OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

DISCLAIMER

This document has been produced without formal United Nations editing. The designations employed and the presentation of the material in this document do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations Industrial Development Organization (UNIDO) concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries, or its economic system or degree of development. Designations such as "developed", "industrialized" and "developing" are intended for statistical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process. Mention of firm names or commercial products does not constitute an endorsement by UNIDO.

FAIR USE POLICY

Any part of this publication may be quoted and referenced for educational and research purposes without additional permission from UNIDO. However, those who make use of quoting and referencing this publication are requested to follow the Fair Use Policy of giving due credit to UNIDO.

CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

UNITED NATIONS

INTERREGIONAL SYMPOSIUM ON THE APPLICATION OF MODERN TECHNICAL PRACTICES IN THE IRON AND STEEL INDUSTRY TO DEVELOPING COUNTRIES

11-26 NOVEMBER 1963

DO 3110

[illegible] P.1963/
Technical Paper/[illegible].6
24 September 1963
Original: ENGLISH

CZECHOSLOVAK EXPERIENCE WITH THE KRUPP-RENN PROCESS

by

J. Mach,
Research Institute of Iron Ore Mines and Renn-Plants, and
B. Verner,
Iron Ore Mines and Renn-Plants, National Establishment, Czechoslovakia

Summary

After a brief survey of historical development and principles of the Krupp-Renn process in its original form, the authors discuss the technology and the production equipment. With regard to the latest results of the Czechoslovak research, they outline possibilities of improving production through the use of novel plant machinery and, finally, they stress the advantages of the Renn-process for countries with specific raw materials situation.

1. Introduction

The world's iron production is steadily growing. While the greater part of the annual increase has - up to the sixties - been absorbed by highly industrialized countries, today this share is shifting chiefly to the developing countries, where a number of engineering projects is being carried out. This growth of iron production, however, is in an increasing measure complicated by two important factors. First, a number of rich ore deposits will be exhausted in the not too distant future and, therefore, it is necessary to utilize leaner ores and to develop suitable dressing methods. Second, the total coke consumption continuously grows and this is coupled with a rapid shrinking of coking coal reserves.

This simple fact provokes an effort to find new methods of iron production, which would enable to by-pass the blast furnace - the biggest consumer of coke. The oldest method, which was not abandoned like the majority of other processes in the pilot-plant stage, is the Krupp Renn process for treating iron ores. At present, this process occupies the second place behind the blast furnace, as far as the volume of iron production is concerned.

The Krupp Renn-process has been developed by Dr.Ing.Johannsen, professor at the Mining College, Clausthal, between 1931 and 1939 in the Krupp Works.

After the World War II, the Krupp Renn-process was introduced also by other countries, especially those which had ample reserves of low-grade iron ores or iron-nickel ores. Today, Renn-plants are in service in Czechoslovakia, Poland, West and Eastern Germany, North Korea, Greece, Japan, Soviet Union and Spain.

The total annual capacity of all the Renn-plants known exceeds 5,500,000 tons of ore. On this total, Czechoslovakia participates with 1,600,000 tons. A survey of all Renn-plants, their raw material basis and quality of products is appended to this paper.

This brief survey shows a wide range of raw materials, which can be treated by the Krupp Renn-process without any preliminary treatment (with the exception of crushing and grinding). This possibility was attractive also for other countries, which have begun to consider the introduction of this new process. In United States, test runs were made on iron ores containing up to 47% Fe and 13% TiO_2. The final product - the luppen - contained 92% Fe and less than 1% Ti. In Spain, tests were made with Portuguese hematite and specular-hematite ores. Czechoslovakia studied the processing of Czechoslovak chamosites and iron ores from Viet-nam. Processing of local ores was also examined in Tanganyika.

luppen with a low sulphur content, which are produced e.g. in Essen-Borbeck or in Chondjin (Korea), are an excellent melting stock for steelworks and are used directly for making special steels e.g. bearing steels. Also nickel-containing luppen are melted directly in steelmaking furnaces, but can be alternatively charged into blast furnaces, in which special alloyed pig irons are produced (Orsk-Chalilovsk). Of special advantage is the melting of nickel-containing luppen in electric-arc furnaces. Nevertheless, the majority of luppen produced in the world is used as an addition to the blast-furnace charge because of the high sulphur or phosphorus content.

The quality of luppen depends on the quality of ore and fuel in the particular country, so that luppen with one or more per cent. sulphur or with only hundredths of per cent. (Korea) are produced. This content thus determines the role of luppen in the following metallurgical processing.

2. The original Krupp Renn-process and its relation to the production equipment

The Krupp Renn-process is basically a metallurgical process, which starts with the reduction of iron ores and goes through the sponge-iron stage to the final production of iron grains or luppen, which are distributed in the pasty slag and are discharged with it. Solid carbon - in the form of certain coals or cokes - is used as the reducing agent; these solid fuels must correspond first to the technical, but also to the economic conditions. The reduction process is carried out basically as a direct reduction (which is an endo-thermic reaction) with a simultaneous evolution of carbon monoxide. Because the reduction processes take place in a relatively thick layer of charge, it can bé assumed, that this direct reduction will be carried out through the stage of CO, while the immediate reduction by the solid carbon will be considerably suppressed. The course of reduction and the formation of product will determine the principal conduct of the Renn-process. This also explicitly defines the choice of a suitable type of furnace for the Krupp Renn-process - the rotary kiln with an acid refractory lining.

The heat, which must be supplied for enabling all the reactions mentioned above, is produced by burning coal or oil in burners and is transferred to the charge by the counter-current heating; theoretically, the co-current heating is not excluded and may have some advantage. In other words, the charge prepared for reduction process travels through the kiln in a direction opposite to the flow of waste gases, which have first a high content of free oxygen; this oxygen enables the combustion of CO or other volatile waste gases and of part of the reducing fuel during the travel through the kiln. The choice of the rotary kiln brought with it the principle, that the heating will not be accomplished by the passing of heat-carrying gases through the charge - as is the case of shaft furnaces -, but that the heat transfer will be carried out over the charging surface of charge directly from the heating gases, by radiation or by the contact with the hot lining. This way of heating the charge in a rotary kiln has the advantage over shaft furnaces in that it enables to process fine-grained material; in shaft furnaces, this is impossible. These principles are regarded as advantages of the Krupp Renn-process and determine the basic sequence of operations.

Fine-grained oxide or carbonate iron ores are mixed with likewise fine-grained reducing fuel and possibly with the other slag-forming additions. This mixture is fed into the charge end of the kiln.

In principle, it is necessary that the reducing fuel should contain few volatile gases or that the liberation of combustible matter should proceed at higher temperatures of charge. In a correctly regulated process, the reduction of iron oxides should be completed at 1000 - 1100°C, i.e. at the point, where the free-flowing charge begins to soften and a plastic phase arises, which manifests itself as a strongly viscous bath. The boundary between the free-flowing and the viscous phase is characterized by a local rise of the charge surface. In this stage, the iron should already take the form of sponge iron. As the bath comes under the direct influence of burners in this zone, the temperature of charge rapidly rises to about 1300°C. This temperature is naturally influenced by the choice of basic raw materials and their properties. By rising the temperatures in this zone - which is called "the luppen zone" -, the viscosity drops from the pasty stage to a value of 1000 to 2000 Poise. The sponge iron is partly carburized and the iron skeleton begins to weld together and form small iron grain - socalled "luppen" - which may range from 1.5 to about 50 mm in size. Because this part of the bath is under the influence of the strongly oxidizing flame, the reduced iron on the bath surface is partially burned. However, a certain excess of coke ensures the continuation of reduction at the rolling-over the bath, so that the fixed iron [illegible] will in economic cases amount to 1-3% Fe.

