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STANDARD PROCESSING METHODS OF BENEFICIATION AND CONCENTRATION - BLENDING, SEPARATING, SIZING AND AGGLOMERATION: ORE PREPARATION IN SOUTH-EAST ASIA AND JAPAN

by

M. Nakatsuyama, Raw Materials Supply Investigation Dept.,
Raw Materials Purchase Div., Nippon Kokan Corporation, Japan

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ABSTRACT

The very remarkable progress in ironmaking techniques in recent years has almost doubled the productivity of blast furnace and decreased the coke ratio by about a half during the past decade.

Among many techniques having realised such epochal developments in operational results, the most important one is the improvement of physical and chemical properties of raw materials to be charged into blast furnace through the advanced techniques of ore preparation.

This paper describes, with regard to these ore preparations, the present situation of various ore beneficiation methods adopted both in mines and steel mills, examines distinctive features, advantages and difficulties of such methods and finally considers possible future trends in this field.

I. INTRODUCTION

The remarkable progress realised in recent years has improved the production efficiency of the blast furnace operation, and especially in Japan where the supply of heavy coking coal depends on imports, the striking decrease in the coke consumption ratio enables to lower down the production cost of pig iron and to promote the economicality of the operation.

The most important role in the development of such ironmaking techniques is played by the improvement of physical and chemical properties of the various raw materials to be charged into blast furnace. Especially the preparations of iron ores is effected for such a purpose. The preparation of ores consists of the screening of ores by crushing and sizing in mine sites (or iron works), the elimination of impurities at the same time, and the production of direct shipping ore of a proposed size for charging into blast furnace.

The low grade ores are treated by the beneficiation plant at mine site, and high grade lump ores or high grade fine concentrates are produced from low grade ores, and then, those products are supplied to the iron works.

For preparing low grade ores, a proper method of concentration suitable to the kind of ores is adopted to produce high grade concentrates. The produced fine concentrates are sent to iron works in Japan as raw materials for sintering and charged into blast furnace after converted into sintered ores.

Recently, as to fine concentrates, a project is planned to produce pellets and nodules of a proposed size for charging into blast furnace by the agglomeration at mine site and supply to the iron works.

This report chiefly describes in detail the "Standard Processing Methods of Beneficiation and Concentration".

II. SUPPLY AND DEMAND OF IRON ORE IN JAPAN

Prior to my lecture on the preparation of iron ore, I should like to briefly explain how the steel industry in Japan uses the iron ores purchased from various countries in the world.

Table 1 shows the progress of the utilisation of iron ores by country during three years from 1959 to 1961.

As you are well aware, the supplying capacity of iron ore resources in Japan is too poor to satisfy the steel production capacity. The domestic iron resources accounted for 36% of all the iron materials consumed in blast furnaces and for making sintered ores in 1959, and this percentage lowered down to 29% in 1961. Table 2 shows such fluctuations in our iron ore utilisation.

The fact that the sintered ore plays an important role in the blast furnace operation will also be touched on in later chapter, and I believe that Table 3 serves the purpose of understanding the actual situation of the imported ores.

The sizes of the imported ores have carefully been examined keeping pace with the rationalisation of the blast furnace operation and the progress in techniques. As a result of such examinations, it has come to be one of the recent trends that even those ores of a size having been allowed ten years ago are crushed again at present to a desirable size to charge ores with an even size into the blast furnace, and this largely contributes to improve the operational efficiency of the furnace. It is becoming a matter of primary concern in Japan which of the combination of thus excellently sized iron ore and the sintered ore or that of the former and the pellet is economically more favourable for the blast furnace operation.

1. Consumption during the Past Three Years in Japan

(1) Results of importation by country.

Table 1 Imported Iron Ores by Country

Unit : 1,000 Tons

Year	Malaya	Philip-pines	India	Goa	USA	Canada	South-America	Others	Total
1959	3,750	1,295	1,877	1,404	539	677	329	518	10,389
1960	5,354	1,202	2,442	1,997	825	1,084	1,271	686	14,861
1961	6,650	1,229	1,699	3,153	946	1,115	4,989	1,118	20,899

(2) <u>Comparison of consumption ratio between imported and domestic ores</u>

Table 2 Comparison of Consumption Ratio

Unit : 1,000 Tons

	Year	1959	1960	1961
Imported ore (A)		10,300	13,357	18,644
Dependency (A)/(C)		64%	67%	71%
Domestic iron resources	Iron ore	1,141	1,161	1,134
	Iron-sand	1,419	1,570	1,786
	Pyrite cinder	1,300	1,447	2,022
	Miscellaneous*	1,858	2,301	2,668
	Total (B)	5,718	6,479	7,610
Dependency (B)/(C)		36%	33%	29%
Total (C)		16,018	19,836	26,254

Notes : (1) Data from "Statistical Survey of Iron and Steel in Japan" of Japan Iron and Steel Federation.

(2) *Miscellaneous materials include mill scale, open-hearth furnace skaull, soaking pit scale, blast furnace flue dust and converter flue dust.

(3) Utilization of imported fine ore and sintered ore

Table 3 Utilization of Imported Fine Ore and Sintered Ore

Unit: M/T

Year		1959	1960	1961
Sintered ore production		6,253,920	7,673,546	12,363,898
Import	Fine ore	3,123,090	4,007,867	8,017,281
Domestic production	Iron ore	904,363	921,190	940,254
	Iron-sand	721,231	853,633	941,982
	Pyrite cinder	1,295,686	1,444,774	2,020,659
	Misc.	766,865	993,813	1,206,529
Total consumption		6,811,735	8,221,277	13,126,705

Note: Data from "Statistical Survey of Iron and Steel in Japan" and "Data for Reference of the Steel Industry" of Japan Iron and Steel Federation.

2. Utilization of Domestic Iron Resources

(1) Situation and utilization of iron sand in Japan

i) Distribution of iron sand beds in Japan

The iron sand beds exist most abundantly in Tohoku District (northern part of Japan), and so-called beach type iron sand in the diluvium occupy the majority of these beds from the geological point of view, and the seashore iron sand holds the second place; the total volume of these two types of iron sand accounts for about 90% of the total iron sand reserves.

The production has increased with the increase in demand. It exceeds that of domestic iron ore resources in recent years. Most of the consumption is for sintering (for blast furnace) and for making electric iron; especially the importance of the iron sand in producing sintered ore is only becoming larger.

Reserves of Iron Sand by District

Unit: 1,000 Tons

District	Hokkaido	Tohoku	Kanto	Chugoku	Kyushu	Others	Total
Volume of shipping ore	5,3[illegible]0	38,990	5,990	1,050	6,450	190	58,010
Percentage to total reserves	[illegible]	67%	10%	2%	11%	-	100%

ii) Utilization

Progress of Production and Consumption

Unit : M/T

Year	Production	Consumption			
		Sintering	Electric iron	Others	Total
1959	1,441,000	721,231	638,601	59,083	1,418,915
1960	1,584,000	853,633	635,904	80,660	1,570,197
1961	1,712,172	941,982	703,446	140,319	1,785,747

iii) Exploitation

For the purpose of stoping iron sand, there are following four cases, depending upon the deposited conditions: namely, the seashore iron sand, the bench iron sand, the mountain iron sand and the sea-bed iron sand.

The seashore iron sand was caused by the accumulation after the alluvial epoch. It consists of loose sand strata, and this difference from the bench or mountain iron sand caused by the accumulation before the diluvial epoch largely affects the actual operations.

The seashore iron sand beds now in operation have the stratum thickness of about 1.5 m - 10 m, the iron content in crude sand of 5% - 18% Fe (the recovery percentage by magnetic separation of 5% - 15%), almost without capping (overburden), and the beds generally occur in approximately horizontal strata.

The stoping of the sea-bed iron sand has recently been conducted partially on commercial basis. The method of stoping is to pump up and magnetically separate the crude sand on a shallow sea-bed of about 5 m - 10 m deep; but there are still needs for further studies on the disposal of waste sand, the limit of allowable depth of operation, etc. The stoping method by means of the dredger involves the stoping of crude sand by pump and by bucket. It is necessary to chose a proper method after careful examinations on the treatment capacity, the cost of facilities, the operation cost, etc., since the above two methods have respective advantageous and disadvantageous features.

iv) Measures to Improve Grade and an Example thereof

The principal minerals in the iron sand are magnetite, ilmenite, ulvöspinel, rutile and the magnetite occupies the most part. Therefore, measures to improve the grade of iron sand are now taken only by means of the magnetic separation. There exist also the gravity concentration, the reducing roasting, which both are adopted only for the special purpose in limited fields of the industry.

Chemical Analysis of Iron Sand Concentrate

Kind \ Chemical composition	Fe	SiO_2	Al_2O_3	P	TiO_2
A	5[illegible].73%	2.36%	2.69%	0.009%	10.92%
B	53.40	4.[illegible]0	2.95	0.133	7.54
C	56.77	[illegible].50	2.9[illegible]	0.170	10.44

Screen Analysis of Iron Sand Concentrate

Kind \ Mesh	+ 30	30-48	48-65	65-100	100-150	150-200	-200	Total
A	6.3%			25.9%	58.2%	6.1%	3.0%	100%
B	20%	71%	6%	3%	0			100
C	2%		48%		28%	21%	1%	100

Note: (1) The grade of crude iron sand is also indicated usually by the recovery percentage (yield) of iron sand concentrate by magnetic separation which represents the content ratio of high magnetic minerals. This percentage does not always agree with the iron contents by chemical analysis, and there are relatively large differences in most cases.

(2) The economically minimum recovery percentage (yield) of crude sand is 5% - 7% (the yield of iron sand concentrate) in case of the wet magnetic separation.

The grade of crude sand dealt with in actual operations is at the yield of 7% - 15% for seashore iron sand, and 20% - 30% for bench iron sand, and the grade of iron sand concentrate by magnetic separation is about 55% - 60% Fe.

(2) <u>Development and utilization of limonite deposits</u>

The iron ore resources in Japan are by far too poor for the ironmaking ability in the country, but limonite deposits have been explored and developed for the purpose of fully utilizing domestic resources. The limonite deposits are classified as follows from the view point of their origins :

1) Chemical precipitation deposit (limonite beds),
2) Residual deposit,
3) Cave filling deposit.

Among these three types, only the first one is worth bringing into operation.

Some of the typical mines developed in Japan are enumerated below :

A. Gunma Mine

The deposit is situated in the skirts of Mount Shirane with the length of 2,200 m, the width of 200 m and the depth of 2 - 25 m. Acidic sulfuric chalybeate springs well up here and there on the upper part of the deposit, of which the temperature is around 20°C. Ore beds are caused by the precipitation of iron hydroxide at a lower acidity.

Excavation is made according to the open-pit mining method. Since 1944, 2.5 million tons of limonite and 160 thousand tons of sintered ore (described separately - nodulising -) have been produced.

Examples of the analysis of the limonite are as follows:

Year	Fe	SiO_2	S	P
1958	48.83%	4.51%	2.48%	0.735%
1959	46.92	4.52	2.[illegible]	0.910
1960	47.44	5.08	2.73	1.042
1961	46.29	3.97	3.23	1.055

B. Suwa Mine

The geology of the area consists of volcanic lavas of the Cainozoic era, agglomerate and volcanic ashes. The limonite beds exist in the plateau of 1,100 - 1,700 m above the sea level, and it is covered by volcanic ashes.

This is a chemical precipitation of chalybeate-mineral spring, containing ferruginous alunite and hydrophosphorous minerals. The depth of the ore beds is 15 m in maximum and 10 m in average. The production has reached 1.25 million tons since 1937. The ore from this mine had been very widely utilized since 1937 when the Thomas process was adopted in Japan (by Nippon Kokan Corporation), but the production has decreased with the suspension of the said process in 1957.

Examples of the analysis of the ore are as follows :

Description	Year	Fe	S	P	SiO_2	F.w.
High phosphorous ore	1952	45.34%	2.24%	2.447%	- %	20.58%
	1953	45.08	2.54	1.922	-	22.17
	1954	44.59	2.37	1.920	-	21.33
	1955	44.85	1.66	2.118	6.61	24.78
Ordinary ore	1956	47.02	0.60	0.684	10.41	22.34
	1957	46.70	0.50	0.700	11.20	21.20
	1958	49.00	0.20	0.500	10.00	25.00

(3) Utilisation of pyrite cinder

The pyrite is one of the most abundant mineral resources in Japan. The crude ore of pyrite is purified to the pyrite concentrate after crushing, grinding and flotation, and then, is treated in the sulfurising roaster as raw-material of sulfuric acid. The residues (pyrite cinder) from such treatments are actively utilised as an effective iron source of sintered ore for ironmaking.

The size of the pyrite concentrate to be charged into the fluid-solid roaster widely utilised at present is 60 - 70% with minus (-)200 mesh. An example of the chemical analysis is as follows :

Analysis of Pyrite Cinder

Description	Fe	SiO_2	Al_2O_3	S	P	Cu	Zn
A	60.60%	7.31%	1.12%	1.654%	0.021%	0.188%	0.41%
B	60.75	6.79	1.00	1.048	0.016	0.222	0.71
C	60.80	7.18	2.07	0.484	0.023	0.232	0.10
D	61.70	6.30	0.63	0.999	0.013	0.142	0.40

In the case of a high content of copper, the pyrite cinder is usually used after decoppering. Examples of the chemical analysis are as follows :

Analysis of Ordinary Pyrite Cinder
and Decoppered Pyrite Cinder

Ordinary pyrite cinder			Decoppered pyrite cinder		
Fe	Cu	S	Fe	Cu	S
57.43%	0.48%	2.14%	57.33%	0.26%	1.87%
58.66	0.48	2.15	58.85	0.21	1.38
57.86	0.48	2.19	58.93	0.20	1.97
56.92	0.52	2.01	57.80	0.21	1.90
56.65	0.46	1.94	58.64	0.20	1.65

Remarks : Decoppering percentage : 60 – 70%
Grade of recovered copper : 65 – 70% Cu
Copper recovering percentage : 98%

3. Sizes of Raw Materials Charged into Blast Furnace and Other Steelmaking Furnaces

The sizes of raw materials to be charged into blast furnace and open-hearth furnace are now being standardised as shown in the following table, and especially it is generally recognised that a size 10 – 35 mm gives remarkable effects in the blast furnace operation.

