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THE PRODUCTION OF HIGH QUALITY SINTER

by

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It comes as a surprise, after an intimate association with the development of sintering practice for more than half a century, to find that there is no aspect of the sintering process more important than that of how to make a high quality product, uniformly and consistently. This was the main problem 50 years ago; this is still the main problem today.

Although the remarks which follow are based on experience in batch plants, they apply to all iron ore sinter production units - whether they operate continuously or intermittently - producing large, intermediate or small tonnages.

It is important to remember that the sintering art has changed. It is no longer sufficient to just stick the material together; it is necessary to make a quality product. High quality sinter is one in which all the fines are removed by careful screening, and all or a large part of the limestone required is converted into lime, chemically combined with the sinter.

Broadly speaking, sintering is an oxidizing or burning process; therefore the volume of air passing through the charge is the all-important factor. The air must pass through fast enough to produce the necessary heat. If the velocity is sufficiently rapid, the combustion will take place with a blowpipe action that will quickly generate the required sintering temperature, but if the flow of air is inadequate, the burning will be like that of burning punk and sufficient heat will not be generated to form sinter.

The first condition then, is to pass a sufficient volume of air in a given time, through the charge to produce a sintering temperature in the mass. This is greatly influenced by two important factors: (1) the porosity of the charge itself and (2) the magnitude of the pressure - in sintering, a negative pressure or suction applied to force the air current through the pores of the charge.

POROSITY

The porosity of the charge is influenced by the following three (3) important factors: (1) moisture, (2) returning part of sintered charge as "return fines", and (3) mixing of the charge.

MOISTURE - Were it not for the fact that moisture added to fine ores increases the porosity of the charge enormously, the sintering process as applied today would be a complete failure. The porosity of fine, dry ore is so small that it becomes impracticable to pass air through the charge in sufficient volume to produce a sintering temperature. Fortunately, however, if 4 per cent of water is added to this same charge and mixed thoroughly, the porosity is greatly increased. If we continue to add water one per cent at a time and test the porosity after each addition, the porosity of the charge will increase progressively until a maximum has been reached. If, at that point, we continue to add water, the porosity will decrease until it has been completely destroyed. The amount of moisture used to obtain maximum porosity is usually the best proportion of water that should be used in preparing the charge for sintering. In actual practice, this depends upon the character of the ore and may vary from 5 to 12 per cent, not including combined moisture. Magnetic ores require the least, and clayey ores the most, amount of water addition to produce optimum conditions for sintering.

RETURN FINES - It is not practical to completely sinter the entire quantity of the charged material in one operation. The sintered charge may therefore be crushed and passed over a screen so that all fine material below a fixed size can be returned and resintered. The size of this screen may vary from 1/4 to 3/4" and the amount of sinter fines returned from 20 per cent to as much as 50 per cent. In the intermittent system returns are rarely more than 25 per cent. Sinter fines make up the greater part of the total returns, so that the addition of the former to the charge greatly helps the sintering unit. Return fines improve the sintering charge just as sinter improves the blast furnace charge.

MIXING OF THE CHARGE - Increase of the sintering charge porosity may be obtained by mixing the fine ores to be sintered with flue dust, roll scale, etc. It is also advantageous to mix fine magnetic concentrate with coarser ores in the preparation of the sintering charge. Obviously, this method will be limited by the materials available.

In the intermittent system there has been recently developed a method for increasing the permeability of the sintering charge by 2-stage mixing. In the first stage, an excess amount of water produces a highly agglomerating effect similar to that of mud; in the second stage, sufficient dry material is added to restore in the charge the amount of moisture most desirable for the sintering process.

SUCTION

A sintering charge of any porosity - optimum or otherwise - will, of course, offer a definite resistance to the flow of air through it. The amount of air that will pass through is proportional to the thickness of the charge and to the suction applied to its under side. The thickness of the charge is very important. In plants using the intermittent system, the depth of the charge varies from 7" with fine magnetic concentrate to 24" with minus 3/8" fines for a hematite ore. Economically, a thick charge has many advantages over a thin one. The cost of igniting and charging a thick layer is no more than that of a thin layer, and requires less sintering fuel per unit of product. The time of sintering - that is, the time required for the sintering zone to travel from the top surface of the charge to the grate - varies from 10 to 18 min. Experience has shown that 18 min. should be kept as a maximum, since a charge requiring more time than this to sinter will tend to dry out on the bottom portion near the grate and slow up the travel of the ignited sintering zone. The zone should move through the charge at the rate of about 1" per min.

The thickness of the charge is also dependent upon the suction applied. In connexion with the intermittent system, we have been advocating for years the use of powerful fan exhausters capable of providing suction of 50" of water. From the results obtained the author is convinced that high suction will become accepted practice more and more in the future. This is especially true for sintering large tonnages of ore. Reduced fuel will reduce sinter costs and will eliminate almost completely iron silicate formation in the finished sinter, thus contributing to the production of quality sinter.

Fig.1, clearly illustrates the positive results that can be obtained by applying increased suction to a sintering apparatus. Here are represented the results obtained with a series of tests made from a large amount of ore prepared to have uniformity in fuel and moisture. This large charge was thoroughly mixed so that the small individual charges taken from it were as nearly alike as possible except for the suction. Vertical distances represent the suction and horizontal distances the number of pounds of sinter produced. Line A applies to sinter produced by placing the charge directly into the pan with more or less irregular packing; line B shows production obtained by carefully fluffing the charge so as to give it the greatest amount of porosity possible and the greatest amount of uniformity. With 17" of suction, the increase in sinter production due to better charging was 18 per cent, while with 40" suction, the increase was 20 per cent. By increasing the suction from 17 to 40", the capacity was increased 145 per cent, and by increasing the suction from 17 to 40", and at the same time depositing the charge into the sintering apparatus with the greatest amount of uniformity and porosity, the capacity was increased 194 per cent. In other words, for every inch of increase in suction, there was an increase in sintering capacity of 6 per cent in the first case and of 8 per cent in the second case. This pronounced increase in capacity has been fully verified on a large scale in practice.

To apply high suction, the sintering apparatus must obviously be airtight from the top surface of the charge to the fan exhauster, so that exhaust fans of superior design are required. High suction fans, when carefully designed and properly constructed, can be operated over long periods of time without attention except lubrication. At one plant, exhausters capable of producing 50" of water suction, were in use for over a year without repairs of any kind, and at another plant for over two years without repairs. This is a real accomplishment, when it is considered that the tip speed of the impellers is over 26,000 ft. per min. The successful operation of these exhausters is due to accurate balancing of the impeller and thorough protection of the impeller from heavy dust by a carefully constructed grate to support the charge, and an efficient dust catcher between the exhauster and pan. In the latest plants 2 suction fans are used in series and operated with about 80" suction. This has proved very successful in producing high quality self-fluxing sinter.

FACTORS AFFECTING QUALITY

IGNITION - Proper ignition of the charge is important, and the time required to accomplish this should not exceed 20 sec. Every square inch of the charge surface must be evenly and fully ignited. Long exposure of the igniting surface to flame dries out the charge and produces uneven sintering. A clean, high-temperature and highly-oxidising flame applied instantaneously to every square inch of surface produces the best results. For this reason, it is preferable to use high grade fuel such as oil, or natural gas or coke oven gas instead of blast furnace or producer gas.

GRATE OPENINGS - In any downdraft sintering apparatus, the grate receives severe punishment. It should be self-cleaning and have an opening equal to at least 20 per cent of the total grate area. The amount of grate opening, however, depends upon the character of the material being sintered. Fine ores, lacking cohesiveness, are readily drawn through the grate by the air blast, and therefore require a grate with smaller openings. It is advisable to place a thin layer of coarse material upon the grate, and when sintering fine ores are added, it is excellent practice to deposit a layer of ore upon the grate without any admixture of fuel, as this inhibits the formation of highly-fused sinter which frequently forms next to the grate.

COOLING - Sinter should be air-cooled since red hot sinter, when doused with water, becomes very brittle and breaks up easily on handling. Air-cooled sinter is much stronger than water-cooled material. Sinter made from a charge containing lime should obviously not be moistened.