The welding of iron luppen in the luppen zone is a complicated technological [illegible]. [illegible] additions, which temporarily exist in the bath, change the basic slag [illegible] the critical zone, or the conditions for more intensive welding of luppen [illegible] the grain size of iron product. Besides, the luppen zone must ensure also the reduction of phosphorus and possibly of other elements - e.g. chromium, copper etc. -, which under the prevailing conditions can be reduced substantially worse in the rotary kiln than in the blast furnace. That is why luppen contain manganese and silicon only in traces. If, therefore, the forming of luppen is influenced by the viscosity and quantity of slag, the composition of slag is of utmost importance for the process proper.

On the one hand, the Krupp Renn-process allows the economical conversion of low-grade iron ores - the volume of slag produced being 1,5 to 2 times the production of iron - but, on the other hand, the maximum iron content in the Renn-charge is limited by 40 to 45% Fe; namely, the slag quantity can not be much lower than 0,8 tons for 1 ton of iron luppen, so as to enable the discharging of luppen with the slag. These two criteria - viz. the viscosity and the quantity of slag - decided the introduction of the Krupp Renn-process.

The limited heat transfer in the kiln demands a grain size of the ore under 15 mm, if possible about 5 mm. The choice of optimum grain size should be coupled with the consideration of other factors, e.g. the reducibility of ore. This will esure, that the reduction of iron oxides to the stage of sponge iron will be completed before reaching the luppen zone. The grain size of slag-forming additions should be the same, but rather smaller than that of the ore. The reducing fuel should not be coarser than 5 mm, but equally should be free of very fine class which leaves partly the kiln in the flue-dust. The behaviour of the coal grain in the kiln will differ from that of the coke grain, because in the case of coal - besides the distillation of the volatile matter - also the decomposition of grains along the cleavage planes may occur.

The biggest advantage of the Krupp Renn-process remains the fact that it permits the working of ores with slag numbers (ratio of CaO to SiO_2) of 0,15 to 0,3. Sometimes, a higher slag basicity is possible - as was also proved by tests -, but this factor must be controlled by an economic criterion, which in this case will be especially the further use of such a slag.

The minimum quantity of reducing fuel may be 25%, using high-quality cokes, but with lower quality, the consumption rises up to 40% (from the weight of ore charged). The counter-current heating of the Renn-kiln needs a higher excess of coke than that necessary for reduction processing. A portion of the above-mentioned coke quantity is burned in the kiln, but the majority leaves the kiln with the slag and in the final stage protects the metallic iron from reoxidation.

As far as the charge side of the kiln is concerned, the regular working of kilns must be assured by a consistent mixing of individual charge components and by a thorough preparation of a homogenized charge mixture.

As was mentioned above, the Renn-kiln product is a pasty slag with iron luppen distributed in it. Therefore, the first operation after leaving the kiln is the cooling of this product, so that it could be further processed. For the most part, cooling conveyors have been used, but in some cases, they have been lately replaced by cooling drums. It was found, namely, that the cooling speed influences the grindability of slag, the iron content of luppen and particularly the iron recovery. If the intensity of cooling is so high, that the slag structure is glass-like and the crystalline phase does not arise, a very brittle substance forms which can be very easily ground. Already during an intensive cooling, the luppen get rid of the slag adhering to the surface of grains and the rest is removed in mills. The final iron content of luppen is higher than with cooling on conveyors. After the installation of cooling drums, the cooling pits between the kiln and the slag mill may be dispensed with and possibly can be used only as an intermediate store yard.

The cooled kiln product is ground in ball mills, impact mills or in combinations of both types. Grinding in ball mills results in a high proportion of very-fine fractions and also in abrasion of luppen surface and so in higher losses of iron. Introduction of impact mills will improve the conditions in all respects, but it remains to find suitable materials for working parts of this type of mill. It is therefore clear, that the processing of the kiln product will depend on intensive cooling, correct grinding and efficient magnetic separation, to attain the highest iro content in luppen at the highest iron recovery.

Principally, dry magnetic separators are used. The optimum magnetic separation system is given by the quality of slag grinding. If using a one-stage grinding in ball mills, one or more re-cleaning operations can be introduced in various stages. If the slag is ground in two stages and possibly in various mill types, the re-cleaning operation may be omitted and the iron content may still be very high.

The further use of luppen will depend first of all on their content of phosphorus, sulphur and possibly other undesirable metal admixtures, which are brought into the process by the charge materials, including reducing fuel. As was already said, the content of silicon and manganese in luppen is negligible, because temperatur conditions in the kiln and the acid slag supress the reduction of these elements.

The carbon content may vary between 0.5 and 1.5% or more and depends on the activity of the reducing fuel used and on the heat conditions in the kiln. Processing of iron ores in the Renn-kiln does not allow a substantial desulphurising because of the composition of normal slag. Therefore, it is necessary to use - if possible - charge components with a low sulphur content. The same holds true of phosphorus. However, when using raw materials with suitable composition, very clean luppen are not uncommon.

Resuming conditions for the introduction of the Krupp Renn-process, the influence of charge quality on the quality of luppen and the influence of mixing and preparation of charge on the operation and process economy must be stressed. As far as the standard of technology is concerned, the most difficult section is the kiln process proper with a controlled distribution of the temperature field according to the demands of technology and heat transfer, which is governed by the kiln heating system.

In the third and last section, which is the processing of kiln discharge, it is necessary to stress the influence of the choice of cooling equipment and of mill type and grinding system on magnetic separation.

3. Further development of original Krupp Renn-process

Considering the volume of iron produced, the Krupp Renn-process is fairly widely used, but the limits of its possibilities have not yet been reached. First of all, the manner of controlling the heat conditions in the kiln has not been modified to any extent. Owing to many years' experience, the Renn-process has been mastered, the throughput of ore has been increased, but simultaneously other indexes - e.g. iron content, recovery and length of campaigns - have dropped. This led to the conclusion that the extreme heat conditions in the kiln are no longer able to comply with all qualitative demands of the process and that it is necessary to take a number of measures.

It appeared, that the rotary kiln as a less efficient heat exchanger is able supporting a more advantageous distribution of temperatures - to substantially increase its ability of heat transfer and thus in the same time fundamentally influence the development of technological conditions of the process. An analysis showed that the present way of heating the kilns with tube burners for coal, oil or gas may lead only towards an unsound intensification of the process by raising the heat load of the discharge and of the kiln; this, moreover, contradicts the technological demands. So the first short-coming was found - the impossibility to work the kiln without a control of combustion in burners, which would be independent of the demands of technology. Secondly, it is not possible to supply through the burner side of the kiln the necessary quantity of reaction air without cooling the discharge end of the kiln, at the same time. This has led the Czechoslovak research workers to the endeavour to separate the combustion space fro the space, in which metallurgical processes take place. In this way, it is possibl to control separately both processes and have them in a harmonic dependence. The operator is able to modify easily the temperature distribution, attain the complete combustion of gaseous products and the arrangement of heat sources in the kiln through the choice of the quantity and - above all - the type of reducing fuel. It is expected, that this modification of heat conditions will lead to better heat-transfer coefficients, which will result in a change of heat quantity transferred in various kiln zones. This would do away with present differences of intensified kiln heating and enable to find optimum heat conditions, which - of course - will be coupled with some other advantages. The kiln output will have a rising tendency in spite of removing the heat overloading of the luppen zone, the top temperatures o gases in luppen zone will be lowered and better controlled. This has to bring longer lining life and thus longer kiln campaigns.

Controlled course of combustion will result in a substantially lower consumption of both reducing and heating fuel. Other advantages are expected in better reduction ratio, higher iron recovery, better grain size of luppen and - indirectly - higher iron content in the final product.