	Blast furnace	Open-hearth furnace	Converter
Iron ore	5 – 50 mm	5 – 100 mm	10 – 30 mm
Limestone	30 – 60 mm	85 – 160 mm	15 – 25 mm

4. Blending of Fine Ore

Since so many kinds of ore are imported to Japan, it is necessary to homogenise the nature and the size of ores to realise a stabilised operation of blast furnace. For this purpose, a large quantity of ores are accumulated in a vast storage yard by size or by description, forming the stock-piles of rectangular or semicircular shape. To make such stock-piles is called the bedding.

The bedding is made with sized ores for direct charging into blast furnace and fine ores for sintering as its objects, and then, ores are taken out from these piles by means of a reclaimer for the purpose of blending them, usually at right angle direction to the long axis of stockpile, and its effect is especially remarkable for fine ores.

The blending operation in Oogishima Raw Material Centre for Nippon Kokan Corporation is presented below.

In Oogishima Raw Material Centre, both screened fine ores from the crushing plants and purchased fine ores are sent to the ore bedding plant. Here special care is being taken in order to minimise variation in chemical composition among stock-piles.

The results show that chemical composition of blended fine ores stay within the range of $\pm$ 0.4% Fe, $\pm$ 0.3% SiO_2, and $\pm$ 0.6% Al_2O_3 to the target values (average 61% Fe).

III. CRUSHING, SIZING, WASHING AND CLASSIFICATION

As the primary process of the standard treating method of the beneficiation of iron ore, the crushing and the sizing are performed, and then the classification is made as to the fine ore.

Furthermore, the most suitable method is adopted among the gravity concentration, the heavy media separation, the magnetic separation and the flotation according to the kind of ore to be prepared as necessity arises to produce the lump ore (direct shipping ore) and the fine-concentrate (high grade fine ore).

1. Crushing

(1) Purpose of crushing

The crushing is made for the purpose of making crushed ores of usable size or of making the ore of proposed size in case the ore size is too large to offer for commercial use with the difficulties in practice, and also it is made for the separation of useful minerals and gangue (liberation) in order to extract useful minerals from mined crude ores.

(2) Crushability

Forces acting when crushing a substance are classified into the pressure, the shock and the abrasion (or shearing). In coarse crushing, it is effective to utilize the pressure, while the abrasion can be successfully utilized for fine crushing or grinding. Though the crushability varies with the kind of rock and ore, the ore is liable to be crushed more easily than the rock or the gangue. The relative difficulty of the crushability can be also known from the characteristic values such as compression, impact and abrasion degrees: the crushability decreases according as these values become high. An example of the compression degree is shown in following Table.

Example of Compression Degree

Kind of material	Compression degree (kg/cm^2)
Basalt	2,500 - 5,000
Granite	1,200 - 3,500
Limestone	1,000 - 1,500
Sandstone	600 - 1,000
Hematite	250 - 1,000
Galena	150 - 200

(3) Methods of crushing and grinding

The size of crude ore may sometimes attain to 300mm or more. In a crushing plant, ores are subjected usually to two to four stages of crushing from the coarse crushing through the fine crushing to obtain a required size, for example 5 - 25 mm (1/5 - 1"). Generally speaking, a larger dressing plant has so much more stages of crushing, and a plant of a minor scale has only one or two stages in most cases in view of the saving of the first cost of facilities and the simplification of operation control. In the latter case, however, the manual crushing is usually made by large hand-hammer prior to the mechanical crushing as the auxiliary operation.

An example of the crusher used in each stage stated above, which is properly selected according to the tonnage of feed ore, the proposed size for crushing, etc. is as follows:

(a) In case the final size of crushed ore is to be around 12mm (½"):

1st stage	Blake type
2nd stage	Gyratory type
3rd stage	Cone or Fine Gyratory type

(b) In case the final size of crushed ore is to be around 6mm (1/4"):

1st stage	Blake or Gyratory type
2nd stage	Symons Cone or Fine Gyratory type
3rd stage	Roll Crusher or Symon Short Head type

The crushing ratio (extent of crushing) is 1 : 2 - 1 : 6 in above described cases.

When a fine grinding is required, for instance, when it is required to obtain a feed of magnetic separation or flotation, it is necessary to grind ores down to 48 - 200 mesh. In this process, such wet grinding machines as the conical ball mill, the rod mill, the Marcy mill are usually utilized. Since the grinding action of these grinding machines chiefly depends on the abrasion as explained above, it is desirable that the size of feed ore is less than 25mm (1") or even about 5mm (1/5") if possible. The critical grinding size is determined by the considerations on the degree of liberation of mineral and gangue and the grinding cost; but because the grinding cost is considerably high, care should be taken not to make overgrinding.

2. Sizing

(1) Concept of sizing

The sizing includes the screening and the classification, of which the former is to classify, by means of a screen or a sieve, grains according to the proposed sizes when treating with relatively coarse sizes, while the latter is to attain the purpose of classification through the utilization of the difference in the settling velocity of particles in the water or in the air when dealing with fine size which cannot be obtained with the screening. Even for the particles of the same size, therefore, the cases may occur where the ones are treated as the float products and the others as the sink products, according to the difference in the specific gravity if any. The limit of the size in an actual operation is 1 - 2mm($^1/25$") in general.

When discussing the size of ore grains, no difficulty will occur if the shape is spheroidal or orthohexagonal. In practice, however, the shape is not uniform at all. Those crushed by pressure are generally liable to be of long plate shape. For example, the proportion length : width : thickness may be 3 : 1.5 : 1, but this proportion becomes usually smaller according as the size becomes fine.

It should therefore be noted that, in screening, the size and the produced volume of undersize products vary with whether the shape of screen holes are rectangular or square or round. This is also the case with the classification.

(2) Purpose of sizing

In order to obtain the size proper for commercial ore and to improve efficiency in every stage of concentration, the sizing plays the following important roles. In each stage of the crushing, those ores already crushed to the proposed size are immediately removed as undersize through the screening to increase the crushing capacity of the crusher, and in the grinding, the classification enables to prevent from overgrinding and improves not only the grinding efficiency, but also the magnetic separation or flotation efficiency.

(3) Method of sizing

The screen is broadly divided into the following two kinds: the fixed and the moving screens.

The fixed screen, called the grizzly, is used for treating large sizes. This type is chiefly installed with a gradient of 30 - 60 degrees before the first crushing stage for its superiorities in solidity and treatment capacity rather than the accuracy of screening size. The maximum size of undersize in screening is about 70 - 90% of the screen aperture, and the treatment capacity is determined by width and aperture of the screen, of which the standard treatment capacity is 125MT/24Hr per 30cm^2 in aperture 25mm (per 1 ft^2 in aperture 1").

The type trommel which is used for relatively coarse grains among other types of the moving screen has an advantage that it can be used both for dry and wet operations, but its major defect is that the effective area in screening is small. The diameter is the most important factor determining the treatment capacity. The capacity is 0.5 - 0.9MT/24Hr per 30cm^2 in aperture 1mm(per 1 ft^2 in aperture $^1/_{25}$") in case of 1.8m (6 ft) diameter and about 3m (10 ft) long. A shaking screen or a vibrating screen is used for screening relatively fine grains within 50 - 60mm (2" - 2$^1/_4$). These types of screen are effective in relation to the floor space, the screening capacity and the accuracy, while they are behind the trommel with regard to the treatment of the wetted ores, especially the ores containing clay. A shaking screen has a length of 1.5 - 6m (5 - 20 ft). A sieve having a dimensional proportion of length : width = 2.7 : 1 has the capacity of 8 - 15MT/Hr per 1m^2 (9 ft^2) and the oscillation number of 80 - 300 R.P.M. with the amplitude of 50 - 200mm (2 - 8"). It is necessary to increase the number of vibration in order to screen fine particles with a higher capacity. The vibrating screen has been devised for satisfying this requirement. Some of numerous types of this screen have such a high vibration as 1,000 - 3,500 R.P.M. with the amplitude of 1.5 - 25mm ($^1/_{16}$ - 1") by means of a special eccentric mechanism, cams and an electrical vibrator.

The Ty-rock screen is used for ordinary purpose, and for fine particles, we have the Low-Head screen and other types. All of these types are distinguished by a larger capacity and fewer choking up of the sieve.

3. Washing

The screening of sticky run of mine is made in the following order. It is at first subjected to a coarse crushing to a proposed size, i.e. usually less than 100mm (4"), and then screened while removing fine clay adhered to ores by water in a scrubber mill and carrying it to a vibrating screen or a trommel with water spraying.

The rate of water consumption in this case, varying with the quality of the ore and the conditions of the mixed fine clay, is as follows in general:

Feed crude ore (Hematite)		Water consumption (about 2kg/cm^2 of pressure water)
1 ton	:	2 tons

4. Classification

The classifier or the cyclone is adopted for classifying fine ores which cannot be easily screened by the vibrating or other screens. As the classifier, such mechanical classifiers as rake, bowl, spiral and drag and some types of cyclone are widely utilized, but other hydraulic classifiers and slime separator are used only in a limited scale.

The treatment capacity of a mechanical classifier closely relates with the size of particles in separation, and separating size of particles is affected by the pulp-density and the flow speed of pulp in the tank.

Most of the cyclone types have a diameter of 75mm - 350mm (3" - 14"), an inlet pressure of 1 - 5kg/cm^2 and a separation point of about 100 - 200 mesh. The control of the separation point and the density of underflow is made through the adjustment of the volume of feed ore, its flow speed and the numerical aperture of under-flow bottom opening.

General requirements of iron works in Japan to the mines in South-East Asia as to the size of ore are as follows:

	Size	N.B.
Lump ore	-100mm - + 6mm	-6mm with a mixing ratio below 20%
Fine ore	-6mm - +150 mesh	for sinter feed

IV. PREPARATION OF ORE

In order to explain the treatment of iron ores, I will try to give summary definitions of the gravity concentration, the magnetic separation and the heavy media separation, and also in view of the recent remarkable progress, the flotation will be touched on briefly together with an example of operation.

1. Gravity Concentration

The ore grains having different specific gravities do different movements when an outside force acts on them at the same time. It is therefore possible to separate two kinds of ore grains from each other.

Usually the hydraulic power and the pneumatic power are utilized as the outside force.

(1) Basis of falling movement of ore grains in water

(i) The free falling movement of ore grains is ruled by the three elements of gravity, buoyancy and resistivity.

(ii) In the actual operation of the gravity concentration, many ore grains are suspended closely to each other and sink down in affecting each other, that is, the movement is ruled by the theory of so-called hindered falling.

(2) Jig separation

The jig separation is to attain the purpose of separation by the differences in falling rate of the grains of different specific gravities and sizes, in the mixture of granular or find granular ores (minerals and gangues) in a current of water oscillating up and down.

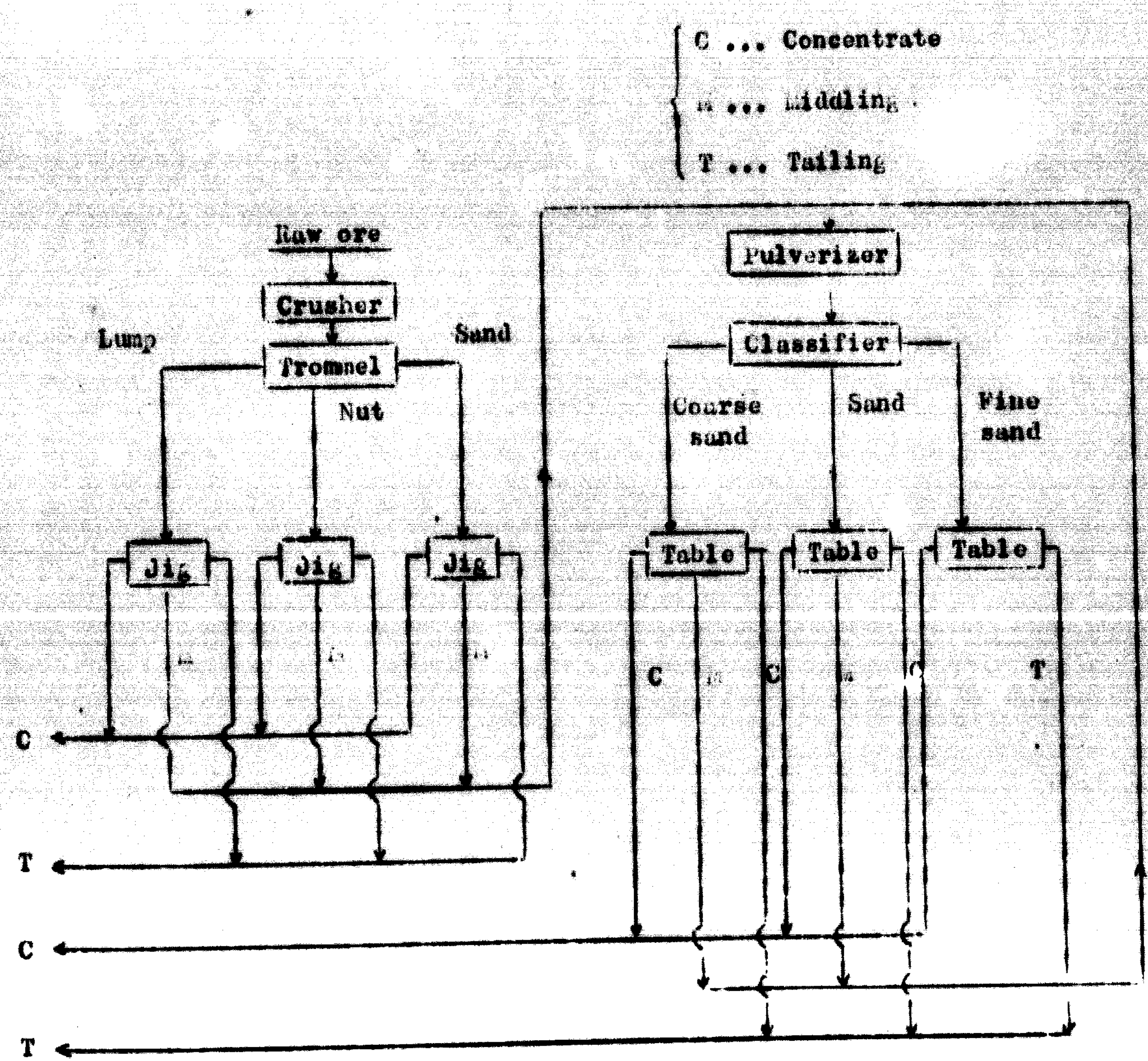
In this method, the mixed ore grains on the screen are subjected to the up and down movements by the repeated up and down current of water, and the ore grains of a larger specific gravity are settled down to the bottom layer of ores and concentrated, and thus the ore grains of a smaller specific gravity are separated and rejected.

