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PROGRESS IN BLAST-FURNACE PRODUCTION IN THE SOVIET UNION[1]

by

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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.

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SUMMARY

At the present time, iron is produced by the classical method (blast-furnace ironmaking) and by direct reduction (mini-plants). The blast furnace will undoubtedly remain the basic processing unit for the primary production of iron for a long time, especially in those countries which have available large supplies of coal, particularly the coking varieties.

Success in the use of formed metallurgical coke has also contributed to the paramount role of blast-furnace production.

The Soviet Union stands first among the advanced iron and steel producing nations in terms of the level of blast-furnace production. The excellent operating characteristics of Soviet blast furnaces are the result of the use of agglomerated raw materials (100% sinter and pellets in the ore portion of the burden), the lowered fines content in the burden, the increased concentration of iron in the agglomerated raw material, and the improved stability of its composition.

Substantially more efficient blast-furnace operations have been made possible as a result of the radical restructuring of the reduction gases in the furnace brought about by the injection of mixtures containing carbon and hydrogen (in the gaseous, liquid, and solid states) together with the oxygen enrichment of the blast, increases in blast temperature, and the use of higher top-gas pressures.

Combined blowing (the joint use of natural gas and oxygen-enriched blast) has become standard practice in Soviet blast-furnace production. A smelting technology involving an increase in the oxygen concentration in the blast to 35 per cent and above has been perfected and successfuly tested. Fuel oil and coal dust are being employed as injectants at a number of plants.

Iron quality is being upgraded through improvements in the uniformity and stability of coke and other burden materials, the use of better slagging conditions, the introduction of automatic temperature control in the furnace and of automatic control of the smelting operation, and the application of synthetic slags and desulphurizers for processing outside the furnace.

The advances recorded in recent years in burden preparation and in continuously improving smelting techniques have provided the impetus for the construction of larger and better designed blast furnaces. Maximum blast-furnace capacity in the USSR is 3,200 m^3; however, furnaces of 5,000 m^3 capacity are being built.

The Soviet Union has achieved a very high level of progress in blast-furnace production and is ready and able to co-operate in this area with interested countries.

Despite the growing use of plastics and other synthetics, steel continues to be one of those materials whose rate of consumption is rising rapidly. Assuming the same growth rate (5.7 per cent) as over the last twenty years, by 1990 the world output of steel will have reached some 1,700 million tonnes, as opposed to 570 million tonnes in 1969.

The basic method for the initial stage in the production of iron and steel at the present time is the blast-furnace process. In addition, techniques for obtaining iron directly have been developed for more than a hundred years. Because of its high productivity and low fuel consumption, the blast furnace has been able, over the last twenty years or so, to withstand competition from other metal-making methods, despite reports that it was virtually being overtaken by the new direct-reduction processes. Nevertheless, the dominance of the blast furnace is now in jeopardy because of a shortage of coking coal. If one considers the plans made for the expansion of iron and steel production throughout the world, the coking-coal situation must be regarded as critical. Even if coke consumption is reduced to 270 kg per tonne of pig iron, by 1990 about 440 million tonnes of coking coal a year will be required if 90 per cent of the total output of steel is to be produced from liquid iron - and this is on the assumption that 35 per cent of the total coke requirement will be replaced by tuyere injection of a liquid, gaseous, or solid fuel utilized at 100 per cent of its theoretical efficiency. Given this rate of consumption, the known coking-coal reserves will last for not much more than twenty-five years. For this reason, direct-reduction processes are the subject of far wider attention now than formerly, and, although on a number of points there is no consensus among experts regarding the prospects for the development of ferrous metallurgy over the next decade, most of them nevertheless concur that in the near future direct-reduction equipment will be in a more favourable position than has hitherto been the case.

As a consequence, two trends will continue to exist in iron and steel production – the traditional methods will be retained and further improved and new techniques will be developed. On the one hand, large-scale plants producing iron in large quantities will be set up, primarily to supply oxygen converters (that is, the relatively expensive process involving coke furnaces, blast furnaces, and oxygen converters), while on the other hand mills with a capacity of about 1 million tonnes per year (so-called "mini"-mills) will be developed to produce the metal from the ore directly, the capital costs being significantly lower in this case.

