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Moscow, USSR, 19 September – 9 October 1968

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USE OF NATURAL GAS, FUEL OIL AND OTHER TYPES OF FUEL IN IRON - AND STEELMAKING [1]

by

Z.I. Nekrasov
Director of Institute
Iron and Steel Institute
Dnepropetrovsk, USSR

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SUMMARY

USE OF NATURAL GAS, FUEL OIL AND OTHER TYPES OF FUEL IN IRON- AND STEELMAKING [1]

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A. Use of natural gas and other blast additives in ironmaking.

Natural gas is the most popular additive to the blast in the USSR. Its consumption ranges from 50 to 100 cu.m. per ton of iron (the average is 8[illegible].7 cu.m. per ton of iron). The principal effect of its use consists of a decrease of 10–20 pct in specific coke rate and a simultaneous gain in blast furnace output by 2–4 pct.

The positive effect of using natural gas on blast furnace process consists in increasing the amount of reducers per unit of the material being reduced, which leads to lowering the degree of direct reduction of Fe from its oxide.

Consequently, the substitution of the coke carbon burning at the tuyeres by the carbon of natural gas increases the amount of combustion products and the gas pressure-drop in the furnace can overcome the permissible values. Hence when injecting natural gas into furnace the amount of blast should be decreased in accordance to the predetermined chart. Due to the heat consumption to decompose natural gas the temperature in the hearth decreases. To compensate this heat consumption it is necessary to increase the temperature of blast or to decrease its humidity following the developed chart.

The best efficiency is obtained by combined effect of injecting natural gas and simultaneous oxygen enrichment of the blast. As oxygen and natural gas affect the temperature in the hearth and the amount of gases in the furnace in opposite directions (natural gas lowers the temperature in the hearth while oxygen raises it, natural gas increases the amount of combustion products while oxygen decreases it), the oxygen enrichment of the blast makes it possible to increase the natural gas consumption and to decrease the coke consumption. By increasing the natural gas consumption the oxygen concentration in the blast can be raised that allows the furnace output to be extended accordingly. The relationship between the consumption of natural gas and that of oxygen ranges from 0.6[illegible] to 0.68 pct provided that gas dynamics and temperature in the hearth would be unchanged. The oxygen, natural gas and blast consumption is determined by calculations.

Coke-oven gas is one of the effective additives to the blast. Due to the high hydrogen content (62–63 pct) it may be considered as a partly converted natural gas.

An experimental operation with the use of coke-oven gas having been carried out, the output of furnace increased by 4.2 pct, the specific coke rate decreasing by 9.6 pct.

The coke replacement ratio was equal 0.63 kg of coke per cu.m. of coke gas. An experimental melt when half of natural gas amount was substituted by the double amount of coke gas was accompanied by a gain in productivity by 3.4 pct and with the decrease of specific coke rate by 1.2 pct.

Decreasing the specific coke rate may be also achieved by the powdered-coal injection into the hearth of furnace. An experimented operation carried out in the USSR showed that the output of the furnace increased by 1.2-2 pct when the coal dust amount injected into the hearth of furnace accounted for 80 kg per ton of iron. The coke replacement ratio for powdered coal was close to one. It is to be taken into account the cooling effect of powdered coal and the need for proper increasing the blast temperature in the zone of burning at the required level.

To decrease the specific coke rate liquid fuel (usually fuel oil) is also injected into the hearth. By injecting 87-95 kg of fuel oil per ton of iron the specific coke rate decreased by 14.2-15.7 pct, the output of furnace increased by 6.1-6.8 pct. One kg of coke is substituted by 0.62-0.64 kg of fuel oil. There is also some information of using the coal-fuel oil suspension.

B. Use of natural gas and other types of fuel in steelmaking.

The following main types of fuel are presently used for the open-hearth heating at the iron and steel works of the USSR:

1. The mixture of coke-oven and blast-furnace gases heated in chequers is used in open-hearth furnaces equipped with two pairs of slag pockets and regenerators and with three uptakes;

2. The natural gas without heating but with its self-carburizing in the central uptake is used in the open-hearth furnaces heated earlier with the mixture of coke-oven and blast-furnace gases;

3. The natural gas without heating but with the carburizing of flame by fuel oil is used in the open-hearth furnaces equipped with one pair of slag pockets and regenerators and with one or two uptakes;

4. The natural gas without heating but with the self-carburizing in flame or the fuel-oil atomised by the natural or coke-oven gases is used in the open-hearth furnaces with one uptake.

The last alternative of heating is the most promising and versatile as it allows the open-hearth furnaces of the out-of-date design (with three uptakes) to be reconstructed enlarging the hearth area (without changing the dimensions of open-hearth furnace itself). This, accordingly, leads to increasing the weight of charge and to improving the techno-economic characteristics of a process. This method of heating provides for using one of the high heat output fuels or of the mixtures of them, which also contributes to improving techno-economic characteristics.

USE OF NATURAL GAS, FUEL OIL AND OTHER TYPES OF FUEL IN IRON- AND STEELMAKING

A. Use of natural gas and other blast additives in ironmaking

Natural gas is the most common blast additive in the USSR proposed by the Institute for Ferrous Metallurgy of the Ministry for Ferrous Metallurgy of the USSR and the Petrovsky Iron and Steel Works. Its extensive implantation in blast-furnace practice began in 1957-1958 after the blast furnaces of the iron and steel works near the Dnieper were supplied with the natural gas of the Shebelinsky gas field. For the first time natural gas was used as an additive to the blast on one of the blast furnaces of the Petrovsky Iron and Steel Works in October 1957. Others blast furnaces of this works as well as those of the Dzerjinsky and those of the Zaporoghstal Iron and Steel works were also supplied with natural gas from Shebelinka in 1958. An extensive natural gas implantation into blast-furnace operation also proceeded during the following years. By the beginning of 1965 more than 80 blast furnaces were supplied with natural gas. Presently the natural gas injection is used in 101 blast furnaces.

The practice of many blast furnaces shows that the main effect of using the natural gas in ironmaking consists in the appreciable decrease of the specific coke rate (by 10 to 20 pct). The output of blast furnaces is simultaneously increased as a rule by 2 to 4 pct.

