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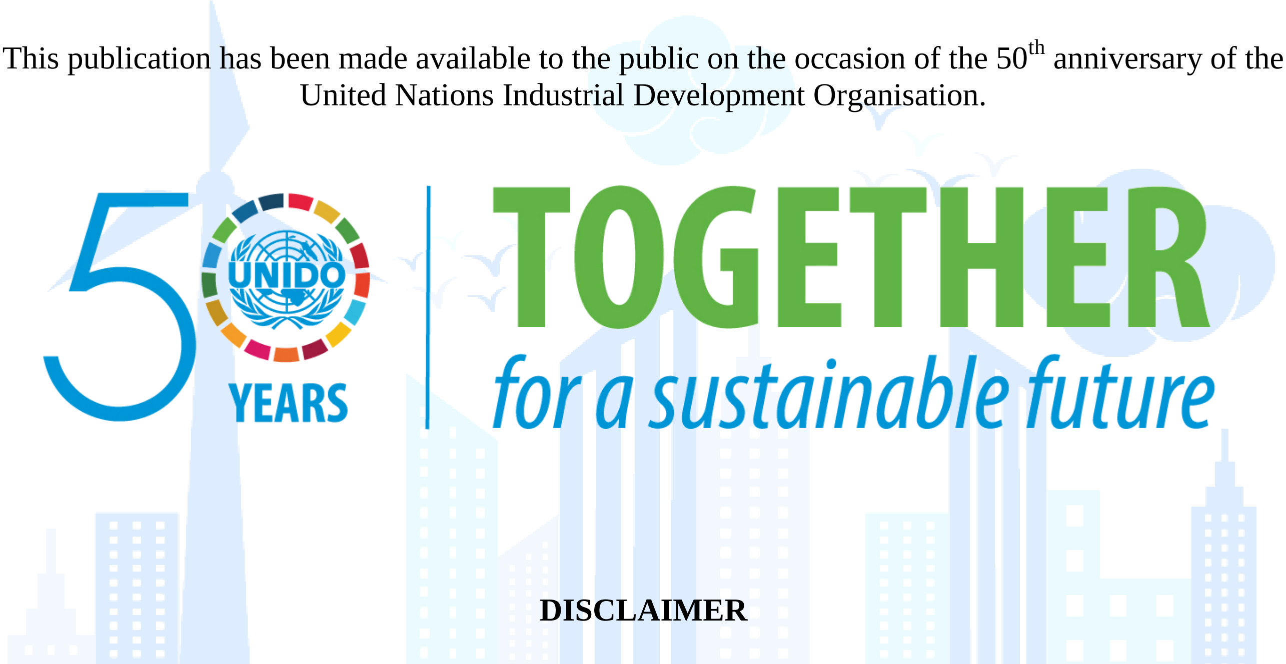

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LARGE SCALE PRODUCTION OF SINTER

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SYNOPSIS

The address contains details of the dimensions of sintering machines, and also covers the principal technological conditions on which large sinter plants are run. Qualitative particulars are given of the fluxed sinter necessary to produce high outputs from blast furnaces.

INTRODUCTION

Since the first sinter plant was brought into operation the basic principle of the methods used for lumping ore fines has remained unchanged; it is that of sintering concentrate by sucking air through a layer of the ignited mixture in continuous-action conveyor-type machines; the reason lies in the simplicity of the method and its high technical and economic indices.

Sintering technology is continually being improved, and sintering machine suction area and output are all the time rising; mechanization and automation are being applied to control of the process and equipment.

The air is sucked downwards through the layer of mixture. In pelletizing, however, in the cooling stage the air is usually blown upwards, the hot air being subsequently used in the drying and preheating stages by sucking it downwards.

The extremely promising method which is called vacuum-blast concentration has not yet been developed on an industrial scale; this method consists of blowing the air upwards, and it is thus possible to sinter with a thick bed.

A method of producing pellets from fine concentrates widely used in the USA is that in which they are roasted on conveyor belt machines of sintering machine type, in which however the gases are recirculated.

The production of pellets from fine concentrates is at the industrial development stage in the Soviet Union. The roasting of pellets has no technical or economic advantages over sintering as a method of lumping fine-grained ore fines (concentrate).

Most blast furnaces in the Soviet Union run on sinter, the mean proportion of sinter in the ore content of the stock being 70.7 per cent in 1961.

TABLE 1

PRODUCTION OF SINTER
(in million tons)

Countries	Years					
	1957	1958	1959	1960	1961	1962
Soviet Union	43.3	49.5	56.9	65.1	70.2	84.0
USA	28.2	25.9	30.0	40.8	41.0	-
West Germany	13.6	14.5	13.9	19.8	21.2	-
Great Britain	9.4	9.6	11.6	15.0	14.8	-
Japan	4.5	5.8	6.8	8.2	13.4	-

PART I

SINTERING MACHINE OUTPUT

The output of a sinter plant is governed by the number of sintering machines installed and their sintering areas, the amount of raw material available, the efficiency of the technological process, and mechanization and automation of all its sections and equipment.

The number of sintering machines to install at individual ore mining and enrichment combines is not calculated on the basis of the amount of sinter required by the blast furnace bay at one works.

A sinter plant must be equipped with not less than two of the new large machines (of 200 m^2 or more); even if there are two machines, 50 per cent of the total capacity is at once out of action when repairs are necessary.

