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TECHNICAL PROGRESS IN IRON-MAKING

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INTRODUCTION

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Blast furnace ironmaking is now at a high technical level. Mechanized blast furnaces with useful volumes of 2000 m^3 are now in use. Furnaces of even greater capacity, capable of melting about 5500 tons of iron a day, are now planned.

Extremely rapid furnace driving rates, with the blast at a high temperature, have been achieved by using fluxed concentrate, raising the pressure of the gases in the furnace, and improving the physical and chemical properties of the charge. Natural gas and fuel oil are now used on a large scale. Coke consumptions of 380 kg/ton of iron have been achieved. Large scale experiments on blowing different fuels into the furnace hearth are being conducted; these experiments are aimed at greatly reducing coke consumption in ironmaking.

Great successes have been achieved in ironmaking. This relates in particular to the production of pig iron in the USSR, Japan, the USA and Sweden, much work having been done in these countries on improving stock quality and constructing large blast furnaces; new and efficient methods of ironmaking have also been developed. The result has been a great improvement in the utilization of blast furnace capacity. For instance, fig 1 shows that in the USSR utilization of blast furnace useful capacity has reached about 1.4 tons/m^3 per day, while the present mean specific consumption of coke is 625 kg/ton of iron for steelmaking.

Much better figures have been achieved with individual furnaces at certain works in the USSR. Daily pig iron production per m^3 of useful furnace capacity has reached almost 2 tons, at coke consumptions of about 500 kg/ton of iron.

The lowest coke consumption in the world has been achieved in Japan. In 1955 it was 711 kg/ton of iron, while the mean coke consumption is now less than 600 kg/ton of iron (1,2). Coke consumption is much lower than the mean figure at certain works. In March, 1962, using 65 kg of fuel oil per ton of iron, the coke consumption at the Fuji Seitsu Works at Kamaishi was 464 kg/ton of iron, while the mean coke consumptions at the three works of this firm in 1962 were respectively 537, 505 and 514 kg/ton of iron (3); a coke consumption of 380 kg/ton of iron was achieved at a blast furnace at the Osaka Works on a charge consisting entirely of fluxed concentrate; the blast was oxygen-enriched and fuel oil was used. It is suggested that in the next two or three years blast furnace capacity utilisation in Japan will reach a mean figure of about 2.2 tons/m^3 a day.

Experience in the USSR, Japan and the USA, also theoretical calculations, have provided grounds for the assertion that, if a combination of effective measures are employed in ironmaking, we can count on producing more than 2.2 tons of iron a day per m^3 of furnace capacity, and on achieving coke consumptions of less than 300 kg/ton of iron. We must assume that the blast furnaces of about 2000 m^3 capacity which have been constructed in a number of countries are not the largest possible. There are plans for constructing furnaces of capacities exceeding 2500 m^3, the daily production of pig iron in which will be about 5500 tons.

Several methods of producing pig iron not using blast furnaces (low shaft furnaces, electric melting, and direct iron production) have also been developed considerably during this century.

Obviously in the near future some of these new processes may constitute serious competitors with blast furnace production. Their principal advantage is that no coke is needed for the process. The process of producing iron in blast furnaces is now, however, ceasing to be purely a coke-fired blast furnace process, since other types of fuel (gas, liquid fuel and coal dust) are proving to be effective partial substitutes for coke.

The development of blast furnace ironmaking has always kept pace with the development of engineering and machine construction. The introduction of turbo-blowers for the blast, the mechanisation of conveyal of the charge to blast furnaces and the mechanisation of other laborious operations, automation of the supply of charge materials and automation of the heating equipment, have all been the basis on which blast furnace capacity has been raised and ironmaking technology improved.

Such great strides have been made in the development of modern blast furnace ironmaking that it is now among the most perfected of the known metallurgical processes. This provides grounds for considering that there may still, in the new technological processes for producing iron now being developed, be room for methods of producing iron in blast furnaces which have already been mastered.

To sum up, the principal problems involved in blast furnace ironmaking are those of raising furnace output, reducing fuel consumption, and lightening working conditions.

In most cases the technical improvements which have been or are to be introduced in the blast furnace process to a greater or lesser extent simultaneously solve all three of the problems enumerated above. Technical improvements can, however, with some degree of tolerance be conditionally subdivided into three groups, and this has been done in fig.2. Let us dwell on the principal measures which have been widely introduced in blast furnace ironmaking, and which have already greatly improved the results of blast furnace operation.

1. PREPARATION OF BLAST FURNACE STOCK

Particular attention is being paid to the production of high grade solid fuel and iron ore products.

Until recently coke was practically the only type of solid fuel used, and special types of coal were required for its production.

The proportion of gas coals in the coking charge can be increased, without any serious deterioration in coke strength, by means of complicated methods of preparing the coking charge (selective pulverization, very fine grinding, or enriching). Coking coals are still, however, the most important part of the materials from which good coke is produced, and the supply of coking coal is limited and in some countries extremely small. For instance, Japan at present imports more than half of the coking coal which it uses from other countries, mainly from the USA, Australia, the USSR and Canada (4,5). The plan for the development of ferrous metallurgy in Japan provides for imports of coking coals increasing, by 1970, to 70% of the total requirement.

Owing to the shortage of coking coals, the problem of developing new methods of producing solid fuel for blast furnace ironmaking from non-coking coals is particularly urgent. Scientists in a number of countries are working on this problem. In particular, a method of producing metallurgical fuel briquettes, with higher mechanical strengths than those of modern cokes produced from selected coals, from any type of coal is being developed in the USSR (6).

The most important factor in improving the technical and economic indices for blast furnace ironmaking is the sintering of ore fines and concentrates; this is mostly done by sintering or nodulising.

Every year the proportion of sinter cake and pellets in blast furnace stock increases. Many works in the USSR and Sweden are running on stock consisting of 100% of concentrate, while the mean consumption of concentrate is about 90%.

The production of fluxed concentrate was a great forward stride in the preparation of raw materials; the higher the basicity of this concentrate the greater the amount of raw limestone it has been possible to eliminate from the blast furnace stock. The principal problem is that of increasing the basicity of the concentrate until no lime at all is used in blast furnace stock; this has been achieved at a number of works in the USSR, Japan and Sweden. Fluxed concentrate is now used in many countries in the world.

We should dwell in particular on the nodulizing of fine iron ore concentrates. This method enables nodules (or pellets) of the required size of 10-40 mm to be produced with only small deviations from the specified dimensions. The nodules have high reducibilities and microporosities, but their principal quality is that, as opposed to concentrate, they can be transported without any great deterioration in their properties.

Among the failings of this method is the difficulty of calcining the pellets either in shaft furnaces or on moving grates, owing to the high temperature required for the pellets to be strengthened by the recrystallization of the magnetite and hematite grains. Another process not yet sufficiently well mastered is that of producing fluxed pellets, and this is a basis on which to produce high blast furnace production figures.