The available data of the natural gas injection into blast furnaces show that the average natural gas consumption for all the iron and steel works amounts to 4 or 5 pct in relation to the blast and to 80.7 cu.m per ton of iron. But at the separate works the consumption of the natural gas varies from 50 to 100 and more cu.m per ton of iron. It appears that the specific consumption of the natural gas established at the works may be seen as optimal under existing conditions and that its further increasing not only doesn't lead to the adequate raising the characteristics of ironmaking operation but it is accompanied by decreasing the output of blast furnaces.

Relative to the extensive use of natural gas injection in ironmaking it is essential to elucidate the theoretical fundamentals of new method of operation and the individual regularities of this process as well as to establish the optimum relations between the blast components.

Effect of the natural gas injection on generating the indirect and direct reductions

The theoretical considerations and the performed investigations give grounds for suggesting that a positive effect of natural gas injection on blast-furnace process consists in increasing the amount of reducers per unit of reduced material. As a result of increasing the amount of reducers processes of indirect reduction at higher and medium levels of blast furnace would intensify. The direct reduction at lower levels of furnace would accordingly drop, which leads to the decreasing of coke rate by about 5.5 kg per 1 pct of direct reduction decrease.

The amount of reducers in hearth gases is increased by about 5 cu.m per cu.m of natural gas injected into the hearth of a furnace; the concentration of reducers in the gases is simultaneously increased. Both the factors lead to the increase of indirect reduction and to the decrease of direct one.

The relationship between the amount and the concentration of reducers in the hearth gases and the consumption of natural gas is shown in Fig.1. As can be seen from this graph increasing in relative amount and concentration of reducers depends not only upon the consumption of natural gas but also upon the specific coke rate: the effect of natural gas on those parameters is increased with decreasing in the specific coke rate.

The referred data of increasing the amount of reducers due to the injection of natural gas into furnace given above are confirmed by the data of Table 1. These data were derived from calculating the amount of reducers (hydrogen and carbon monoxide) under the real conditions of a blast furnace operation for several periods each with the varied amount of the injected natural gas per ton of iron.

Table 1

The amount of reducers per ton of iron depending on the amount of natural gas injected into the furnace

Natural gas consumption, cu.m/t of iron	CO amount at the blast tuyeres, cu.m/t of iron	H_2 amount at the blast tuyeres, cu.m/t of iron	Total amount of reducers, cu.m/t of iron
0	948	96	1044
124	883	312	1195
170	903	377	1280

The data of Table 1 show that in third period the amount of carbon monoxide produced the blast tuyeres due to the injection of natural gas decreased by 45cu.m per ton of iron(as a result of decreasing the total amount of carbon burned at the blast tuyeres) while the amount of the other reducer, viz. the hydrogen increased by 28 cu. m per ton of iron. The total amount of reducers increased by 236 cu.m per ton of iron or by 22.6 pct.

Calculations show that as a result of the natural gas injection into blast furnaces the direct reduction of Fe from its oxide (r_d by M.A.Pavlov) decreased in these furnaces from 50-60 to 30-35 pct.

Effect of the natural gas injection on the blast furnace gas dynamics

At the constant blast consumption the amount of combustion products produced in the hearth per unit of time increases in proportion to the consumption of natural gas injected into the hearth. In this case the velocity of gases in the stock column and their pressure drop in the furnace proportional, as it is known, to the square of gas velocity, increase.

An approximate changing of velocity and pressure drop of gases in the furnace at the constant blast consumption depending on the natural gas consumption per ton of iron is illustrated in Fig 2. The pattern of curves shows that difference in specific coke rate essentially affects the changing of velocity and pressure drop of gases. When adding natural gas to the blast and at the lowered specific coke rate both of indexes increase to higher values. This graph shows that when injecting 100 cu.m natural gas per ton of iron the gas velocity and loss of heat increase by about 7-10 and 15-20 pct respectively.

Effect of the natural gas injection on the blast consumption and on the intensity of coke burning

In most cases of natural gas injection it is necessary to decrease the consumption of blast per unit of time for the pressure drop of gases in the furnace not to exceed an optimum value.

Decreasing the consumption of blast leads to lowering the intensity of coke combustion and may result in fall of the furnace output. Fig.3 shows the decrease of blast consumption and that of the intensity of coke combustion depending on different amounts of natural gas injected into the furnace at the specific coke rate of 700 and 500 kg per ton of iron if just the same level of pressure drop of gases should be kept in the furnace. When injecting, for instance, 100 cu.m of natural gas per ton of iron the decrease of blast consumption may be expected depending on the specific coke rate, approximately by 5-8 pct and lowering the intensity of coke burning by 19-25 pct.

Effect of the natural gas injection on the blast furnace output

In spite of lowering the intensity of coke combustion when injecting natural gas the output of the blast furnace, far from decreasing, is somewhat higher. When injecting natural gas with the lowering of coke combustion intensity the decreasing of specific coke rate simultaneously occurs by the same or higher value. This factor affects the changing of furnace output in the direction opposite to the action of lowering the coke burning intensity. The actual output of furnace is established depending on the relationship between the coke burning intensity and its specific rate.

Effect of the natural gas injection on the specific coke rate

It is established that each cu.m of natural gas decreases the specific coke rate by about 1 kg. The specific coke rate is decreased, mainly, as a result of lowering the degree of direct reduction and, partly, due to direct substituting the coke carbon combustion at the tuyeres by the natural gas carbon. Moreover, the specific coke rate is decreased as a result of lowering the moisture of blast and raising its temperature, which is usual when adding natural gas to the blast.

Effect of changing gas and stock compositions on the coke combustion intensity and the furnace output

When injecting natural gas into the furnace some additional factors occur that favourably affect the coke combustion intensity and the furnace output increasing them against the calculated values. One of these factors is upgrading the hearth gases by hydrogen that decreases their specific weight and viscosity. As a result a possibility arises to increase somewhat the blast consumption and, consequently, the coke combustion intensity at the previous pressure drop of gases in the furnace.

The second factor is increasing the burden ratio as a result of decreasing the coke specific rate. This factor increases the active weight of stock column and accordingly creates a possibility to operate with the higher-than-normal pressure drop of gases in the furnace, i.e. with the higher blast consumption and the higher intensity of coke burning. Due to the positive affect of the factors shown above the real lines characterizing the blast consumption and the intensity of coke combustion should be located on the graph of Fig.3 when injecting the different amount of natural gas well above the lines plotted in Fig.3 on account of calculated data. It may be concluded that taking into account the interaction of all the factors the conditions of gas dynamics of the furnace allow for increasing the consumption of natural gas only up to that value at which the lowering of the coke combustion intensity is still compensated by the decreasing of its specific rate and the output of furnace is maintained at the previous level or is even somewhat increased.