The number of average sized (125-150 m^2) sintering machines which should be installed at one sinter plant is not more than 12, but these should be in two separate sintering bays. A bay should not contain more than 6 machines, for more than this number involves difficulties in organizing the supply of materials to the machines and in handling the finished product.

Initial raw material quality can be subdivided, according to its effect on sintering machine output, into three categories.

1. Sinter ore and dry coarse concentrates of optimum granulation.
2. Fine concentrates produced by wet magnetic separation from finely impregnated quartzites of Krivoi Rog type.

Under equivalent conditions, when sintering these fine concentrates output is 33 per cent lower than when sintering good sinter ores.

If, however, the materials are effectively prepared, by granulation and introducing intensifying agents, good output figures can also be achieved when sintering fine concentrates.

3. The most widely encountered case - mixtures of good ores and fine concentrates.

I. Sintering Machine Suction Area and Output

A great many sintering machines with suction areas of 2.5 x 30 = 75 m^2 (the K-2-75) are used in the Soviet Union. The K-2-50 machine is already obsolete, since most of these machines have been modified to increase the area to 2.5 x 25 = 62.5 m^2.

Lengthened machines of 2.5 x 50 = 125 m^2 and 2.5 x 60 = 150 m^2, based on the K-2-75 machine, are being produced and are now in use.

Large, wide machines of dimensions [illegible] x 78 [illegible] 31[illegible] m^2 (these are called 200 m^2 machines) are now in the stage of construction and installation.

Small sintering machines are also no longer being constructed abroad.

Most of the new machines have pallets 2.5 m wide and are 30–56 m long.

New, large sintering machines with sintering areas of 160–223 m^2, their pallet width 3.66 m, are now being built and used in the USA, Belgium, Australia and Canada. Some machines are being built with pallets 4 m wide.

The easiest method of increasing sintering machine area is to lengthen them, and this can even be done at existing sinter plants.

The use of pallets 2.5 m wide has been thoroughly mastered, and this can be regarded as the minimum pallet width for new machines.

The advantage of greater pallet width lies not only in the possibility of increasing sintering area, but also in the fact that the lower D : M ratio reduces the relative useless amount of air sucked through unit suction area; another advantage is that the proportion of lower quality sinter produced at the sides of the machine is lower.

The pallets are still 1.6 m long, and this length can be considered optimum.

In the K-2-75 machine the pallet sides are 300 mm deep. Since the gas-permeability of mixtures is not good enough, however, the ideal thickness of the mixture on the pallets is only 250 mm.

The characteristic side depth of the types of pallet used abroad is about 350–450 mm.

Most sinter plants in the USA form the mixture into large lumps, and the machines run on deep layers, almost as deep as the sides.

It is extremely desirable to increase layer depth, since in this way output can be greatly raised.

Increasing the depth of the layer is conducive to improving the structure, strength and lump composition of the sinter, also to raising the yield of good sinter and reducing wear on the machines through lower pallet speeds; as a result of improved regeneration of heat there is a saving of fuel, and mean grate temperature is lower.

2. Sintering Machine Output

Suction area dimensions and sintering machine output must be greatly increased.

Machines based on the K-2-75 machine and lengthened to 50–75 m are now in use; these machines could be made up to 100 m long. The pallets of the K-2-75 machine can widened to 2.5-3 m by utilizing the projecting brackets at the side. A machine with 4 m wide pallets is being brought into use. This will increase suction area as follows:

$2.5 \times 75 = 153$ m^2 (at Karaganda)
$3 \times 75 = 225$ m^2 (possible)
$4 \times 78 = 312$ m^2 (called the "200 m^2" type)
$4 \times 100 = 400$ m^2 (possible)

Increasing the suction area three or four times provides the same scale of increase in output.

The output of a K-2-75 machine running on a mixture of ore and concentrates is up to 2500 tons a day.

The output of the 312 m^2 machine may be more than 10,000 tons a day.

The daily output of the 120-125 m^2 machines used in the USA (at Pittsburg, Gary, Sautz Works, Indiana Harbour, etc.) is up to 4500 tons (the mixtures are not indicated).

A number of sinter plants in the Soviet Union are producing up to 8 million tons of sinter a year; the sinter is cooled in the machines at these plants.

If machines are not more than 30 m long, only the sintering process is performed in the suction area. With longer machines (50-75 m long, or even up to 100 m), both the sintering and cooling processes are carried out in the suction area. Since more than half the suction area is required for cooling the sinter fully, sintering machine output should be related to sintering area, also indicating the cooling area.

3. Preparing Mixture for Sintering

Uniform preparation, using an accurately batched and efficiently mixed and nodulized mixture, is a guarantee that sintering machine output will be high and sinter quality good.

If the composition of the mixture on successive pallets is uniform, the sintering process follows an even course, and all the links in the production process in the machine can be regulated automatically.

Uniformity of mixture composition is ensured by blending the ores efficiently at the ore beds and by means of automatic equipment for feeding weighed batches of the components of the mixture.

There is a tendency at present, in the Soviet Union and abroad, to use two-stage mixing, and to lengthen the mixing drums of existing machines. The more effective nodulizing of the mixture in elongated drums is an extremely effective measure when sintering normal, but fine, sinter ores. When sintering fine concentrates which have been nodulized by the ordinary methods, and which have poor gas-permeabilities, however, it is insufficient merely to loosen up the mixture.