(3) Shaking Table Separation

The shaking table has a mechanism horizontally shaking the table at approximately right angles to the direction of the flow of washing water on the plane inclined surface of a table. The ore grains of a smaller specific gravity are drained away with washing water to the direction of the slope of table, while those of a larger specific gravity move to the direction at right angles to the water flow by the inertia action of the horizontal shaking of the table, and thus the separation is effected between these two kinds of ore grains.

This method is adopted for separating oxidized ores which are not suitable to the flotation, as well as for utilizing it often as an auxiliary operation in the flow of flotation process.

(4) Example of gravity concentration



2. heavy media separation

The heavy media separation was adopted in 1948 for the first time in Japan, and by 1960, this method has been used in more than fifty mines (chiefly in coal, copper and pyrite mines).

The types of the machine used in the metal mines are Akins and Airlift-Cone types and mostly Wemco Drum type in the coal mines. The treatment capacity of a unit is about 20 - 100T/hr.

In many cases, the heavy media separation in metal mines is conducted as an preparatory operation (rough separation) of the flotation or the magnetic separation, while that in coal mines, for obtaining the final products.

The size of ore grains treated in the heavy media separation is usually limited to the range of 5mm - 60mm(1/5" - 2-2/5") at present. It is however expected that, in the future, the treating technique of fine particles will largely be developed by general adoption of the sink-float separating machine suitable to treat fine grains below 5mm (1/5") (Cyclone type or Humbolt type).

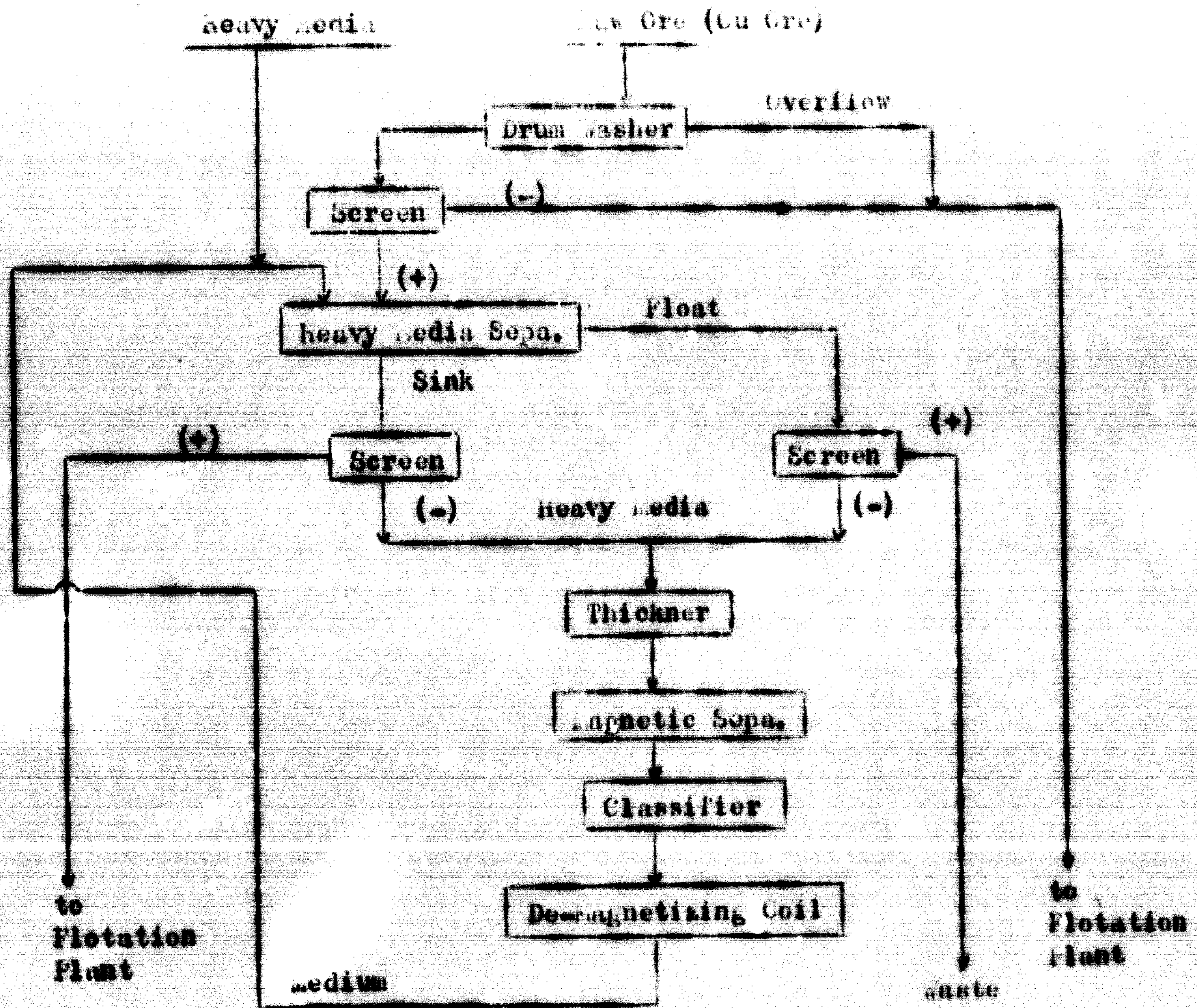
As the heavy medium, the ferro-silicon or the galena is used in case of relatively high specific gravity of the heavy media, and the pyrite or the magnetite is used in case of a lower specific gravity.

For treating those of low specific gravity as the coal, the pyrite cinder is mainly utilized.

In order to obtain satisfactory results in an operation of the heavy media separation, it is essential to keep the specific gravity of the heavy media always at the rated value, and for this purpose, the accurate control is usually made by means of the automatic gravity meter.

An example of the heavy media separation is shown below:

Flowsheet of Heavy Media Separation



3. Magnetic separation

The magnetic separation has been, for its convenience and efficiency, adopted since some hundred and fifty years. The importance of this process is increasing more and more in all the fields of the ore dressing method, not limited to the magnetic iron ore.

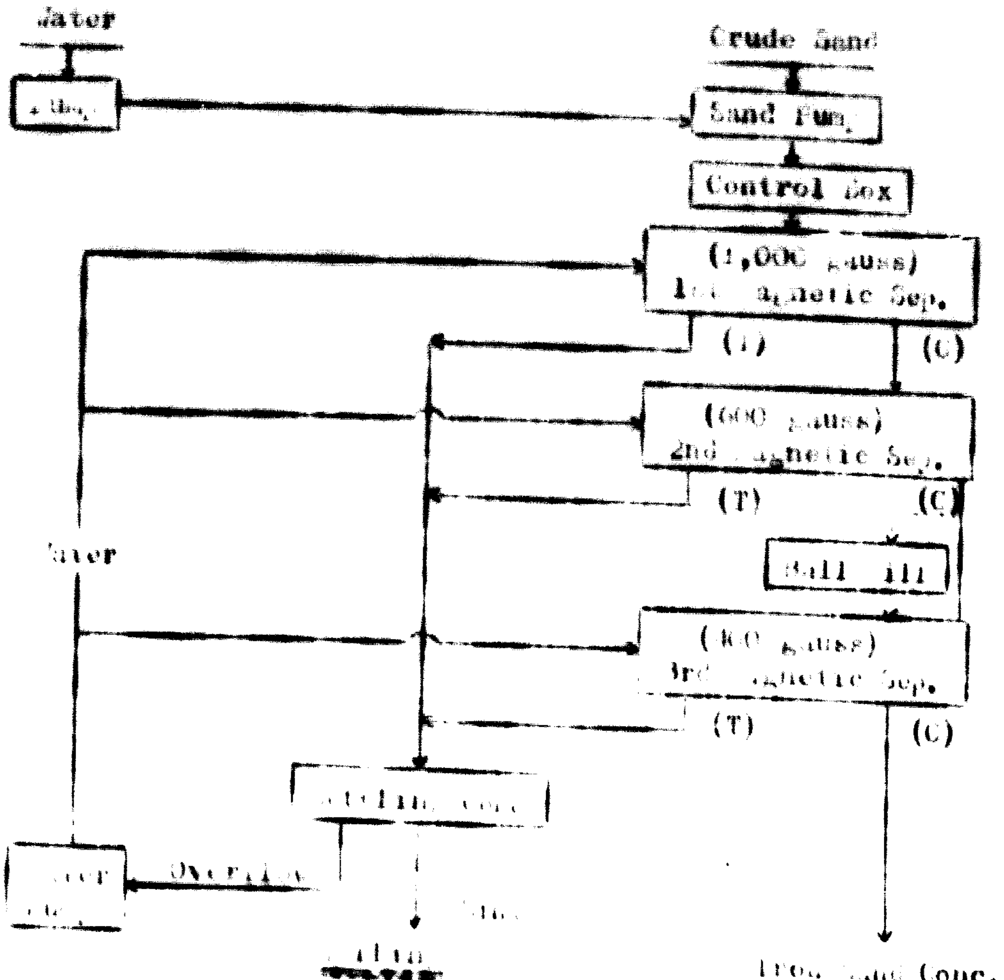
So far, the low intensity magnetic separators of about 500 - 2,000 gauss have been used for the purpose of separating high magnetic minerals such as the magnetite and the pyrrhotite (special kind of pyrrhotite). In recent years, high intensity magnetic separators of 10,000 - 25,000 gauss have been remarkably developed for treating low magnetic minerals such as garnet and wolframite, and are now put to practical use for separating specular hematite and limonite in some cases abroad. Thus, this type of separator is expanding its fields of utilization larger and larger toward various sects of the mining industry.

The most general use of the magnetic separator in Japan at present is to recover iron sand concentrate from crude sand. It is also actively utilized in various fields including the separation of magnetite and pyrrhotite, the recovery of medium in heavy media separation and the recovery of iron content of blast furnace slag or openhearth furnace slag in ironmaking.

Most of these magnetic separators are of wet type, and the treatment capacity of a unit is 40 - 50T/hr (crude sand). As to the used magnet, though some separators use electromagnetic type, in commonly used separator, the permanent magnet is widely utilized and this type of separator is expected to be developed further in the future.

An example of the flowsheet of the magnetic separation of iron sand is shown below:

Flowsheet of Magnetic Separation of Iron Sand



4. Flotation (an example of treatment of cupriferous magnetite)

It has been a subject of long study to obtain high grade concentrates through the treatment of iron ores by flotation, but this method is not so widely utilized for the economical reasons.