SULPHUR - Sulphur elimination is of vital importance in the preparation of certain sulphur bearing iron ores, and this element should be reduced to 0.10 per cent or less for use in the blast furnace. The all-important point to remember in sulphur elimination is to keep carbon content of the charge at a minimum, so that the heat released by the combined burning of the carbon and sulphur is just sufficient to produce a sintering temperature. If more carbon is present, the oxygen combines with the carbon in preference to the sulphur, thus fusing some of the sulphur compounds from which it is extremely difficult to remove the sulphur. The extreme sensitiveness of this action is shown by Table 1. Increasing the coke from 2.43 to 2.90 per cent raised sulphur in the sinter 0.01 per cent with material crushed to 1/4" and 0.09 to 0.13 per cent with material crushed through 5/16" screen. Fine crushing also favourably affects sulphur elimination.

TABLE 1

RESULTS OBTAINED IN SINTERING TESTS MADE WITH SIDERITE ORE CONTAINING 2 PER CENT OF SULPHUR

Ore Size, In.	Coke (Per Cent)	Iron (Per Cent)	Sulphur (Per Cent)
Below:			
1/4	2.90	51.84	0.10
1/4	2.43	51.64	0.09
5/16	2.90	52.04	0.13
5/16	2.43	52.04	0.09

FUEL - Coke breeze crushed to pass a 10 mesh screen is an excellent fuel for mixing with the charge to be sintered; anthracite culm when available, is also a satisfactory fuel. Bituminous coal is not suitable because of its volatile constituents which are not only wasted but tend to condense out tarry compounds that clog the pores of the charge, and interfere with the flow of air. The fuel must be finely divided to obtain uniform distribution throughout the charge and avoid intense local temperatures. There is seldom sufficient time to burn large particles of fuel, with the result that the unburned fuel is wasted so far as the sintering operation is concerned. Ores containing 6 per cent sulphur have sufficient fuel to produce a sintering temperature. Blast furnace flue dust always has an excess of fuel for sintering; in fact, a ton of dust with 15 per cent of carbon has enough fuel to sinter 3-1/2 tons additional of fine ore or concentrate, providing the charge is properly arranged and treated with high suction.

CHEMICAL AND PHYSICAL PROPERTIES - The object of sintering is to prepare a material for treatment in the blast furnace; therefore the chemical and physical qualities of the sinter are of major importance. The full significance of the fact that sinter may be good, bad or indifferent in the blast furnace has been fully recognised only within recent years. The author has been frequently confused by conflicting reports regarding the effect of sinter in the blast furnace, and well remembers being told that more than 10% of sinter could not be used in the furnace without introducing operating difficulties, because the sintered material melted and reached the tuyere zone without reduction. Many authorities considered it necessary and desirable to form iron silicates in order to make a sufficiently strong sinter. This soon proved to be undesirable and the problem was recognized as one of converting all varieties of ore into a sintered product with sufficient strength for blast furnace use, and without the formation of iron silicates.

The factors which are involved in the production of such a sinter are: control of temperature at which sintering occurs; the time that the charge is exposed to that temperature; and the quantity of sintered fines returned to the charge.

In the early days of sintering, the sole objective was agglomeration. After some forty years, it became apparent that sinter could play an important active role in the pig iron production process itself. High quality sinter in the blast furnace burden increased the output of a given furnace and, at the same time reduced coke requirements. With the establishment of this fact, and the determination that burdens could carry any quantity - up to 100% - of sinter, the sinter process has become of vital importance to every iron production operation, large and small.

THE SINTERING PROCESS

By means of high suction and an improved arrangement of the charge to be referred to later, the author has obtained some very interesting results in sintering fine red hematite ore. Sinter, sufficiently strong for blast furnace use, was produced repeatedly with 3.5 per cent coke in the charge. An excellent sinter was also made by adding 16 per cent flue dust, so that the charge sintered contained only 2.84 per cent carbon. This is considerably less than one-half the amount of fuel required heretofore for sintering this ore.

Fig. 2 is a photomicrograph showing crystals of hematite and magnetite embedded in glass, as they appear on a polished surface. The metallic constituents of the sinter appear either as magnetite or hematite. The magnetite occurs as a recrystallization product of the original hematite in cluster of minute octahedral crystals. The original fine hematite powder has been recrystallized in clusters of minute, sharply definited, hexagonal crystals of the same material.

The art of sintering has changed within the last few years. For the blast furnace a self-fluxing sinter is most desirable. A typical analysis of this sinter is as follows:

Total Iron (Fe)	55.80%
$FE_2 O_3$	53.71
$FE_3 O_4$	24.89
$Si O_2$	4.82
CaO	7.90
MgO	2.39

Note the large percentage of Fe_2O_3 in this sinter. It was made with 12% dolomite. With 50% of this sinter in the blast furnace charge, the production of pig iron was increased 20%.

Another type of calcium sinter made with 50% of limestone in the sintering charge is as follows:

Total Iron (Fe)	48.45%
Fe_2O_3	69.21
FeO	5.03
CaO	19.02
Silica (SiO_2)	3.80
MgO	0.27

Note the high percentage of Fe_2O_3 and lime. The type of sinter may be especially useful in Open Hearth Furnace operation as the time of treatment will be greatly reduced.

Fig.3 is a photograph of two sinters made from the same ore and with the same suction of 50" of water. The product shown on the right was made with 3.5 per cent coke, and is an ideal product for the blast furnace, completely free from iron silicates. Notice the great porosity and the thinness of the walls of its cellular structure, also that incipient fusion only was attained, and not a smelting temperature. The sinter on the left hand had more return fines and 4.5 per cent coke. Here a pronounced smelting or slagging action is observable. This sinter has been fused entirely too much for the most economical results in the blast furnace. The extreme sensitivity of sintering charges to fuel under high suction is again clearly illustrated by these two exhibits - one charge having only one per cent more coke than the other.

When properly conducted, the sintering process can be carried out with extraordinarily high termal efficiency. From the thermal point of view, it may well rank as the most efficient process in the entire metallurgical field. The siderite ore referred to in Table 1 contained only 2.43 per cent coke, plus 2 per cent sulphur as combustible; yet there was sufficient heat to bring the entire mass to the point of incipient fusion, drive out all the water in the charge, and eliminate 31.56 per cent CO_2, the latter being an endothermic reaction. This was also true of the hematite ore where 3.5 per cent coke was sufficient to sinter the charge and eliminate about 12 per cent CO_2. The reason for this high efficiency may be readily explained.

Consider a sintering charge about 16" thick deposited on an intermittent sintering unit. The igniting flame is applied instantaneously to every square inch of the top surface and maintained for about 30 sec. The sintering zone then moves downward in a plane whose area is the size of the entire sintering unit parallel to the grate surface. This sintering zone - that is, the region where the actual sintering occurs is very thin - probably never more than 1/16". Immediately after ignition, this zone is drawn beneath the surface of the charge, while the incoming air must pass through incandescent sinter before reaching the ignited sintering zone. By the time the air reaches the sintering area it has already reached a highly heated condition. On the under side of the sintering zone are the highly heated products of combustion passing through the part of the charge immediately ahead of the sinter zone. As these products of combustion filter downward through the pores of the charge, their heat is quickly transferred to the charge. Thus there is not only preheated air, but also a highly preheated charge providing excellent conditions for economical combustion.

In April 1938, the following statement was read before a meeting of the American Institute of Mining and Metallurgical Engineers:

> "The writer believes that in the future the sintering plant will attain a position of much greater importance as an adjunct to the blast furnace, and that before long, all the fines from ore will be converted into self-fluxing sinter. In the still further distant future, he can visualise the sintering of all ore preparatory to treatment in the blast furnace, so that only coke and sinter will be fed into the furnace.
>
> "The role of prophet is a precarious one, but the prediction can safely be made that the first blast-furnace superintendent to use 100 per cent of self-fluxing sinter properly made, so as to be completely free from iron silicates, will have a most pleasant surprise awaiting him, not only with reference to the greatly reduced coke consumption but also in regard to the increased capacity of the blast furnace and the great uniformity of the furnace operation."