The basis of successful sintering, using fine concentrates, in sintering machines lies in coarse nodulizing, and in granulating the mixture to 3-8 mm.

The production of granulated sinter is more economic than pelletizing.

The initial elements of new or reconstructed plant must be trough- or drum-type mixers, with screw conveyors in which the materials are mixed without increasing their moisture content.

The mixture must be wetted and granulated in long drums or disc-type granulators.

Drums 12.2 m long and 3.66 m in dia. are widely used in the USA. Drum revolutions are regulated, and sometimes the angle at which the drum is tilted is also regulated.

Drums are universally used for nodulizing multi-component mixtures. The grains which they provide are not, however, of uniform dimensions, and there is a large proportion of fines.

The other failing of long drums is that they occupy a great deal of space; only 10-15 per cent of the space inside the drum is taken up by the mixture.

The advantages of disc-type granulators include the following: grains of a uniform 8-3 mm are produced, with a lower moisture content than with drum nodulizing, and this is also very important as regards sintering; the granular structure of the sinter is also uniform. Disc area is more than 50 per cent utilized; the granulators require much less work space than long drum granulators.

It is easy to apply half the fuel to the grain surfaces in the disc granulators. The process and its output can easily be regulated by altering the tilt of the discs, the revolutions, and their side height.

The failing of the disc-type granulators is that the maximum possible disc diameter of 5.5 m is comparatively small, and this means that a large sintering machine requires not less than two granulators; another disadvantage is that the construction (inclined rotating disc) is less durable than the drum type.

(When producing 8-15 mm pellets, however, even a small machine requires not less than three long and three short (for applying the coating to the grains) drums; there must also be a screening and recirculation cycle. These are David Works details).

Two trough-type mixers followed by a single 5.5 m dia. disc granulator are the primary elements used for 94 m^2 machines at Cleveland in the USA.

The 125 m^2 machines at Indiana Harbour and Youngstown, which produce [illegible] tons a day, are each served by two disc granulators. The granulators are located parallel to one another, and the mixture is supplied to them by means of a rotating channel.

From the granulators the mixture flows by gravity through a funnel onto a slewable conveyor belt feeder, which rocks horizontally and distributes the mixture across the width of the sintering machine.

In every case, the flux and fuel used for granulating require to be more finely pulverized.

The granulated sinter has a high bulk density, and its strength is good.

4. Addition of burnt lime

Burnt lime is included in the sinter mixture used in the Soviet Union today on a large scale.

Burnt lime is an extremely effective intensifier of the sintering process for all known types of ore, since it possesses a combination of many useful properties. It is a powerful intensifying agent not only for sintering acid ores, but also for sintering fluxed concentrates, even if they are highly basic.

The addition of burnt lime to the ore in railway trucks prevents it from freezing in winter. The addition of lime to the ore beds greatly improves the free-flowing properties of wet or damp concentrates, and makes them easier to transport and feed into the hoppers.

The mixture is preheated before sintering by the large amount of heat evolved when the lime is slaked.

The sintering rate is greatly increased, because the mixture is extremely well and strongly lumped and its initial gas-permeability increased.

Lime tends to increase the moisture capacity of the mixture, and is conducive to "super-moistening" of the lower levels in the mixture.

We know that lime has a cementing action, thus tending to make the lumps stronger.

When unfluxed concentrate is sintered lime exerts a particularly vigorous effect, since it tends to reduce the high initial softening temperature of rich acid ores; lower-melting and more fluid, molten substances are formed and this enables sintering to be conducted for lower fuel consumptions.

In the case of some ores the thickness of the viscous-plastic region, with poor gas-permeability, also the viscosity of the molten substance, are reduced, while in the case of other ores the sintering zone widens to the optimum width and the strength of the cake is improved.

The addition of lime when sintering fluxed concentrate and raw limestone is also extremely effective, since the evenly distributed, dispersed slaked lime enters into chemical compounds with the ore grains before the limestone, even in the solid phase; this is conducive to the production of a primary liquid phase of more suitable composition and properties (calcium ferrites).

There is no need to use kilned fluxes, even when sintering highly basic concentrate, since the addition of lime is quite sufficiently effective.

Adding lime improves the strength of the sinter by generally improving the course of the process and reducing the fuel consumption.

In the USSR limestone is roasted in special circular rotating kilns; air is sucked through a circular layer of an ignited mixture of pulverized limestone and coke. (O.P.R. kiln).

Before roasting, the limestone is pulverized (in a hammer mill); the 3-10 mm fraction is separated from the primary product and despatched for roasting; the 3-8 mm fraction is used for fluxing the concentrate, and the >10 mm fraction is returned for repulverizing.

The O.P.R. kilns are included in the production line, and the hot, roasted granulated lime is fed direct onto the mixture batch conveyor. The lime is slaked as it mixes with the green mixture and while it is being damped and lumped.

If the limestone is pulverized to between 3-8 mm and 3-10 mm, with the consumption of carbon about 5.5-6.5 per cent and discharge beyond the circular grate effective there is up to 90 per cent decarburization during roasting. The figure when the limestone is pulverized to 15-0 mm is about 75 per cent.

Kiln output is about 300-350 tons a day.

5. Devices for Feeding the Mixture

The greater the width of the pallets the more difficult does it become to feed and spread the mixture onto them.