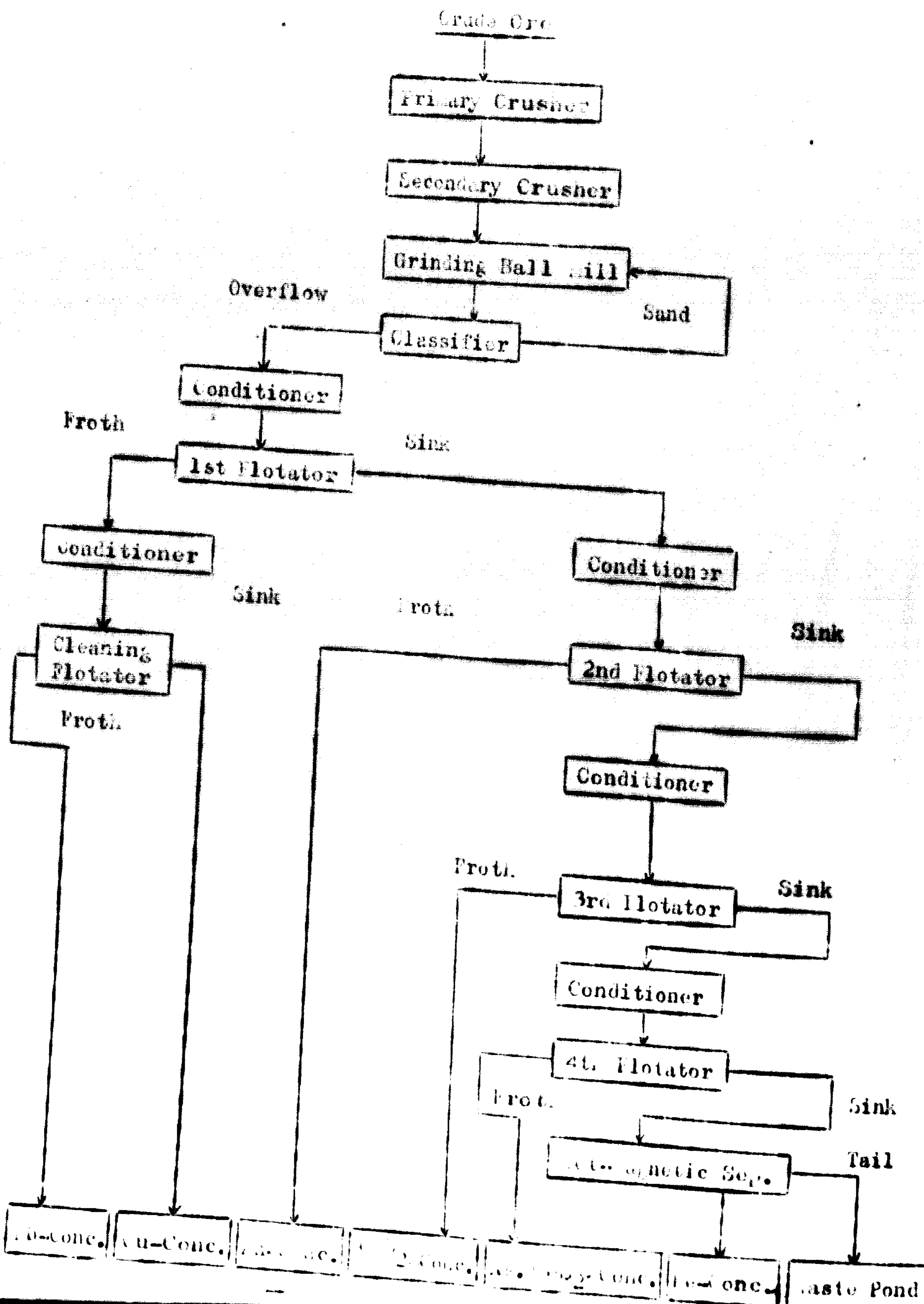
In order to put this method to practical use, it is necessary to make fundamental studies on the mineralogical composition of crude ore, the grade variation of valuable minerals and on the possibility to favourably effect the liberation of valuable minerals and gangue in producing concentrates. There are in Japan magnetite deposits involving such non-ferrous minerals as copper, lead, zinc due to the causes of ore deposits. As to the run of mine ore from such ore deposits, the differential flotation of copper, lead and zinc is first effected; the rough concentrates of copper and lead are recovered as the froth of the first flotation, and then, the rough concentrates are separated to copper concentrate and lead concentrate through the cleaning flotator. The sink-ores of the first flotation are feeded to the second flotation cell, and the zinc concentrate is recovered as froth in the process of the second flotation.

The pyrite concentrate is recovered as the froth in the third flotation from the sink-ores of the second flotation. In a mine in Japan, where the crude ore of pyrite contains arsenic, high arsenical pyrite concentrate is recovered from the sink-ores of the third flotation in the course of the fourth flotation.

The sink-ores of the fourth flotation are feeded to the wet type magnetic separator, where the magnetite concentrate is recovered, and thus the purpose of the differential flotation and the magnetic separation is attained.

An example of the flowsheet of the differential flotation for sulphide minerals bearing magnetite is as follows:

Flowsheet of Differential Flotation for
Sulphide Minerals (Cu, Pb, Zn, Fe)
Bearing Magnetite



In Japan, the cases are rare where the flotation is made for a single purpose of obtaining iron concentrate. The magnetite is recovered as by-product of the recovery of valuable non-ferrous minerals. This form of production has so far been adopted as the auxiliary means for producing additional ironmaking raw materials. However, with the remarkable progress in this field, such a method will be adopted for treating new resources; and if the advantages of such a method is recognized from the view point of the payability of the enterprise, it will greatly contribute to the full utilization of undeveloped iron resources.

V. [illegible]

I have described the preparing methods of ores as above, and now, I should like to explain how these methods are applied to the actual operations, showing flowsheets of the typical mines in Japan and South-east Asia.

Country \ Kind of ore	Magnetite	Hematite	Limonite
Japan	Kamaishi (1)		
"	Chichibu (3)		
"			Gunma (2)
Malaya			Temangan (5)
"		Dungun (6)	
Philippines	Larap (4)		

Annual Production (1962)

Unit : Dry T/T

Mine	Iron Ore			Non-ferrous mineral	Working method	
	Lump	Fine	Total		Open-pit	Under-ground
Kamaishi	199,708	289,236	488,944	24,070		o
Chichibu	34,420	45,790	80,210	46,179		o
Gunma	13,827	43,634	57,461	-	o	
Dungun	1,995,538	864,214	2,859,752	-	o	
Temangan	476,758	29,034	505,792	-	o	
Larap	-	968,535*	968,535	-	o	o

* in the year ended Sept. 30, 1962, wet volume

In the examples of Kamaishi and Chichibu Mines presented as the typical mines in Japan, the cupriferous magnetite is separated to the Cu-concentrate and the magnetite concentrate.

These of Gunma and Temangan, Malaya Mines show the simple crushing and screening process performed in the operation of limonite ore reserves.

In Dungun, Malaya and Larap, Philippines Mines, a special crushing and sizing process emphasizing the washing is adopted due to the special features of the produced ores however in the latter mine, the magnetic separation is also adopted at the same time.

VI. AGGLOMERATION

If an outside force acts on the ore to mechanically break it, and the ore is screened to a size we desire, then the fine ore is produced in consequence. Also in the pig and steel producing process in an iron works, the blast furnace flue dust is spontaneously produced from the blast furnace and the converter flue dust from the converter.

In mines, when the blasting is made for excavating ores, in case of digging mechanically and of loading or unloading ores to the wagon or truck for transportation, the volume of produced fine ores attains a considerable amount also caused by the increase in the volume of handling ores.

If these fine ores are processed to raw materials possible to be charged into blast furnace, the role played by such a process will surely be very important in the economic problem of the blast furnace operation.

1. Briquetting

For the above purpose, various processes have been devised and are effectively utilized. The most basic one among these processes is to add a proper volume of moisture and binders to the fine ore, to form through the pressure forming from outside, to increase compressive hardness through a proper drying or after formed, and thus to make ore briquette for charging into blast furnace. Such a method is usually called the briquetting. The optimum size of fine ore usable in this method is below 10 mm. The binders such as lime (slaked lime), bentonite, cement, green vitriol, pitch and other organic matters are added in a bit.

In order to increase the compressive hardness after forming, the hardening is made in a continuous baking oven or in a badge type baking oven, but a satisfactory effect cannot be expected.

2. Nodulising

In this process, the fine ores are continuously charged into the rotary kiln, and the pulverized coal, the gas or the liquid fuel is injected in counter-current to the charged ores from the lower end of the kiln as the fuel to constitute a sintering zone in the kiln. The charged raw materials are sintered to granular shape of about 10 - 30mm by the rotary motion of the kiln and then discharged.

This method was operated at Oshi plant in Gunma Mine of Kokan Mining Corporation (a subsidiary company of Nippon Kokan Corp.) in Japan, of which the process is explained.

<u>Nodulizing of fine ore</u> (at Oshi Plant in Gunma Mine)

This method is the nodulizing (patent No.225, 416 in Japan) by means of a rotary kiln, which is adopted in Gunma Iron Mine (operated under the management of a subsidiary company of Nippon Kokan Corporation).

The ore beds in Gunma Mine are caused by the limonite ore bed mined as the direct shipping ore. In addition to such ore beds, the Mine also comprises partially linonite ($2Fe_2O_3 \cdot 3H_2O$) beds and laminates of jarosite ($K_2O \cdot 3Fe_2O_3$), and these layers are called the low grade limonite for their low iron content.

Chemical Analysis of Low Grade Limonite

Fe	SiO_2	S	P	K_2O	C.W.	F.W.
38%	6%	7%	0.8%	4.5%	13%	15%

The outline of the application of this method is as follows: the above low grade ores are crushed to below 30mm and charged into the rotary kiln, then, by means of heavy oil, the sintered ore by nodulizing is produced through the processes of dehydration, desulfurization, sintering (temperature of 1250°C) and cooling.

The sintered ore by nodulizing is generally converted into the hematite, and granularised (size : 10 - 30mm) in the proximity of the discharge mouth of the rotary kiln, and put into the product storage tank after cooling.

Chemical Analysis of Sintered Ore by Nodulizing

T.Fe	FeO	SiO_2	S	P	K_2O	Size of Nodule
57%	10%	8%	0.2%	1.3%	5%	-30mm - +10mm

The mine is equipped with two rotary kilns (2.3m dia. x 38m), of which the results of operation are as follows:

Annual supply of low grade ores (1961)	71,600T/Year
Annual production of sintered ore by nodulizing (1961)	39,500T/Year
Product yield	55%

(capacity of rotary kiln) ..... 100T/day/unit in sintered products)

The construction cost of the plant and the cost of direct services (excluding the cost of charged low grade ores, the cost of depreciation, the assignation of expense of the head office) are:

Construction cost :	¥200,000,000 ($555,600)
Direct cost of production :	¥1,717/T ($4.77/T)

3. Sintering

It was in 1929 that the method to charge the prepared fine ores into blast furnace was started in an industrial scale in Japan. The A.I.B. machines were introduced to Yawata Iron Works and the Dwight-Loyd sintering machines to Kamaishi Iron Works, and in the next year the Greenawalt type machines have come into operation in Wanishi Iron Works.

This method has come into wide use in the country since that time, and the production of sintered ore in 1961 (including pellet) reached 13,370,000 tons.

In these days when the importance of the sintered ore and the pellet in the blast furnace operation becomes recognized more clearly than ever, the sintered ore, especially the self-fluxing sintered ore will be watched with keener interest in relation to the coke ratio.

(1) Nature of fine ore to be used for sintering

Screen Analysis of Fine Ore
(Feed Raw Material)

by Homer and Anthes

Aperture according to ASTM screen	For sintering feed	For pelletizing feed
3/8"	4.1%	- %
1/3	2.3	-
7 mesh	11.7	-
18	7.0	-
35	27.1	-
45	18.2	-
100	20.3	0.4
170	2.1	11.6
200	4.1	n.d.
230	3.1	11.3
-230	-	76.7

As shown in the above table, the upper limit of the size of fine ore is 10mm (⅜") and those in a condition of size distribution that the mixture of fine particle of minus 100 mesh is less than 10% are regarded proper as the sintering feed.

The size distribution of sintering feed fine ore in Japan is as shown on the attached graph.

It is reported that, in the sintering operation in Y Iron Works in the country, 1% decrease in fine particle content of minus(-)150 mesh resulted in 0.6T/hr increase in the sintered ore production, and 1 BTU increase in the permeability brought 0.21T/hr increase in the production.

(2) <u>Sintering feeds and method</u>

Principal raw materials supplied for producing sintered ore in Japan are the imported fine ore, the fine ore caused by the sizing for preparation, the pyrite cinder, the iron sand and the magnetic ore concentrate, and a certain quantity of the fine ores generated in the works are added.

As previously indicated, several percent of pulverized coke of below 3mm and fine limestone of below 3mm as flux are added to the raw material of below 10mm, and after sufficiently mixing and adding moisture of about 10%, this mixture is sintered at about 1,200°C.

Since the product thus manufactured has a high porosity and a good reducibility, the rate of utilization of the sintered ore is increasing year by year.

Progress of Rate of Sintered Ore
Utilization in Blast Furnace

Country \ Year	1958	1959	1960	1961
Japan	53.0%	49.0%	47.0%	55.8%
United States	38.5	43.8	53.0	58.0
U.S.S.R.	56.3	69.5	70.0	74.0
United Kingdom	34.3	43.0	46.3	48.0
West Germany	41.2	42.0	46.8	48.0
Italy	63.5	62.0	56.0	54.0

Among the impurites contained in the sintered feed, the existence of the arsenic (As) is especially significant, and it is generally known that the residual percentage of As is relatively high in case of the self-fluxing sintered ore containing CaO.

The principal raw materials of the sintered ore are the fine ores of magnetite and hematite, and in both self-fluxing and ordinary sintered ores, the magnetite bring exothermic reaction during the sintering operation is preferable to the hematite or limonite in view of the operational efficiency.

4. Relative Merits of Sintered Ore and Pellet

In proportion that the control of blast furnace operation is promoted and the rationalization becomes more exhaustive, comparative discussions of the sintered ore and the pellet will become more active.

Essentially, it is the common sense that the fine ores of a size suitable to the sintering are used for sintered ores and those of a size more fine than the above are used for pellet. Ores produced in a mine are, as a matter of course, charged into blast furnace in the form of pellet when those ores are improved to a proposed grade by the beneficiation processing after finely grinded as an operational condition.

It is virtually impossible to compare the economicality between the sintered ore and the pellet in an actual furnace, in view of the present operational conditions in the industry in Japan. In the United States and other countries, however, the results as shown in the following table have been obtained from their respective comparative operations.

Comparison of Self-fluxing Sintered Ore
and Pellet in Blast Furnace Operation

Name of works	Kind	Burden (%)	Tapped volume of pig (T/D)	Coke ratio C.R.	Remarks
Port Kembla	Self-fluxing sintered ore	90%	3,090	0.60	Size of sintered ore 10 - 40 mm
Fairness	"	90	2,800	0.50	Basicity: 1.6
Bethlehem	Pellet	100%	2,950	0.55	
Armco	"	100	2,800 - 2,900	0.62	

(Hearth dia. : 7.78m = 26ft in both cases)

In both cases where the self-fluxing sintered ore is sized and where the pellet is charged, the blast furnace operation shows good results. It is considered that there is no remarkable difference between the contributions in these cases to the operation efficiency.