Naturally, a novel heating of the kiln needs a novel system of combustion, which was found in a modified cyclone chamber, in which all types of fuel may be burned. If a solid fuel is used, liquid slag from the ash results and is removed from the kiln.

The change of the heating system is one of the intensification measures for the Renn-process. Another step, which should lead to a higher luppen production, is the preheating of charge by hot waste gases. This preheating has its specific conditions and especially its temperatures are limited. Nevertheless, it is possible to heat the charge - i.e. including the reducing fuel in some cases - to 400 - 500°C. The limiting condition in the Renn-process is not the heat content of waste gases and its recovery, but the temperature of charge behind the preheater i.e. in the charge end of the kiln. This temperature determines the temperature of gases above the charge in the kiln, which must not exceed 900 to 1100°C, according to the type of raw materials used. As was shown on a mathematical model of the kiln, it is possible to recover about 50% of waste heat in this case and, therefore, it is more advantageous to combine this method with the preheating of reaction air up to 250°C. This will result directly in a lower consumption of heating fuel and will - to a certain extent - influence the heat balance of the process. At present, all possible consequences of this new approach are not yet verified, so that the overall heat recovery cannot be predicted. All the same, a substantical fuel economy may be expected.

Supposing a constant throughout, the introduction of cyclone burners or charge preheating must to show itself as a factor which should theoretically enable to shorten the kiln length. If we work under condition of equal geometric relations of charge travel, it is possible to raise the throughout instead of shortening the kiln length. Another possibility is to increase the diameter of present kilns - retaining the original length - and thus attain further substantial increase of output. Naturally, all these intensification measures influence favourably the economy of the Renn-process, improve the labour productivity and open a new perspective to this interesting method of iron production.

The cyclone firing chamber and the preheating of charge form another advantageous condition for better heat recovery from waste gases. Thanks to higher exit temperatures of waste gases, the lower limit of ecomical waste heat recovery of present Renn-kilns gets in an economically advantageous area. It has to be stressed that the work with the new cyclone firing chamber - which is controlled by principles of the mathematical model - may create very favourable conditions for the automation of the kiln process proper, which is unthinkable with the present standard of kiln working. Thus it will be possible to create desirable conditions for continuous release of heat for power stations and to remove the well-known disproportion in demands of metallurgists and power men in cases, when power units are coupled with metallurgical equipment.

When methods of controlling temperature conditions in the kiln are known, certain types of coal can be gradually substituted for reducing cokes; certain anthracites with a low content of volatile matter are already used in Renn-plants as a current charge component. But here we have those types of coal in mind, which have a higher content of volatile matter than anthracite or coke. In this case, it will be necessary to burn a majority of volatile matter in the kiln and the rest outside the kiln, but this will allow to use the same type of fuel both for reduction and heating The coal fines to 0 - 3 mm. will be fed to the cyclone firing chamber and the coarser fraction 3 - 10 mm. will be used for reduction. The firing conditions in the cyclon with the grain up to 3 mm. will improve by lower losses of the finest coal dust in waste gases; this dust represents normally about 3% of unburnt matter, when supplyin the cyclone with a finely ground coal.

From all, what has been said in this section of the paper results that the most neglected field has been the kiln technology proper in spite of its fundamental influence on the creation of economical conditions for the new process. But this should not purport that this is the only field which should be developed further. As far as the preparation of charge is concerned, simple automatic or mechanical systems are known and somewhere already applied. In this direction, it is - for the time being - necessary to base on the general development of equipment and complete preparation lines and of their regulation and control. On the other hand, cooling of kiln discharge, its grinding, screening and magnetic separation should be designed wit a respect to demands of this technology. In certain cases, the generally used equipment will continue to form the basis, but it will be necessary to judge separately and develop individually the combination of individual sets and the choice of partial flow-sheets for the treatment of kiln discharge. In addition to a new equipment for kiln discharge cooling - i.e. cooling drums with a negative slope - the choice of new types of mills should be seriously considered. These should work on the principle of comminuting the matter through impact with an increasing effect, whic should correspond to different specific gravities and end with a plastic deformation o metal grains. The end product would be very clean and the metal loss through abrasion of lumpen surface would represent a fraction of present losses. The above mentioned cooling of kiln discharge should ensure both speed and quality of cooling, so that the cooled kiln product could be transported from cooling drums or other cooling machinery immediately and continuously to the mills and thence to the magnetic separation building.

4. Technical and economical results of the Krupp Renn-process

The output of Renn-kilns is influenced by a number of factors, especially by the metal content of the ore. This is a quantity, which is in principle not arbitrarily variable, but is given - as a rule - by local conditions and will decisively influence a number of economical results. As far as the heat economy is concerned, the claim on the volume of heat needed for the reduction is substantially less pretentious than the total heat needed for heating the charge, evaporation of water and causing heat losses. Therefore, the decisive criterion of heat consumption is not the metal content of ore, but the weight of ore charge. In such a case, the increase of metal content to the maximum - i.e. 40 to 45% Fe - at the same throughput of ore results - in comparison with an ore containing 30% Fe - in an increase of luppen production by as much as 30%, all this at a relatively low consumption of coke and coal per 1 ton of ore throughput. Naturally, this is possible only in the Krupp Renn-process, where the proportion of slag, which is modified for the purpose of viscosity, is smaller than in any other process, where the basicity is modified. Every modification of slag for the luppen zone - if it demands an addition of certain fluxes - will thus result in a lower metal content of charge and a lower output at a higher specific consumption of fuel per 1 ton of luppen. For this reason, the metal content of ore is a major factor influencing the output. Other factors influencing the output of Renn-kilns are dependent on the choice of suitable equipment, with the help of which we are able to control the output of Renn-kilns. First, it is the choice of modern equipment which allows correct and regular dosing and mixing of individual charge components, thus ensures the regularity of reduction processes and shows the way towards continuous lines with a possible automation. Above all, such an equipment precludes troubles and failures in operation, which result in a decreased throughput and thus in a lower average output.

The kiln size has an unquestionable influence on the output of Renn-kilns. The output increases with a power of kiln diameter. A certain kiln length corresponds to each kiln diameter to ensure a correct relation between the mechanical and thermal capacity at optimum heat conditions. It must be stressed, that the consideration of isolated mechanical capacity of the kiln - i.e. the throughput of charge - is quite wrong.

By far the most important factors which allow to increase the output of Renn-kilns, are the intensification measures mentioned in the preceding section of this paper. These are the new heating system and the preheating of charge. Though it is not fitting to compare specific outputs of various kilns per unit of effective volume, an exception may be made in this case to demonstrate numerically the above-mentioned claims. Thus, for instance, a rotary kiln of 3.6 m. in diameter and 60 m. length, fired by standard coal burners, will have a specific output 0.8 ton/m^3/24 hours at optimum heat conditions in the kiln. The same kiln, fired by the cyclone burner, will increase its specific output to 1.06 ton/m^3/24 hours. Moreover, if this kiln with the cyclone burner will be fed with a preheated charge, the calculated specific output at certain optimum cases may reach as much as 1.58 ton/m^3/24 hours. In the same way, it is possible to calculate relations for other kiln diameters. These calculations will be published in the journal "Czechoslovak Heavy Industries" and - owing to time limits - are not included into this paper. Methodology of this calculation is based on the analysis of a mathematical model of production kiln work and the real parameters of growth progression are determined by superposition at equal determining criteria of properties of geometrical and physical system, including marginal conditions.

The <u>recovery of iron</u> from the charge to lumpen is given primarily by the metal content of charge, as was the case of the output. In principal, it can be said that the specific losses of metallic and chemically bound iron in waste slag after magnetic separation are roughly constant per unit of this waste material. If, therefore, the proportion of slag increases with the decreasing metal content, the overall iron recovery will drop, because the absolute iron losses will also grow with a greater proportion of slag. It must be stressed once again, that this influence cannot be principally controlled by external measures, because it is given by the raw-material basis.