Various types of feeder have been considered and developed for machines with pallets 2.5 m or more wide; these include tilting, vibrating and drum types, also combinations of these.

The type most widely used in the Soviet Union and the USA, which is also the most rational type, is a combination of a shuttle-type distributor and a drum feeder; this combination distributes the mixture evenly enough across the machine without the large grains gathering together to any great extent. This type of equipment is suitable either for 2.5 m wide machines or for the new, wider (3.66-4.0 m wide), machines. The shuttle-type feeders distribute the mixture uniformly across the drum feeder hopper, and consequently also across the machine.

The rate at which the drum feeder rotates is synchronized with the speed of the pallets. The depth of the slot above the drum feeder is regulated by means of a hand-operated gate valve, while the depth of the layer fed onto the sintering machine is regulated by adjusting the level of the lower edge of the baffle plate.

6. Gas Suction Systems

In the case of long, wide sintering machines with the usual method of gas suction from one side, the flue system may be slewed relative to the axis in the direction of suction, and the current of gases drawn through will not be uniform across its width.

Gas suction from both sides is widely used in the USA. The advantages of this method are that the air is more uniformly distributed across the machine, there is a less complicated system between the sintering and return paths of the pallets, and there is no decrease in the inclination of the vacuum chamber walls.

The gases are sucked through from both sides either through gas mains directed at both sides alternately, or by splitting up all the vacuum chambers along the axis of the machine and fitting two gas offtakes from each vacuum chamber, with this system the outgoing gases enter two collectors on either side of the machine, then proceeding to two exhausters.

Locating two collectors in this manner along the machine is also extremely effective in the case of long (2.5 x 75 m) machines in which the sinter is cooled.

According to the technical particulars, as fitted to the K-2-75 machine the D-II-6500 exhauster provides a suction delivery of 87 $m^3/min/m^2$ of pallet area, at 150°C and 1000 mmwg.

This, however, is also insufficient for well prepared mixtures. The types of exhauster used in the USA and Britain, also with the large sintering machines now being brought into use here, have specified deliveries of 90-110 $m^3/min/m^2$.

As mixture preparation improves, exhauster capacities should be reviewed, the tendency being to increase them.

7. Cooling of Sinter

Cooling the sinter is highly desirable, since if this can be done in the sintering machine the sinter can be supplied direct to the blast furnaces on the rubber-covered conveyor belts. If cold sinter can be supplied by conveyor belt to the furnaces there is no need for expensive rail transportation systems, and manual labour on discharging the sinter is avoided; working conditions at the bunkers are improved, and blast furnace charging apparatus life is lengthened.

In spite of the great technical and economic advantages of using cold sinter, however, in practice cooling it is an extremely complex operation.

The circular sinter coolers mounted beyond the sintering machines, which are employed here and abroad, have not justified themselves, since their efficiency is low, the apparatus is cumbersome, and they break up the sinter even more.

Even when air is blown or sucked through the sinter by means of powerful flue gas pumps, cooling is slow and ineffective. The sinter cannot be transported by rubber-covered conveyor belt because the rubber strips are frequently burned through.

When air is blown through a 2 m deep layer of lump sinter, with a relatively small cooling surface (and moreover a high heat content and low thermal conductivity) in circular coolers, the air tends to pass through the wide channels between the lumps without penetrating into the numerous pores in the sinter; as a result cooling is extremely slow. The temperature of the air sucked through is low, while the amount required is immense.

In addition, as the temperature of the sinter falls more and more air must be sucked through for each successive ^{0}C of cooling, since for convectional heat the coefficient of heat transfer is proportional to the difference between the first powers of the temperatures ($T^{0}_{sinter} - T^{0}_{air}$), while for radiant heat it is proportional to the difference between the fourth powers of the temperatures ($T^{4}_{sinter} - T^{4}_{air}$).

The primary stage of cooling, down to about 400-300^{0}C, is therefore a less complicated and more effective operation. Further cooling the sinter down to 90-60^{0}C is extremely slow, and requires a vast amount of air and equipment with large capacity.

It is an accepted fact that, in the sintering process, the upper layer of sinter is automatically cooled by the air being sucked through at the same time as the lower layers are being sintered.

Only the lower incandescent layer of cake requires further cooling. On the basis of what has been stated above it is much more effective, from the thermal and technical points of view, to cool the lower part of the cake, which is at a high temperature, in the sintering machine than to cool a mixture of cold and hot sinter in a cooling machine.

Of all the possible methods of cooling, cooling the cake in the sintering machine itself (by the air suction method) is the most effective means of utilizing air, also the method with which air consumption, in m^3/^{o}C, is lowest, since with this method all the large surface area of the channels between lumps, and of the pores in the cake, is cooled simultaneously.

On the other hand, however, if the sintering machin is used for this purpose it becomes an extremely costly plant.

In the Soviet Union, the sinter is cooled in several sintering machines with sintering areas of 75 m^2 (elongated K-3-75 machines); these are elongated by 20-30 m by including a cooling area of 50-75 m^2; the total air suction area is 125-150 m^2. Air is sucked through the sintering area by a D-II-6500 exhauster, and through the cooling area by a separate collector with a D-21.5 X 2 flue gas pump (its delivery according to the technical particulars is 450 000 m^3/h at 150^{o}C).