This prediction, made by the author 25 years ago, has been thoroughly proven on a large scale operation. It also applies to small iron production units.

INTERMITTENT SINTERING PLANTS

It would be pointless to draw any comparisons between the intermittent and the continuous processes. Each has its advantages and specific areas of preferred application. The detailed comments on batch-type plants which follow are given because, clearly, the intermittent sintering installation may be provided in smaller capacities than the continuous strand unit. This basic distinction may be particularly interesting in the newly developing countries, where modest iron production capacities may be the immediate need. This is not to say that continuous sinter plants may not be designed for small tonnage output, nor that intermittent installations are not in operation producing large scale quantities of sinter.

The first commercial iron ore sintering installation in the steel industry was a batch-type plant, designed 50 years ago to use a process and facilities invented by the author. The same process, modified and improved with respect to details of equipment but fundamentally unchanged in principle, is still being used today. There are now two intermittent processes available in the industry; the AIB (or GHH) and the original Greenawalt process. More than 90% of all batch-type sintering plants installed have been of the latter type.

The essential difference between the two is in the method of removing the product from the pan in which it has been sintered. In the former, the pan is moved by crane to a dumping station; in the Greenawalt the pan is stationary, but rotating so that the finished sinter may be "poured" out into a fixed hopper-duct beneath the pan. For small plants of 300 to 1000 tons of sinter per day, the initial cost of the two intermittent installations do not differ greatly.

The intermittent process has the following advantages:

Flexibility of control producing a higher quality sinter, simple or self-fluxing.

Relatively low initial capital cost.

Ease of extending an initial installation to add capacity as needed.

Low operating and maintenance costs. In small capacity plants the operating costs favour the intermittent system.

Intermittent sinter plants may be designed with one or more sintering pans or units. Five standard grate areas are available in the Greenawalt pan: 50, 100, 150, 250 and 400 square feet each. Pans can carry a charge up to 24" deep, from the top of the pan to the automatic self-cleaning grate.

Production rates, as noted, govern the capacity of finished sinter for a given pan. Normally a charge containing 45% to 55% Fe will produce 3 tons per square foot of grate area per day. This figure is based on a finished sinter; screened over a mechanical screen with 1/2" openings.

For sintering fuel, coke breeze, anthracite fines or charcoal may be used, but it is important that they be crushed and screened for maximum uniformity and minimum fines. Coke breeze and anthracite fines should not exceed 1/8" and charcoal 3/16". Normal consumption of coke or anthracite averages 90 to 110 pounds per metric ton of finished sinter. With charcoal, consumption varies with ash and moisture contents. In an established operation in Brazil, high quality sinter is being produced at a rate of 3 tons per square foot of installed grate, using 8% (160 pounds per ton) of charcoal, with an average of 20% moisture, 44% F.C. and approximately 33% ash.

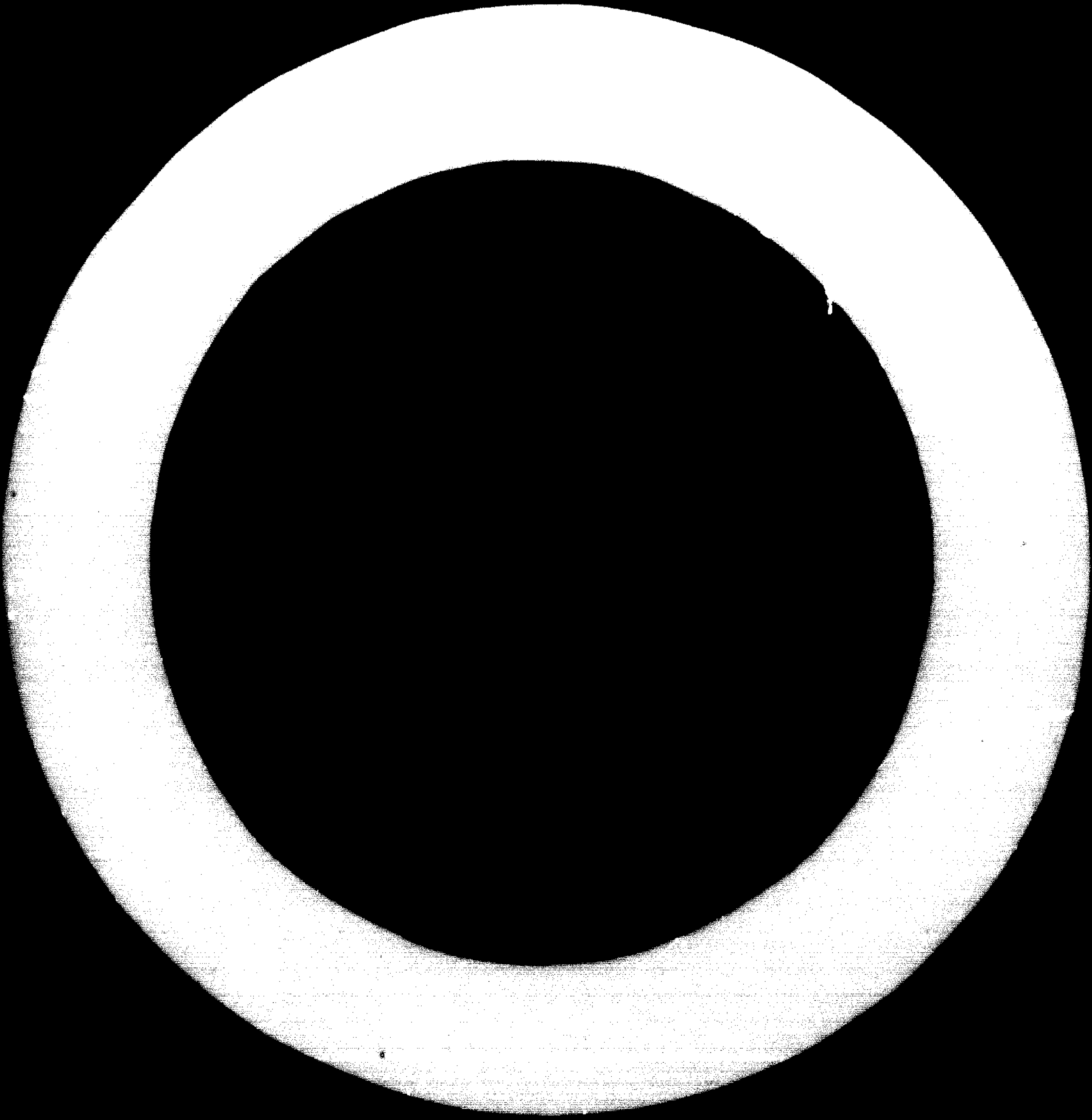
Ignition fuel may be gas or oil. Number 2 fuel oil or its equal is preferred. Average consumption is 0.5 gallon per ton of finished sinter.

Electric power is consumed primarily in driving the suction fans. Given an air tight suction system, 10 to 12 kWh per ton of sinter is required plus an additional 5 to 6 kWh for material handling and mixing, and for dust collection. The average power consumption is therefore 15 to 18 kWh per metric ton of finished sinter.