It is important to appreciate the effectiveness of using pellets in blast furnace production correctly. Articles have been published which indicate that substituting pellets for raw ore is very effective. The results obtained in a 1530 m^3 capacity furnace at the Armco Steel Corporation works at Middletown are particularly interesting (7); the result of changing from a charge containing raw ore and a small amount of pellets to a charge consisting of pellets alone was that iron production rose from 1326 tons/day to 2669 tons a day, while the consumption of dry coke dropped from 787 kg/ton of iron to 632 kg/ton. This result should be taken as critical. Allowance must be made for the fact that changing to the charge consisting of pellets reduced the consumption of ore by 356 kg/ton of iron and the consumption of lime by 118 kg/ton of iron, and that the blast temperature was increased by 97°C. Moreover when gauging the efficiency of pellets as a metallurgical raw material they should be compared with concentrate of the same composition, not with ore. This comparison was made with a furnace of useful volume 981 m^3, melting an all-prepared charge in which 50% of the iron was introduced in the form of concentrate, at a works at Duisburg-Ruhrort; the concentrate was replaced by pellets (8). As a result of the comparison, the authors reached a very important conclusion. It was established that high blast furnace outputs can only be achieved, when using pellets, if their size is very consistent and they are very strong in both the cold and the hot states. As a rule, the fines should be screened out in blast furnace bays. The same high output can, however, also be attained when using concentrate, provided that its strength and reducibility are sufficiently high and that the fines are screened out of it before it is loaded into the skips. It should be noted that the concentrate used in these experiments was fluxed and contained 8.52% CaO, while the pellets only contained 0.5% CaO.

The conclusion was drawn, in West Germany, that high grade concentrate from which the fines have been screened is equally as effective as pellets. In Japan, also, concentrate and pellets are considered equally effective raw materials for blast furnace ironmaking. Pelletising is only considered advisable, in Japan, in cases in which very fine ore is supplied to a works (4). Evidently comparing the two products does not reveal any differences. Either type of raw material is effective for blast furnace ironmaking provided that they have the ideal mechanical and chemical properties and are also of the required granulation.

All fines smaller than 8-10 mm must be entirely removed both from concentrate and from pellets, and formed into lumps. Blast furnace production figures can be greatly improved by this.

Unfortunately in many cases the attempt to raise concentrate plant output leads to the production of concentrate of low strength and containing a large amount of fines, and it is charged into blast furnaces in this form. Screening the fines from concentrate, or even from pellets, is an extremely effective measure for raising blast furnace output and reducing fuel consumption. To sum up, the charge for blast furnaces must be of a specific grain size. On the basis of theoretical and laboratory research it is advisable that the diameter of the largest lumps should not be more than double that of the smallest lumps (9,10), i.e. for instance concentrate should be supplied in three size groups: 10–20 mm, 20–40 mm and 40–80 mm.

Excellent results have been achieved, as regards rapid driving and coke consumption, at the Osaka Iron and Steel Co. works in Japan for the very reason that the concentrate and coke used have good physical and chemical properties. In spite of being highly oxidised, the concentrate used at this works is extremely strong, and contains a very small amount of fines smaller than 5 mm. Coke larger than 45 mm is pulverized to 45 mm and the fines smaller than 10 mm are then screened out. The materials are also effectively distributed in the furnace. As a result, when using 100% of fluxed concentrate at this works and no fuel oil, a low coke consumption was achieved, and the chemical energy of the gas was very efficiently utilized; the carbon dioxide content varied between 20 and 22% (4).

Increase in the iron content of the charge is another very important means of raising blast furnace output. Theoretical calculations and operating experience have shown that increasing the amount of iron in the stock is particularly effective when using relatively lean ores with siliceous gangue; when remelting concentrates containing about 55% of iron increasing the iron content by 1% reduces the coke consumption by 2%, and sometimes even more. Output is also increased by about the same amount.

Relatively rich charges are melted in Japan, the USA and Sweden. For instance the yield of slag in Japan is 300-400 kg/ton of iron, while it is 400-450 kg in the USA and 500-700 kg/ton of iron in the USSR.

Effective means of enriching iron ores have recently been developed and introduced, and the degree of enrichment is continually rising.

It is entirely natural that the question of the ideal degree to which to enrich iron ores must be solved from the technical and economic standpoint. The higher the iron content of concentrates the higher the expenditure on enriching ores, and this is illustrated by curve CD in fig. 3, the expenditure in the blast furnace bay at the same time decreasing (curve AB in fig. 3). The fact that the curves AB and CD intercept at point K indicates that this is the ideal degree of iron ore enrichment (the points K' on the X axis). Normally this corresponds to the minimum iron cost.

Methods of enriching iron ores by which extremely rich concentrates (69-72% of iron) are produced have now been developed. Calculations show that, for a number of ores, the ideal iron content of concentrates for blast furnaces now lies between 65 and 67%. Quite understandably as cheaper and more effective methods of enriching ores are developed there will be an increase in the number of orefields the ores from which should be enriched to produce extremely rich concentrates, and the ideal level to which to enrich these ores will also rise.

The short experience of melting iron on rich fluxed concentrate at one of the blast furnaces at the Krivoi Rog Works should be mentioned (11). Fluxed concentrate containing about 60% Fe and 6.5% CaO was prepared from rich (65.4% Fe) Krivoi Rog ore concentrate. When the fluxed concentrate was used, the yield of slag dropped from 660-680 kg/ton of iron to 311-350 kg/ton. The blast rate was increased by 200 m^3/min, and it was 50-60°C hotter, and the natural gas consumption was increased by 3000 m^3/h. The result was a 17-24% increase in blast furnace output, and a decrease of almost 13.5% in coke consumption. The conclusion was drawn that increasing the iron content of the fluxed concentrate from 51 to 59.5% can raise furnace output by 32-35%, with a 20.5% decrease in the specific consumption of coke. It is important to note that, although the iron was melted using sulphurous coke (1.78% S) the iron was satisfactorily desulphurized in the furnace. It should be taken into account that the decrease in the yield of slag is accompanied by an equivalent increase in the amount of sulphur discharged through the furnace top (12).

In addition, therefore, to preparing fluxed lump materials (concentrate, pellets or briquettes*), rich lump-form materials from which the fines have been removed, and which have preferably been graded, should be more widely used in practice.

The research work being conducted in a number of countries into the production of what are called "ore-coal" fluxed materials, i.e. briquettes or pellets made from rich concentrates containing iron, lime and carbon, must also continue. This is of particular importance for metallurgical regions in which sulphurous coals are used for coking, and where low-sulphur non-coking coals are available. Calculations have shown that if a furnace is run, with a slag yield of 750 kg/ton of iron, on coke containing 1.0-2.1% of sulphur, a 0.1% increase in the sulphur content of the coke increases the consumption of coke by 1.4%. If a richer charge is used with a slag yield of 500 kg/ton of iron and a coke containing 2.5% of sulphur, a 0.1% increase in the sulphur content of the coke increases the consumption of coke by 5% (13). In addition, therefore, to using low-sulphur coals, research aimed at reducing the sulphur content of the coke is also very important. Very few results of work along these lines are yet available.

2. INCREASE IN BLAST FURNACE CAPACITY

A large number of 1800-2000 m^3 capacity blast furnaces have in recent years been constructed in a number of countries. Experience of operating blast furnaces in the USSR has shown that, if the materials are sufficiently satisfactorily prepared, the amount of iron now melted in a 2000 m^3 furnace is 2900-3450 tons a day, and this is above the highest iron output figures from other countries.

A 2800 m^3 blast furnace is now under construction in the USSR. A design has been produced for a 2700 m^3 capacity blast furnace, and the conference of blast furnace workers has recommended that such furnaces should be constructed (14,15).

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* A method of hot briquetting ore fines with additives containing lime is now being studied at several places (8).