High proportion of fines in the charge means a bigger volume of fluedust, but above all a greater proportion of non-recoverable fluedust, notwithstanding the fact, that the processing of collected dust taxes the equipment heavily. In spite of this, it appears economically unsound to lower the advantages of the Renn-process by agglomerating the charge in order to limit the flue-dust.

The attainment of high iron recovery is to a great extent influenced by the standard of kiln working and of the following equipment for processing the kiln discharge. It must be emphasized once more, that the mastering of optimum heat conditions in the kiln means the attainment of a correct distribution of individual kiln zones, especially of the reduction zone. Moreover, a correct choice of burner and reaction air mixing chamber should ensure minimum losses of unreduced iron in the kiln discharge. As the temperature conditions govern to a certain extent also the grain-size distribution of luppen, this is a further argument for correctly controlled heat conditions. Higher proportion of fine and very fine luppen means higher losses of metallic iron in waste slag. Again, the speed of cooling the kiln discharge must be briefly mentioned, together with the proper choice of mill units and the necessity of dispensing with the cooling pit, where reoxidation of finest metallic iron grains occurs. The choice of the magnetic separation system should also not to be overlooked, because, under certain conditions, it may have a great consequence for iron recovery. All factors mentioned above influence materially the recovery of iron, which in individual Renn-plants varies between 80 and 92%.

<u>Quality of luppen</u> is another important index of the technical and economical standard of production. It is given especially by the metal content and by the grain-size distribution of luppen (granulometric analysis). Metal content of luppen is one of those analytical indexes, which exert an inversely proportional effect upon the nominal volume of luppen production. It may be said generally that the proportion of luppen under 1.5 mm. markedly lowers the overall metal content of product through a great quantity of slag dust; the elimination of this dust would require special modification of separators. Economical consequences of the metal content may be expressed as a change of costs of the pig iron production. Roughly, it can be said, that 1% of increase in metal content of luppen will lower production costs in blast-furnace works by 1 to 1.5%.

Equally important consequences result also from the grain size of luppen. Experience of blast-furnace-men shows that the majority of luppen smaller than 1 mm. leaves the furnace in the flue-dust. Therefore, the endeavour of technologists should be directed not only to a consistently higher metal content, but also towards the grain size of luppen produced.

In connection with the quality of lumpen, several accompanying elements must be mentioned, which may either lower the economic effect of the Renn-process or complicate further use of lumpen. First, it is the sulphur which on the average needs about 30 kg. of limestone per 1 ton of pig iron produced from lumpen. This is valid for a sulphur content in lumpen of about 1%. If the sulphur content in lumpen is high, the proportion of lumpen in the blast furnace charge is - as a rule - lowered. From the economic point of view, it will be advantageous to produce lumpen with such a low sulphur content, which would allow a direct melting of lumpen in steelmaking furnaces. If the lumpen are used for melting pig iron for the basic Bessemer process, the phosphorus content is desirable.

In another case, the quality of lumpen may be lowered by undesirable metal admixtures - e.g. copper - if high-iron waste slags from non-ferrous metal production or certain types of pyrite cinder are used as charge components. Sometimes it may be an increased chromium content which goes over to lumpen. In certain conditions, even a low admixture of nickel is undesirable, because it may unfavourably influence further use of lumpen.

On the other hand, it is possible to use the Renn-process for an effective production of iron lumpen containing 6 to 10% nickel, with an original nickel content in ore of about 1%. Nickel content in lumpen will be governed by the iron content of ore and by the conditions, under which the process is controlled in respect to iron recovery.

As far as the arsenic is concerned, it may be said that it goes quantitatively over into lumpen.

5. Conclusions

All which has been briefly said in this paper about the Renn-process, points to the fact that this process can utilize a wide range of raw materials and that it produces iron lumpen of various quality and, therefore, with various possibilities of utilization. This gives a certain flexibility to the process. First of all, it must be stressed that the Renn-process allows a rapid introduction of iron production especially in areas, where suitable conditions for erection of iron and steel works with blast furnaces do not exist owing to the lack of high-grade ores and metallurgical coke. This argument is supported by the fact, that the erection of Renn-plants was at its peak just before and especially during the Second World War. The second advantage of the Renn-process is the possibility of processing raw materials, which can not be economically treated by other known metallurgical processes, because these ores are intimately mixed with the gangue or contain the iron in the silicate form. These two main facts account for the further expansion of the Renn-process after the war. A typical example of a developing country is the Democratic People's Republic of Korea which has ample reserves of high-grade ores and low-sulphur fuels, but no coking coal. This allows to produce high-quality luppen which represent a major proportion of melting stock for Korean electric steelworks.

It must be emphasized that the Renn-process is a relatively new method in comparison with other metallurgical processes. In spite of its important position in the world's iron production, it is in fact at the beginning of its development. If the endeavour of research workers to produce liquid iron instead of luppen meets with success, it would solve a number of complicated problems, which the Renn-process has to cope with at the present, in spite of all its advantages mentioned above. For example, the maximum iron content of 45% Fe might be shifted to an arbitrary level, the problem of functional slag viscosity would cease to be a decisive criterion and new possibilities for an economical utilization would arise, because all main advantages of the Renn-process would be preserved.

In comparison with the blast-furnace process, the economic advantage of the Renn-process may be illustrated best by the consumption of fuel and limestone for the production of pig iron from ores with different iron contents. For instance, the iron ore with 40% Fe and about 15% SiO_2 is for the Renn-process near the upper limit of critical metal content and for the blast furnace at the lowest limit of utilization. For the production of 1 ton of pig iron in the blast furnace, 1440 kg. of metallurgical coke and 1100 kg. limestone are needed. If this ore is processed in the Renn-kiln and the luppen ore remelted in the blast furnace, the consumption will drop to only 375 kg. coke and 30 kg. limestone. This means an economy of 1065 kg. metallurgical coke, which was replaced by 1170 kg. low-grade fuel. Besides, there arises an economy of 1070 kg. limestone, too. At a lower iron content in the ore, the comparison would be even more favourable.

Like all processing equipment, the Renn-plants have also specific conditions for the most economical production. Conversion of ores with less than 30% Fe will raise the price of luppen beyond a tolerable cost area or - in another sense - perhaps over the price of scrap. Thus, the annual luppen production will be out of proportion to capital expenditure. Therefore, it is necessary - from the economic point of view - to use for the Renn-process ores with more than 30% Fe, if possible. Somewhere, this will be given by mining conditions, somewhere else, it will be necessary to use a suitable mixing of ores and, finally, it may be found, that a low-cost precontration of charge will be advantageous even for Renn-kilns, as for example in Poland.

The judging of the Renn-process only from the point of view of scrap prices can not be explicitly agreed with. Consideration of economic needs which would respect the relation of production costs of luppen to the production costs of other replaceable raw materials, should represent the main decisive criterion for the introduction of the Renn-process. Comparison of domestic relations with relations on the world market is another criterion. Finally, comparison of domestic mining and production costs with the efficiency and overall effect of the expended labour. In our opinion, these criteria are more appropriate than the scrap price question and will be to a full extent valid especially for developing countries, where the needs of national economy will constitute a decisive factor.

One of economic conditions of introduction of the Renn-process is also the assessment of a minimum acceptable plant size. For operation reasons, a correct time distribution and utilization of labour, good use of equipment and uniform production throughout the year corresponds to a plant with at least three kilns. The capacity of such a plant will then depend on the kiln size and on the technical and operating standard of the equipment. Plant with 3 kilns of 3.6 m. in diameter and 60 m. length will have a yearly throughput about 300,000 tons of ore with a certai metal content. If these kilns will be equipped with cyclone firing chambers, the throughput may rise to 360,000 tons. Moreover, in the case of the preheating of charge, the kilns should process over 500,000 tons ore yearly.