Effect of the natural gas injection on the temperature in the hearth of furnace

When 1 kg of the carbon of coke incompletely burns (into CO) at the tuyeres the heat liberation is equal to 2340 Kcal but when 1 kg of the carbon of methan (the dominated part of natu-

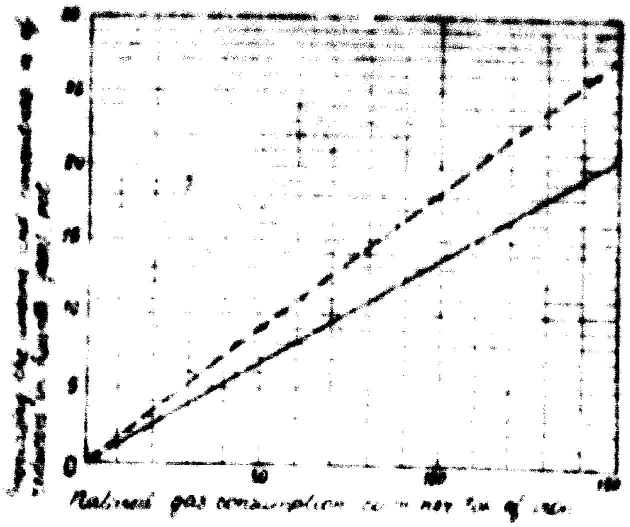

Fig.1 Increasing the amount and concentration of reducers in hearth gases at the constant consumption of blast depending on the natural gas consumption and on the specific coke rate

----- Specific coke rate = 700 kg

- - - Specific coke rate = 500 kg

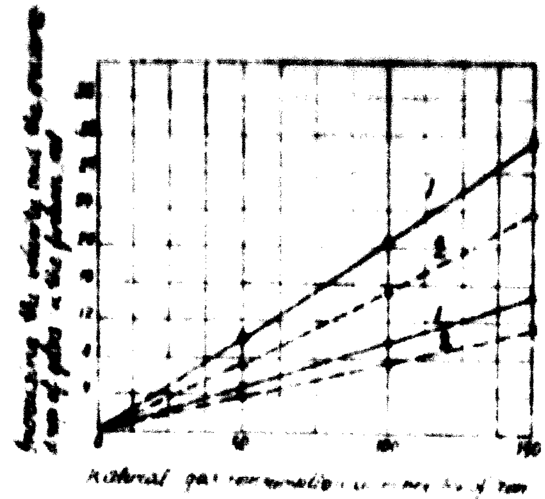

Fig.2 Increasing the velocity and the pressure drop of gases in the furnace at the constant consumption of blast depending on the natural gas consumption

x- -x - x
x- -x x increasing the gas velocity in the furnace

o- - -o- - o
o o -o increasing the pressure-drop of gases in the furnace

1 - specific coke rate = 700kg;
2 - specific coke rate = 500kg

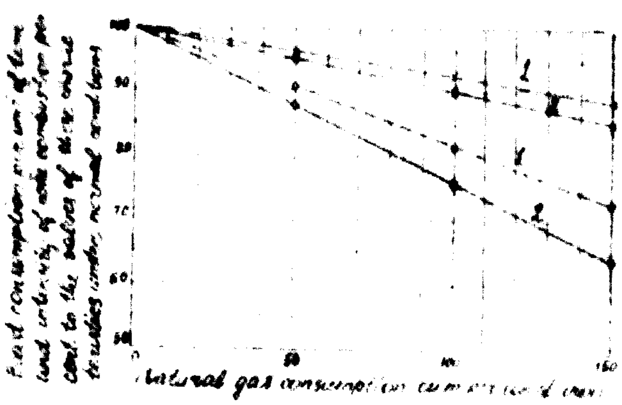

Fig. 3 Decreasing the blast consumption per unit of time and the intensity of coke combustion when injecting natural gas into the furnace at the normal level of pressure drop in the furnace

x-- x - x
x - -x - -x blast consumption, pct

o- - -o- - -o
o- -o - -o intensity of coke combustion, pct

1 - specific coke rate=700kg;
2 - specific coke rate=500kg

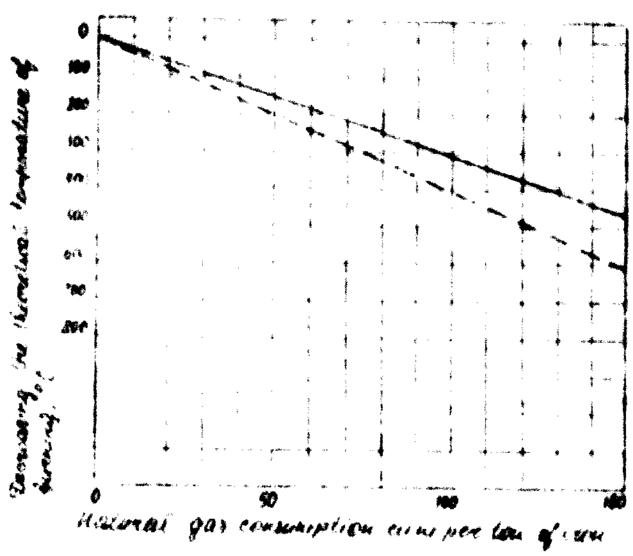

Fig.4 Decreasing the theoretical temperature of burning when injecting natural gas into the hearth of furnace

---- original specific coke rate=700kg

- - - original specific coke rate=500kg

ral gas) burns, it liberates 758 Kcal of heat only. By burning methan by 70 pct more gases are produced than when burning the carbon of coke. Consequently, the theoretical temperature of natural gas combustion is considerably lower than that of the carbon of coke. When burning together natural gas and coke at the tuyeres the higher the relative consumption of natural gas, the lower the temperature of gases. By decreasing the specific coke rate the effect of naturel gas on the temperature in the zones of burning is increased. The tentative date of the theoretical decrease in temperature of combustion versus the natural gas consumption at the specific coke rate of 700 and 500 kg is shown in Fig.4.