It has been found in practice at NIGOK and the Dzerzhinsky Works, where the machines are lengthened by 20 m, that the sinter is only fully cooled if the cooling area is equal to the sintering area.

At the same time, the electric motor driving the flue gas pump does not run at full load, the power reading being on the left hand side of the characteristic, at a vacuum of about 400 mmwg.

At the Karaganda Works, where the machines have been lengthened by 30 m to provide a total suction area of 150 m^2 in order to include a cooling area, the sinter is effectively enough cooled.

The reason is obviously that at the low vacuum of less than 400 mmwg developed by the flue gas pump the gas-permeability of the cake itself is low; the suction area must therefore be increased.

A better expedient is to instal a second deep vacuum exhauster in the first, hot, cooling stage, followed by flue gas pumps at the end in the region in which the gas-permeability of the cake is higher.

PART II

SINTER QUALITY

As regards its manganese and phosphorus contents, blast furnace sinter is subdivided into open hearth (OH) and converter sinters according to the type of iron for steelmaking produced.

The manganese content of the OH sinter is raised to 1.5-2 per cent, while the phosphorus content is the same.

The manganous ore (KRIVOI Rog type) is added to the mixture in the iron ore beds; it can also be added directly to the mixture.

To improve the free-flowing properties of viscous moist manganous ores, also to increase the amount which can be introduced, it is recommended that the manganous ore should be mixed with dry (hot) dust from the furnace throat in the stockyard (on the bed).

The addition of lean manganous ores increases the silicon dioxide content of the sinter; on the other hand the sintering process is to some extent intensified, and this tends to reduce the high temperature at which Krivoi Rog type iron ores begin to soften.

1. Sinter Basicity

Sinter with a basicity of 1.3-1.4 is already being produced from magnetite ores and concentrates with high natural basicities and relatively low silicon dioxide contents; this has entirely eliminated the necessity for including limestone in blast furnace stock.

In spite of the much greater amount of flux consumed when sintering acid Krivoi Rog ores in the Ukraine, the basicity of the sinter is still 1.1-1.2. The factor preventing basicity from being increased to a figure at which limestone need no longer be used in the blast furnace charge is the considerable brittleness (small grain size) of sinter produced from the Krivoi Rog or similar ores.

The basicity of the sinter used abroad is much lower than in the Soviet Union.

The production of strong fluxed concentrate from acid ores is an important factor in the task of improving the technical and economic figures for blast furnaces.

2. Sinter for OH Furnaces

Sinter for OH furnaces is already being produced at many works, and is proving a successful substitute for the scarce rich lump hematite ores.

The advantages of this sinter include the fact that it can be fluxed to a basicity of 1.5-2.5, and that the raw limestone need not be used in OH furnace charges; the magnetite ores can be oxidized during sintering and the sulphur removed from them. Rich ores and concentrates in fine dust form can be lumped.

Scale is included in the mixture for the OH sinter as an enriching additive.

The necessary proviso for the sinter to be utilized in OH furnaces is that it should be in lump form and contain no fines.

The sinter is given exceptionally high strength by adding 10-20 per cent of pure iron chips to the mixture.

When the iron, silicon and manganese in the chips are oxidized, this being accompanied by an increase in volume, the sinter acquires a fine-grained, sound and strong structure; a considerable amount of heat is evolved when the chips are oxidized.

The amount of coke required for sintering is thus so greatly reduced that, if the mixture contains 25-30 per cent of chips, sintering can be conducted without adding any fuel.

If the chips are dirty or rusty, this has no great effect.

As a means of improving the granulation, it is recommended that there should be wider gaps in the grates for screening out material for reprocessing, also that a secondary screening of the sinter should be carried out.

Strengthening the sinter by introducing magnesian additives is not a suitable process for sinter intended for OH furnaces.

3. Sinter Quality Indices

The quality of fluxed sinter is characterized by its basicity, chemical analysis uniformity, and mineralogical composition; the latter governs the strength of its structure, its lump composition, and its reducibility.

The iron content of sinter is governed by the richness of the ore sintered.

Fluxed sinters have characteristically high reducibilities and smaller mean lump sizes.

The strength and lump composition of sinter is best gauged by its granular composition found from samples taken at the OH furnace bunkers.

The drum test on fluxed sinter does not provide a sufficiently accurate picture of its physical properties, since the test is made on lumps, while the main mass of the sinter is made up of 25-12 mm fraction "nuts".

The "drum number" of the 5.0 mm fraction indicates the test strength of the sinter (its fusibility), and that of the 25 mm fraction its impact strength, i.e. the brittleness of the sinter. The "drum number" depends to a great extent on the size of the lumps, and there have been cases in which stronger lump sinters have provided worse figures.

4. Mineralogical Composition of Fluxed Sinter, and its Effects on Strength and Reducibility

Fluxed sinter has enabled the reducibility of sinter to be greatly improved, but the increase in brittleness has resulted in deterioration in its strength and lump composition.

In spite of the large amount of additional heat required for the endothermic reaction of the dissociation of limestone, the fuel consumption on sintering has not only not increased, but has on the other hand even dropped slightly.

The reason for this lies in determination of the heat of silicate formation, and mainly in decrease in the maximum temperature in the zone caused by the formation of a lower-melting liquid phase. The FeO content of the sinter decreased considerably.

Increase in the fuel consumption causes more liquid phase to form, and increases the fusibility of the cake.