In these conditions, the calculation of capital costs of a future plant will be very complicated, because the erection of a complete metallurgical works - not only th Renn-plant - will be materially influenced by the quantity of raw materials and by geographic conditions. Therefore, the plant layout will be quite different. Nevertheless, a number of data is available, so that a prospective consumer can receiv in a short time a summary of capital costs according to real conditions of a future unconventional metallurgical works. Generally, it may be said that capital costs will improve with reducing the size of a modern Renn-plant in comparison to a Renn-plant in its original layout. Layouts and examples of architectural designs of original and future Renn-plants are appended to this paper.

Therefore, the erection of modern Renn-plants may be recommended for areas, where a rapid construction with low capital costs and without dependence on metallurgical coke is required. Decision on the construction of a Renn-plant and of a complete metallurgical works without blast furnaces may, of course, be made only on the basis of a thorough examination of suitable raw materials and power sources of a particular country.

Appendix

Fig. 1.

Fig. 1a. Layout of an original Renn-plant

1. Bridge for transporting raw materials from homogenizing storage yards
2. Charge preparation
3. Flue-dust collection
4. Bridge for transport of charge mixtures
5. Flue dust chambers
6. Charge feeding building
7. Rotary kiln
8. Kiln firing and kiln discharge cooling
9. Discharge storage pit
10. Discharge crushing plant
11. Magnetic separation

Fig. 2.

Fig. 2a. Layout of a modern Renn-plant

1. Bridge for transporting raw materials from homogenizing storage yards
2. Preparation and preheating of charge
3. Flue-dust collection
4. Combustion chamber for waste heat recovery for power generation
5. Rotary kiln
6. Kiln firing, slag granulation, final grinding and magnetic separation of kiln discharge

Table - Survey of Renn-plants in various countries

Plant	Type of ore	Analysis of ore (%)					
		Fe	SiO_2	Al_2O_3	CaO	MgO	P
***CZECHOSLOVAKIA**							
Ejpovice	polosiderite	31.12	23.77	6.46	3.57	1.50	0.50
Mnisek	+ chamosite	32.01	24.33	9.22	2.43	1.59	
Králuv Dvur	+ hematite	32.13	24.55	11.61	3.09	2.11	0.30
POLAND							
Szklary	Fe-Ni ore	9.11	61.6	2.77	1.60	13.60	
Sabinow	siderites	33.31	25.30	7.50	2.42	1.30	0.13
GFR							
Essen-Borbeck	imported ore	35					
Salzgitter-Watenstedt	intermediate products of limonite dressing	31-35	19-26	7	5	3	
GDR							
VEB Maxhütte Unterwellenborn	chamosites + limonites siliceous	22.30	15.77	6.40	3.60	2.19	.35
St. Egidien	Fe-Ni ore	11.67	43.45	3.73		19.02	
N. KOREA							
Chondjin	magnetite	45-53	21-32	1.6-2.7	0.56-1.45	0.31-0.92	0.045-0.064
	limonites	40-52	8-28	1-9	0.16-4.0	0.37-1.6	0.04-0.65
GREECE							
Larymna	Fe-Ni ore	24.1-36.5	15.5-33.3	10.4-14.5	2.4-2.9	2.1-2.6	
JAPAN							
Kuji	iron sands	30.44	31.42	7.36	2.17	2.74	TiO2 3.21
USSR							
Orsk-Chalilovsk	limonites						Cr
	Akkerman	32-45	24-26	19-24	1.15	1.08	1.25
	Orsk-Chalil	17-19	37-44	4.6-7.6			0.4-1.16
SPAIN							
Avilés	hematite	30-45	21-40	5-7	1.8-2.7	0.1-0.3	0.5-0.8

Notes:
*) Analysis applies to metal-bearing charge
**) Only 0.12 to 0.16% S using low-sulphur co
***) In Czechoslovakia and Poland, also luppen
lower the overall average metal content