VII. CONCLUSION

As previously mentioned, undeveloped ore deposits in a remote area, of which the ores have so far been regarded as not paying as an ironmaking raw materials because of the geographical situation, or other ore deposits which could not be the objects for development because of the low grade of crude ores in spite of the large quantities of deposits, are now becoming spotlighted as supply sources of ironmaking raw materials, with the development of the crushing, sizing and beneficiation. This means that a country having such ore deposits may very well be an iron producer by itself, only if the availability of metallurgical fuel at low cost is anticipated.

More excellently sized direct shipping ores of a high grade will be sent to the markets from the already developed mines now supplying ironmaking raw materials. The fine ore of high grade will be able to find hopeful markets for producing sintered ores or pellets depending on the size of fine ore.

The ores of low grade incidental to the production of high grade ores can be recovered as high grade concentrated ores of uniform quality from those ores, due to the progress made in the beneficiating process, and these products will also be sent to the iron works at commercial base price.

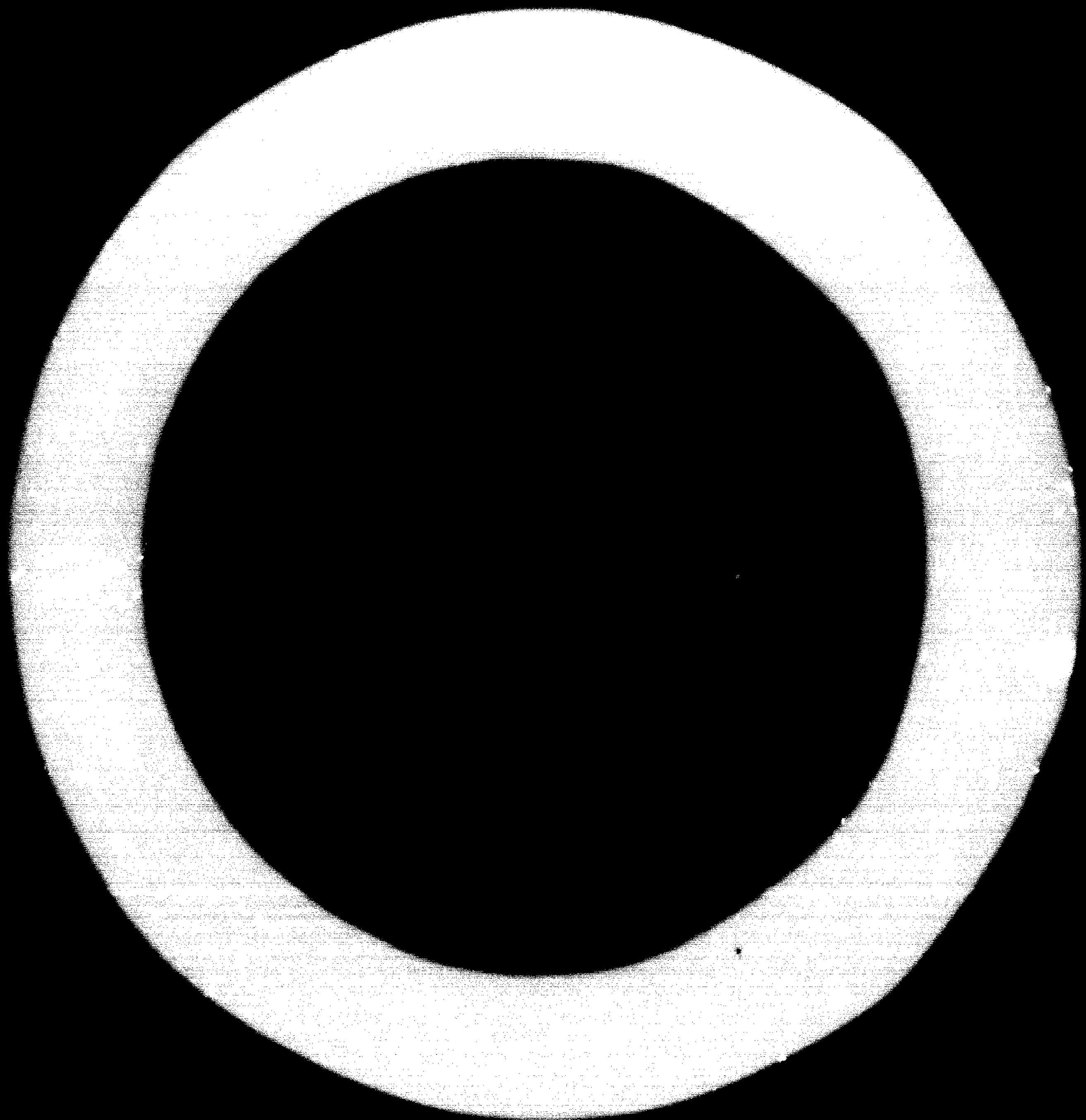
These facts mean the availability of the ore reserves of deposits by far larger than expected ore reserves to date on the mines, and the mines' life becomes longer than before, and this will enable to realise a more favourable payability in the enterprises. On the ironmaking side, the volume and the supplying period of shipping ores from a same mine in a same country can be expected to be extended and the stability of such a mine as a source of raw materials will be raised up.

The progress made in the beneficiating techniques, especially the magnetic separation enabled to develop deposits of low grade magnetic minerals, and the differential flotation enabled to separate copper minerals from magnetite in treating cupriferous iron ores, and thus rough separated magnetite can be recovered as a high grade magnetite concentrates through the magnetic separation.

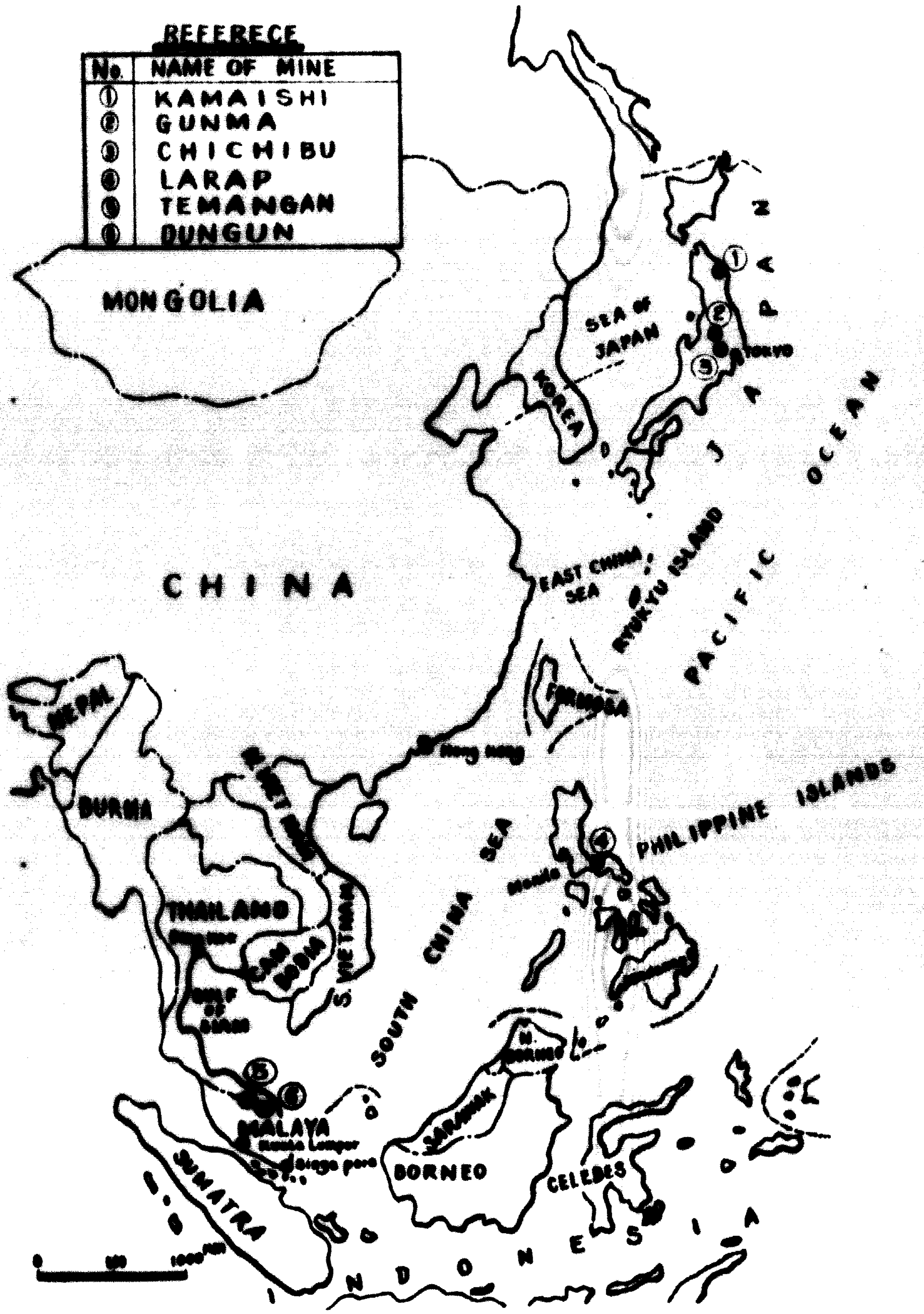
As a result of the adoption of pellet to be charged into blast furnace and the promotion of development of the direct reducing ironmaking process in recent years, it is expected that the demand for fine ores will steadily increase in the future.

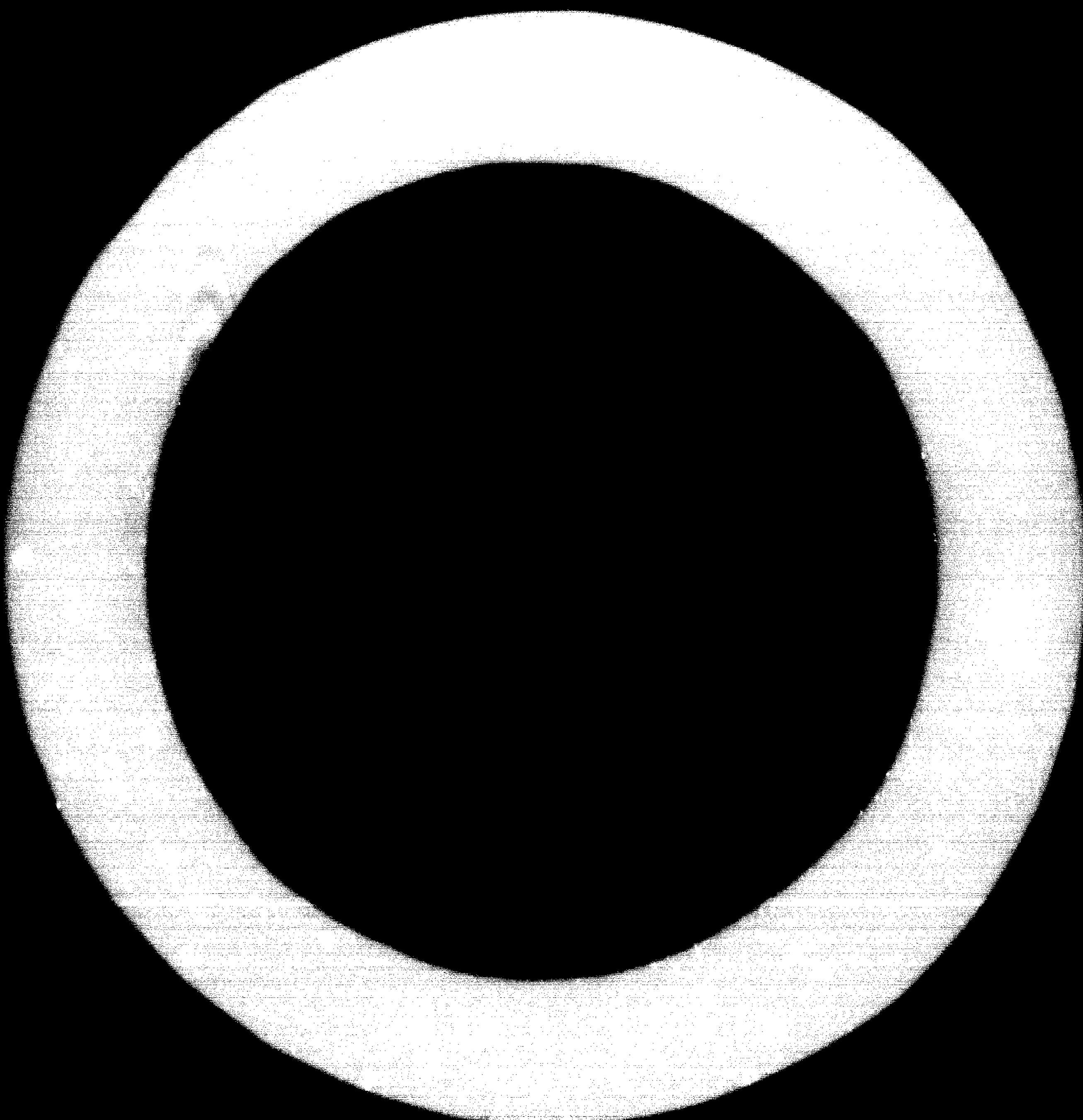
I believe that, if the heavy media separation, the magnetic separation and the flotation are properly combined, while taking the kind of iron ore, the scale of the ore deposit, the distance of transportation of products, the geographical conditions of the mine, etc. into consideration, not only low grade magnetite deposit, but non-magnetic low grade hematite and limonite deposits left unused for many years for the defavourable economicality have become possible to be developed, and concentrated ores from these deposits may be supplied to the iron works on the commerical basis.