Principal dimensions of these furnaces:

Useful volume, m^3	2000	2300	2700
Hearth diameter, mm	9750	10500	11000
Bosh parallel diameter, mm	10900	11700	12300
Throat diameter, mm	7300	7300	8100
Total height, mm	31250	33050	33950
Useful height, mm	29400	30200	31200
Bosh angle	79°09'	79°22'	79°10'
Stack angle	84°21'	83°23'	83°35'

The stock is conveyed to the skips by conveyor belt; the fines of less than 8 mm are screened from the concentrate before it enters the bunkers. The hot blast stoves for the 2700 m^3 blast furnace have double-wall checkers, and the blast is heated to 1400°C. This furnace has two cast iron tapholes, two slag notches, and 24 air blast tuyeres. Mechanisation and automation are used to a great extent for individual operations in the bay (automation of charging and of the hot blast stoves, rotating launders for removing the iron and slag, contactless control of the charging mechanisms, automatic weighing and control of raw material feed, etc.).

Conveyor belt stock supply with an automatic electric drive system for filling the skips has already been installed in the USSR for 2000 m^3 capacity blast furnaces, and the system has been mastered. For instance, at one works the conveyor belt system handles an average of 255 four-skip batches, or about 6500 tons of concentrate and lime, a day, and if necessary charging can be carried out at a rate of 15-18 batches an hour (16). One of the main advantages of supplying the stock by conveyor belt, as opposed to in wagonloads, is that the fines can be screened out of the concentrate. With this system the mechanisms for batching, weighing and screening the concentrate and coke run automatically, and the main hoist skips, the coke skips and the skips of fines for concentration are despatched. The automatic system provides highly flexible programming of the charging of different grades of additive and two grades of concentrate (17).

A large staff is required, however, to handle this system, and the capital outlay and running costs are higher than those for supplying the stock in wagonloads.

Large scale research into the running of large blast furnaces has confirmed the advisability of constructing 2000 m^3 furnaces, and has opened the way to the creation of even larger plants.

3. FUEL SUBSTITUTES FOR COKE

A great deal has been done, in recent years, on the partial replacement of coke by cheaper and less scarce types of fuel. For instance untreated natural gas is blown into the furnace hearth in many furnaces in the USSR and a number of other countries, and in many cases coke oven gas is used. All the blast furnaces in the South and Centre of the USSR have been converted to run on natural gas.

The introduction of natural gas as a fuel for blast furnaces in the Soviet Union has been accompanied by a 1-3% increase in output, and the specific consumption of coke has dropped by 9-18% (18,19).

There is some interest in briefly examining why natural gas enables coke consumption in blast furnaces to be reduced.

This true economy in the consumption of coke is due to the fact that when natural gas is blown into a furnace and dissociates it enriches the flow of gases passing through the stock with reducing agents, carbon monoxide and hydrogen.

These gases, the hydrogen in particular, being active reducing agents greatly improve the reduction of the stock in the direct reduction region, and this reduces the amount of heat required low down in the furnace. Materials and thermal balances for blast furnaces have shown that, when they are blown with natural gas, the hydrogen plays more than twice as great a part in the reducing processes.

Blowing with natural gas has moreover enabled the blast temperature to be considerably raised, and has reduced its moisture content; this also has had a favourable effect on the consumption of coke.

The ideal amount of untreated natural gas is 80-120 m^3/ton of iron (4-6% of the blast), at blast temperatures of 1000-1100°C, at different works in the USSR. These ideal figures correspond to the minimum consumptions of coke. The higher the consumption of natural gas by comparison with the ideal amount, the worse is the reducing hydrogen utilized, the less rapidly is the coke burned, and the smaller is the saving of coke per unit volume of gas blown in.

There is a natural desire to find methods by which the ideal amount of gas to blow into furnaces can be increased, i.e. to create conditions under which increasing the amount of gas will not reduce the speed of the process but will reduce the consumption of coke. There are three possible ways of solving this problem:

(a) by further raising the temperature of the blast,

(b) by enriching the blast with oxygen,

(c) by using converted gas.

The first of these methods is extremely effective, and should be used on the largest possible scale both with untreated gas and with converted gas.

Theoretical calculations have shown that the consumption of gas can be increased to 200-250 m^3/ton of iron, and the consumption of coke reduced by 30-35%, if the blast is enriched with up to 30-35% of oxygen.

Experiments conducted at the Dzerzhinsky Works have shown that enriching the blast with 24.5% of oxygen and blowing in 9000 m^3 of gas per hour provided an additional output of 90 tons of iron a day, and a saving of about 5% of coke (20). It was established that the greatest effect is produced by adding 15-20 m^3/min of gas to each additional percent of oxygen above 21% in the blast. The rate of combustion of the coke remained practically constant when this was done, but the specific consumption of coke dropped and output increased by 1.5%.

At another works, the concentration of oxygen in the blast was raised to 30% and the consumption of gas to 8% of the blast; furnace output increased by 2.5-4% to each percent of oxygen, and the consumption of coke dropped by 2-3% per 1% of gas.

Natural gas can be converted by various methods (conversion with oxygen, carbon dioxide or steam). The opinion has been expressed, in the USSR and France, that it is best to use the products of the thermal dissociation of natural gas. Theoretical calculations made regarding the effectiveness of using preheated gas or highly heated products of conversion, particularly products of the steam conversion of gas, have provided extremely hopeful results. The many different methods of supplying converted gas have not yet, however, been sufficiently verified on an industrial scale for final conclusions to be drawn regarding the most rational method of utilising natural gas in blast furnace ironmaking.

In a number of countries, these including the USSR, France and Japan, coke has been partially replaced by fuel oil. Fuel oil is used on a particularly large scale in Japan, since this fuel costs less there than coke. More than 50% of all the furnaces are now being run using oil (4).

At the Chusovsk Iron and Steelworks in the USSR, injecting 92 kg of fuel oil per ton of iron reduced the consumption of coke by 15%; furnace output was raised by 5-8%, and the cost of the iron was reduced (21,22).

In the USSR we have recently started to use fuel oil in large blast furnaces. On the basis of experience of running blast furnaces using fuel oil it can be stated that we have mastered methods of using it on a scale of 50-100 kg/ton of iron. The mean factor for substitution for coke is as high as 1.4 kg of coke per kg of fuel oil.

Experience of injecting sulphurous fuel oil is worthy of attention. Injecting 87.2 kg of fuel oil with a mean sulphur content of 1.73% into a blast furnace per ton of iron, with the temperature of the blast raised by 81°C and the same blast moisture content, reduced the consumption of coke by 20.7%, and also reduced the cost of the iron. The sulphur content of the iron remained practically unchanged. The introduction of sulphur with the fuel oil was entirely compensated by the reduced amount of sulphur introduced with the coke. It has been recommended that the plentiful high-sulphur fuel oil (containing more than 3% S) should be more widely utilized in blast furnace ironmaking (23).

For a long time metallurgists have been engaged on the problem of blowing solid fuel reduced to dust form into blast furnace hearths with a view to reducing the consumption of coke.

Experiments conducted in the USSR and abroad (24,25,26) have confirmed that coal dust, the amount equivalent to 17-20% of all the carbon burned in the furnace, can be blown into furnaces, and that this is effective. It has been established that the factor for replacement of coke by coal dust fuel is 1.02-1.13 kg of coke per kg of coal dust. The use of coal dust containing 16-18% of ash and 1.7-3.0% of sulphur did not adversely affect the quality of the iron produced (24).

The calculations in reference (26) proved that, with the ash content of the coal blown in constant, the factor for replacement of coke is practically independent of the volatiles (or carbon) contents of the fuel, since the volatiles are utilised in the furnace shaft.