Netherthelass, considering the present state of direct iron production, it can be said that the blast furnace will be the principal system used in the initial production of the metal for a long time to come, particularly in those countries where large coal reserves (including coking coal) are available. The capacity of blast-furnaces has risen by more than three times in the last ten years. The 5000-m^3 furnace under construction in the USSR is expected to have a capacity of up to 12,000-15,000 tonnes of iron per day.

With respect to a number of technical performance figures, Soviet blast-furnace production occupies a leading position among countries having highly advanced iron and steel industries. In 1971, 89.3 million tonnes of iron were produced. The best average annual productivity was 2.25 tonnes/m^3/day, at a coking rate of 455 kg per tonne of iron and with a sulphur content of 0.018 per cent in the iron. The high performance figures recorded in the Soviet Union are achieved through the use of lump raw material (100 per cent agglomerate and pellets in the iron-ore part of the burden), reduction of the fines content in the burden, increasing the iron concentration in the lumped raw material to 58-59 per cent, injection of additives containing carbon and oxygen (gaseous, liquid, and solid), oxygen enrichment and maximum heating of the blast, and the application of a rational melt technology.

An increase in iron production of some 25 to 30 million tonnes is planned for 1975, and this figure will rise even more substantially in the period 1980-1990. At the same time, productivity will increase to 2.5-3.0 tonne/m^3/day, while the coke rate will fall to 320-350 kg per tonne of iron. The further development and improvement of blast-furnace production in the USSR will take place along the following lines:

(1) A radical improvement in the preparation of the burden for smelting (by greater iron enrichment, stabilization of the chemical and granulometric composition, and improvement of lumping methods), thus ensuring far better gas dynamics and further intensification of the process;

(2) A fundamental change in the composition of reduction gases through the application of combined blasting with a high concentration of oxygen and an appropriate proportion of gaseous, liquid, and solid additives containing carbon, hydrocarbons, and hydrogen, and also through the use in the melt of reduction gases heated to a high temperature;

(3) Improvement of the quality of the iron;

(4) The construction and putting into operation of large blast furnaces with a capacity of 5000 m^3 and above.

Ways to improve the preparation of raw materials for blast-furnace processing

The worsening shortage of coking coal noted above focuses attention on the use in metallurgy of formed coke obtained from gas and low-caking coal, which are abundantly available.

A method has been developed in the USSR for the production of formed coke - the L.M. Sapozhnikov method - and is now near the stage of industrial application. A blast-furnace heat conducted with 25 per cent of the conventional coke replaced by the formed variety indicated that there was virtually no change in the coke rate, but that productivity rose by 4.3 per cent.

There also appears to be promise in the use of burden materials based on formed coke and containing, in addition to carbon, an iron-ore component and fluxes. Because of the large surface of the reacting materials, when they are heated in any gaseous medium the reduction processes are activated, with slag-formation occurring in the lump itself. Because of this, and also because of the possibility of optimally shaping and sizing the material, there is an improvement in the gas-dynamic conditions of the melt.

During the next 10-15 years the existing methods of raw-material preparation now in general use will be improved mainly through procedures which are already tried and familiar.

One of the key trends here is further increasing the iron content in the iron-ore portion of the burden through the beneficiation of mined and oxidized ores. According to data supplied by the Institute of Ferrous Metallurgy (USSR), increasing the iron content in the agglomerate by 1 per cent results in a 2.[illegible] per cent increase in blast-furnace productivity and a 1.6 per cent drop in the coking rate.

Given the existence of a theoretically possible limit to ore and concentrate enrichment, a further sharp upturn in the iron content in blast-furnace raw material can be achieved through metallization of the material. This technique is also being applied in the Soviet Union.

An important trend in raw-material preparation is stabilization of the chemical and granulometric composition of the agglomerate and pellets. By standardizing the iron ores and concentrates, it will be possible to keep the fluctuation in iron concentration within the range of ± 0.2 per cent. Within the same time period, measures will have been taken at all the country's agglomerate mills to produce cooled high-strength agglomerate with piece sizes of not more than 75 mm and a fines content (0-5 mm) of not more than 5-9 per cent.