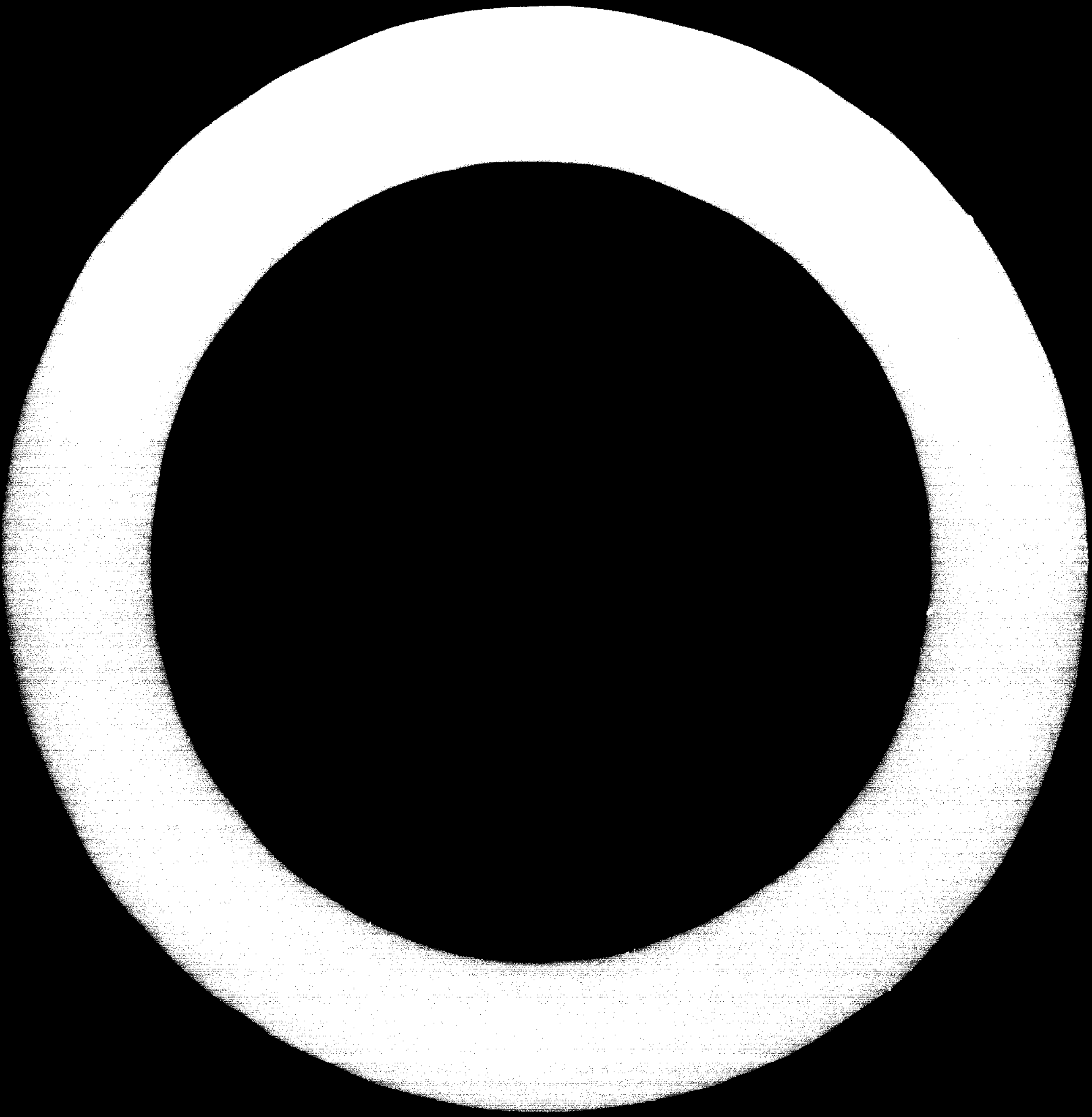
Well designed intermittent sintering plants operate at an overall yield of 95%.

Five men, including supervision, are required per shift. The same labour force can operate a batch plant with four pans as is needed for a one pan installation. Furthermore the pan size has little effect in the operating crew that is needed for the sintering operation.

Figures 5 to 11 illustrate some of the primary elements of an intermittent sintering plant.



FIGURES



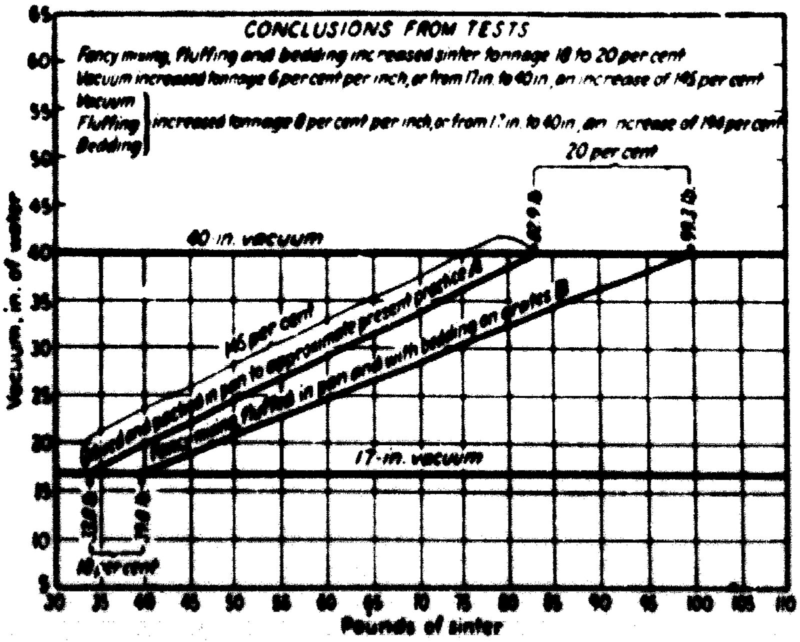


Fig. 1 - Results obtained by applying increased suction to sintering apparatus

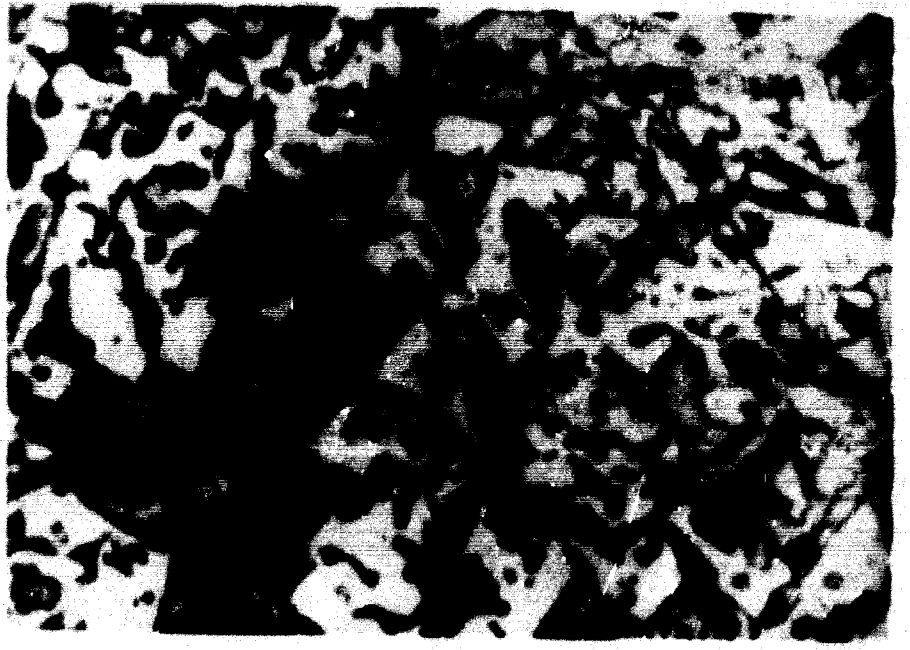


Fig. 2 - Crystals of hematite and magnetite embedded in glass, as they appear on a polished surface

Large, light gray angular areas represent hematite crystals in reflected light. A few dendritic groups of magnetite crystals are shown at the side.