The theoretical temperature of combustion at the previous level can be provided by the additional heating of blast and/or by decreasing its humidity. The rated value of heating degree or decreasing the humidity of blast depending on the natural gas consumption at the specific coke rate of 700 and 500 kg is shown in Fig.5.

With the use of the small amounts of natural gas (up to 30–40 cu.m per ton of iron) added to the blast it can go without the extra heating of blast or decreasing its humidity. The case is that due to increasing the amount of reducers in the hearth gases when injecting natural gas into the furnace the reduction processes at the upper and at the middle levels of furnace improve and materials entering the hearth offer the more degree of reduction, hence they require less heat to treat them finally. In spite of decreasing the temperature in the hearth materials entering there receive from gases enough heat to complete the process of reduction of smaller amount of oxides and of iron and slag smelting.

However, the further increase of natural gas consumption can lead to the temperature in the hearth to be lowered below a permissible level, at which it can operate normally. In these cases blocking up occurs in the hearth, air and slag tuyeres begin to burn heavily and the furnace idle times sharply increase. If in this case it is impossible to raise the temperature of blast and to lower its moisture content the specific coke rate is to be increased that decreases the efficiency of natural gas utilization.

Consequently, from the point of view of temperature conditions in the hearth of the furnace the natural gas consumption can only rise up to such a value at which the amount of heat transferring from gases and depending on the combustion temperature is sufficient to meet the heat requirement of hearth.

Combined use of natural gas injection and oxygen enrichment of blast in blast-furnace operation

By combined using natural gas and oxygen-enriched blast still more favourable effects can be obtained than by utilizing natural gas alone both in raising the blast furnace productivity and in reducing the specific coke rate. The case is that oxygen and natural gas affect the basic parameters of blast-furnace process, viz. the temperature in the hearth and the pressure drop of gases in the furnace, in opposite directions, which makes it possible to considerably raise the consumption of both of these blast components without changing neither the temperature in the hearth nor the pressure drop of gases in the furnace. Thus, for instance, the natural gas injection increases the amount of gases in the hearth, which leads to increasing the pressure drop of gases in the furnace. The oxygen enrichment of the blast decreases its nitrogen content, which leads to the amount of gases in the hearth and the pressure drop of gases in the furnace to be lowered. Consequently, it is possible to choose such a relationship between natural gas and oxygen added to the blast that the amount of gases produced in the hearth per unit of gases would not be changed. Injecting natural gas and oxygen exert the similar opposite effect on the temperature in the hearth of furnace: natural gas lowers this temperature while oxygen raises it. The correct selection of the relationship between natural gas and oxygen allows the temperature in the hearth of furnace to remain unchanged.

Due to the opposite effect of natural gas and oxygen on the blast-furnace process parameters shown above it is possible to increase consumption both of natural gas and of oxygen considerably. Decreasing the specific coke rate should account for the natural gas injection but increasing the furnace output for the oxygen enrichment action.

The results of a lot of experimental operations indicate that the furnace output rises by about 2.5 pct per 1 pct of increasing the oxygen concentration in the blast. The specific coke rate decreases in proportion to the rise of the specific natural gas consumption by about 1 kg of coke per cu.m of natural gas injected.

Determining the natural gas, oxygen and blast consumption

Changing in the content of blast by the non-compensated injecting natural gas, oxygen and other different additives leads to the irregularities of gas dynamics and temperature conditions of blast-furnace process. Natural gas injecting, for example, at the previous blast consumption leads to the rise of pressure drop of gases in the furnace, to the hard driving of the furnace and stock hanging; the oxygen-enriched blast increases the temperature in the zones of combustion and contributes to the sublimation of slag-producing components of the burden including silicon monoxide, which in its turn, also leads to the hard driving of the furnace, hangings and slippings of the stock. Hence in any changing the blast content it is necessary to take care to keep unchanged the gas dynamics and temperature conditions established in the furnace under consideration. When injecting natural gas such measures are the decrease of blast consumption and the rise of its temperature, when using oxygen-enriched blast, the natural gas injecting or the moistening of the blast, etc. Some methods considered below are to change the blast conditions of the furnace when natural gas injecting and oxygen enrichment in such a way that gas dynamics and temperature conditions of the melt would remain unchanged.

Determining the natural gas consumption at the normal (atmospheric) blast

The natural gas consumption at the normal blast is determined by two groups of factors: the temperature group and the gas dynamics one. The first group of factors includes: an initial development of direct reduction, an original extent of artificial moistening of blast, reserves for increasing the temperature of blast.

If to proceed from this group of factors the higher the original extent of direct reduction of Fe from ferrous oxide, the greater the artificial moistening of blast and the higher the reserve of increasing of its temperature are, the more natural gas consumption may be assumed.

The second group of factors is characterized by the original values of a gas pressure drop in the furnace and by that of a coke burning intensity, by the active weight of stock column and by the top gas composition.

This allows the consumption of natural gas to be increased to such an extent when the output of furnace becomes higher or remains equal to the output under normal conditions. The decrease of furnace output relative to the normal conditions indicates that an optimum value of natural gas consumption is exceeded.

Determining the natural gas consumption at the oxygen-enriched blast

When rising the oxygen concentration in the blast the natural gas consumption is to be increased in a definite relation. This dependence is shown in Fig.6 for the specific coke rate of 700 and 500 kg. Keeping this dependence between the rise of oxygen and natural gas consumption the temperature in the hearth and the pressure-drop of gases in the furnace would be constant.

Determining the natural blast consumption depending on the natural gas consumption

When increasing the natural gas consumption it is necessary to decrease the normal blast in a relation that is determined by the requirement to keep constant the value of gas pressure drop in the furnace. The tentative dependence of blast consumption changing (m^3 per minute) on the natural gas consumption (m^3 per hour) is shown in Fig. 7.

Determining the consumption of oxygen-enriched blast depending on the natural gas consumption

The blast requirement decreases at the same natural gas consumption when it is enriched by oxygen. This may be seen in Fig. 7, where the higher the oxygen concentration of the blast, the higher the lines indicating it are located.

Changing the weight of coke charge

When raising the natural gas consumption both to the normal and the oxygen-enriched blast the specific coke rate is reduced that leads to the increasing of burden ratio per unit of coke weight. When the burden ratio at the constant weight of ore part of burden is controlled by the weight of coke charge a dependence may be estimated between the amount of natural gas injected into the furnace and decreasing the coke charge.

