ore in crucibles (People's Republic of China).

Fig. 6.
Direct reduction of iron ore in crucibles (People's Republic of China).

ore is reduced within this layer and the energy required for the reduction process is taken from the slag-bath, which has a temperature between 1,500 and 1,600°C. The carbon dioxide gas generated during the process escapes through the layer of the burden which, owing to the fact that it is comparatively thin, offers no appreciable resistance to the passage of the gas. Since the particles of the burden are small and thus have a large surface area in relation to their weight, the carbon-monoxide is utilised for pre-reduction within the layer of the burden.

The gas escaping at the surface contains on the average twice as much carbon-dioxide as carbon-monoxide. It is claimed, therefore, that the energy contained in the coal is considerably better utilised than in the case of either the conventional blast furnace or in a low shaft furnace. The gas escaping burns away on the surface of the burden in the form of small flames spread over the whole area of the furnace top. In the contact zone between burden and slag the reduced metal is melted to form small globules, which then descend through the slag layer and collect in the furnace bottom.

At present, four Lubatti furnaces which are in production, make pig iron from pyrites and various iron-rich dusty residues. In a furnace of 1,500 kVA, rating, fitted with six electrodes, a daily output of 10 tons is being achieved, the iron having the following percentage composition :

C	...	...	2
Si	...	...	1·5
Mn	...	...	1
P	...	...	0·11
S	...	...	0·23

Power consumption is 3,222 kWh/ton of pig iron produced, the make up of the burden to produce one ton pig iron being as follows in kilogrammes :

Pyrites ashes	...	...	1,500
Iron sand	...	...	8
Manganese ore	...	...	64
Mill scale	...	...	209
Limestone	...	...	420
Sand	...	...	29
China clay	...	...	80
Loam	...	...	2
Bauxite	...	...	11

The carbon required for reduction is added in the form of anthracite and coke fines. Slag amounting to 763 kg/ton of iron produced results from this burden. Despite the high sulphur content (1·9 per cent) a 90 per cent desulphurisation of the burden is achieved.

Advantages and problems

The main advantages claimed from the Lubatti process are the following :

1. Fine ores and fine coal can be used.
2. A wide variety of raw materials such as ore dust, pyrites ashes, etc. can all be used conveniently.
3. The reducing agent can be any type of coal, coke or brown coal dust.
4. It is claimed that low-carbon irons can be produced.
5. Pre-reduction of the burden by the utilisation of carbon-monoxide is possible.
6. The furnace has a good thermal efficiency, owing to the insulating effect of the burden which is continuously maintained above the level of molten slag.
7. Consumption of electrodes is very low compared to electrode consumption in conventional arc furnaces.
8. The capital cost of the furnace itself is low and it can be housed in a simple building and needs no complicated and expensive ore-preparation plant.

The only major difficulty which has so far presented itself is the problem of finding a durable refractory lining for the hearth, although carbon-rammed linings are satisfactory where they come into contact with the slag, the carbon of this type of lining is picked up by the metal and therefore slowly consumed. On the other hand, magnesite bricks are suitable for the furnace-bottom but are unsuitable for the side walls as they are attacked by the slag.

DISCUSSIONS

Mr. D. N. Sharma. TISCO : Dr. Nijhawan has given very valuable information on the latest developments in Russia. I would request him to comment on any aspect new to us in India, for example use of thermocouples in the hearth, stack, to study the life of their furnace lining etc.

Dr. B. R. Nijhawan (Author) : I did in particular note that they had two sets of control cabins, one containing all the instruments for the routine control operation and another entirely for research and development work. The Russians have developed much better cooling plates and at short intervals thermocouples had been inserted right from the stack to the hearth level, each of them being specially regimented for maintaining charts, watching fluctuations in temperature and for effecting optimum uniformity. The most impressive factor is that complete freedom is given to research and development work irrespective of the position whether it is going to yield useful results or not. A large integrated plant for research and development work in iron and steel technology at Tula was entirely at the disposal of the research worker. Their confidence in research is such that it might not be very long before they start producing steel directly from the iron blast furnace.

As regards furnace lining, I was told that the average life of blast furnace lining was about nine years. The furnace produces over six million tons of pig iron before it is blown out. Separate shafts of the furnace were kept ready for switching on to a relined hearth so that the time required for the change over was of the order of 3 to 4 months.

Mr. Manohar Singh, Banaras Hindu University, Varanasi : I shall be obliged if Dr. Nijhawan will please comment on the following two points :

1. What is the extent of oxygen enrichment that is possible in a blast furnace ?
2. It has been claimed by some that oxygen helps in avoiding hanging and chanelling in the furnace. I would like to know how this exactly works.

Dr. B. R. Nijhawan (Author) : According to Russian work, air blast enriched in oxygen really produces little beneficial effect as far as pig iron production is concerned unless concurrent action is taken to humidify the air blast to a suitable balanced composition. In Russia, humidification is done to the extent of 30 gm/cu. m ; oxygen enrichment yields good results for ferro-alloy production in iron blast furnace.

As regards the second question, I would say that introduction of oxygen will not appreciably eliminate hanging and channelling. The effect I mentioned was that of moisture addition which lengthens the combustion zone. It has been established that moisture does improve the general penetrability and this is one of the physical effects claimed apart from the hydrogen generation which is said to improve the reduction process. The mechanism of reduction of iron ore by hydrogen is different from that effected by CO. In Russia, it is felt that hydrogen reduction is more diffused than in the case of CO and this in itself brings about a general improvement in the tone of the furnace. Oxygen enrichment has been discarded for pig iron production but some experimentation work is in progress for ferro-alloys and the results are said to indicate considerable improvement in the output of ferro-alloys and reduction in the coke rate.

Now to further emphasise the effect of moisture addition I would add that for each extra gram of moisture added per cubic metre of air blast, you need theoretically 90°C increase in the blast temperature to account for the endothermic reaction of steam decomposition, or speaking the other way round, you need 22·4°F air blast increase in temperature for every 1 grain of moisture added per cft. This is a theoretical basis, but in practice in Russia they actually increase the temperature by 250°C for every 10 gms of moisture per cubic metre. Unless you compensate for the heat loss from the endothermic reaction, resulting from humidification, by increase in blast temperature, humidification as such is useless and will in consequence be damaging the entire operation of the blast furnace. I would like to stress the point that it is not oxygen enrichment or blast humidification alone that have to be attempted industrially but the blast humidification must be accompanied by an increase in the blast temperature depending on suitable addition to stove capacity, and arrangements to increase the sensible heat of the air blast ; this is one point to be very clearly borne in mind should we consider implementing this technique in Indian environments. In India, as you know, the moisture content of the air varies very considerably during monsoon and winter, so one of the advantages of blast humidification will be that you will get rid of these fluctuations in the humidity of the atmosphere. You will get a very uniform operation of the blast furnace but, as already pointed out, this must be accompanied by a suitable increase to get a higher blast temperature. These aspects have been discussed theoretically in many Russian and American journals such as :

1. The enrichment of furnace gases by hydrogen and CO accelerated reduction processes ;
2. Improvement in aerodynamic conditions of the furnace following on the reduction in the gas volume generated per unit coke weight ; and
3. General uniformity in furnace operations arising out of freedom from atmospheric moisture fluctuations, etc.

Blast temperatures in the U.S.S.R. are of the order of 900-950°C at some works—the average being 800–850°C. They are now going to raise these temperatures to 1,100–1,200°C. The moisture additions were made after the blowers and before the stoves to prevent corrosion of blower blades resulting from humidified blast.