<u>Varying the composition of the reduction gases in the furnace and the thermal support for smelting process</u>

One of the main ways of reducing coke rates and improving smelting efficiency is through the inclusion of various additives in the blast, which either alter the composition of the reduction gases in the furnace and thus cut down the degree of direct reduction (oxygen with natural coke and heated reduction gases), or directly replace the carbon of the coke by the carbon of the additive (coal dust). Certain of the additives improve smelting performance by altering the composition of the gas in the furnace and by directly replacing the coke carbon (motor fuels, masut (fuel-oil), tar, masut-coal paste, and others).

Combined blasting - that is, the use of natural gas together with an oxygen-enriched blast - has become an established feature of Soviet blast-furnace operation.

When natural gas was used alone, the r_d (the degree of direct reduction of iron from ferrous oxide) dropped from 50-60 per cent to 30-35 per cent; this was accompanied by a reduction in the coke rate by 15-20 per cent and an increase in productivity by 2-4 per cent. Oxygen-enrichment of the blast, with the natural-gas rate appropriately increased, leads to even higher performance figures. Increasing the oxygen content in the blast by 1 per cent increases furnace productivity by 2.0-2.5 per cent, while the addition of 1 m^3 of natural gas will save 0.9-1.0 kg of coke. A technological process developed by Soviet metallurgists for running a blast furnace with a 30-per-cent oxygen blast and the appropriate rate of natural gas has made it possible to achieve productivity rates of 2.0 tonnes/m^3/day and coke rates of 430 kg/tonne of iron with an iron content in the ore portion of the burden of about 53 per cent.

The USSR has devised a smelting process with the oxygen content in the blast increased to 35 per cent and more which has been extensively and successfully tested under plant conditions. The use of this technological advance results in a significant reduction in the cost of the iron.

The large natural-gas reserves in the USSR have led to the extensive use of this resource as a partial substitute for blast-furnace coke. Theory and practice show that coke gas can be an even more efficient substitute for coke. A special feature of the use of coke gas results from its composition - 60-63 per cent hydrogen and 25-28 per cent methane - which justifies its being regarded as partially converted natural gas. By virtue of the presence of 25-28 per cent methane, coke gas can be used as an ordinary blast additive; however, because of its high hydrogen content it can be injected into the furnace in the same way as converted gas (coke gas plus technical oxygen). Heats conducted in the Soviet Union with half the natural gas injectant replaced by the equivalent quantity of coke gas have demonstrated that this results in a 3.4 per cent increase in productivity coupled with a 1.2 per cent decrease in the coking rate. An even more striking effect will be achieved if coke gas and oxygen are used together, and also if heated coke gas is injected. Coke gas can be heated to 700-800°C without the separation of carbon black, thanks to the presence in the gas of relatively small amounts of methane and the high content of hydrogen, the presence of which inhibits the CH_4 thermal dissociation reaction. The Soviet Union is at present building an apparatus for the injection into a high-capacity blast furnace of heated coke gas with the blast simultaneously oxygen-enriched to 30 per cent. Calculations indicate that this will result in a productivity of over 2.0 tonnes/m^3/day and a reduction in the coking rate by 100 kg per tonne of iron.

Theoretical studies and individual testsmelts have also demonstrated the high degree of efficiency to be gained through the use of: converted gas obtained by oxidising natural gas to CO and H_2 in special equipment (converters) and heated to a high temperature; high-temperature top gas previously purged of CO_2 and H_2O; and heated reduction gases obtained in other ways. By way of example, a coke-rate reduction of 95 kg per tonne of iron and reduction in the raw natural-gas rate of 100 m^3 per tonne of iron have been achieved in the Soviet Union by injection of converted gas obtained from a mixture of top gas, natural gas, and water vapour heated to 1,200°C.

Because of a number of technical difficulties, the injection of heated reducing gases has not yet passed beyond the stage of experimental testing. Nevertheless, the use of these gases in blast-furnace production is so effective that there is every reason to look forward to the introduction of this technology in the very near future.