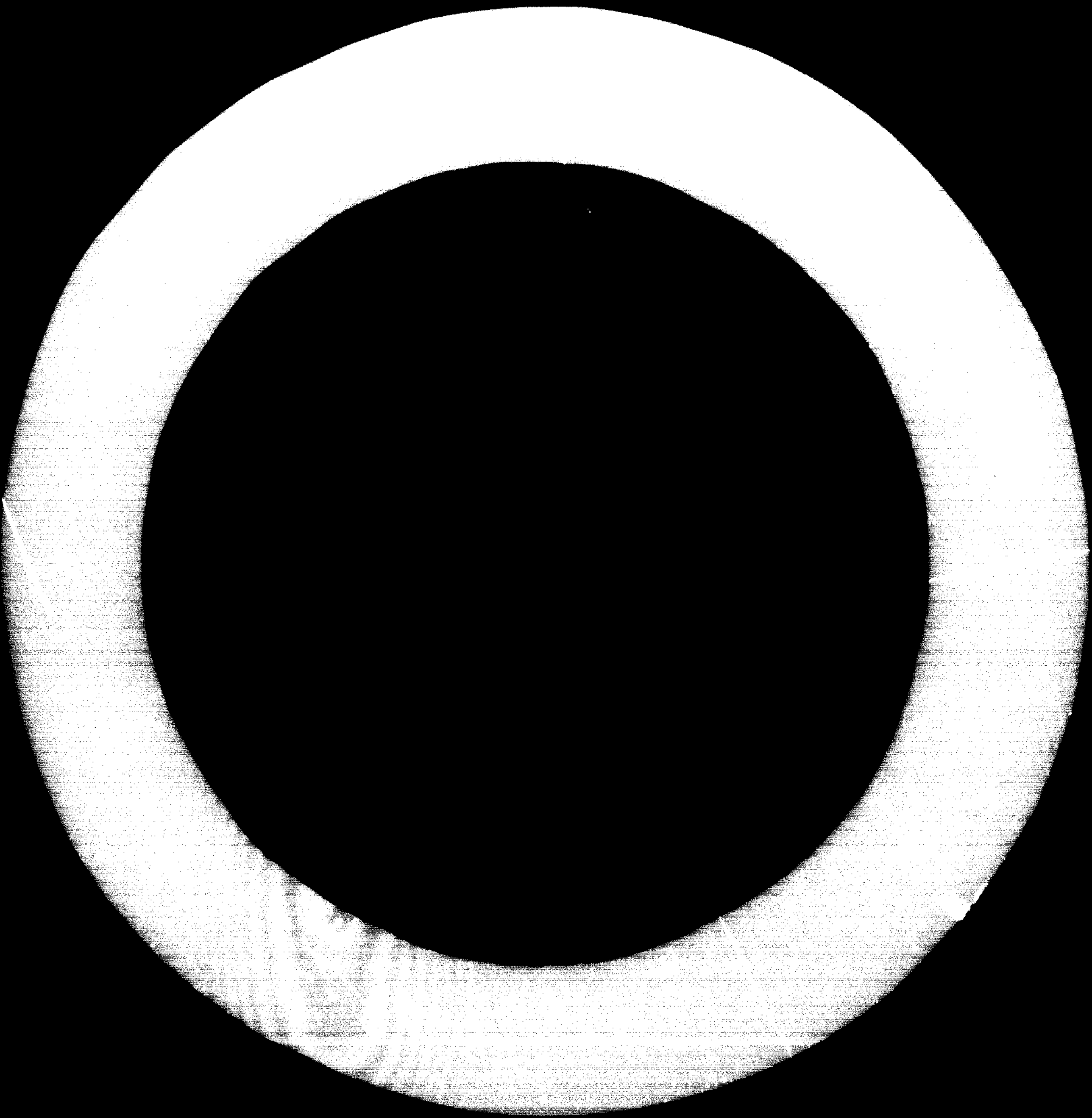
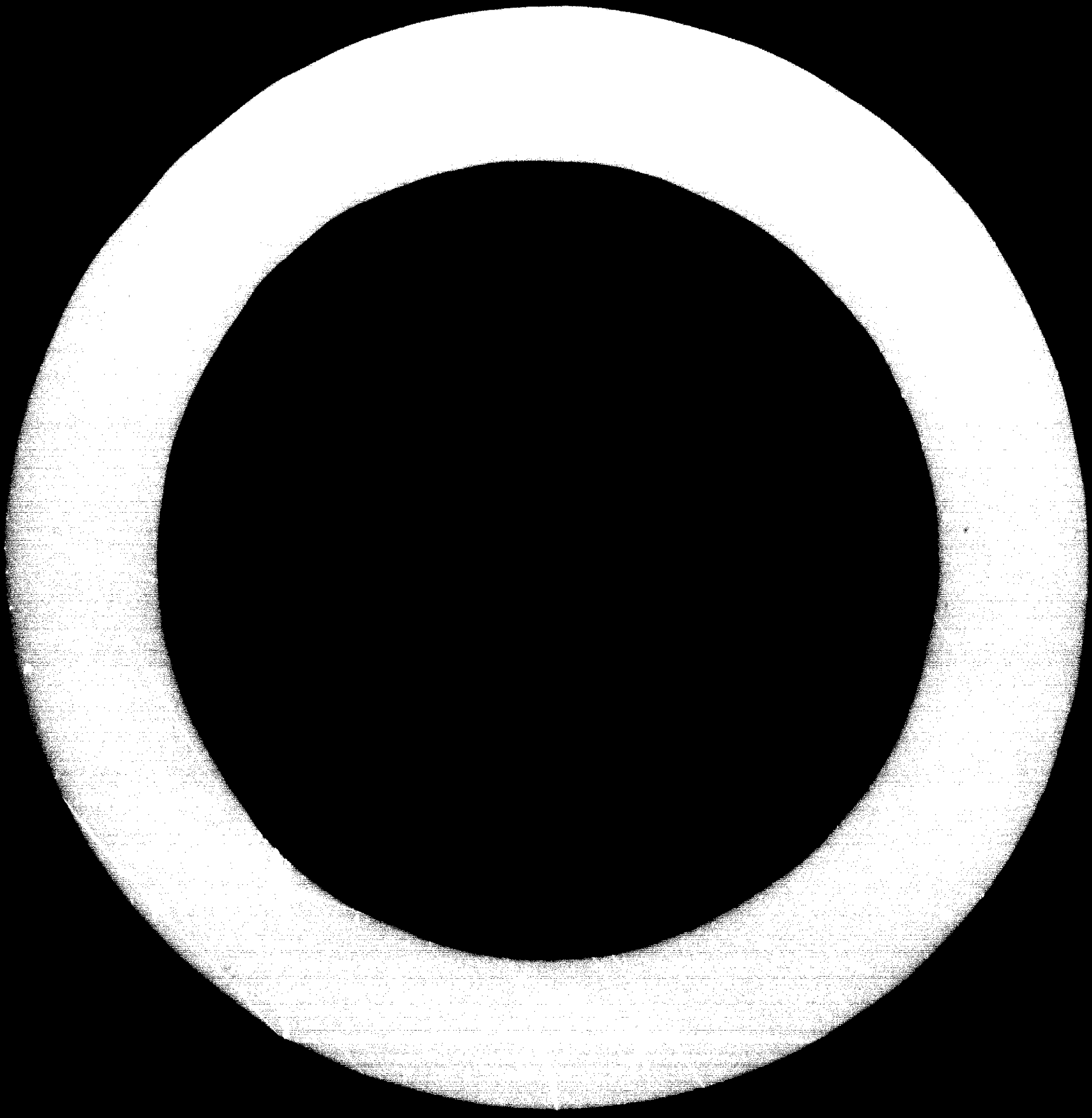
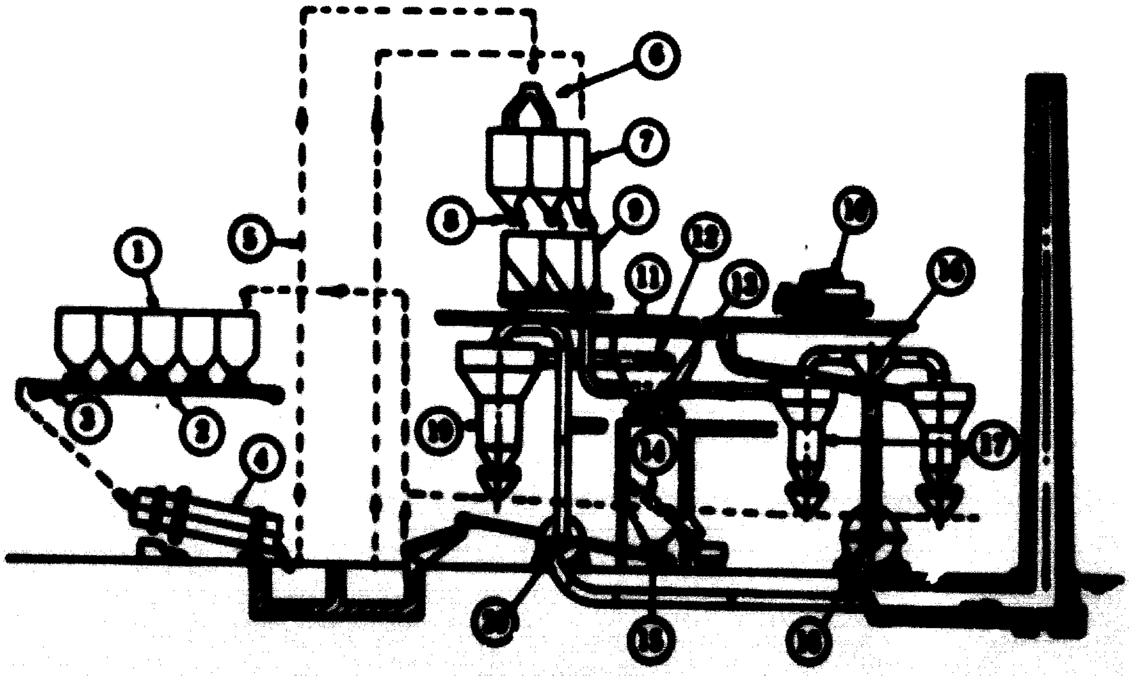