Estimating this dependence it is necessary to take into account the coefficient of coke substituting by natural gas calculated previously for the given conditions.

Coke-oven gas injecting into blast furnaces

Coke-oven gas is one of the effective additives to the blast contributing to the decrease of specific coke rate. Due to the substantial content of free hydrogen (62–63 pct) and relative small content of methan (25–26 pct) coke-oven gas may be considered as a partly converted natural gas. Its calorific value is about two times lower than that of natural gas. This means that when utilizing it in the heat installations (steam boilers of steam power plants, soaking pits of rolling mil. plants, etc.) 1 cu.m of natural gas is equivalent to 2 cu.m of coke-oven gas, that can be directed at this case into blast furnaces. Calculations and experimental melt in one of the blast furnaces of the Zaporozhstal' Iron and Steel Works were carried out by the Institute for Ferrous Metallurgy of the Ministry [illegible] Ferrous Metallurgy of the USSR to determine the relative efficiency of utilizing coke-oven gas in blast furnaces in relation to natural gas. Half of the natural gas amount was substituted in this case by a double amount of coke gas. The calculations showed that in substituting half of natural gas amount by coke-oven gas as it was described above a .8–1.0 pct gain in furnace output and a .5–.6 pct decrease of specific coke rate may be obtained. These values double when natural gas is completely substituted by coke-oven gas in the same ratio. An experimental melt when half of natural gas amount was substituted by the double amount of coke-oven gas leads to the more favourable results: the gain in output amounted to [illegible].4 pct, the specific coke rate decreased by [illegible].2 pct.

The first tests of injecting the coke-oven gas alone were carried out on the one of blast furnaces of the Kuznetsky Metallurgical Combine in May 1957 and in July 1958. The coke-oven gas consumption was 3.5–5.6 pct to that of blast. At separate periods of time the gain in the furnace output amounted to 1.1 pct and the specific coke rate decreased by 2.6–5.2 pct.

More extensive tests were carried out at the same Combine in 1962–1964. It was found out that the evenness of furnace driving was improved by injecting the coke-oven gas into the furnace. With the use of [illegible] cu.m coke-oven gas per ton of iron produced the gain in output amounted to 4.2 pct. The specific coke rate decreased by 9.6 pct. The coke replacement ratio was 0.63 kg per cu. m.

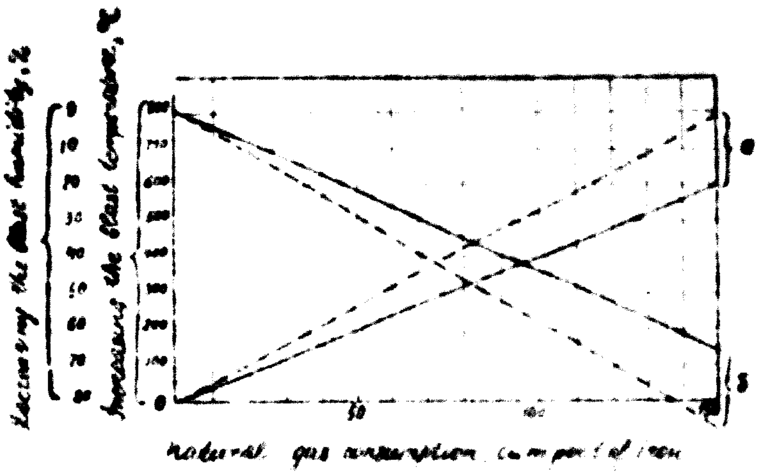

Fig.5 (left) a)Additional heating of blast when injecting natural gas into the hearth required to keep the previous theoretical temperature of burning.

b)Decreasing the blast humidity when injecting natural gas into the hearth equivalent in its heat effect to increasing the blast temperature

- - - - original specific coke consumption = 700 kg

— — — original specific coke consumption = 500 kg

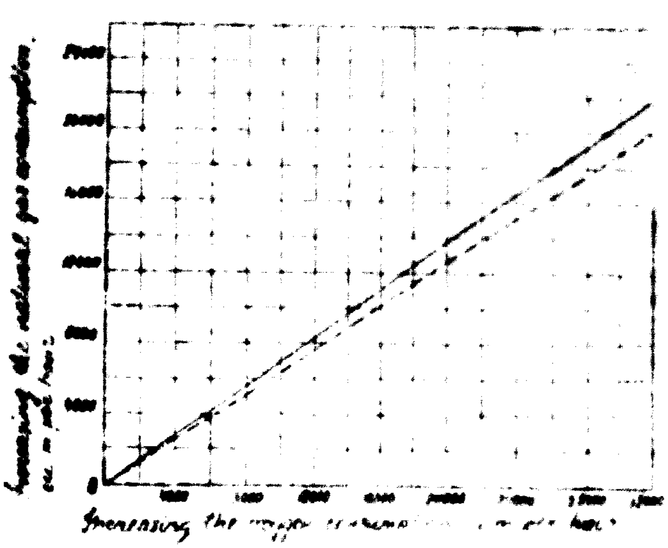

Fig.6 Dependence of natural gas consumption on oxygen consumption, when keeping the theoretical temperature of burning and pressure drop in the furnace at the same level

- - - - - specific coke rate = 700 kg

— — — specific coke rate = 500 kg

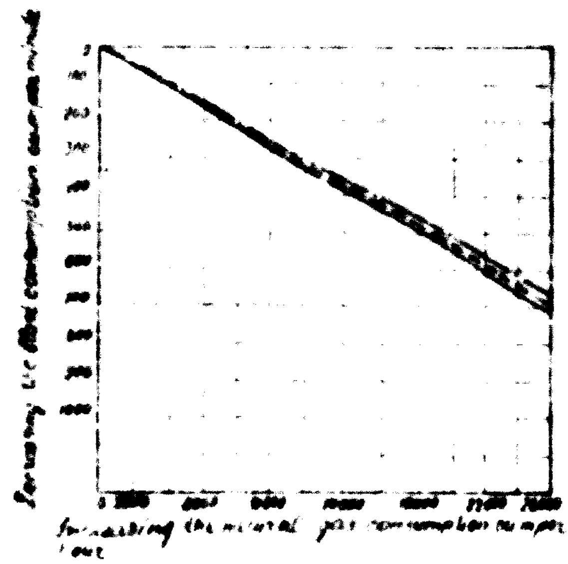

Fig.7 Changing the blast consumption (cu.m per minute) depending on changing the natural gas consumption (cu.m per hour) when keeping the pressure drop of gases in the furnace at the constant level

- - - - - O_2 concentration in blast = 21.0 pct

— — — O_2 concentration in blast = 25.0 pct

-I-▲- O_2 concentration in blast = 30.0 pct

Powdered coal injection into blast furnaces

A substantial decrease of specific coke rate may be obtained by injecting powdered coal fuel into the hearth of furnace. As the substitutes of coke it is most expedient to use in this case the ground anthracites or non-coking coals with a possible lower content of ash and that of sulphur and with a high calorific value.