When, on the other hand, optimum fuel consumption has been reached, sinter wear strength, or "drum number" only decreases slightly, while sinter reducibility deteriorates abruptly, and mean lump dimensions become very much smaller owing to the development of brittleness.

Most sinter plants in the Soviet Union run on low fuel consumptions, with a view to producing easily reducible sinter even at the cost of reducing its strength and the output of good sinter cake.

The production of easily reducible and at the same time strong fluxed sinter is an extremely important factor in running blast furnaces efficiently, improving their coefficients of utilization of useful volume and reducing coke consumption.

Although this problem is extremely complex, practical methods of solving it have already been found. Detailed study of the mineralogical composition of sinter and the effects on this of variations in a number of technological factors, conducted in recent years, have contributed to this.

Industrial fluxed sinter produced from Krivoi Rog hematite ores, the acid gangue in which consists of finely impregnated quartz and the basicity of which is 0.9-1.4, consists of the minerals magnetite and hematite, which form a finely-branched skeleton structure with numerous bonds. The slag binder consists of ferrocalcium olivanes (saturated with lime to different extents), unrecrystallized glass, and a small amount of calcium ferrites. There are also small amounts of calcium silicates, and residual free quartz. The strongest structural components are the magnetite and hematite, also the olivanes and calcium ferrites. The calcium silicates and inclusions of free lime greatly reduce the structural strength.

The mineralogical compositions of fluxed concentrates produced from ores the gangue of which contains aluminium oxide, carbonates, silicates, manganese oxide and various other minerals, is more complex, but these mainly also consist of magnetite and hematite with a slag binder consisting of iron-calcium and magnesium olivanes, aluminosilicates, unrecrystallized glass, and also primary unmelted grains of ore.

The greater the amount of fuel used, and the higher the basicity of the sinter, the greater the amount of liquid phase and slag binder, while at the same time the amount of primary unfused grains of the mixture decreases.

The extent to which the quartz is utilized in the molten substance increases (olivines), and calcium silicates start to appear in the structure.

At basicities of 0.5-9.0 the substance mostly formed is dicalcium silicate - $2CaO - SiO_2$ (bellite). Tricalcium silicate is only formed when the basicity is high.

Calcium ferrites primarily form in the solid phase, and are unstable compounds. They only crystallize out of the molten substance in large quantities if the basicity is high and the amount of fuel small.

However well the flux and fuel are pulverized, they are distributed at dispersed points in the main ore content of the mixture; for this reason, the sinter is structurally a highly heterogeneous substance, and elementary volumes in the primary grains of coke and limestone contain inclusions of free lime and calcium silicates formed at high temperatures, also even metallic iron, while primary hematite and quartz which undergo no physical/chemical changes are also present.

Dicalcium silicate, or bellite, is worth special attention in view of its bad effect on sinter strength.

While bellite is being precipitated from the molten substance and the sinter is cooling, the bellite may undergo a number of polymorphous transformations, these being its α, β and γ modifications.

The transformation of β-bellite (β-2CaO - SiO_2) into γ-bellite (γ-2CaO - SiO_2) is accompanied by an 11 per cent increase in its volume; this creates internal stresses in the structure and cracks the sinter; the result is that the lumps break up during transportation and storage.

We know that if magnesium oxide is present, or if it is added to the mixture, this is conducive to stabilizing the β-modification of bellite, and the result of this is a great improvement in the strength and stability of the sinter. Cr_2O_3, P_2O_5, etc. are also conducive to the stabilization of β-bellite.

Sinters produced from rich ores are stronger, since they contain larger amounts of the strong structural components hematite and magnetite, while less silicates and brittle unrecrystallized glass are formed.

The highly basic sinters are stronger, since they contain a strong ferrite-calcium slag binder, also because they only contain a small amount of dicalcium silicate; tricalcium silicate, which is not subject to polymorphous transformations, is formed instead of the dicalcium silicate.

Extremely strong sinter, only containing a small amount of lower oxides and highly reducible, can be produced from fine rich concentrates with extremely low carbon consumptions of not more than 3 per cent. The reason for this is that the primary magnetite is oxidized and recrystallized, the latter process being accompanied by grain growth and the development of numerous bonds.

The reducibility of sinter produced from Krivoi Rog ores improves in proportion to decrease in the consumption of carbon and the FeO content, and to increase in the degree of basicity.

5. Sinter Strengthened by Adding Magnesium Oxide

The addition of 2-3 per cent of magnesium oxide to the mixture, which tends to stabilize the β-bellite modification, is already the practice at a number of sinter plants in the Urals; this has been found greatly to reduce the brittleness of fluxed sinter. The magnesium oxide is added in the form of dolomite screenings. The addition of magnesium oxide to mixtures including Krivoi Rog lean and acid ores, the gangue in which consists of quartz and does not contain any components so favourable to the properties of blast furnace slags as aluminium oxide and magnesium oxide, is particularly important. At many works in the Ukraine, dolomitized limestone is introduced directly into blast furnace charges, particularly when melting low-manganese irons.

The introduction of dolomitized limestone into sinter mixtures is not only conducive to dilution of the blast furnace slag, but also greatly strengthens the sinter itself, lengthens its life in storage, and improves its lump composition.

The lump size of sinter containing magnesium oxide is extremely consistent and large, and it can be stored for long periods without breaking up.