Experiments made at TRSTD, in France, have established the effectiveness of blowing in a paste consisting of coal fines and preheated oil; the ease with which this method can be operated, also the ease and flexibility with which the amount of fuel introduced can be regulated, are also noteworthy. From the economic point of view it is better to use coal dust than liquid fuel, although it costs 2-3 times as much to prepare, store and supply to the furnace (26).

A blast furnace technology in which 15-20% of the coke is replaced by other types of fuel is thus already being employed on a large scale in a number of countries. Large scale research is being conducted into methods of using various substitutes for coke, and obviously a blast furnace technology with which the consumption of coke will be less than 350 kg/ton of iron is due to be developed.

4. BLAST FURNACE DRIVING RATES INCREASED

The rate at which blast furnaces are driven can be expressed in various ways, these including:

(a) in terms of the time for which the materials are in the furnace between charging and the production of iron from them on the hearth (in hours),

(b) in terms of the time spent by the gases in the furnace (in sec),

(c) in terms of the amount of coke used per hour per m^2 of hearth cross-section (in $tons/m^2h$),

(d) in terms of the volumetric intensity of combustion of the coke or the driving rate - the amount of coke consumed per day per m^3 of useful furnace volume (in $tons/m^3 \cdot day$).

In my opinion, the most correct method of obtaining a characteristic of the rate at which a blast furnace is driven is to take the amount of coke consumed per unit of time per unit of furnace volume or, to particularise, the number of tons of coke per day per m^3 of useful furnace volume. This quantity effectively illustrates the gas-dynamics aspect of the blast furnace process, also the driving rate, since the amount of coke consumed in a blast furnace per unit of time is proportional to the amount of the blast and the amount of gases.

If a furnace is fired on some other fuel (gas or oil) as well as coke, rapidity of driving is best determined from the total amount of carbon in the fuel and converted for a comparison fuel ($tons/m^3 \cdot day$).

For any specific blast furnace running conditions there is an ideal rapidity of driving, at which the best indices are attained.

If the furnace is driven more rapidly than the ideal rate, the first result is a slow increase in the consumption of coke, followed by a more rapid increase in this consumption; the result is that furnace output attains a certain maximum, but then begins to drop rapidly, and the good effects of speeding up the process become adverse

This is illustrated in fig.4, curve "a" in which is plotted from the results of running blast furnaces at the Dzerzhinsky Works (20). If the melting conditions are improved and, for example, more lump-form stock is used and the pressure in the furnace increased, the ideal value of rapidity of driving increases; this is illustrated by curve "b" in fig.4.

It is considered, at a large number of works in the USSR, that to attain maximum output furnaces must be driven 5-7% more rapidly than the rate corresponding to the minimum consumption of coke.

In many countries, including the USA, until recently blast furnaces were run with the rate at which they were driven relatively little accelerated (0.6-0.8 tons/$m^3 \cdot$ day). The primary reason was that the raw materials were not sufficiently well prepared for melting; the opinion was held that the time for which the ore is at moderately high temperatures is the decisive factor in conducting the blast furnace process on a specific consumption of coke, while in many cases blast furnace output capacity exceeded the amount of iron required.

In the Soviet Union, where the national economy is developing at a high tempo and the amount of metal required constantly increasing, a great deal of attention is paid to the question of accelerating the blast furnace process. Blast furnaces in the USSR are normally driven at 1.0-1.15 tons/$m^3 \cdot$ day, and not slower than 0.8 tons/$m^3 \cdot$ day, and the coke consumption figures are good.

Accelerating the blast furnace process can naturally only be effective if it does not cause an increase in the consumption of coke, i.e. if the furnace driving rate is raised and the conditions at the same time created under which the reducing process in the moderate temperature region is correspondingly speeded up (by making up the charge effectively, using iron ore materials with high reducibilities, and by increasing the reducing power of the gases).

The most effective means of increasing the rate at which a blast furnace is driven are:

(a) improving the gas-permeability of the charge in the furnace, one means of doing this being to screen the fines out of the stock before charging it into the furnace,

(b) increasing the pressure, and consequently reducing the volume of gases in the furnace,

(c) enriching the blast with oxygen, this reducing the amount of gases per unit of coke burned.

A development which has been widely introduced in recent years, particularly in the USSR, has been that of running blast furnaces with a higher gas pressure in the furnace. About 90% of the iron melted in the USSR is produced in blast furnaces running on a throat pressure of 0.6-1.5 atm.

The idea of running blast furnaces at higher pressures was advanced by the Russian engineer P. M. Esmanskii back in 1915 (27). He also indicated how this could be done. P. M. Esmanskii appreciated the basic advantage of running blast furnaces at increased pressures, this being that the reducing processes taking place in the furnace shaft could be improved.

These theoretical arguments were somewhat clarified a great deal later and, most important, supplemented by the considerations involved in utilising increased gas pressures for accelerating the speed at which blast furnaces are driven (28,29,30).

Experience of running blast furnaces in the USSR has shown that if the pressure of the gases in furnaces is raised it is possible not only to drive them more rapidly, but also to increase the proportion of ore charged to the coke consumed. Increasing the gas pressure in the throat by the actually attained amount (to 1.8 atm) has been accompanied by a 1.5-2.0% increase in furnace output, and coke consumption has dropped by about 1% per 0.1 atm (31,32).

Another method of accelerating the blast furnace process is that of using oxygen. A great deal of experience of melting various types of iron on oxygen-enriched blast has been accumulated, and theoretical research into the matter has proved that enriching the blast with oxygen is extremely effective when melting ferroalloys in blast furnaces. In this particular case, if the blast is enriched to 30-35% of oxygen output is raised considerably (by 50-90%), and coke consumption is reduced by about 15%. The temperature at upper levels in the furnace is also greatly reduced, and the furnace is easier to run; the gas can be more simply purified.

When melting irons for casting or for steelmaking, increasing the proportion of oxygen in the blast to 25-26% enables furnace output to be increased by 3-3.5% per absolute percent of added oxygen.

When standard irons were being melted, increasing the oxygen content of the blast to over 24-26% disturbed the running of blast furnaces if the stock was not sufficiently well prepared, causing hanging in particular to occur. This was evidently caused by the sublimation of slag-forming agents, mainly silicon oxide SiO, at high temperatures, these agents condensing in the upper regions of the furnace; on condensing they were deposited on the surfaces of lumps of coke and obstructed the passage of gas to a greater or lesser extent (33,6).

Measures such as increasing the moisture content of the blast, blowing in lime, or using natural gas can be utilized for preventing excessive increase in the temperature in blast furnaces running on oxygen-enriched blast. As indicated above, combined blast (oxygen + gas) is a means of increasing blast furnace output and at the same time reducing coke consumption.

Careful preparation of the stock, increase in the pressure of the gases in the furnace and combined blast are therefore powerful and effective means of accelerating the running of blast furnaces with low coke consumptions.

5. INCREASE IN BLAST TEMPERATURE

Only twenty years ago many iron - and steel - producing regions were unable to raise blast temperature to above 500-550°C, since this disturbed the running of blast furnaces. Various theoretical arguments were produced regarding the reasons for this disturbance in running.

Measures recently taken (improving the gas-permeability of the stock, increasing the gas pressure, using fluxed concentrate, and sometimes increasing the moisture content of the air) have enabled conditions to be created under which blast furnaces can be run normally and effectively on blast temperatures of 900-1150°C. For instance, more than 90% of the iron produced in the USSR is melted on blast at over 800°C. In many furnaces the blast is heated to 1000-1150°C. It is particularly effective and necessary to heat the blast when using natural gas. At present the amount of coke saved through increasing blast temperature is equivalent to 30-80 kg per 100°C, and depends on furnace running conditions. The graph in fig.5, plotted from Dzerzhinsky Works figures, illustrates this, showing the effects of blast temperature on the specific consumption of coke, and on the furnace driving rate, for a blast furnace running under various conditions (20).