Fig. 3 - Two sinters made from same ore with suction of 20 inches of water



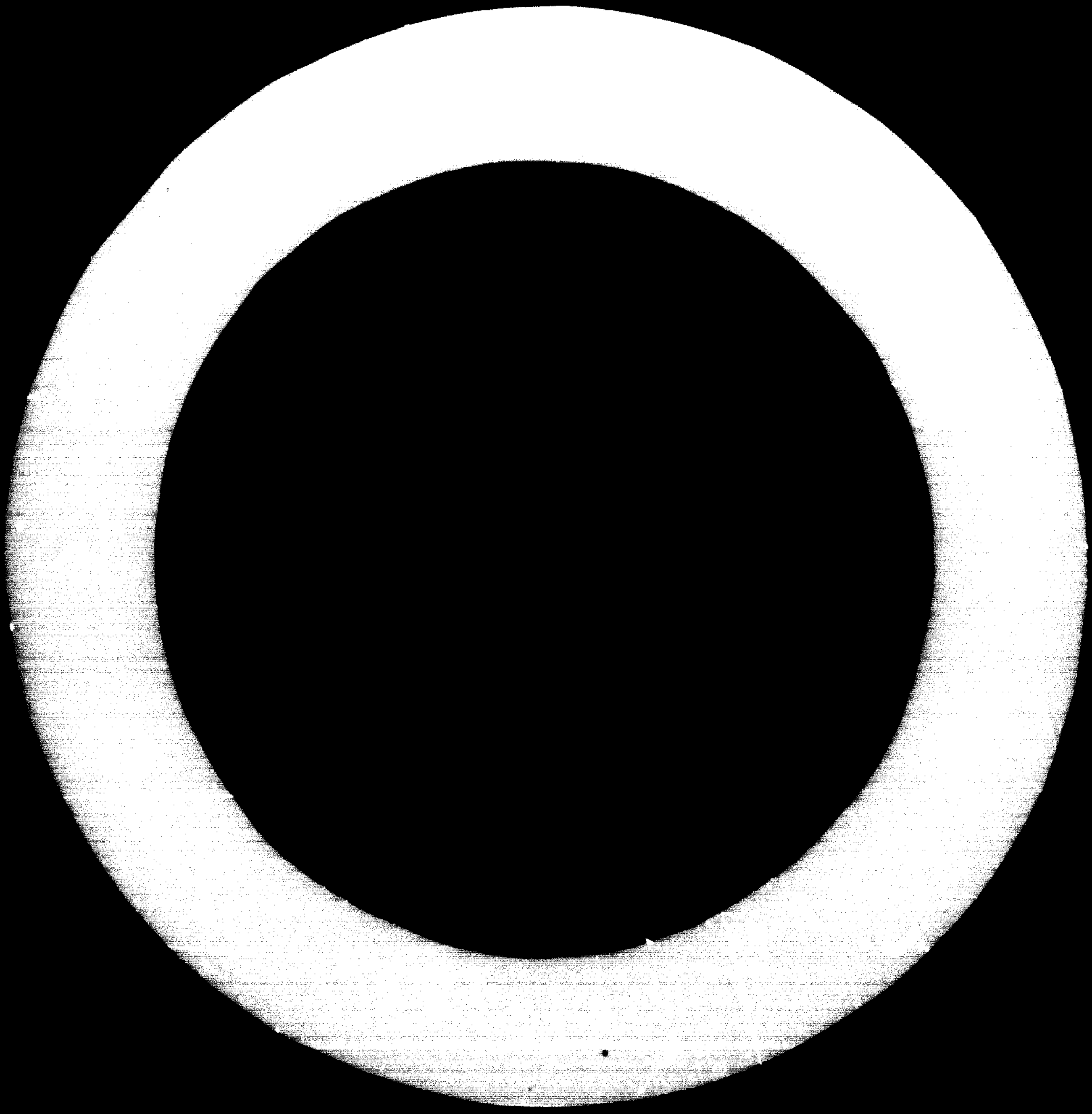


Standard Flowsheet

1 - Bunkers of Raw Materials (ore dust, fine ore, flue dust, return fine, coke breeze, slime, etc.)
2 - Table Feeders (for supplying raw materials)
3 - Belt Conveyor (for transporting raw materials)
4 - Mixer
5 - Transporting Equipment (skip hoist or belt conveyor)
6 - Distributor
7 - Storage Bin (for bedding, main charge, top charge)
8 - Roll Feeders
9 - Charging Car
10 - Ignition Hood
11 - Sintering Pan
12 - Sinter Hopper
13 - Sinter Crusher
14 - Screen
15 - Table Feeder (for feeding return fines)
16 - Suction Valve
17 - Cyclone Dust Collectors (for sintering pan)
18 - Exhaust Fan
19 - Cyclone Dust Collector (for cooling fan)
20 - Cooling Fan