The full-scale tests of injecting the powdered coal into the hearth of furnace were carried out in the USSR at Dzerjinsky Iron and Steel Works in 1955. The ground anthracite dust containing 16-18 pct of ash and 1.7-[illegible] pct of sulphur was utilized as a fuel. It was ground to the size of .05-.08 mm, which provided for the complete combustion in the zone of combustion. When injecting powdered coal in the amount of 5-6 pct of total consumption of coke this consumption reduced by about the same value.

In 1956 powdered coal was injected into one of the blast furnaces produced ferromanganese at the Novo-Tulsky Iron and Steel Works. The consumption of it amounted to .119 t per ton of ferromanganese.

An pilot-plan injecting the powdered coal into the hearth of the large blast furnace was carried out by TSNIICHM at the Karagandinsky Iron and Steel Works in 1964-1965. It was shown that a part of coke may be principally substituted by the powdered coal. The powdered coal consumption was increased up to [illegible] kg per ton of iron. The coke replacement ratio (recalculated to carbon) was close to unity. The furnace output increased by [illegible] pct.

An experimental operation with the combined utilization of powdered coal and natural gas was carried out by the Institute for Ferrous Metallurgy at the Zaporoghstal Iron and Steel Works in 1967. As a result of injection into the hearth of blast furnace the ground solid fuel of AS grade in a rate of 21.[illegible] kg per ton of pig iron the specific coke rate decreased by 5 pct and the output of furnace increased by [illegible] pct. The coke replacement ratio amounted to [illegible].7 kg of coke per kg of coal instead of 1 kg per kg by calculation.

When injecting powdered coal fuel into the hearth of furnace it is necessary to take into account the cooling effect of powdered coal which at the moment of entering into the furnace has a temperature [illegible]°C while the coke substituted by it enters into the zone of combustion with a temperature 1500°C. In order to prevent the fall in burning temperature it is necessary to raise the blast temperature by a value depending on the quantity of powdered coal injected, its humidity, and chemical composition, which should be calculated separately for each case.

Injecting liquid fuel into blast furnaces

Along with injecting gas and solid fuels into the furnaces the injection of liquid fuel (usually fuel oil) into the hearth also found an extensive use. Accordingly to the data of 1965 some 170 blast furnaces in Japan, France, USA, Great Britain, German Federal Republic and in other countries operated with the injection of liquid fuel.

The efficiency of using liquid fuel depends on the local conditions. At the Nizhny Tagil Metallurgical Combine in the USSR when injecting 87-[illegible] kg of fuel oil per ton of iron, increasing the temperature of blast by 50-[illegible]°C and decreasing its moisture content by 4-5 g per Nm^3 the specific coke rate decreased by 14.[illegible]-1[illegible].7 pct, the output increased by 6.1-6.8 pct. The coke replacement ratio by fuel oil amounted to .6[illegible]-.64 kg of fuel oil per kg of coke.

Recently some attempts to use injecting the coal-fuel oil slurry in blast furnaces took place.

3. Use of natural gas and other types of fuel in steelmaking

The Fifth Year Plan of the national economy development of the USSR in 1966-1970 makes provisions for high rates of steel production, which will allow more than 120,000,000 tons of steel is to be produced in 1970 including more than 70 pct of open-hearth steel.

The high part of open-hearth steel in total steel production is attributed to the fast technical progress in this branch of steelmaking above all due to the intensification of production processes thanks to oxygen and natural gas using; by reserves of the latter our country occupies the first place in the world.

Presently in the USSR (only in the system of enterprises subordinated to the Ministry for Ferrous Metallurgy of the USSR) more than two thirds of open-hearth furnaces operate with natural gas. The rest of furnaces (less than one third) operates with mixture of coke-oven and blast-furnace gases. A part of furnaces operating with natural gas has one-uptake design and uses fuel oil to carburize the flame, the other part is of out-of-date design with three uptakes and self-carburising of gas in the central uptake.

Prior to the natural gas applying in ferrous metallurgy the principal types of open-hearth fuel were a mixture of coke-oven and blast-furnace gases, fuel oil and producer gas with the preliminary heating of gas fuel, which considerably complicated the furnace design.

The natural gas using the suitable methods of burning allows the higher techno-economic characteristics to be obtained that with fuel oil, hence the substituting of all other fuels of low calorific value by natural gas has an economic advantage. The appreciable expansion of natural gas as an open-hearth fuel during the last decade proved the expedience of this trend. The out-of-date three-uptake open-hearth furnaces and preheating of fuel have been replaced by the new open-hearth furnaces more simple in design and maintenance. These furnaces have one or two uptakes and one pair of regenerators to heat the fanned air only.

Presently only one-uptake open-hearth furnaces are constructed and old three-uptake furnaces are gradually reconstructed into one-uptake furnaces. In foreign steelmaking the open-hearth furnaces of one-uptake design dominate among the furnaces of other design both in their numbers and in the amount of steel produced; to heat these furnaces natural gas and fuel oil are used.

The expansion of one-uptake open-hearth furnaces is due to more simple design of port and down structure of furnace, to substantial less resistance of air- and fume ways, to smaller consumption of refractories for building and maintenance of them, to decreasing the time of repairs. Moreover, in modernizing the three-uptake open-hearth furnaces into those of one-uptake design it is possible to enlarge the hearth area by 20-40 pct without substantial changing the dimensions of furnace itself and, consequently, to increase the weight of charge.

However, when heating open-hearth furnaces by natural gas using the known methods, the flame is non-luminous and in this case the techno-economic characteristics deteriorate.