The improvement in the physical and chemical properties of the stock materials when various gases or other types of fuel are blown into a furnace enables the temperature of the blast to be further raised, to 1200°C or more.

6. PIG IRON DESULPHURIZED OUTSIDE THE BLAST FURNACE

Thirty five years have elapsed since the first production tests were carried out on desulphurizing iron outside the blast furnace (34). Since then a great number of experiments have been conducted on desulphurizing iron with different reagents (12). In many cases desulphurization outside the furnace has been conducted on an industrial scale. Desulphurization outside the furnace is not yet, however, widely employed. The main reason is that the known and tested methods of desulphurizing iron outside the blast furnace have not been perfected to an extent such that they can be recommended for large scale use in large blast furnace bays. Moreover the transition to rich, self-fluxing ferrous stock has made desulphurising outside the furnace much less effective than it was when lean ores were used with untreated lime in the stock. This circumstance reduced interest in the method.

Desulphurization outside the furnace is, however, a possible means of further reducing fuel consumption in blast furnaces, and may prove to be extremely effective when developing new methods of producing steel. The development of improved and cheap methods of desulphurising iron outside the furnace is still, therefore, an important metallurgical task.

7. INTEGRATED AUTOMATION AND MECHANIZATION OF IRONMAKING

Mechanization and automation have been applied in blast furnace production on a considerable scale. The part of the process in which mechanisation and automation have been most applied is the charging of the stock materials into the furnace. Combined automation of running the hot blast stoves has been achieved at many works in the world.

Mechanization of the running of a number of departments in blast furnace bays is, however, still far from perfect. These departments include hearth maintenance, tapping and handling the products after tapping.

Combined automation must next be applied to control of the blast furnace process, the purpose being to run blast furnaces on the ideal working conditions. With this in mind, attention has basically been directed to the development of an integrated method of regulating the ironmaking process, this method embracing all its aspects including the control and forecasting of the thermal state of the furnace, and regulation of the flow of gases and the reducing processes taking place in the furnace. Various methods of solving this problem have been suggested, and certain aspects have already been tested; these include automatic distribution of the blast around the tuyeres, and regulation of the flow of gases in the throat. Computers are to be more widely used, primarily for investigating the laws governing the blast furnace process and its dynamic characteristics, and later to fulfil the functions of controlling the blast furnace ironmaking process.

8. METHODS OF PRODUCING METAL WITHOUT BLAST FURNACES

The methods of producing metal without using blast furnaces include the production of iron in electric and low shaft furnaces, also various methods of direct production of iron.

We know that the production of iron in electric furnaces has been developed to a greater or lesser extent in Norway, Italy, Sweden, Switzerland and Japan. The coke used for melting iron in electric furnaces need not have the same strength as the coke used in blast furnaces. If electric power is available, the capital outlay on erecting an electric furnace bay is lower than in the case of blast furnaces. It is sometimes stated that an advantage of melting iron in electric furnaces is that the coke consumption is only 50% of the amount used in blast furnaces; another advantage is that unprepared raw materials can be used. This argument, however, should be clarified. In the first place, experience with electric furnaces has shown that the use of unprepared materials is highly undesirable, since the indices for the process are very adversely affected. In the second place, it was shown earlier that a considerable proportion of the coke can also be replaced by other types of fuel when using blast furnaces. The principal failings of ironmaking in electric furnaces, which have prevented it from being adopted on a large scale, are that electric furnace output is low (up to 200 tons a day) and that power consumption is high (2300-3000 kWh/ton of iron). Power consumption can be greatly reduced if the stock is preheated and reduced before charging.

What are called low shaft furnaces for ironmaking have been developed since the Second World War; considerable numbers of these furnaces are now in use. They have either been tested or are running in West Germany, Belgium, the German Democratic Republic, Switzerland, the USA, France, Italy and India. Experience has shown that the solid fuel used in these furnaces need not be so strong (this is better than using coke). The stock must, however, be efficiently prepared. By comparison with normal blast furnaces these furnaces have a number of serious failings, including much lower outputs and higher fuel consumptions; this has greatly reduced the interest in these furnaces.

Interest in the problem of producing iron direct from ores has recently increased. These are a large number of methods of producing pure iron, iron powder, sponge iron or cast metal direct from iron ores or ore concentrates. This problem requires special treatment, and is outside the terms of this address. I would only indicate that, in my opinion, a more urgent matter is the question of the wider development of methods of direct production of iron not only to produce iron powder, but also for the mass production of steel.

Up to the present time, therefore, several methods of producing iron or steel without using the blast furnace have been mastered, but these have as yet only been adopted on a very limited scale.

CONCLUSION

Ironmaking in blast furnaces has reached a high technical standard. Furnaces providing daily outputs of about 3500 tons have been constructed and are in use. Furnaces with useful volumes of 2700 m^3 are projected, and the outputs from these if run on well-prepared stock may be about 5500 tons of iron a day.

The introduction of a number of highly effective measures, and primarily the use of fluxed concentrate, increase in the gas pressure in the furnace, high blast temperatures, the blowing of fuel into the furnaces, and the use of combined blast, have made it possible to drive furnaces extremely rapidly with low consumptions of coke. Coke consumptions of 380 kg/ton of iron have already been achieved, and the output from a number of furnaces is about 2 tons/m^3 of useful furnace volume per day.

An extremely effective measure, but one which is not sufficiently employed, is that of screening the fines from concentrate or pellets. Oxygen combined with reducing gases and other fuels added to the blast provides great opportunities for enabling blast furnaces to be driven more rapidly and reducing coke consumption.

Several methods of producing iron without using blast furnaces have been developed and mastered; these are as yet only employed on a limited scale, but can be recommended for use in certain regions where metallurgy must be developed on a small scale and coal suitable for the production of high grade coke is not available.