FIGURE IV

STANDARD FLOWSHEET OF INTERMITTENT TYPE SINTER PLANT



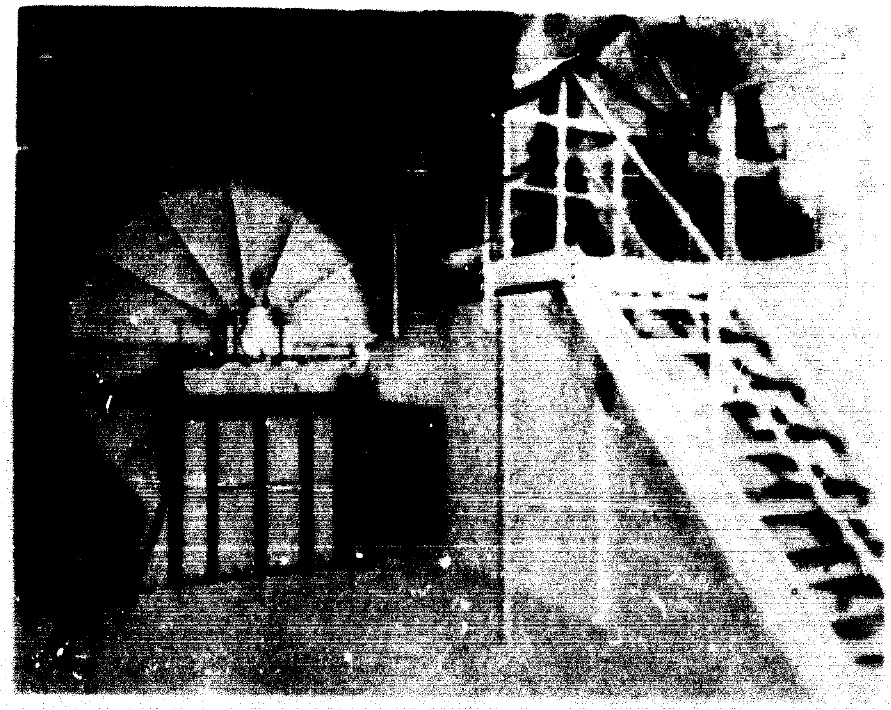


Fig. 5 - Air Tight Suction Fan

Fig. 6 - Charging Car

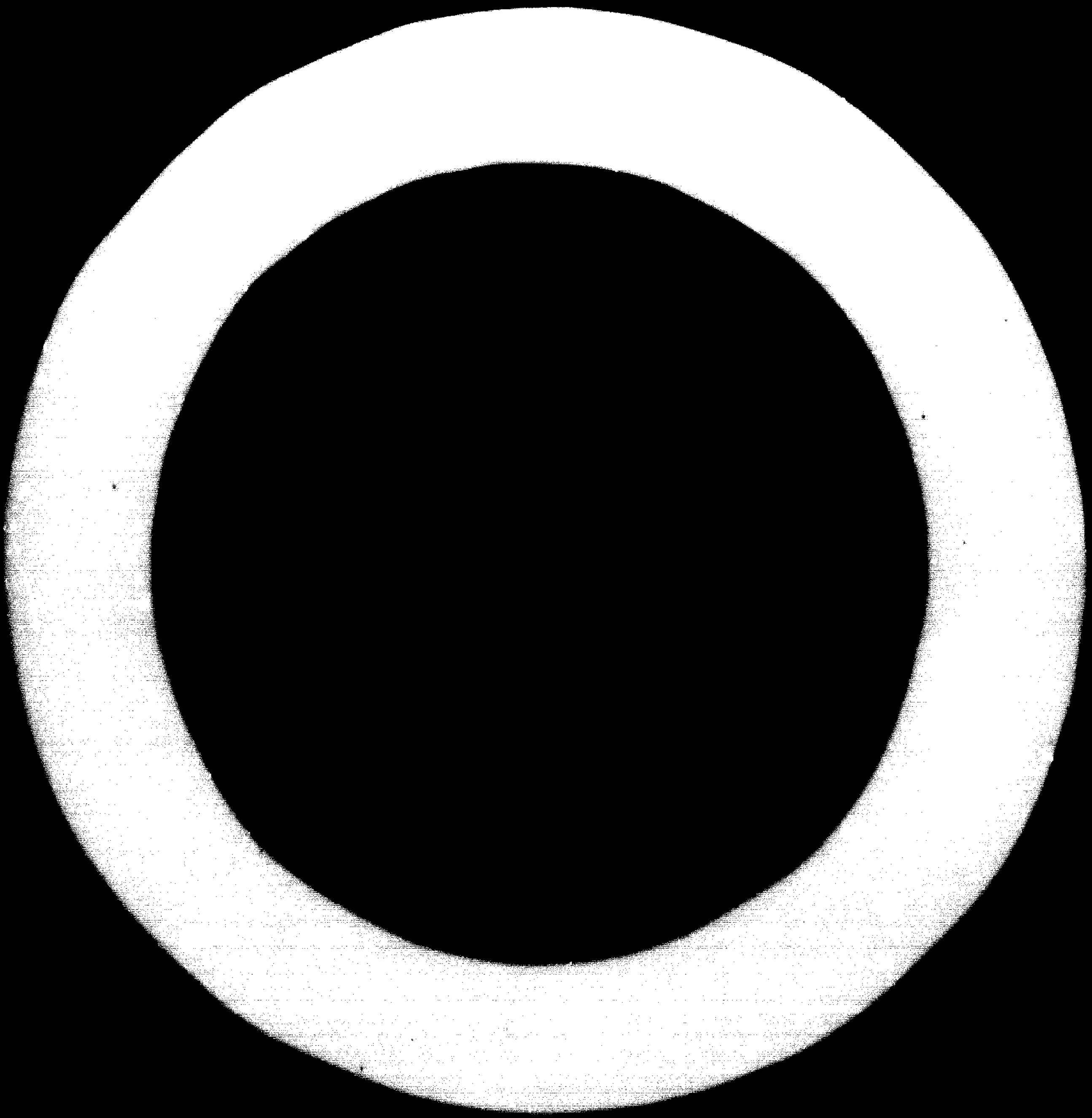
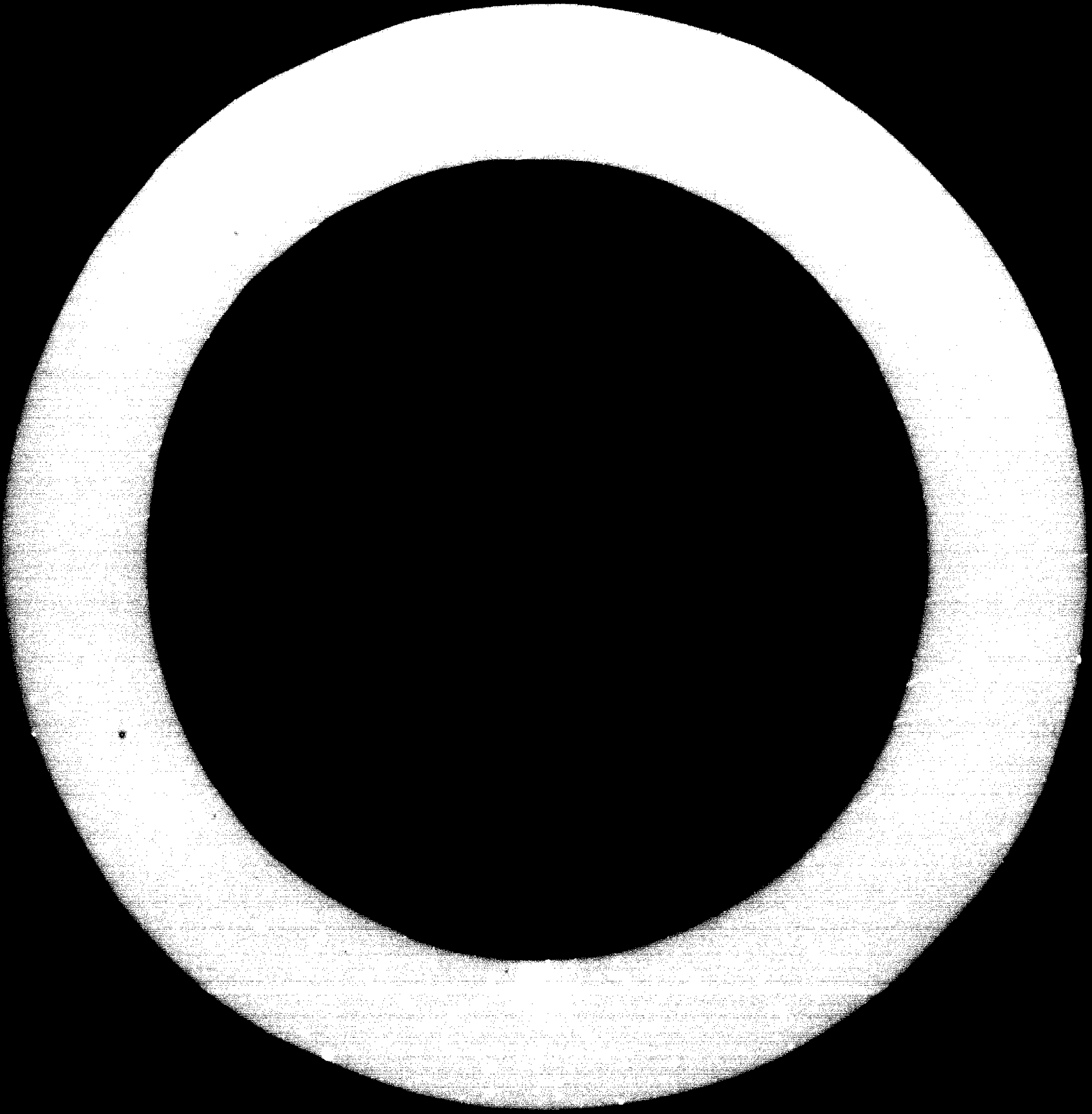