FIGURES



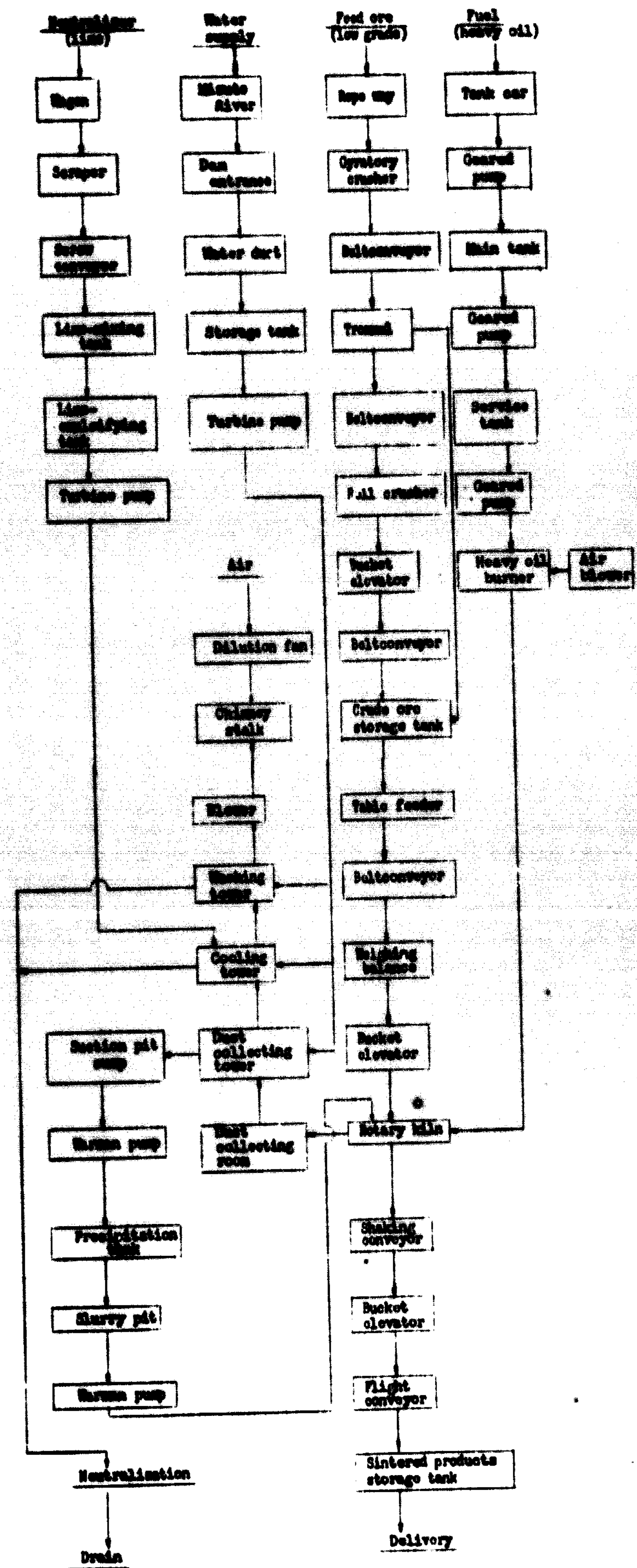
LOCATION MAP OF TYPICAL IRON MINES IN JAPAN AND SOUTH-EAST ASIA

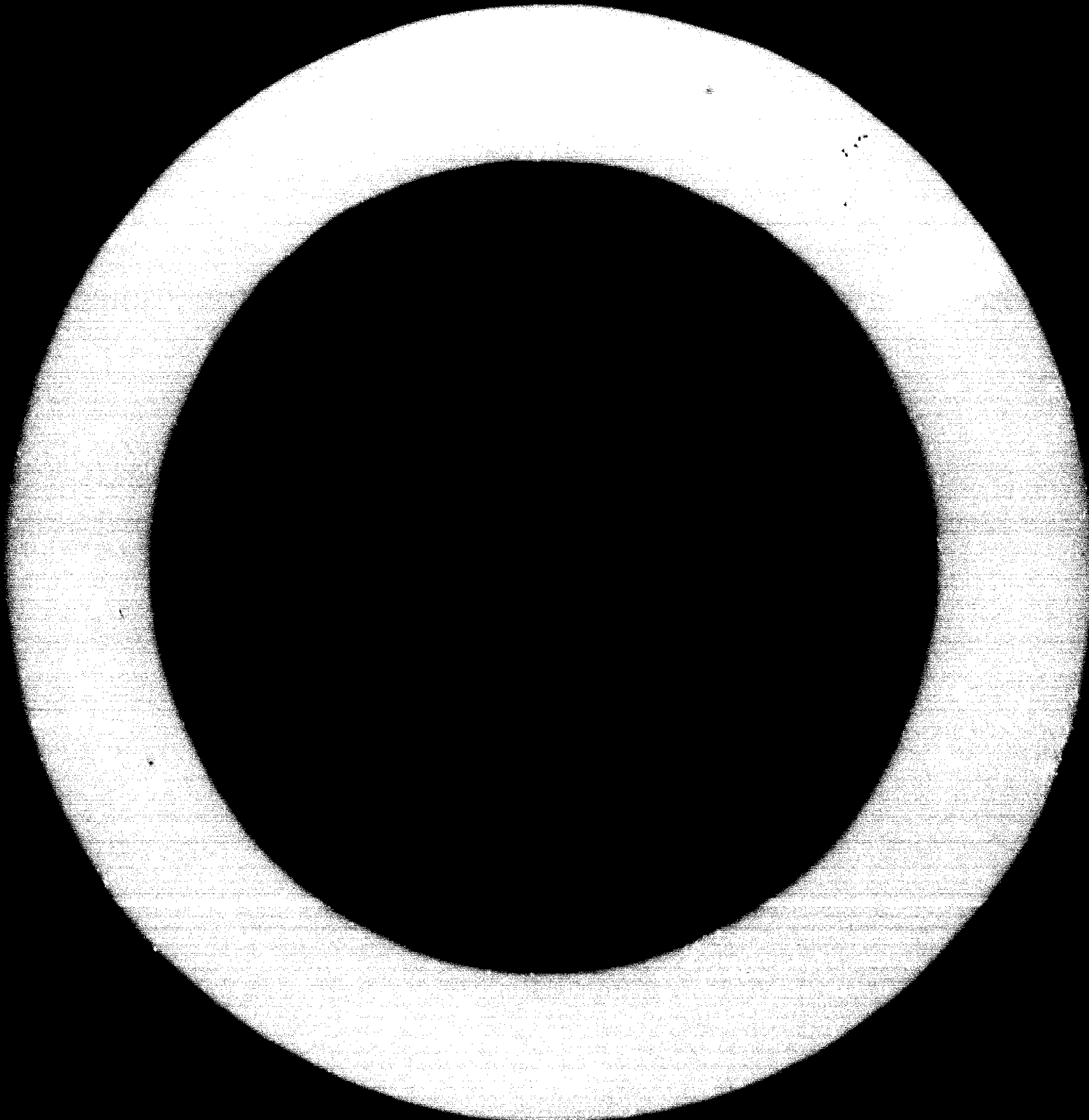




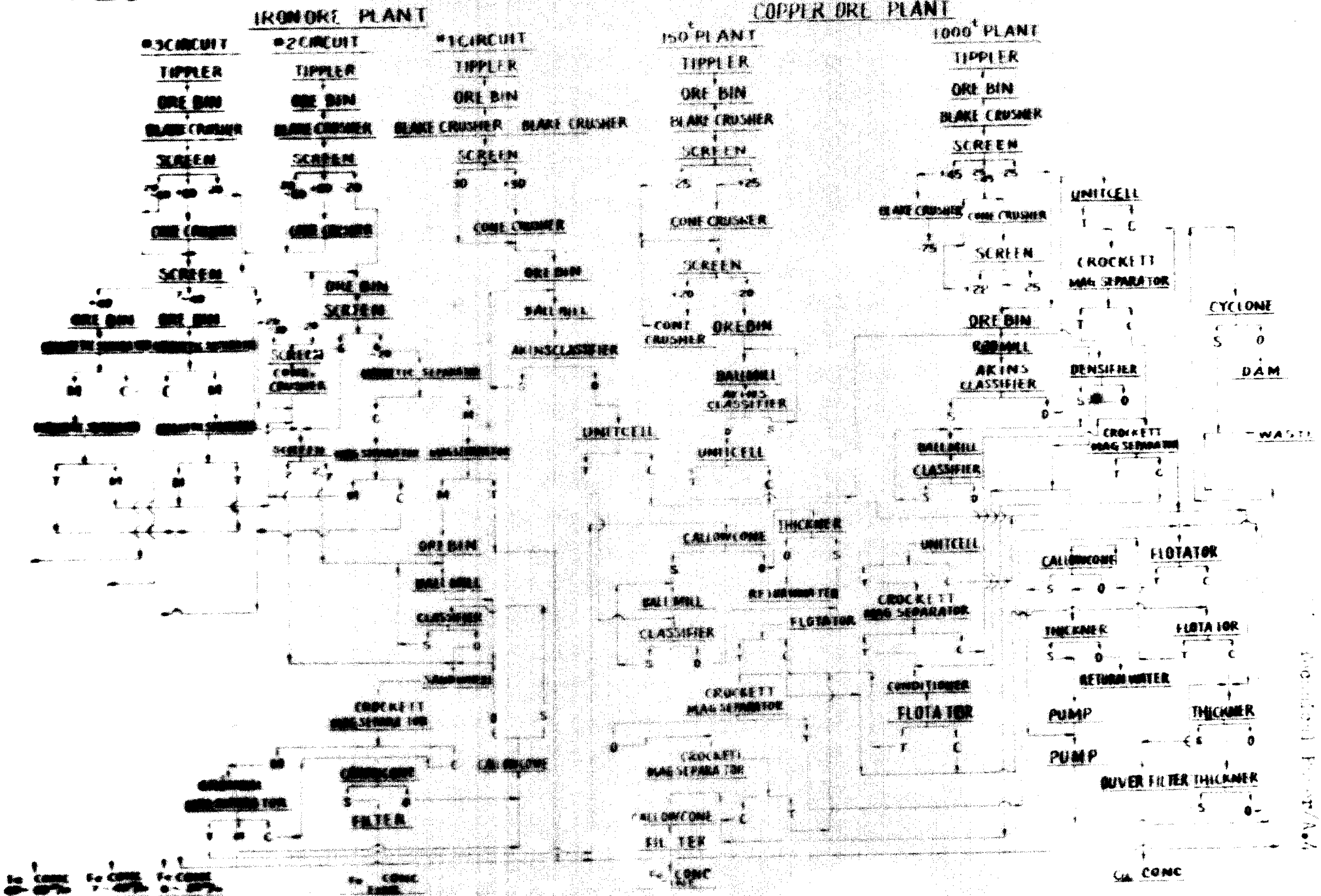
Flowsheet of Agglomeration Plant

Gunma Iron Mine



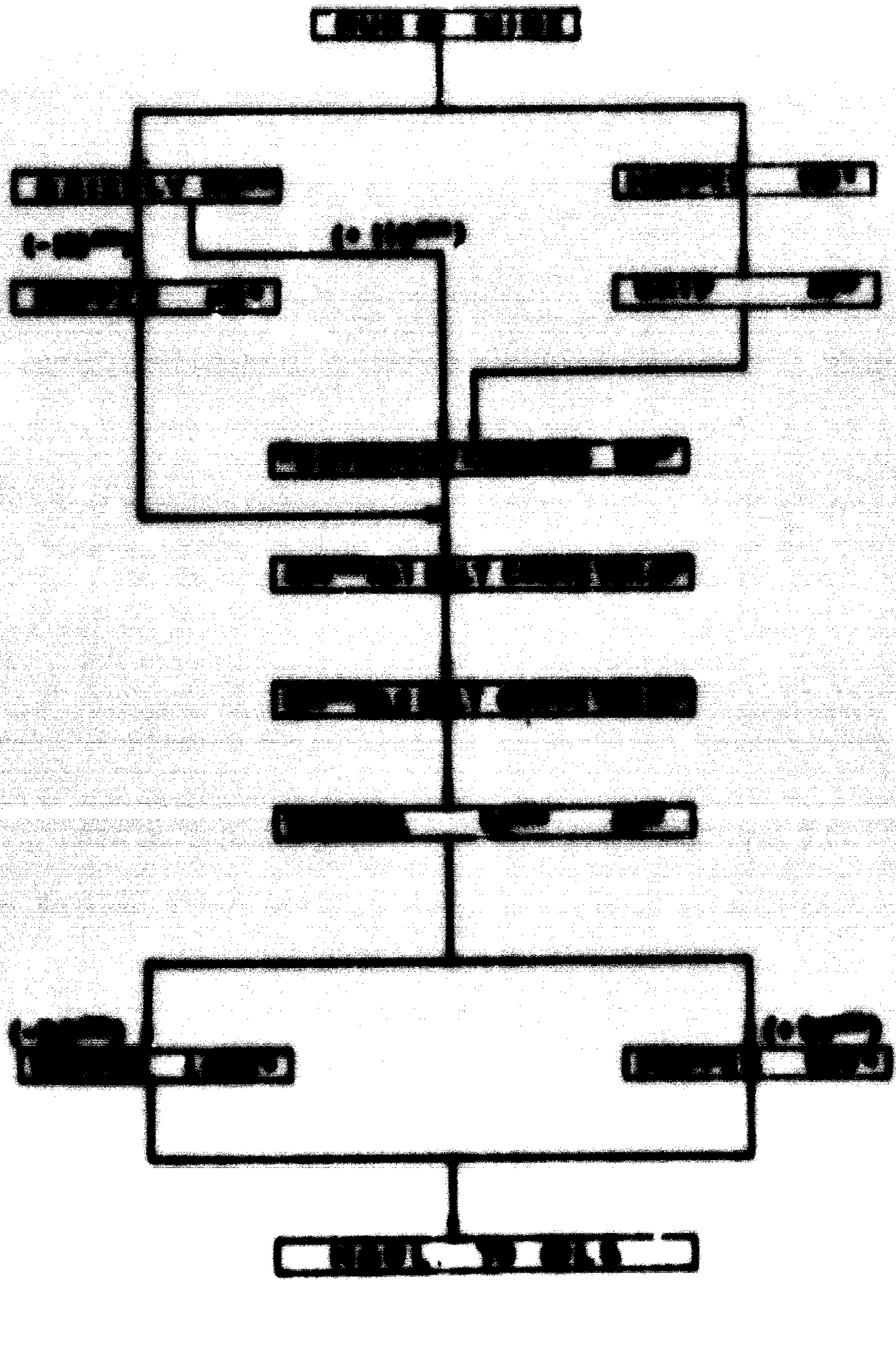


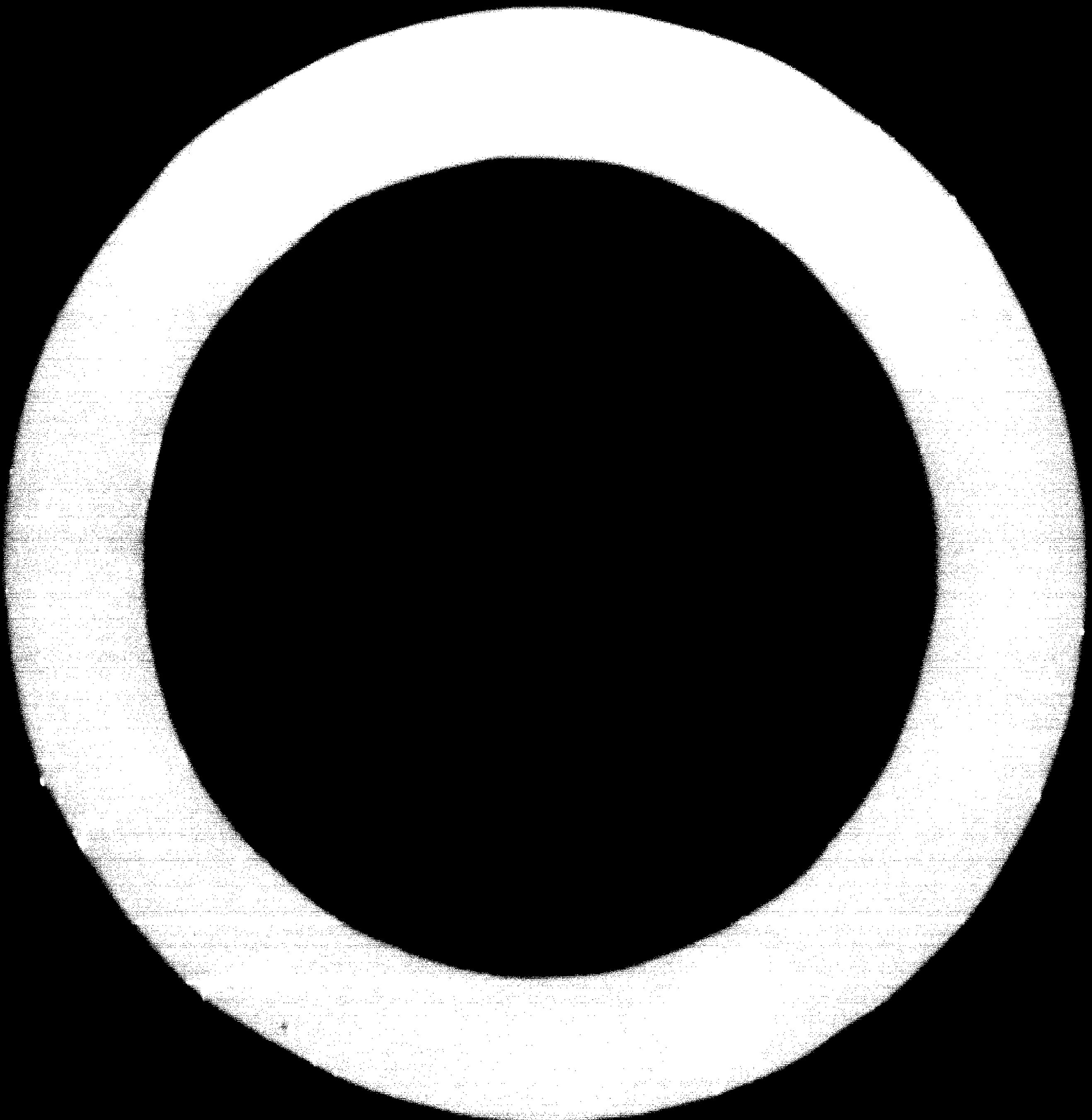
FLOW SHEET (1) KAMAISHI IRON MINES DRESSING PLANT



FLOW SHEET (2)

