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THE HyL PROCESS

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Summary

The HyL process produces sponge iron from lump ores or agglomerates. Natural gas or naphtha may be used as the source of the reducing agent. Operating and investment costs are given, together with a discussion of the role of the process in steelmaking and the situations for which the process is especially suited. Such situations often exist in both emerging and developed economies.

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1. Description of the Process

1a. Lumps or agglomerates of iron ore are reduced to sponge iron by contact with a reducing gas containing carbon monoxide and hydrogen. Many kinds of ores (hematite, magnetite, etc.) can be treated, and the pieces of ore may be formed by simple crushing, or by pelletizing, sintering, extruding, etc.

1b. In present commercial operations, the reducing gas is made in the plant by subjecting natural gas to the steam reforming process. However, if local conditions warrant, it can be made by steam reforming of naphtha, the gasification of coal, or any other means capable of yielding a $CO-H_2$ mixture. This gas is heated before going into the reaction chamber containing the ore lumps where iron oxide is reduced at 1600-1900°F. Since this temperature is below the melting point of iron, the material does not melt, but is reduced to sponge iron by diffusion of gas into the solid.

1c. The process uses a number of batch reactors, each of which requires 12 hours to carry out the complete treatment of an ore charge. To provide for steady operation, the plant uses four identical reactors, so that a fresh batch of sponge iron is produced every 3 hours. The entire plant operates continuously, 24 hours a day, 7 days a week. The process and plant have been extensively described in the literature, to which reference is made for further details.(1)

2. History of the Process and Its Industrial Applications

2a. About 20 years ago, when the industrialization of Mexico began to accelerate, a need for flat steel products became acute in Monterrey. With imports restricted by the Second World War, the men of El Norte turned to their own resources and in 1942 organized a new steel company, Hojalata y Lamina S.A. The first installation produced sheet by rerolling imported semi-rolled products. Integrating backwards, the company installed its first electric furnace in 1945, so that it might produce its own ingots by melting imported scrap. Additional furnace capacity was set up in 1948, at which time the difficulties of obtaining foreign scrap became increasingly troublesome and expensive.

2b. As is characteristic of rapidly developing economies, domestic scrap was scarce and the problem of iron supply became acute. Hojalata y Lamina responded to this situation by installing its own iron-making facilities, thereby continuing its policy of vertical process integration from finished product toward raw materials.

However, since the production rate of the steel works was at that time too small to justify a blast furnace, they decided to produce the desired amount of sponge iron in a process of their own invention.

2c. The pilot plant for the new process began operation late in 1955, drawing reducing gas from a steam-methane reformer designed by the M. W. Kellogg Company. By the end of the year, the pilot operation was so satisfactory that Hojalata y Lamina S.A. decided to build a large plant rated to produce 200 tons per day by the new HyL process. With assistance from Kellogg, this plant was designed, built and placed in operation in November, 1957, an unusually short period of time for bringing about the first industrial realization of a new process. Kellogg was then made world-wide licensing agent, and began work on a second large plant of improved design rated at 500 tons of sponge per day.[2] This plant began to produce in 1960, giving Hojalata y Lamina S.A. the world's largest integrated steelworks based on sponge iron as the primary metal source. In 1963, Kellogg was joined by its associated company, Swindell-Dressler Corporation, in the further development and application of the HyL process.

3. Raw Materials

3a. It is generally true of chemical and metallurgical processes that the better the raw materials, the better will be the performance of the plant. The reduction of iron ore is no exception to this rule, in both the blast furnace and in the direct reduction processes. Iron ores are complex mixtures of iron compounds and many other chemical substances. These latter, which may include silica, alumina, sulfur, phosphorous, and titanium are not wanted in the finished product, and must be regarded as impurities to be removed during the process sequence in which the iron compounds are converted to steel. The HyL process removes most of the oxygen present in the ore as iron oxide, and a large part of the sulfur. The process does not remove silica, alumina, and similar non-ferrous substances. These impurities must be taken out in the ore treatments which precede the process, or in the steel making which follows it.