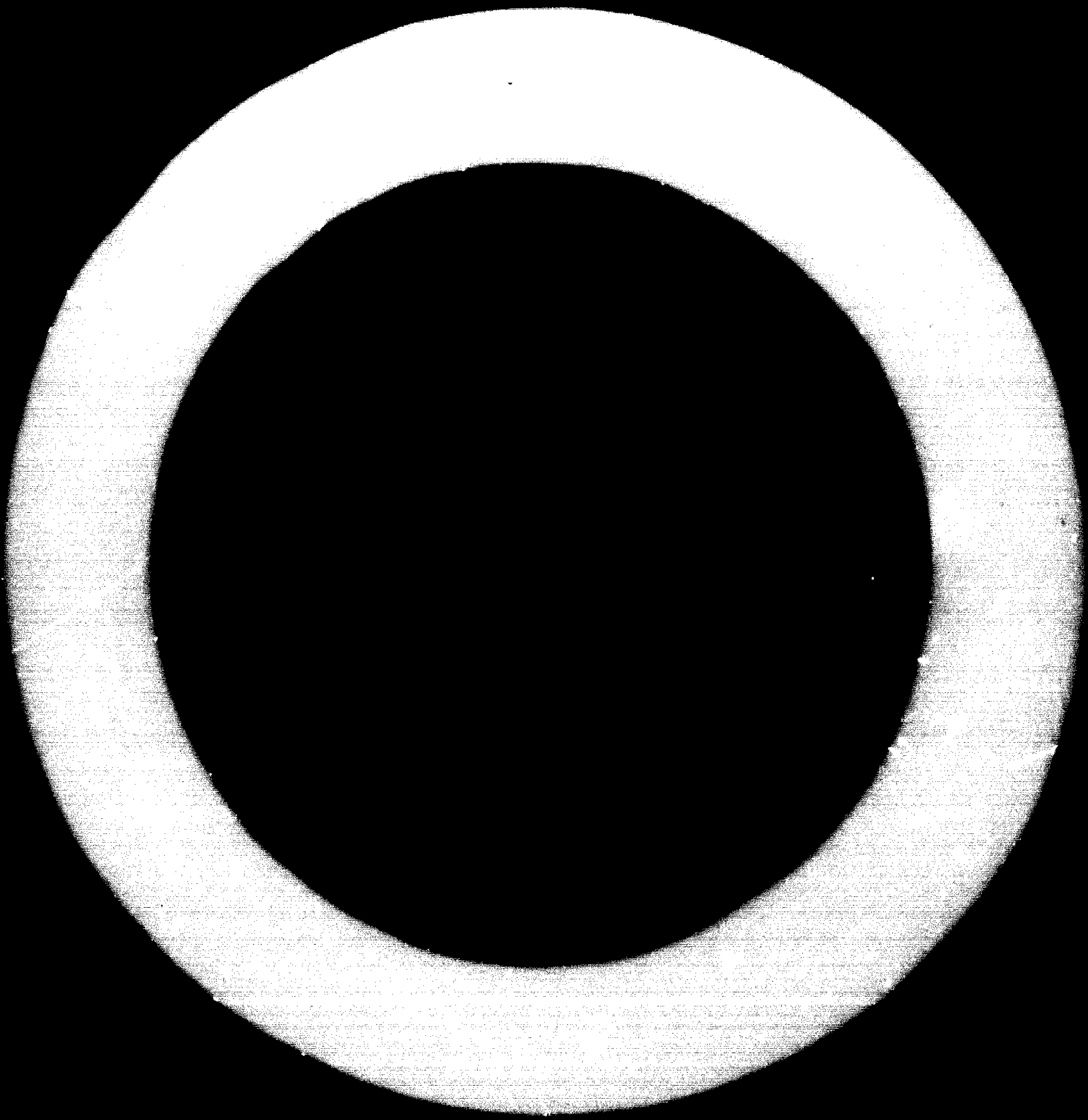
nts in various countries

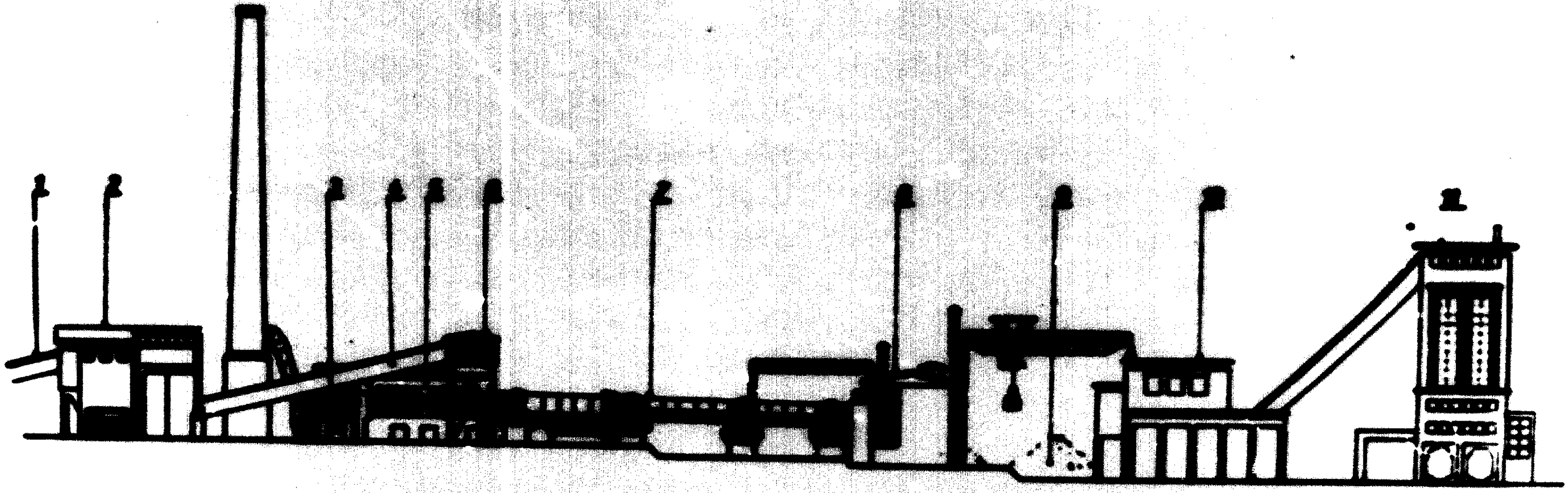
			Kilns			Analysis of luppen (%)					
	Ni	Moisture %	Number	Diam.	Length	Fe	C	P	S	Ni	Cr
.42 .77 .31		4.74 6.25 4.12	10 3 3	3.6 3.[illegible] 3.6	[illegible] [illegible] [illegible]	2.74*** 3.22*** 3.69***	 1.01	1,25 1,06 1,29	1,32 1,29 1,15		
 .54	0.73	21 [illegible].92	3 1 2	3.6 4.2 3.6	50 70 60	7[illegible].0 78.20***		0.13 0.25	0.52 1.08	6.75	
		 14-15	6 2 1	4.6 4.2 4.6	110 95 110	94-95 92.5	 0.6-0.8	 0.8-1,1	 0.6-0.8		
.75		6.25	2	3.6	60	83.55	2.00	0.37	1.70		
	0.84	15.6	2	4.2	90	78.55		0.18	0.31	5.78	
5-0,7 -0.035			6	3.6	60	94.9- 97.72	04 -1.24	0.126- 0.174	0.002- 0.157		
	0.4- 1.5	3	1	4.2	90	90	0.8		0.3	4	1.9
			2	3.6	60	95	15-2.0	0.2	0.1		
	0.52		1	3.6	[illegible]	72-79 85-90	0.14-0.1[illegible] 0.93	0.25-0.30 0.26	0.20 max. 0.20	1.32- 2.3 1.25	0.44-0.92 0.73
02-0,05			1 1	3.6 4.2	40 90	91-94	0.8-1.2	0.6-1.0	0.3-0.4**		

hed by other iron-containing materials.