The natural gases of the USSR are basically "dry" and readily produce luminous flame if they burn together with the liquid fuel (fuel oil, tar).

Most of the burner installations used to heat the one-uptake open-hearth furnaces are two-channel gas-fuel oil burners with the central feeding of fuel oil. However, using the gas-fuel oil heating it is necessary to have two fuel services in the shop and two types of heating installations or one but more intricate combined installation on the furnace, which makes the operation of furnaces more costly and complicated. Moreover, open-hearth furnaces require the low-sulphur fuel oil that costs more than natural gas. Hence the methods of natural gas burning are intensively developed providing for obtaining the luminous flame without fuel oil.

When changing the fuel the three-uptake open-hearth furnaces heated with the mixture of coke-oven and blast-furnace gases a so called method of self-carburizing of natural gas in the central uptake was used, which was developed by the Institute for Ferrous Metallurgy. In this case the hot air from regenerators is fed into the furnace proper not through two uptakes but through three ones. A part of gas (40-50 pct) at low pressures (≥ 1000 mm WG) is supplied to the central uptake (previously a gas uptake) at the level of charging floor and the rest of gas is supplied at the low or high pressure higher into the end of caisson. In this case the amount of air entering through the central uptake should provide for burning of this gas with α = .5-.6 and the temperature of air should be 1050-1200°C. It was established that the luminiosity of self-carburized natural gas considerably increases and exceeds the luminiosity of the flame of heated coke-oven and blast-furnace gas mixture. A more essential advantage of the method described is the fact that no changing of furnace design is required as well as giving a possibility to have reserves of fuel. However, this method of heating doesn't allow for improving the design of furnace operating with heating of the air only and, consequently, to obtain all gains from the natural gas utilisation.

The new method of open-hearth furnace heating with the self-carburized natural gas developed by the Institute for Ferrous Metallurgy (see Fig.8) is the most promising one. The essence of this method of heating lies in organization of flame from two streams: an upper flow of natural gas of low pressure that emerges with a low velocity (50-150 m per sec.) from the nozzle of a large diameter with the purpose to create conditions to decompose the hydrocarbons into the substances (soot carbon, acethylene, benzene, etc.) providing the flame luminiosity; and the lower high-speed flow of the natural gas of high pressure and of the high oxidizing blast (oxygen, compressed air, superheated steam, etc.). As a result of interaction of both these flows a sharp grazing flame is produced having a high-temperature low edge with the sufficient luminiosity and the high oxidising ability.

The principle of two-layer burning of fuel and the simple and reliable design of gas-oxygen burners of high- and low pressure allow for controlling over a wide range (through changing the burner angle of inclination and the natural gas redistribution between them) the oxidising and radiation characteristics of flame having the high aerodynamic properties depending on the period of a heat. In this case oxygen and other oxidizing components of flame are used most efficiently.

The new method of heating allows the open-hearth furnaces of out-of-date three-uptake design to be effectively reconstructed into the furnaces of one-uptake design with the simultaneous enlarging the hearth area and doubling the weight of charge without changing the dimensions of the furnace. Additionally, it allows for eliminating the necessity of constructing the fuel oil installation which is difficult to locate at an operating iron and steel works. It can also lead giving up the costly and deficit fuel (low-sulphur fuel oil) in the one-uptake open-hearth furnaces heated with fuel oil as well as simultaneous improving the techno-economic characteristics of their operation.

The developed design of burner installation makes it possible to go over to the heating with any consumption of fuel oil without retooling the furnace as burners are equipped with replaceable fuel oil nozzles. It also makes it possible to partly or completely substitute natural gas by coke-oven gas produced in considerable amounts at the integrated iron and steel works; the heating capacity of coke-oven gas at the some works increases to 6000-7000 Kcal per cu.m when separating hydrogen to produce ammonia.

Two methods of open-hearth furnace heating with self-carburized natural gas have been developed and introduced. The method of heating the one-uptake open-hearth furnaces having the port ends of one- or two channel and operating by scrap-ore process using hot iron and oxygen to intensify the combustion of fuel and to blast the melt has been introduced in 640-t furnaces of the Krivorogstal Iron and Steel Works and in the 220-500-t furnaces of the Dzerjinsky and Zaporozhstal Iron and Steel Works. This method of heating is used at the metallurgical combines and works having oxygen.

The second method of heating is designated for the furnaces operating by scrap process with cold iron but without using oxygen as well as for iron melting furnaces. This method is