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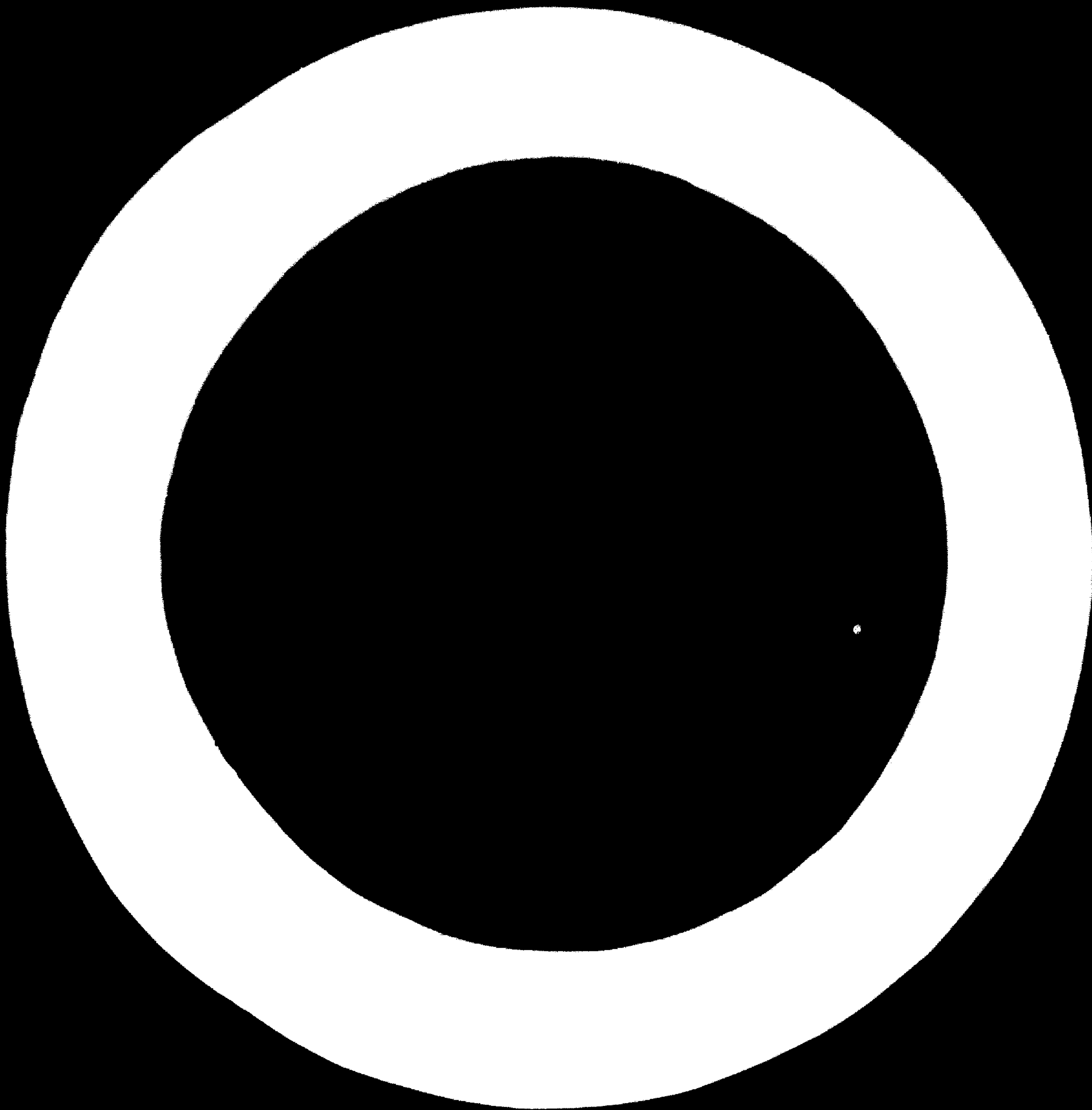

FIGURES

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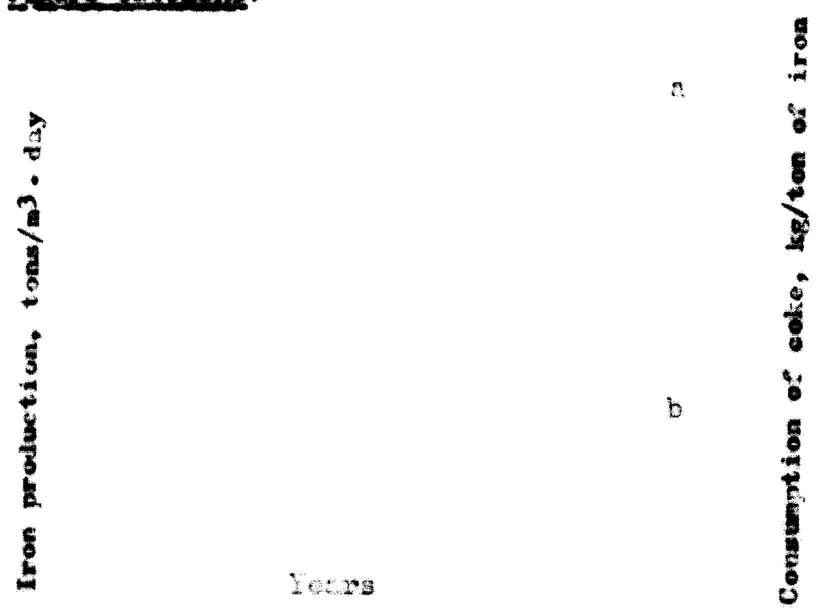


Fig.1 Utilization of useful volume of blast furnaces and consumption of coke.

a - production of iron

b - consumption of coke

Technical progress in blast furnace ironmaking

Measures principally directed at more rapid driving of furnaces

1. Intensified process.
2. Increase in gas pressure in furnace.
3. Improvement of particle size composition of burden.
4. Enrichment of blast with oxygen.

Measures directed mainly at reducing consumption of coke

1. Use of gaseous, liquid or dust-form fuels.
2. Use of fluxed and self-fluxing concentrate.
3. Increased blast temperature.
4. Increased iron content in concentrate.
5. Decrease in manganese content of iron.
6. Iron desulphurized outside the blast furnace.

Measures for raising furnace output and simultaneously reducing coke consumption

1. Increasing furnace volume.
2. Automation of blast furnace process.
3. [illegible] blast (gas + oxygen).
4. Improvement of burden quality (fluxed concentrate, pellets, fines screened out, increase of iron content of concentrate).

Fig. [illegible] for technical progress in blast furnace ironmaking.

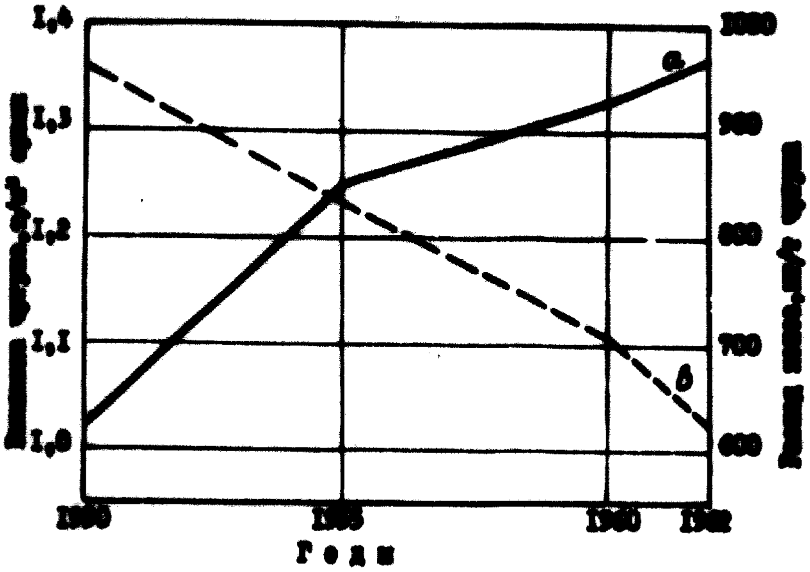


Рис.I. Использование полезного объёма доменных печей и расход кокса.