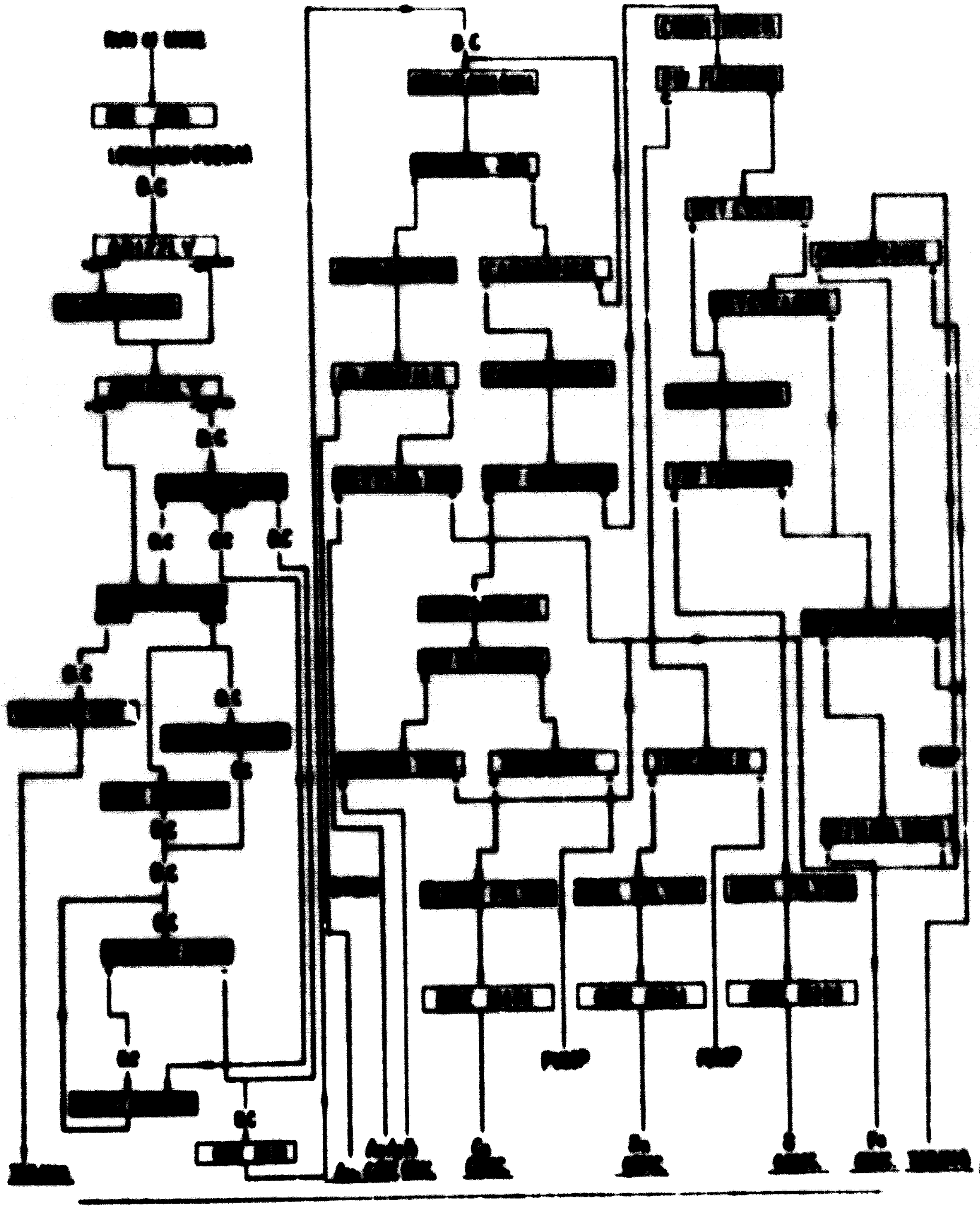
GUNMA IRON MINES DRESSING PLANT



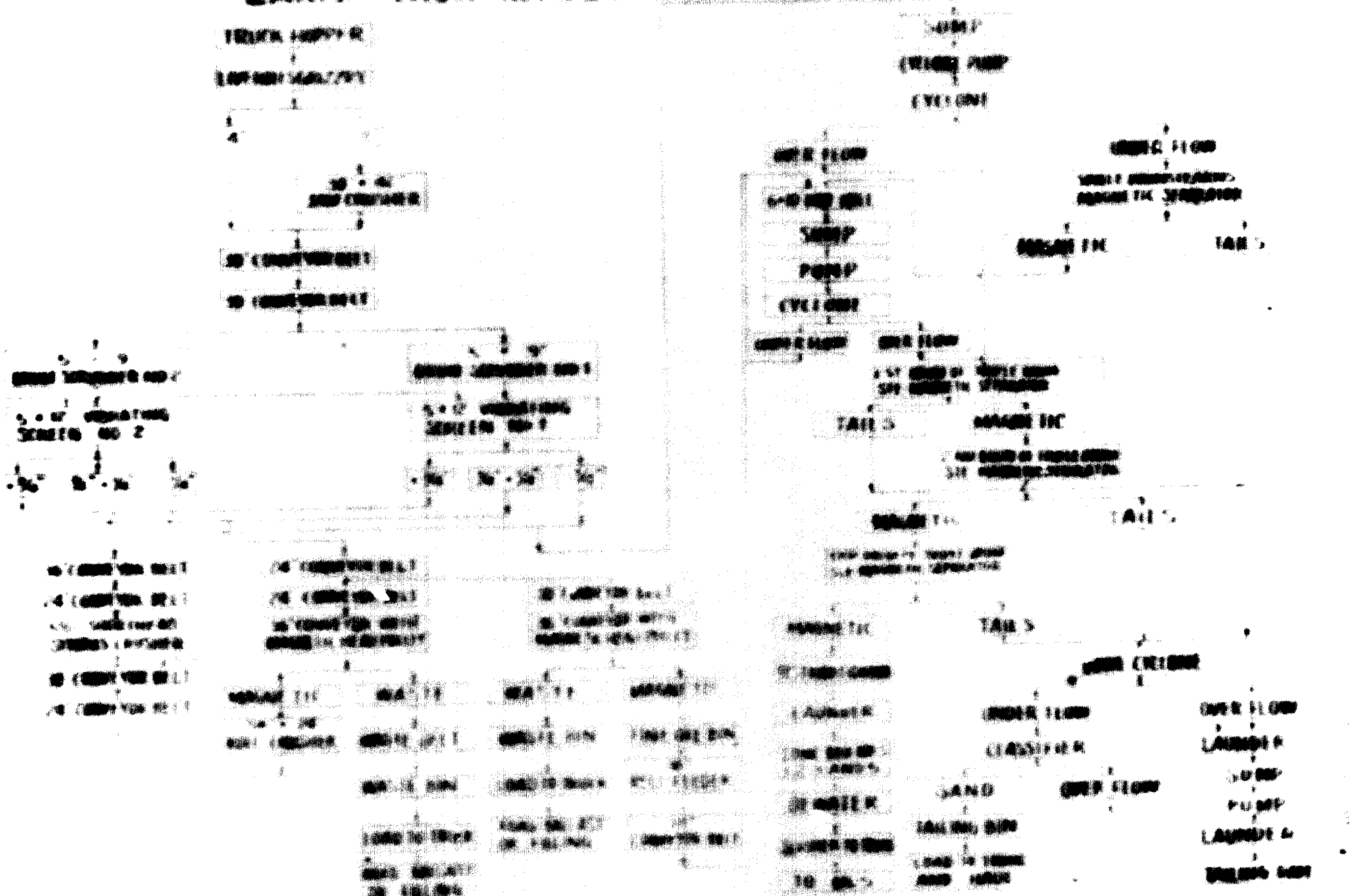


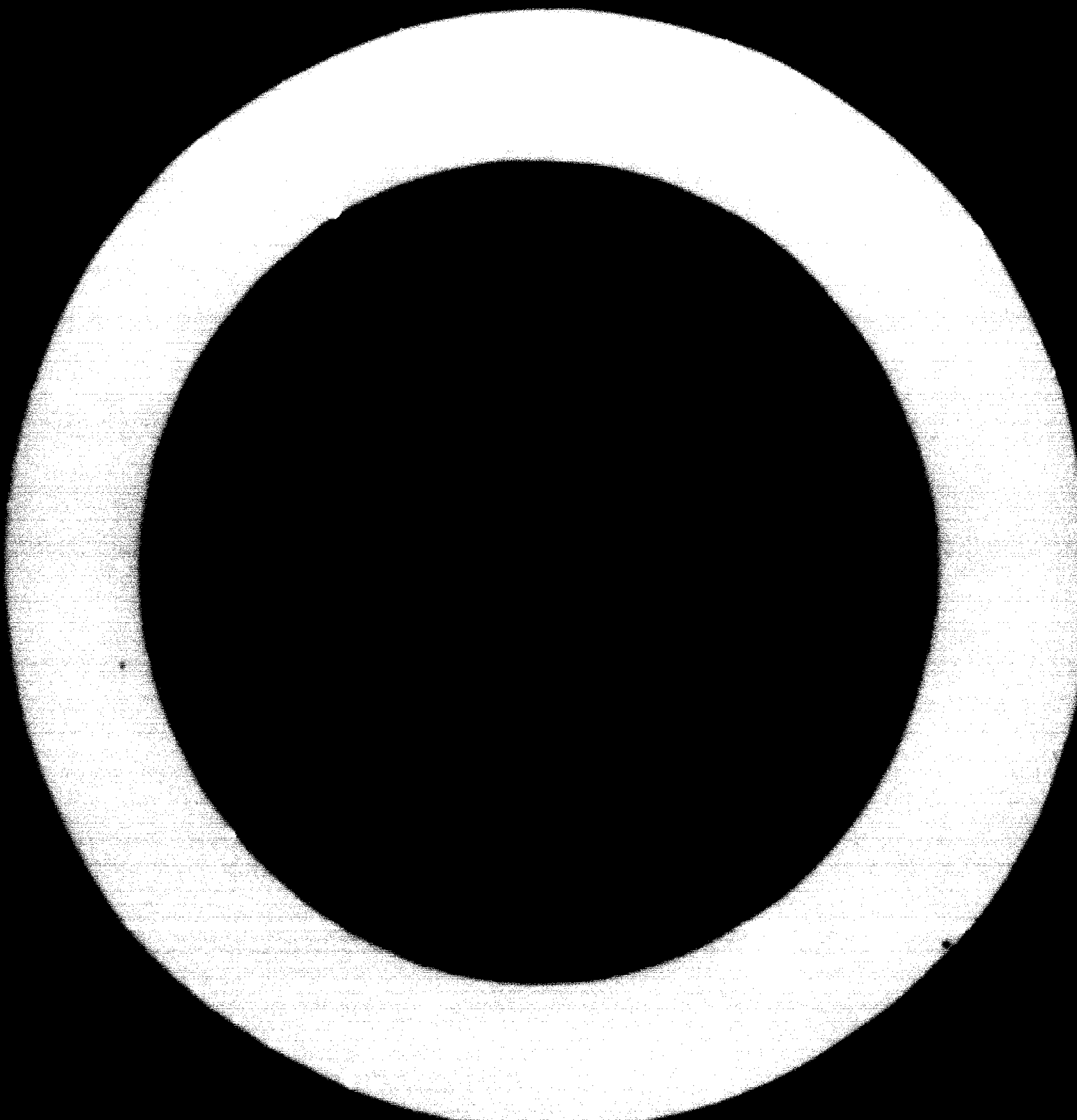
FLOW SHEET (3)

CHICHIBU IRON MINES DRESSING PLANT



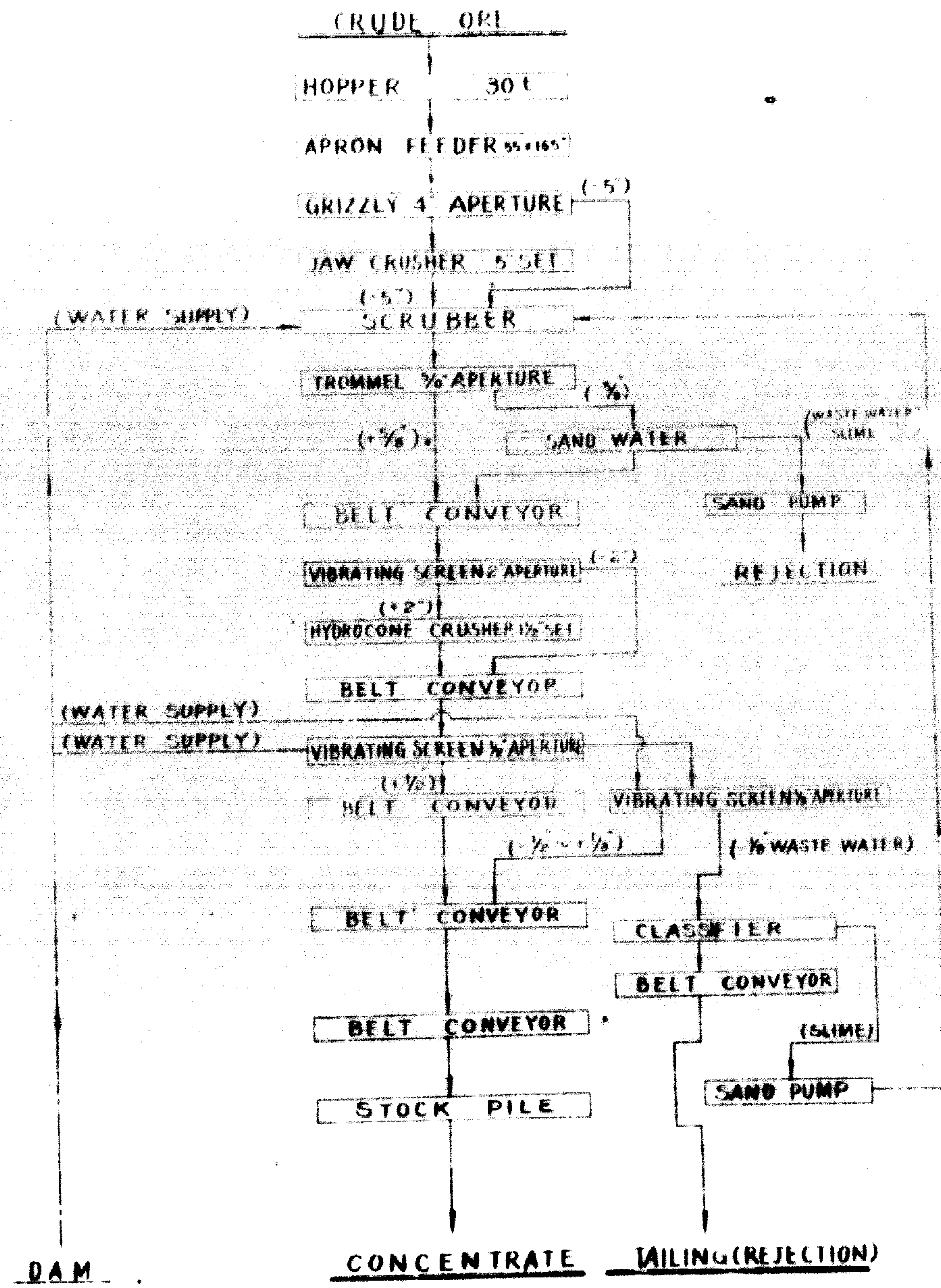
FLOW SHEET (4)
LARAP IRON MINES DRESSING PLANT





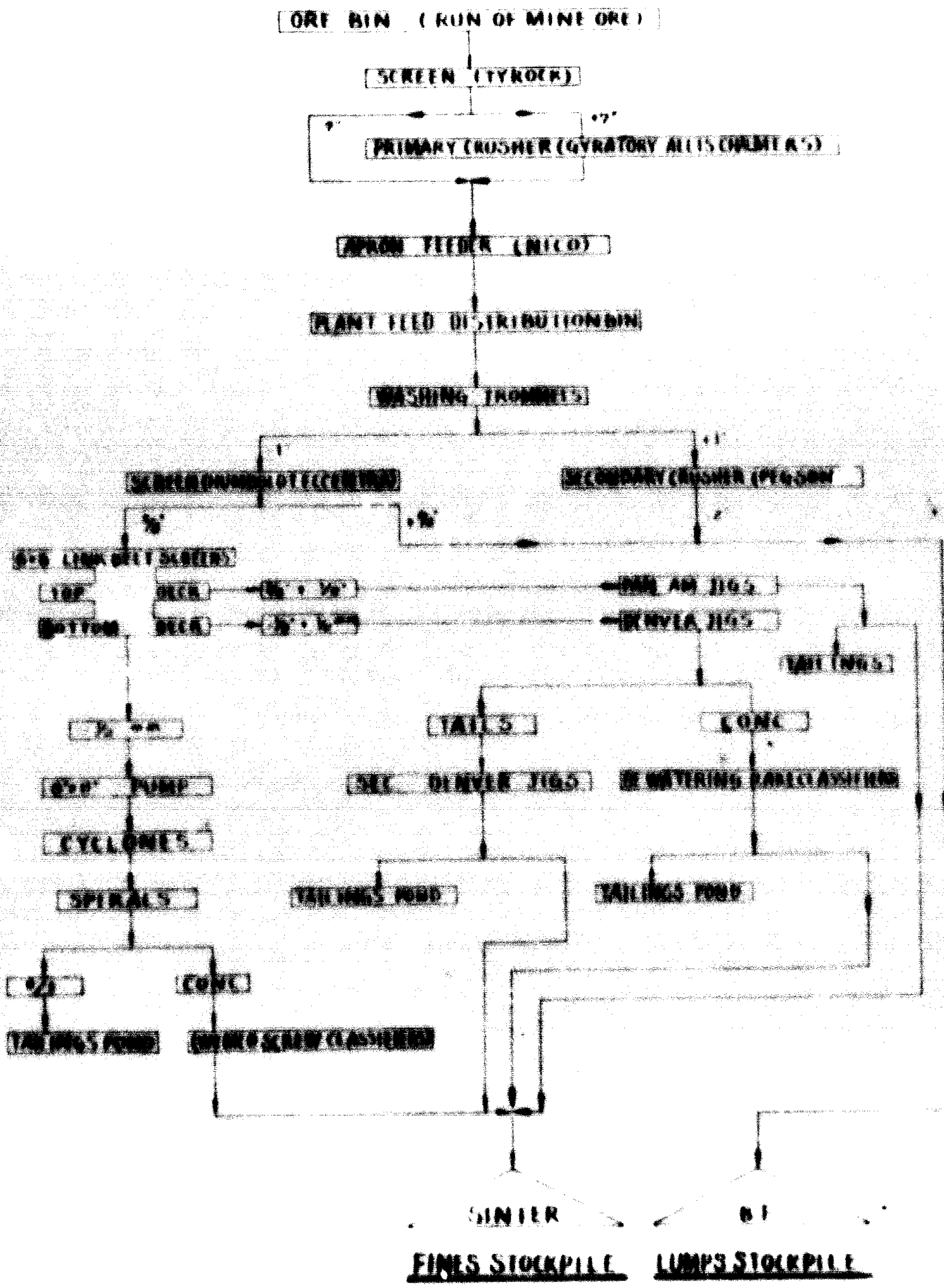