When magnesium oxide is added to the mixture, sinter machine output drops slightly because the sintering rate is lower; the yield of sound lump sinter is, however, extremely high.

The large scale adoption of this method has been retarded by the slightly lower output of the sintering machines, also by the principal difficulty which lies in pulverizing and feeding the two types of limestone at existing works, where there is a shortage of available handling capacity and bunkers.

The addition of magnesium oxide to fluxed sinter produced from lean acid ores provides great opportunities for improving sinter strength (and grain size composition); it also, consequently, provides prospects for raising the basicity to a value at which raw limestone need not be used in the blast furnace stock.

6. Sintering Two Types of Sinter

It has been proved that fluxed sinter of precisely the basicity (1.3-1.4) required to form a normal slag in blast furnaces has the worst grain size composition. Fluxed sinter with a basicity of 0.4-0.7 is the strongest, and lump size is the optimum and better than that of unfluxed sinter.

Highly basic sinters (iron-flux) also have satisfactory grain size compositions.

For this reason the idea of sintering two types of sinter, with low and high basicities, simultaneously has now been advanced; these two types both have good grain size compositions, and the suggestion is that they should be used together in blast furnace stock.

The addition of quicklime not only intensifies the sintering process, but also improves the quality of the sinter. To prevent inclusions from forming, however, the granular lime should be well roasted, slaked and mixed.

If necessary, the lime should be ground.

Effective mixing of mixtures containing many components is the basic factor in producing sinter of consistent composition and good strength.

In the first stage, mixing is best if the mixture is not wetted, while in the second stage wetting and lumping provide the best results.

7. Fuel for Sintering

To prevent the process of silicate formation from developing and the reducibility of the sinter from deteriorating, also to reduce the mean lump size, the consumption of fuel (coke) must be at the low optimum level.

The size to which the coke is ground is also very important; we know that if the coke size is large the lower layer of the cake is over-fused, the (mean) FeO content increases, and reducibility deteriorates.

If the same amount of coke in dust form is used the FeO content is reduced, while the sinter contains fine pores and is less fused.

Pulverizing to 3-0 mm is only suitable for sintering coarse-grained mixtures. When sintering fine concentrates (and granulating them), the coke must be pulverized to 2-0 mm.

Another no less important factor is that the fuel and mixture should be well mixed, also that it should be "adjusted", i.e. that when the mixture is deposited on the pallets the proportion of fuel should decrease downwards through the layer of mixture.

With the normal method, however, in which the mixture is deposited on the pallets in a single layer, the fuel is uniformly distributed throughout the layer, while the proportion of fuel may even be higher at the lower levels, if the large lump coke segregates downwards towards the grate.

If the fuel content is uniform throughout the layer of mixture, higher temperatures are developed in the combustion zone in the lower levels, and these levels will always be more fused and stronger than the upper part of the cake.

We know that the reason why the temperature in the lower layer sintering zone is higher, and why this layer remains incandescent for longer, lies in the regeneration of the heat conveyed downwards by the air being sucked through the mixture.

To keep the temperature consistent throughout the depth of the layer of mixture, also consequently to ensure that the mineralogical structure is uniform throughout the cake, there must be 30-40 per cent more fuel in the upper layer than in the lower.

Uniform fusibility through the cake can be achieved if the mixture is poured onto the pallets in two layers, the carbon content of the upper layer being 30 per cent higher than that of the lower.

According to data from abroad, pouring the mixture on to the pallets in two layers reduces the total amount of fuel used by 10-15 per cent. The two-layer method of applying the mixture, however, requires considerable capital outlay on installing two feed systems and preparing two different mixtures.

The two-layer method has the failing that the beneficial segregation of large grains of mixture downwards towards the grate does not take place. A viscous mixture, which impairs the gas-permeability of the cake as a whole, accumulates in the upper level of the lower layer.

This method was at one time widely used in Western Europe, but is not now being installed at new sinter plants.

The carbon content of the lower layer against the grate can also be reduced by employing a thick bed layer.

8. Ignition of the Mixture

The ignition of the mixture is an important operation, which governs the entire further course of the sintering process and the quality of the sinter.

If the length of the hearth is 1.25-1.75 m and the temperature 1000-1350°C, the surface of the mixture is only at these temperatures for at most 20-40 sec; thereafter it is rapidly cooled by cold air sucked through.

The reason why the hearths are so short is that they are run on gas with a low calorific value and producing a large volume of products of combustion; as a result it is impossible to maintain the required temperature and a simultaneous high excess of air.

Simply lengthening the hearth without maintaining an excess of air in the gases might result in slower combustion of the solid fuel in the layer of mixture.

The mixture must, however, be ignited not only by lighting the fuel at the surface, but also by introducing additional heat from above, this heat making up for the lack of regenerated heat in the upper layer.

At present natural gas with a high calorific value is used on a large scale in industry; this makes intensive oxidizing ignition of the charge in longer hearths quite possible, and means that the required additional heat can be introduced from above into the upper layer.

Hearths have been adapted for high calorific value gas, and lengthened, at many sinter plants both in the Soviet Union and abroad.

Practice has proved that if high calorific value gas is used with an excess of air the surface need only be beneath the hearth for 90 sec to ensure efficient ignition (this is equivalent to 3.0-3.5 m long hearths). The surface is effectively strengthened and the yield of good sinter and sintering machine output are raised.