Together with the use of gaseous additives for the partial replacement of coke, liquid-fuel injection has also become quite common. The theoretical principles behind the use of liquid hydrocarbons are somewhat different from those relating to natural gas. This is explained by the different carbon-to-hydrogen weight ratio: in natural gas it is 3, and in mazut, 7. Consequently, when mazut is used, the amount of hydrogen in the gas will be lower and the coke saving will depend both on the direct substitution of mazut carbon for coke carbon (mainly) and also on the decrease in direct reduction (r_d). Liquid fuel can also be used to good effect with oxygen blast enrichment since heat is lost as the hydrocarbons decompose and, consequently, the tuyere hearth temperature will be lowered.

Mazut injection into blast furnaces in the USSR began as early as 1960, and by 1964 this additive was in use at 20 furnaces in the Urals. However, after natural gas was brought to this region, mazut consumption in blast furnaces dropped off and at the present time this product is being used at fewer furnaces.

Soviet blast-furnace experience shows that mazut is an extremely efficient substitute for coke, particularly when gaseous additives are not available. Reliable designs have been developed for mazut injection equipment, and a blast-furnace operating procedure has been worked out for the addition of mazut both to an atmospheric blast and to a blast enriched by oxygen.

The difference in furnace performance achieved through mazut injection depends on the specific conditions - the mazut consumption rate, changes in blast temperature and humidity, and so on. At one blast furnace in the Urals the injection of 95 kg of mazut per tonne of iron resulted in a drop in the coke rate of 15.7 per cent (152 kg/tonne of iron) and an increase in productivity of 8.8 per cent; the replacement ratio was 1.6 kg of coke to 1 kg of mazut.

The delivery of pulverized coal to the furnace hearth is another effective means of economizing on coke, primarily through the direct substitution of the carbon of the additive for the carbon of the coke. With this method, the degree of direct reduction remains at virtually the same level. Theoretical research has shown that coal-dust injection can be a means of saving coke throughout the entire r_d variation range, even when opportunities for effecting economies through an increase in the reduction potential of the gas have been totally exhausted. The limit on the quantity of fuel injected would seem to be the attainment of minimum gas permeability by the burden column, preventing the furnace from operating evenly, and also the possibility of gasifying large amounts of pulverized coal in the limited space of the blast furnace's oxidizing area. Coal-dust fuel can thus be successfully used both under present operating conditions and in the future when coke consumption will be considerably curtailed. Experience in blast-furnace operation shows that various coal grades can be used for injection (low-ash, high-ash, high-volatile), while, other conditions being equal, higher replacement ratios are achieved by injecting low-ash, high-carbon coals. Simultaneously with the injection of the coal, natural gas may also be fed in, resulting in additional coke economies. To compensate for the lowered tuyere hearth temperature, when coal is injected the blast may be enriched with oxygen, thereby contributing to improved furnace productivity.

Coal-dust fuel is periodically used at a number of the blast furnaces in the Soviet Union at the present time.

The Soviet Union has now designed and perfected an industrial pneumatic system for the injection of coal-dust fuel into blast furnaces which offers a high degree of reliability and uniformity, both with respect to time and to distribution around the circumference of the furnace, over a wide range of flow rates. It is our opinion that development of this design opens up very favourable prospects for replacing scarce coke by inexpensive coal.

The successes of the Soviet Union in perfecting smelting processes involving the injection of a variety of additives unquestionably put it in a good position to lend assistance (on the basis of reciprocal advantage) to developing and other countries in the acquisition of equipment and the application of blast-furnace technology involving the injection of natural gas, liquid and solid fuel with an atmospheric blast and with a blast oxygen-enriched to 35 per cent and more, for the purpose of ensuring a substantial reduction in coke rates and an increase in furnace productivity coupled with lower production costs for iron.

One effective technique for holding down the coke rate is the use of a high-temperature blast. The blast heat of 1200-1250°C achieved at the present time does not constitute a limit, and by efficient air-heater design and the use of high-quality refractory materials it can be increased to 1400-1500°C. It is important to note that, with lower coke rates and the use of oxygen-enriched blasts, the amount of heat carried into the furnace by the heated blast drops, because of the considerable reduction in the volume of blast per ton of pig. For this reason, heating the gaseous blast additives is today of growing importance.