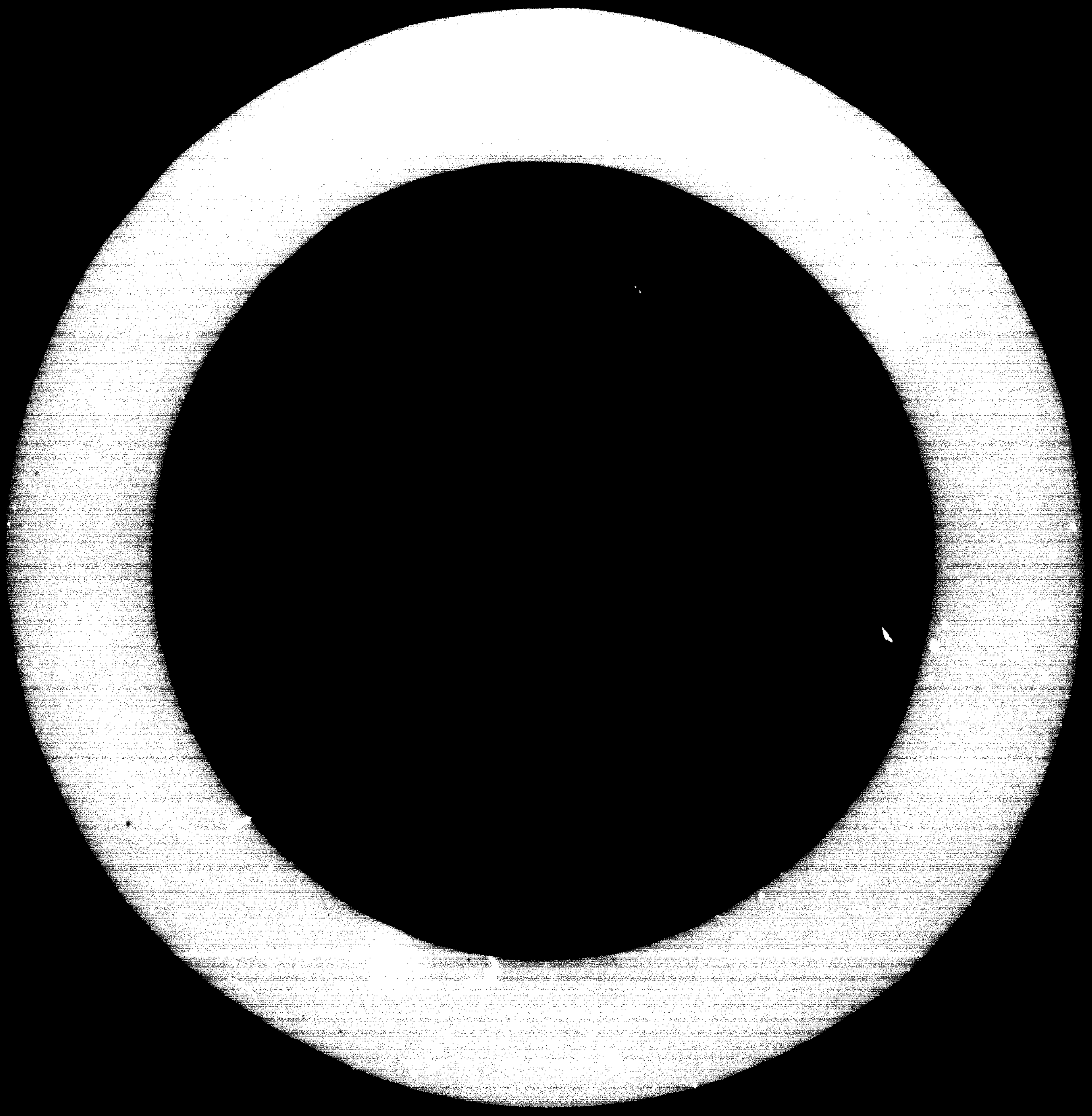
0 to 1.5 mm diam. are included, which

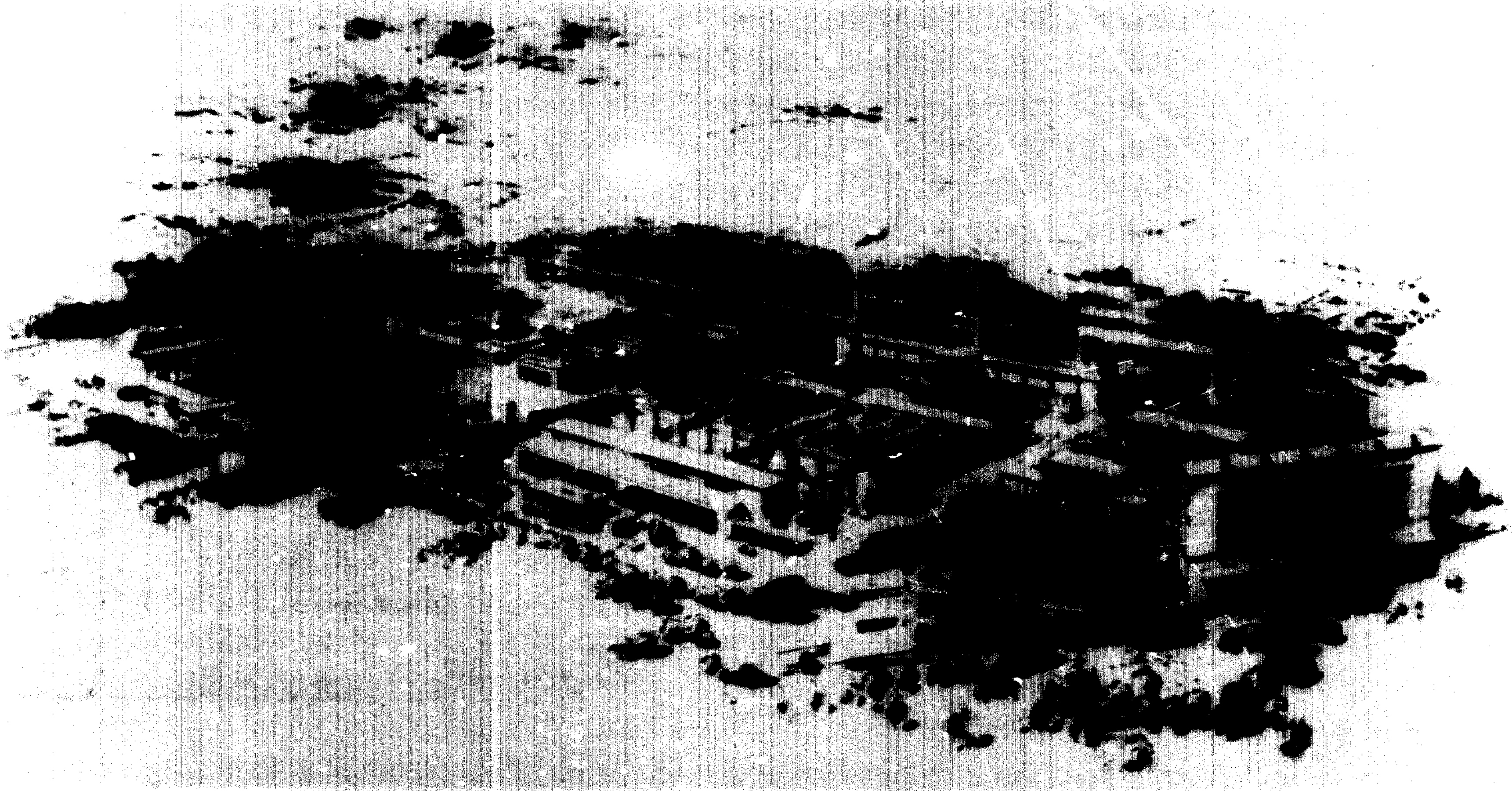
FIGURES