а – выплавка чугуна

б – расход кокса

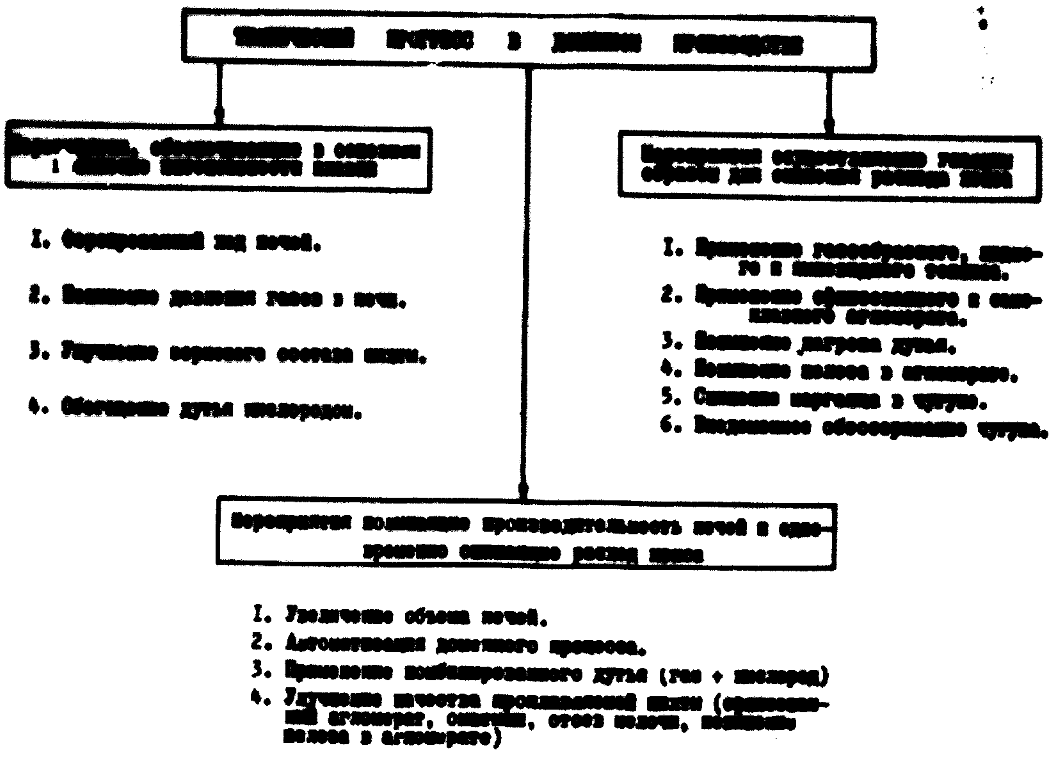


Рис. 2. Классификация мероприятий по техническому прогрессу в доменном производстве

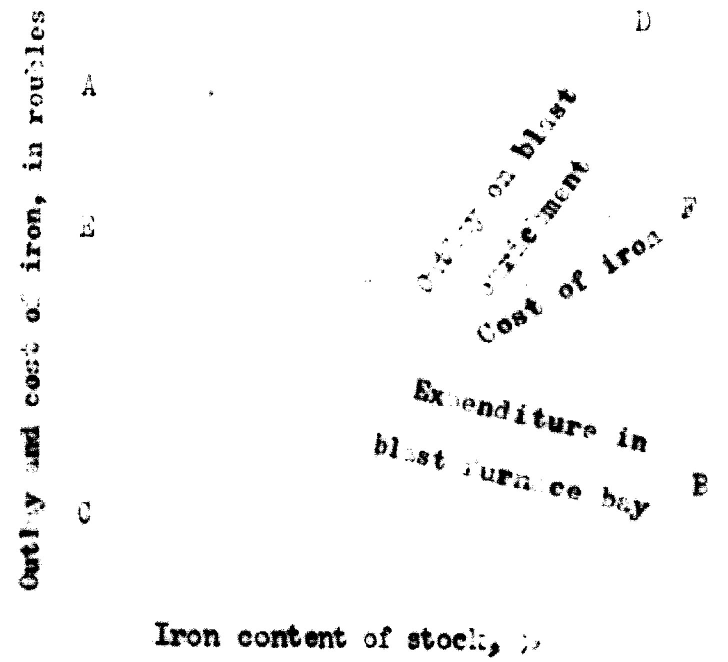


Fig. 3 Diagram illustrating graphical determination of the ideal iron content of the ore used in blast furnace stock.

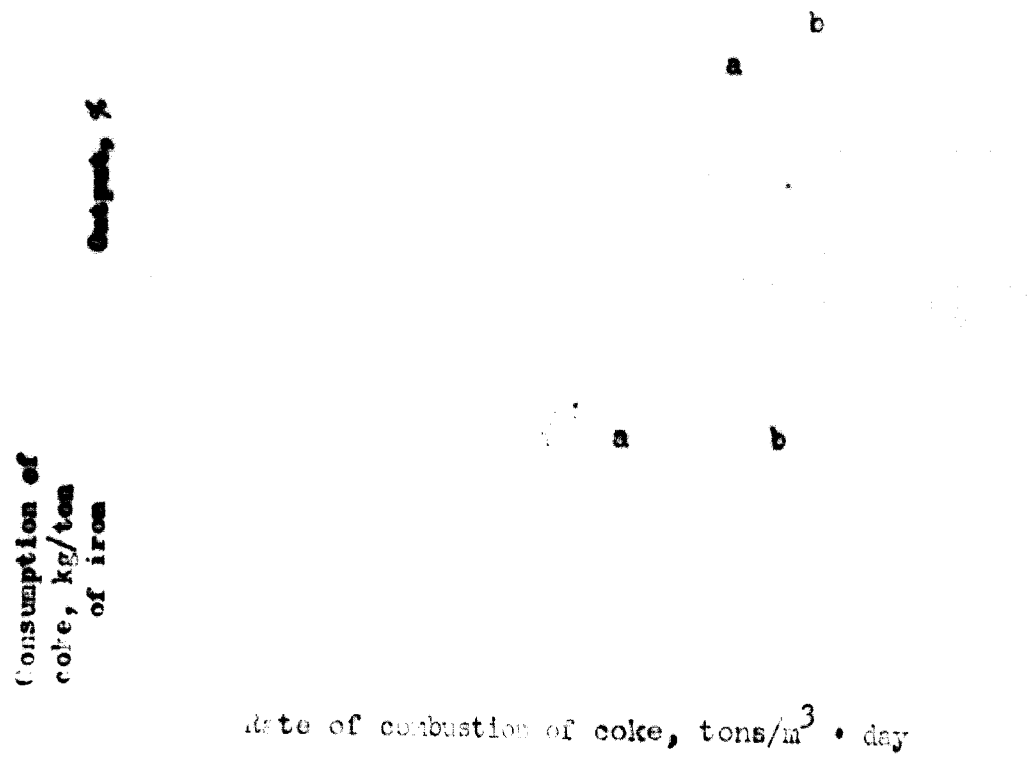
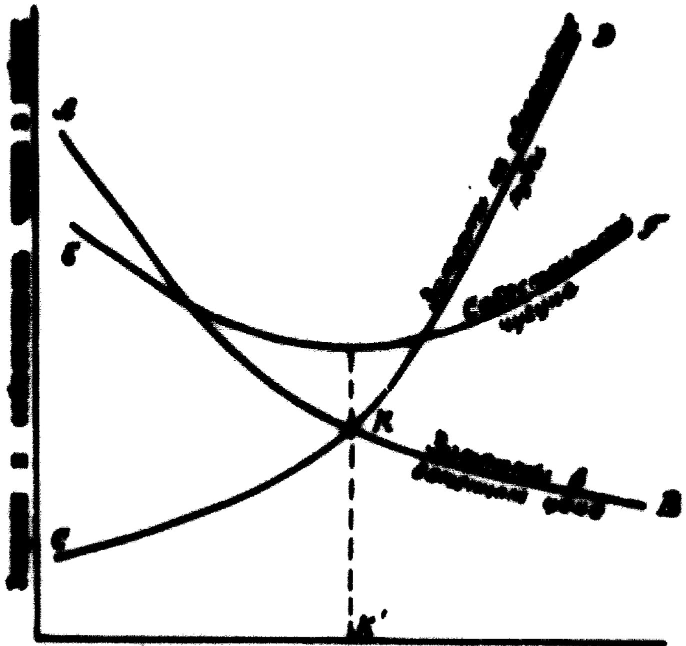


Fig.4 Effects of rate of combustion of coke on coke consumption and furnace output.