The change-over to using high calorific value gas has enabled hearth depth to be reduced and simplified hearth design.

It is advisable, to maintain a consistent temperature and steady excess of air at the surface, to use a large number of small "Tube within a tube" type burners, arranged in several rows.

In this type of hearth the temperature is maximum at the surface of the cake, while the temperature of the low roof does not exceed 1100°C and stands up to prolonged use.

No water-cooling is necessary, since the hearth walls extend beyond the sides of the pallets and rest on the moving carriage.

9. Grain Size Composition of the Sinter

The grain size composition of the sinter is basically governed by the strength of the sinter cake.

The lower limit size of the sinter can be raised, however, and larger fines screened out for reprocessing, by means of a larger spacing between the bars of the fixed screen.

When brittle fluxed sinter is being produced, on the other hand, to avoid considerable losses of sintering machine output the spacing between the bars must not be greater than 12-16 mm.

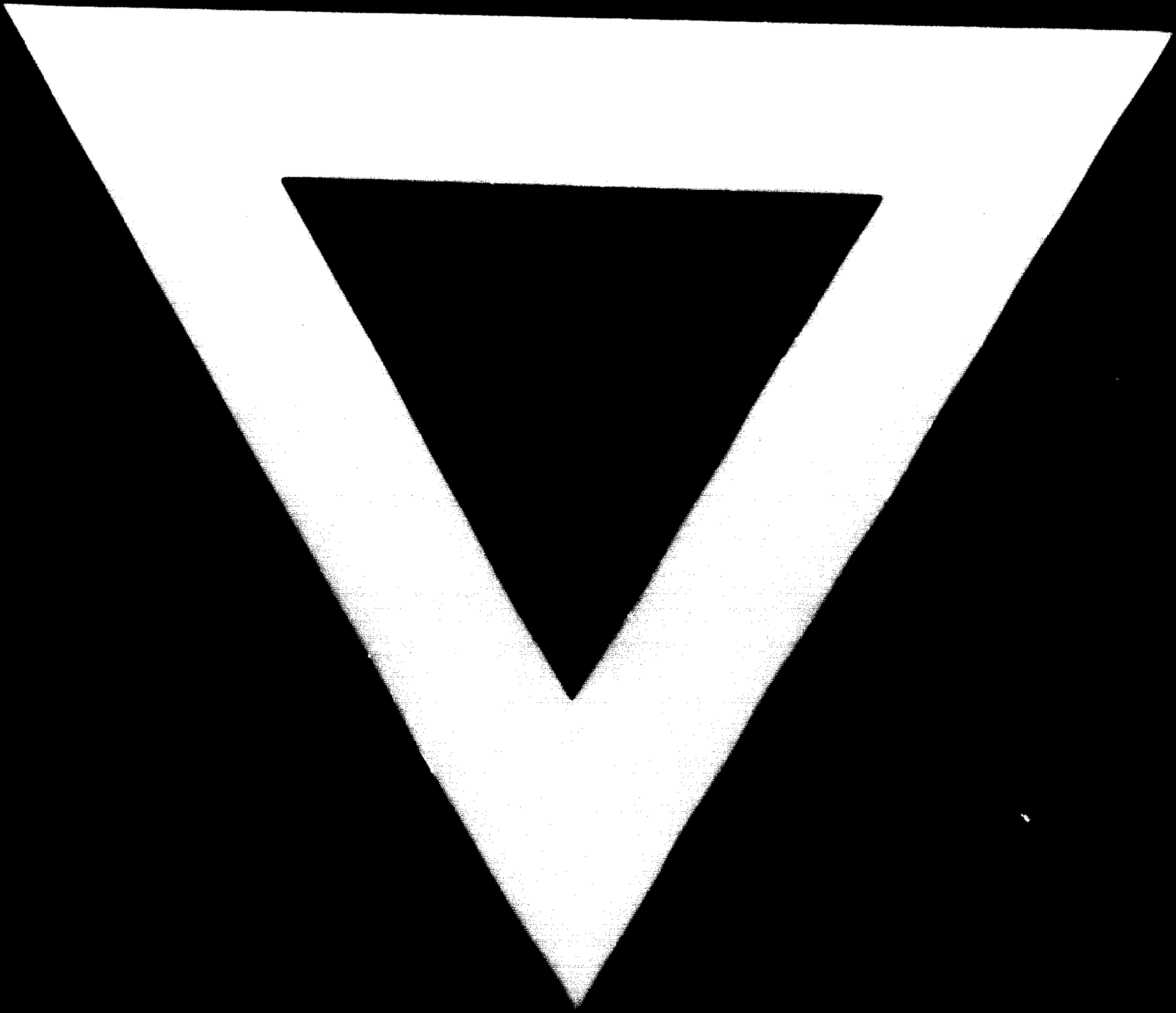
A good method of making screening more effective is to instal thin (but strong) bars, in order to increase the useful screening area from 20 to 60 per cent.

Mechanical screens are widely used for separating out fines for reprocessing; the more effective the screening process the more can the spacing between the bars be reduced. Mechanical screens are, however, less durable and require additional maintenance.

Two-stage screening of the cake is now being used, the two stages being a fixed screen followed by a mechanical one.

The two screens can be installed successively, first the fixed one then the mechanical one; any remaining fines are screened out in the second stage.

A better type of instaliation is, however, one in which a vibrating screen is installed immediately below the fixed screen.



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