The blast-furnace process can be intensified by increasing the pressure of the gases in the working area of the furnace, which results in a contraction of the volume and a lowering of the speed at which these gases travel and creates the necessary conditions for increasing the blowing rate and the quantity of carbon burned at the lance. Under plant conditions, increasing the pressure by 0.1 gauge atmosphere yields a 1 per cent increase in productivity. In the USSR virtually all blast furnaces operate with stepped-up pressure in the working chamber, the maximum top-gas pressure being 2.0 gauge atmospheres. Plans for a number of furnaces call for a top-gas pressure of 2.5 gauge atmospheres.

Improving Iron Quality

Under modern conditions, the quality of the iron must satisfy the following major requirements:

(a) It must contain a minimum quantity (governed by the subsequent stage of processing) of harmful components (sulphur, phosphorus, arsenic) and undesirable substances (Pb, Zn, Cu, *et al.*);

(b) It must contain extremely low quantities of silicon and manganese;

(c) It must be stable with respect to composition and content of chemical elements (root-mean-square deviation of not more than 0.2);

(d) It must contain the smallest possible quantity of non-metallic inclusions, gases, and graphite flakes.

These requirements can be met by improving the technology of blast-furnace melting, and specifically by:

- Improving the homogeneity and stability of the iron ore and coke to be melted;

- Increasing the sulphur-absorptivity of the slag (by raising its temperature and including slag-diluent and sulphur-absorbing agents);

- Controlling the thermal conditions and progress of the heat automatically through the use of computer systems.

Iron quality can also be greatly improved by treating it outside the furnace with synthetic slags and desulphurizing agents.

The Soviet Institute of Ferrous Metallurgy has developed and introduced an industrial method for the desulphurization of iron in the pig-transport ladles. This method offers a high rate of productivity (6 to 8 ladles of iron are processed simultaneously), low consumption of the desulphurizing agent, and the possibility of controlling the rate of the desulphurization process and of obtaining a metal with the desired content of sulphur (down to the trace level). Cast iron processed by this method is distinguished by excellent casting and strength properties.

Defective casting due to non-metallic inclusions is completely eliminated. This technique of desulphurizing the iron outside the furnace can be recommended for general introduction at iron and steel works in the developing countries.

Major trends in increasing the capacity and improving the design of blast furnaces

Recent progress in the preparation of burden raw materials and further technological advances have stimulated efforts to increase the capacity of blast furnaces and improve their design. The construction of high-capacity furnaces means significantly lower capital investment, sharply increased labour productivity, and lower coke rates through a reduction in the heat expended per unit of iron. Heat losses per unit of external furnace surface are practically independent of capacity. Therefore, a large furnace with a high output of metal is advantageous. It has been calculated that increasing furnace volume by 1,000 m^3 results in a reduction of heat consumption by 43,600 kcal per tonne of iron. Translated into terms of coke (assuming a combustion heat in the tuyeres of 2,340 kcal per kg), this means a saving of 18 kg per tonne of iron.

It is extremely important to bear in mind that, as the cross-sections of blast furnaces are increased, difficulties are encountered in the proper distribution of the gas flow over the cross-section, which may lead to poorer utilization of the chemical and thermal energy of the gases and, consequently, to an increase in the coke consumption rate. For this reason, if large blast furnaces are to be built, in order to take fuller advantage of their properties, improvements must also be made in the quality of the raw materials in size (stability, optimality of dimensions and form) and in physical characteristics (initial and furnace strength).

The study and analysis of large-furnace operation indicates that increasing the hearth diameter is not as yet an obstacle to increasing the volume. The optimal volume of the furnaces to be built will be determined by the capacity of the iron and steel plant.

The largest blast furnace in the Soviet Union at present has a volume of 3,200 m^3, although a 5,000 m^3 plant is now being built. Once this unique furnace has been made fully serviceable, it will have a daily output of 12,500 - 15,000 tonnes of iron with a minimal coke rate.

The great experience which our metallurgical industry has amassed in the planning and building of large blast furnaces of varying sizes and high performance enables us to assist developing countries with technical documentation, equipment, and specialists in the planning and building of blast furnaces.

In conclusion it may be said that in the area of blast-furnace production the USSR has achieved a very high level of progress. This progress provides a basis for co-operation in the area of improved production technology with interested countries at whatever level and to whatever extent is felt to be desirable.

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