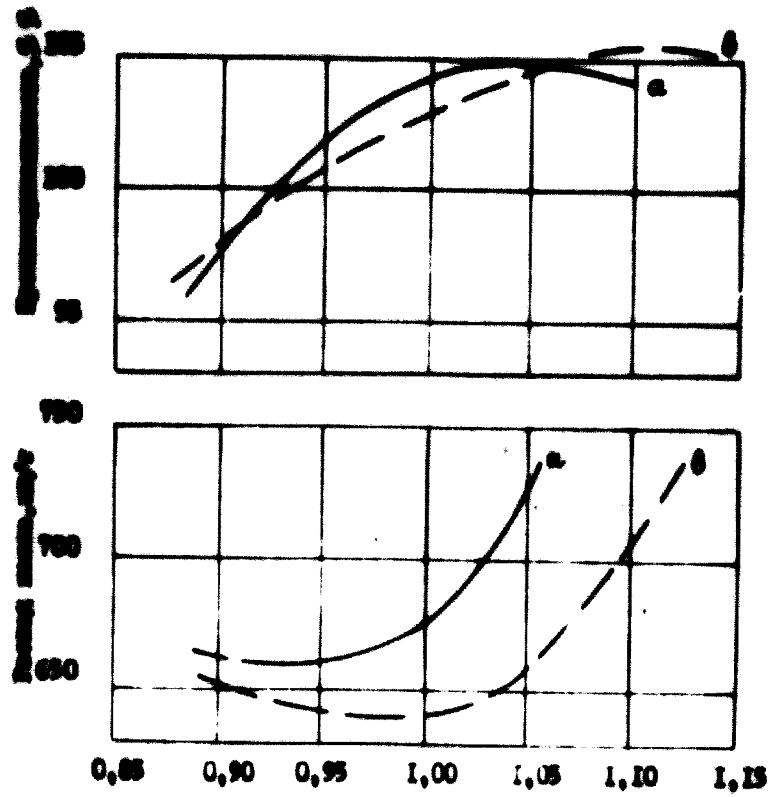
a - stock containing 90% of concentrate, blast temperature [illegible]°C, gas pressure at throat about 1.2 atm;

b - better quality stock, and slightly higher gas pressure in furnace.



Содержание кокса в шихте, в % р

Рис.3. Схема графического определения оптимального содержания кокса в рудной части доменной шихты



Интенсивность горения кокса, т/м³ сутки

Рис.4. Влияние интенсивности горения кокса на его расход и производительность печи.

а – в шихте 90 % агломерата, нагрев дутья 890°, давление газа на колошнике около 1,2

б – при более качественной шихте и несколько больших давлениях газов в печи

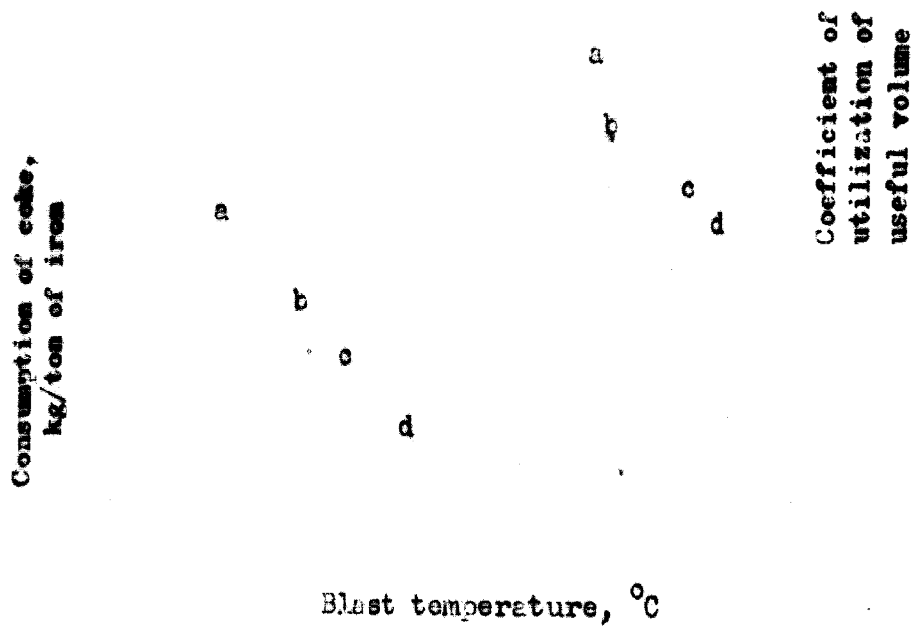


Fig. 5 Effects of blast temperature on the specific consumption of coke and the coefficient of utilization of useful volume, for blast furnaces working under different conditions:

a - 1953-1954, standard concentrate; b - 1955, fluxed concentrate, basicity 0.5; c - 1956-1958, concentrate with 0.8 basicity, increased gas pressure;
d - 1959-1962, natural gas injected, fluxed concentrate of 1.0 basicity, increased gas pressure below throat.

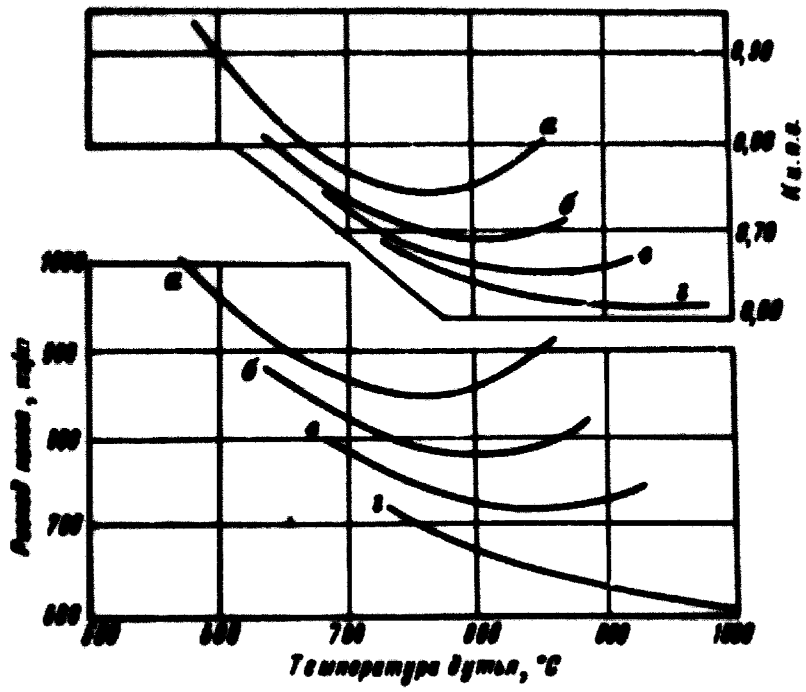


Рис. 5. Влияние температуры дутья на удельный расход кокса и величину к. и. п. о. в различных условиях работы доменной печи:

а — [illegible]—1954 гг., обычный агломерат; б — 1955 г., офлюсованный агломерат основностью 0,5; в — [illegible]—[illegible] гг., агломерат основностью 0,8 и повышенное давление газа; г — [illegible]—[illegible] гг. вдувание природного газа, офлюсованный агломерат основностью 1,0 и повышенное давление газа под колошником

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