FLOW SHEET (5)

TEMANGAN DRESSING PLANT

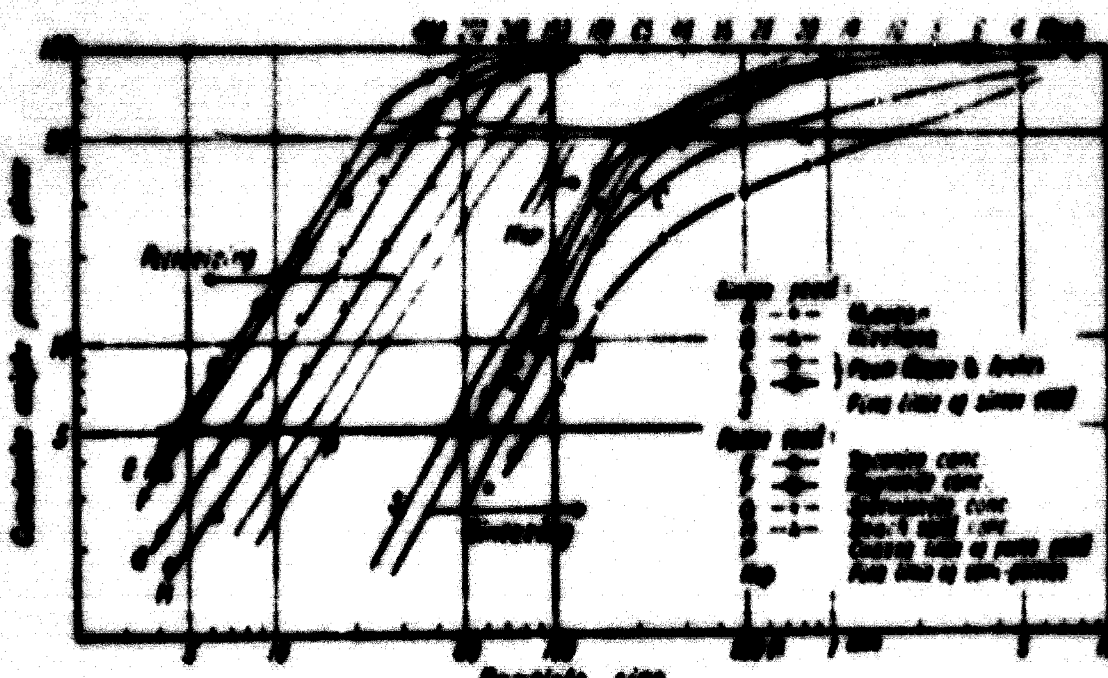


FLOW SHEET (6)

BUKITBESI (DUNGUN) WASHING PLANT



Examples of Size Distribution of Sintering and Pelletizing Feeds



Size distribution curves of sinter and pellet raw feed materials.

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