Fig. 7 - Charge Mixing Drum

Fig. 8 - Ignition Car



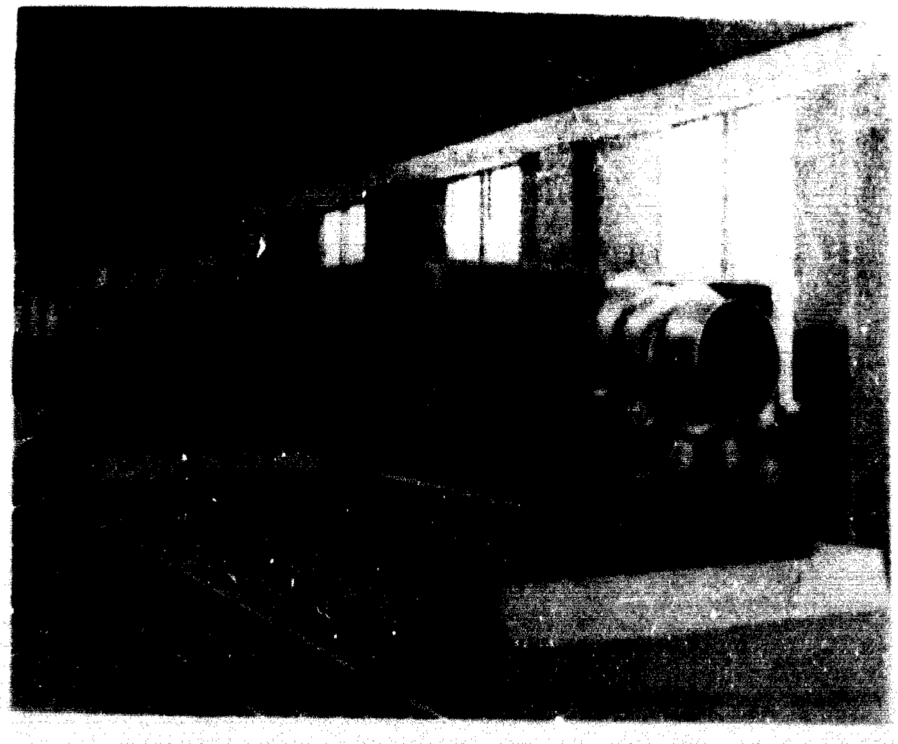
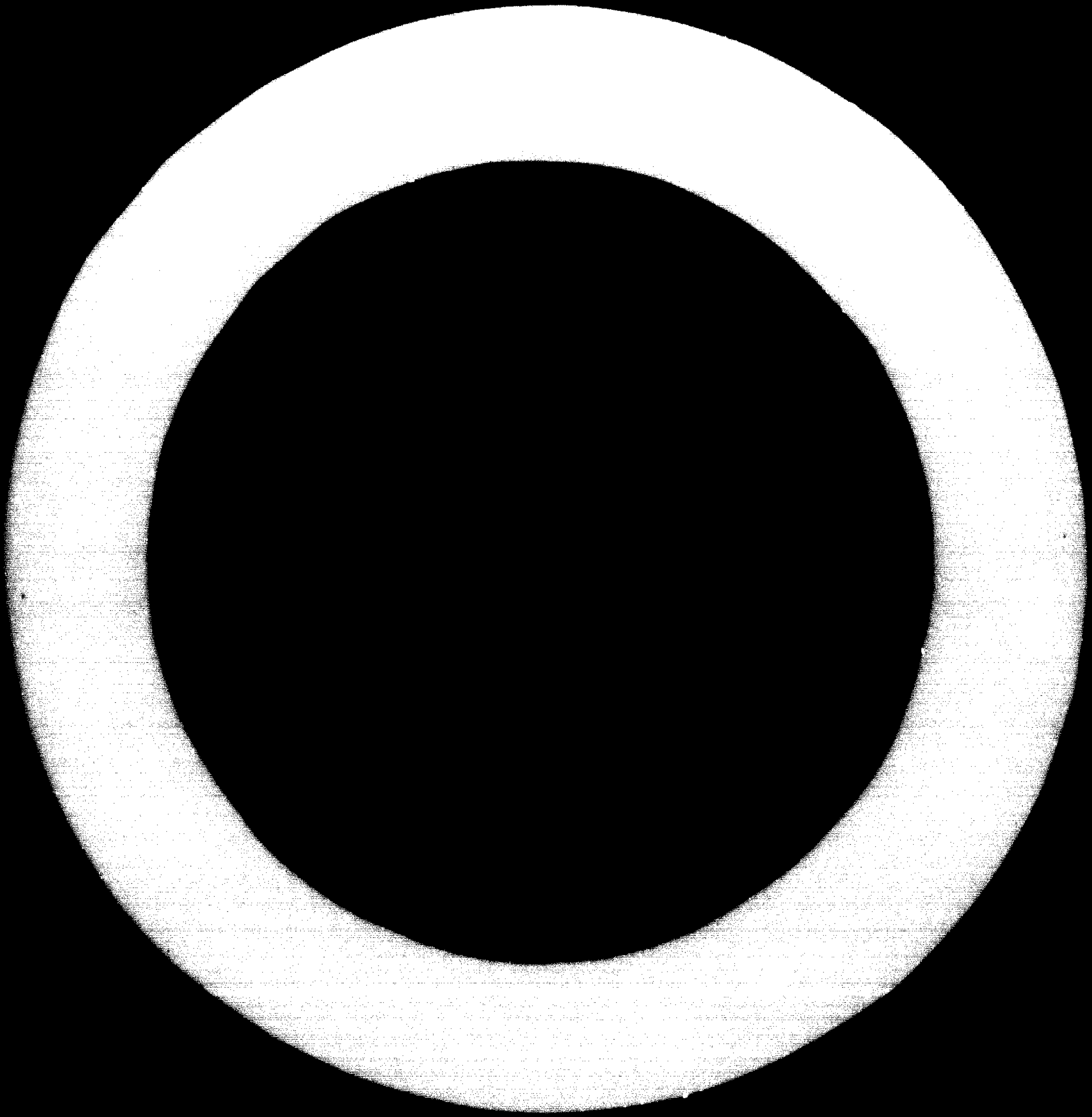


Fig. 9 - Rotating Sinter Pan

Fig.10 - Rotating Sinter Pan



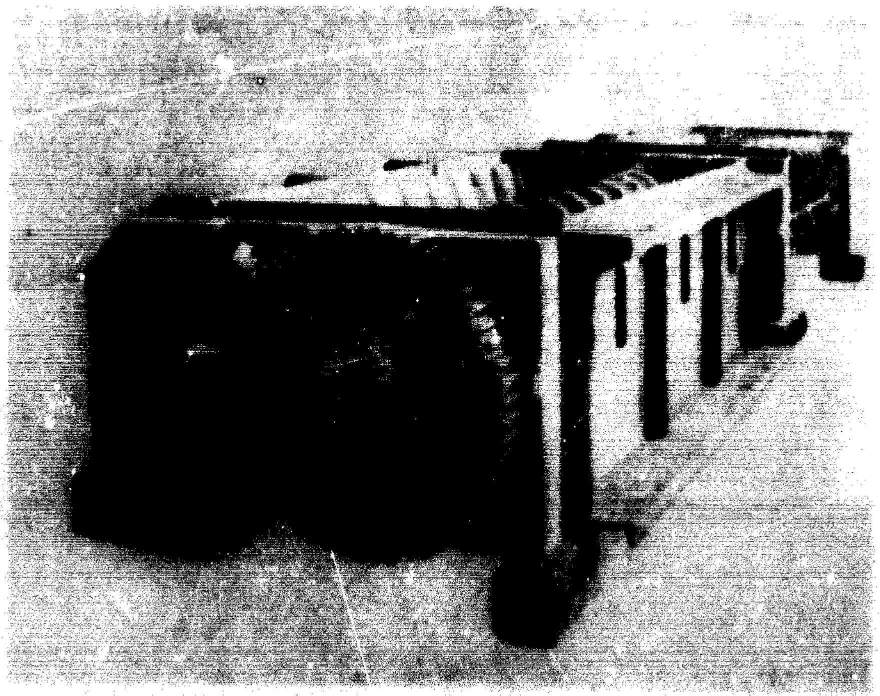


Fig.11 - Sinter Crusher

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