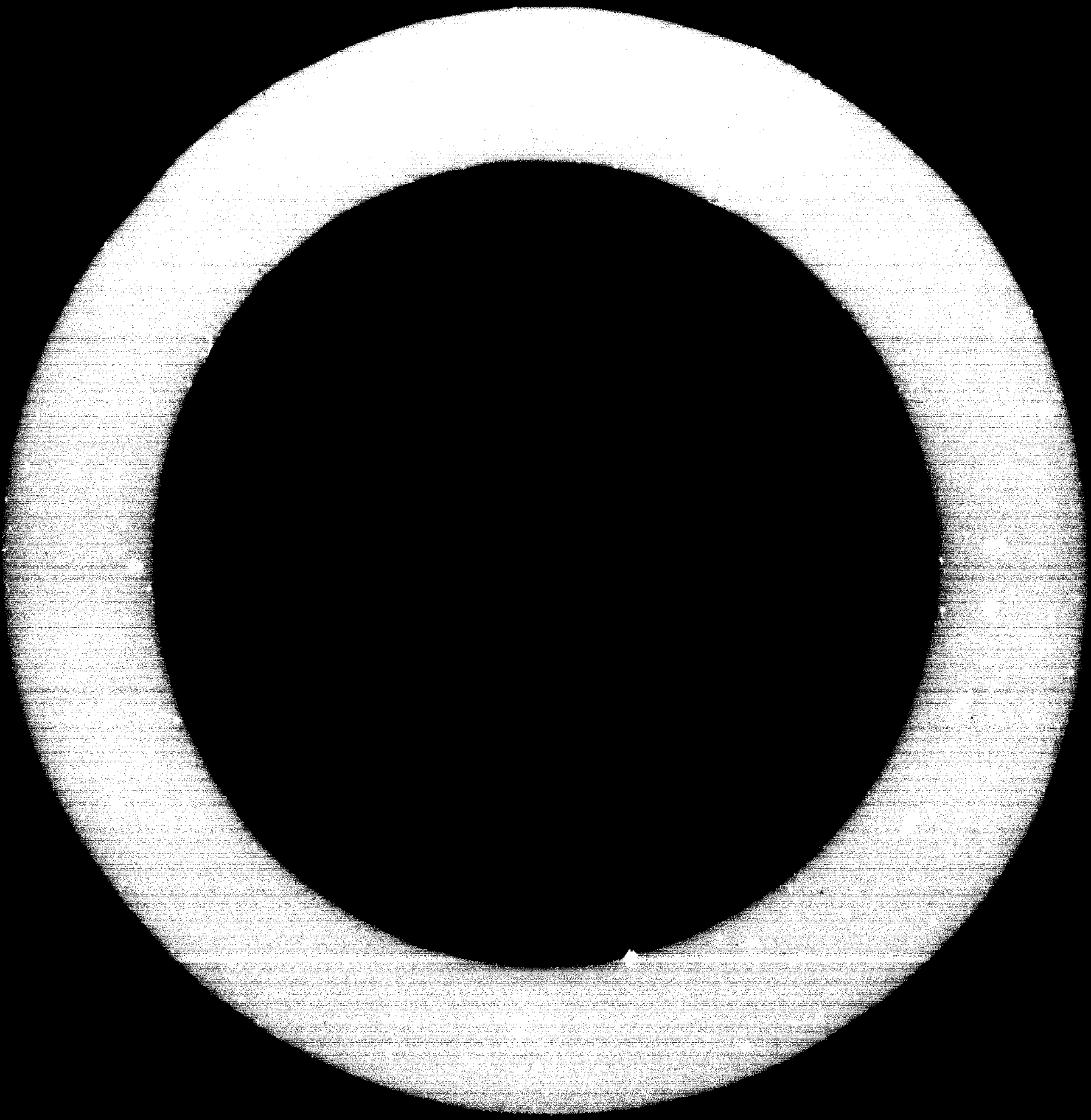


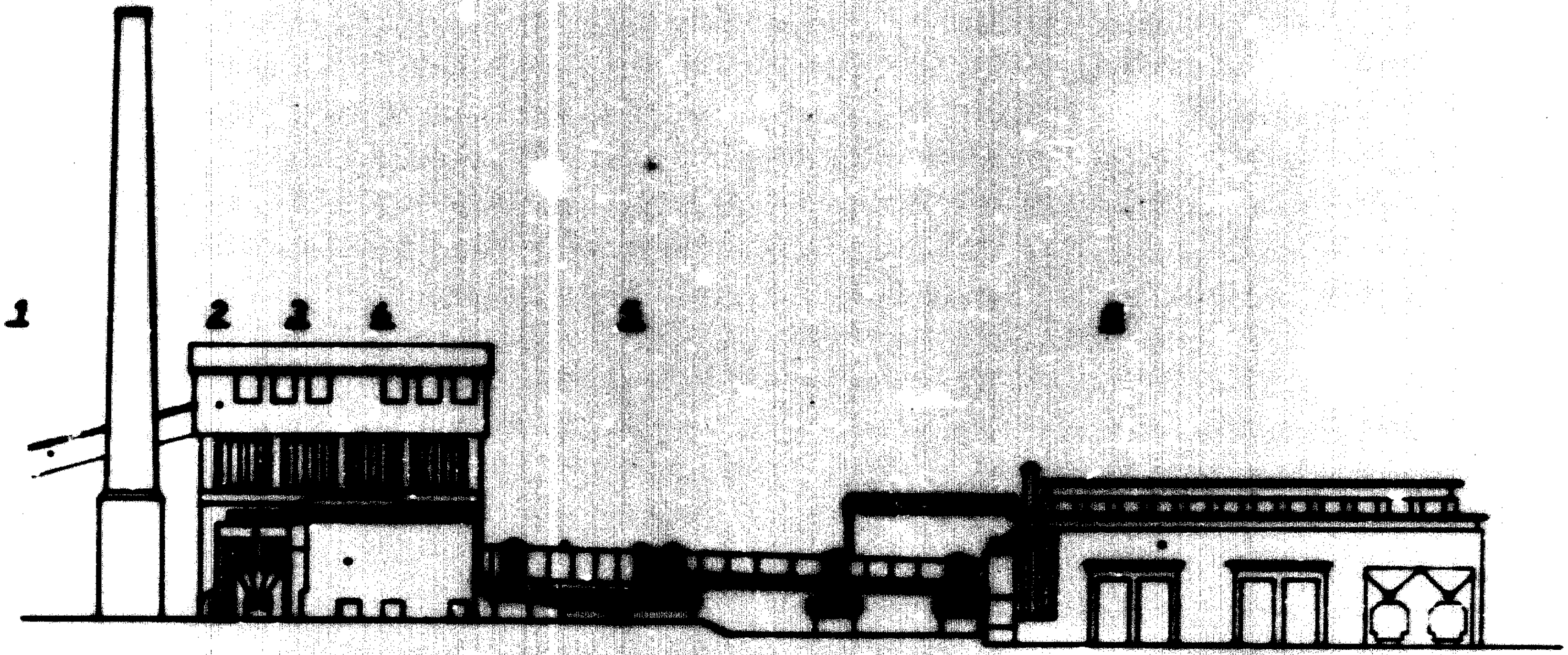
1.



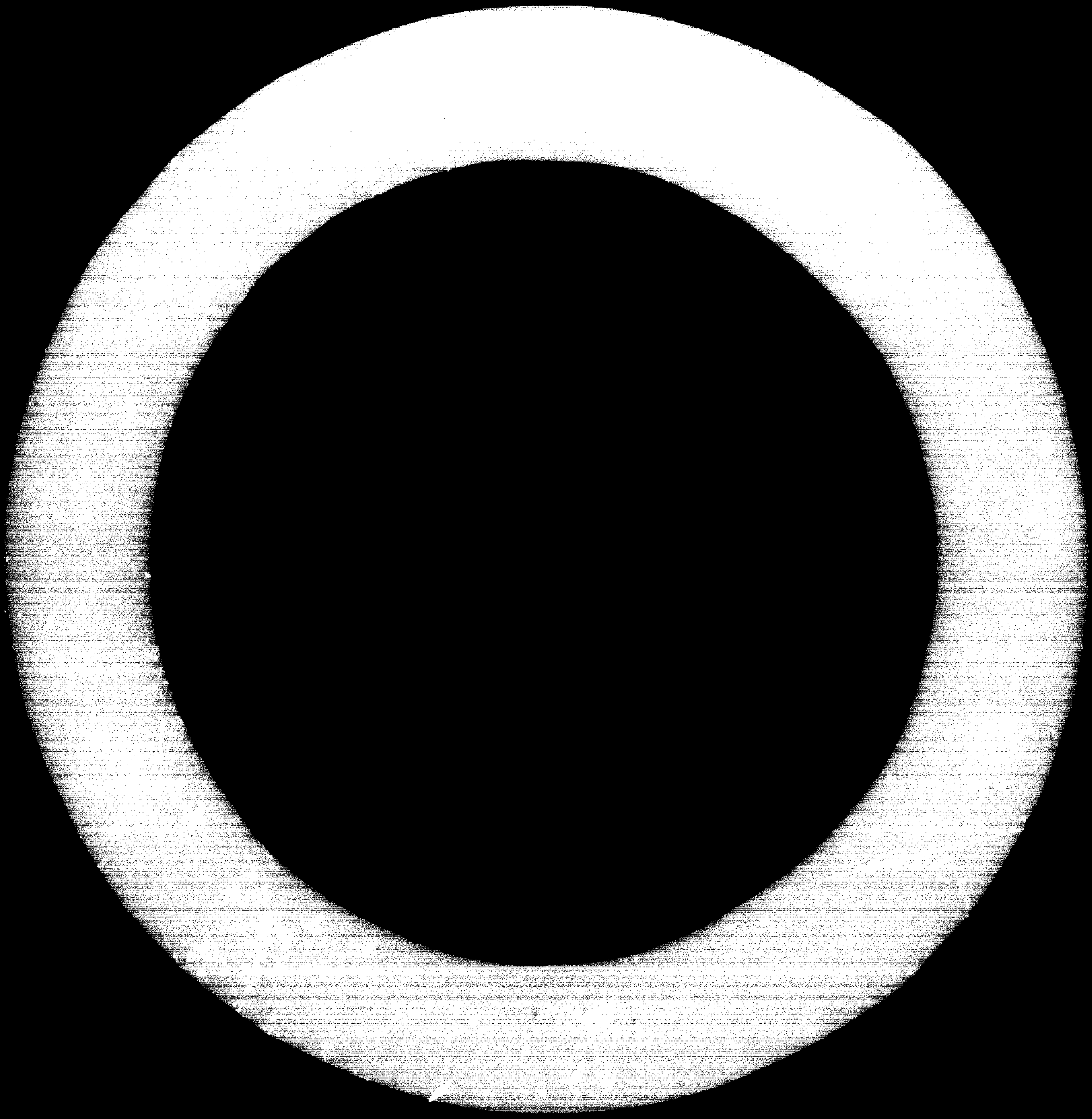


1.a





2.




2μ

10.7.74