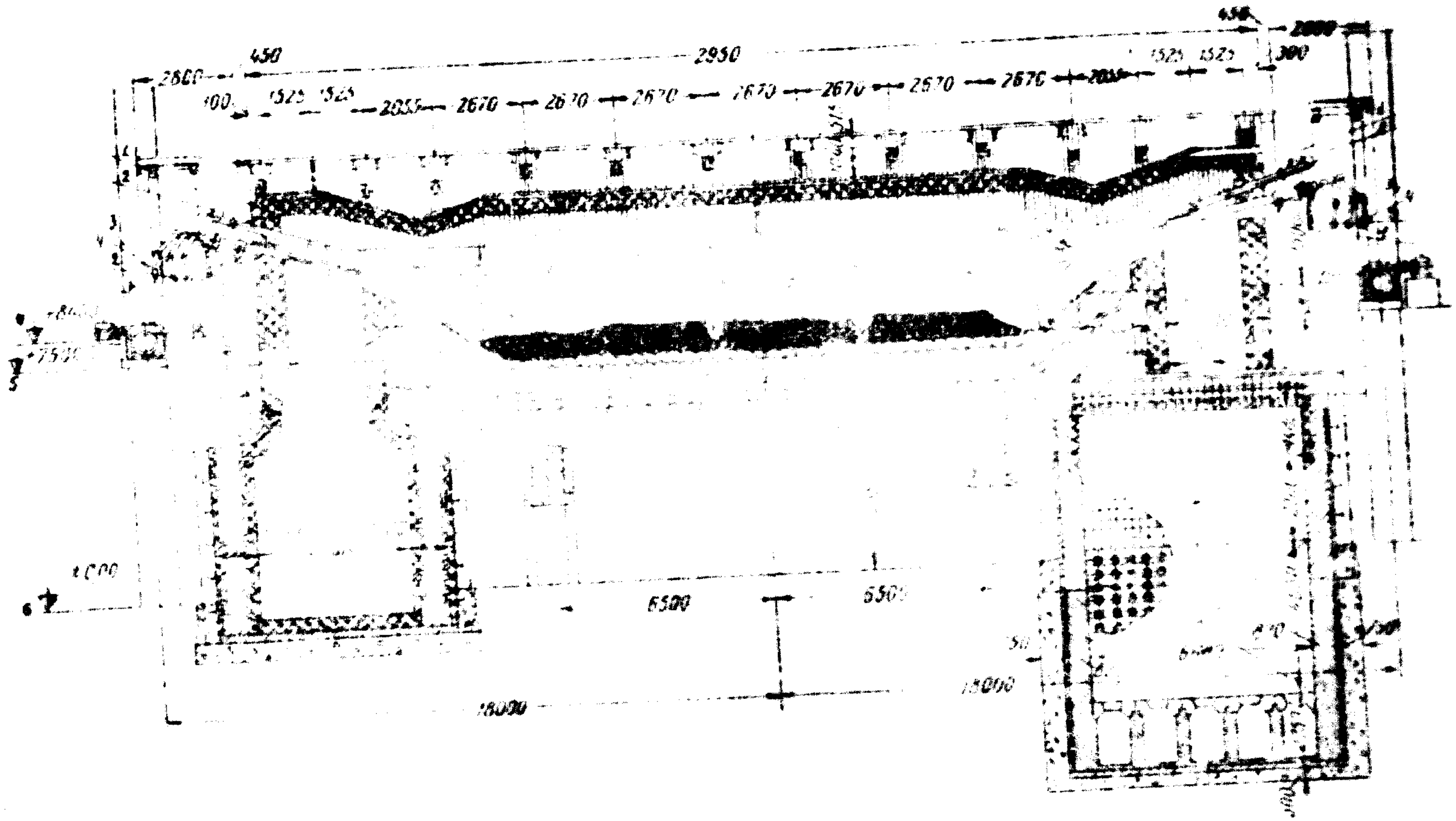

Fig.8 The layout of burners and location of flame in 600-t open-hearth furnace heated with natural gas with self-carburizing in flame. Fig.8 conventionally shows:

on the right - location of flame during charging and preheating;

on the left - location of flame during melting and refining.

1 - water; 2 - natural gas; 3 - oxygen; 4 - air; 5 - level of charging floor; 6 - level of shop floor, 7 - sill level.

used at the iron and steel works operating without oxygen and at the machine-building works.

The advantages of the developed method of heating are confirmed by the techno-economic characteristics of furnace operation. Thus, the output of 640-t open-hearth furnaces of the Krivoroghstal Iron and Steel Works operating with the use of oxygen rose under otherwise identical conditions by 5 pct, the oxygen and fuel consumption decreased respectively by 9 and 3 pct; the yield increased by .7 pct.

The reconstruction of two three-uptake design open-hearth furnaces of the Zaporoghstal Iron and Steel Works with the use of new heating method allows the output to be raised more than by 35 pct at the simultaneous enlarging the charge twice as much; it also reduced the time of repairs as well as lowered the consumption of refractories by 25 pct.

The method of open-hearth furnace heating with natural gas self-carburized in the flame doesn't change the grades of steel produced. The sulphur content in metal decreases in this case, which is also confirmed by the reach experiance of three-uptake open-hearth furnaces operating with the natural gas and its self-carburization.

As a result of thorough investigations and generalization of the experience of the open-hearth furnace operations with different types of fuel it has been established that transferring the open-hearth furnaces to the natural gas heating improved the techno-economic characteristics of their operation.

It may be seen from the most important techno-economic characteristics quoted in Table 8 that the highest output was obtained at the one-uptake open-hearth furnaces using natural gas with self-carburizing in flame as well as using natural gas with fuel oil. The output of three-uptake open-hearth furnaces heated with natural gas with self-carburizing in uptake is a little less, and three-uptake open-hearth furnaces heated with the mixture of coke-oven and blast-furnace gases and the preheating of fuel have the lowest productivity.

The further development of one-uptake open-hearth furnace design as the most advanced allows their output to be raised and other characteristics of their operation to be improved.

Table II

Techno-economic characteristics of open-hearth furnace operations

Works	Furnace design	Type of fuel and method of heating	Weight of charge t	Output t/h	Specific consumption of fuel, kg of reference fuel per ton of steel	O_2 consumption cu.m per ton of steel		Average heat load 10^6 Kcal/h
						in melt	total	
A	one-uptake	natural gas + fuel oil	858.8	70.4	124.6	-	35.7	61.4
B	- " -	- " -	908.5	86.1	80.3	17.7	35.8	46.0
C	- " -	- " -	570.4	49.1	117.3	25.7	41.2	39.8
D	- " -	- " -	655.9	60.7	116.9	-	35.6	49.0
E	- " -	- " -	570.4	53.2	115.9	15.6	27.8	39.4
F	three-uptake	- " -	573.5	49.5	105.4	12.3	23.9	33.5
	one-uptake	natural gas with self-carburising in uptake	601.4	52.4	118.9	16.6	49.3	43.7
	three-uptake	mixture of coke-oven and blast-furnace gases	601.5	49.7	104.8	-	35.1	33.0
G	one-uptake	natural gas + fuel oil with self-carburising in flame	633.4	64.5	100.7	13.1	45.6	46.2
H	- " -	natural gas with self-carburising in flame	483.4	48.0	83.1	14.0	54.8	27.9
	three-uptake	natural gas with self-carburising in uptake	487.4	46.0	81.3	11.0	52.7	26.5
I	one-uptake	natural gas + fuel oil	477.4	41.8	131.4	18.4	30.9	38.6
	three-uptake	natural gas with self-carburizing in uptake	476.7	38.4	123.7	22.0	35.3	33.4
J	one-uptake	natural gas + fuel oil	459.9	52.3	90.0	16.6	40.3	35.3
	two-uptake	- " -	445.0	46.6	161.0	15.5	43.6	32.0
	three-uptake	natural gas with self-carburizing in uptake	451.5	41.8	131.0	-	44.6	33.0
K	one-uptake	natural gas + fuel oil	421.0	42.8	92.0	5.8	39.7	27.5
	three-uptake	mixture of coke-oven and blast-furnace gases	422.0	44.0	92.0	-	39.9	

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