3b. A detailed cost calculation must be made for each specific case, to determine whether to beneficiate the ore before or after reduction. It is unavoidable, however, that impurities in the ore increase the cost of steel making regardless of the processes used. Hence the importance of using good ore, obtained either by beneficiation, or by the selection of high grade natural deposits.

3c. Another characteristic of ore which has important economic consequences is "reducibility". This encompasses all those attributes of the ore which determine the time and temperature needed for reduction, together with the physical properties of the resulting sponge. While all ores can be reduced in the process, some are converted to iron metal much more readily than others, with a consequent effect on production and capital costs. The reducibility of an ore cannot be determined by a simple chemical analysis (as can be done for impurities), but must be established by reducing a portion of the ore in a production unit or a pilot plant where it is subjected to all of the conditions prevailing in the industrial process.

3d. A final ore property which should be mentioned here is that of lump size. For the HyL process, the ore must be in the form of lumps or pieces, whose sizes cover a moderate range in the span from 1/8" to 2". Such lumps may result from the crushing of natural ore, or they may be formed by pelletizing, sintering, or other standard agglomeration techniques. Pulverized or naturally powdered ore cannot be used directly, but excellent results may be obtained with agglomerated, high purity concentrates.

3e. It should be noted that the general effects attributed above to impurities, reducibility and size are not restricted to the HyL process. Similar consequences arise in all ore reduction processes, including the blast furnace.

4. Equipment and Materials in the Plant

4a. Most of the equipment and machinery used in the plant is generally similar to that found in petroleum refineries. There are high temperature catalyst zones, piping, control valves, heat exchangers, and control instruments - all in the oil refinery fashion. Associated with these are the familiar conveyors and other solids handling equipment of the metallurgical world. This apparatus is readily available in the developed economies. When installing such a plant in an emerging nation, it will be necessary to obtain a substantial part of the equipment from metallurgically advanced areas. In addition, the construction labour force must contain workers experienced in welding, electrical installation, pipe fitting, rigging, etc. In this respect, of course, HyL is no more demanding than the steel plant as a whole, or than many of the other plants needed in a development programme.

4b. The importance of good maintenance in a sponge iron unit is great, just as in most of the other manifestations of modern technology. This topic has been treated extensively in other publications of the United Nations and need not be discussed at length here. It suffices to say that adequate preparation must be made, both financially and technically, for the essential activity of plant maintenance.[3]

5. <u>Labour Requirements</u>

5a. Elsewhere in this paper are presented data on typical rates of labour required in the process. Since skilled and professionally trained people are precious assets, it is important to consider the degree of industrial sophistication required for the operation of any manufacturing establishment.

5b. The HyL process was brought into being and is now operated at Monterrey, Mexico. This city, in the state of Nuevo Leon, has transformed itself into a prosperous, expanding, industrialized economy that might well serve as a model for many new nations. Staffed by its own people, and financed largely with its own earnings, this community has made an inspiring record of accomplishment and self-improvement. The history of its steel industry sheds light on the calibre of employees needed to operate an HyL sponge iron plant. Steel production began in Monterrey in 1903 at the Cía Fundidora de Fierro y Acero. Mexican steel capacity increased greatly on the outbreak of the Second World War. As has been noted above, the firm of Hojalata y Lamina was started in 1942, with initial attempts at sponge iron production being delayed until 1953. Commercial operation was achieved in 1957, only six years ago. The industrial leaders of the city of course recognized the value of skilled people, but they were forced to carry on their pioneering ventures with small technical staffs, augmented by a few foreign consultants and associates. Even today, the number of mature, university trained engineers in the Monterrey steel industry is small compared to that found in the siderurgical districts of Europe and the USA. This situation will eventually change as the young graduates of the Monterrey Technical Institute and the University of Nuevo Leon acquire experience, and it is to be expected that they will then greatly accelerate the industrial development of their country.[4]

5c. However, it is clear from the record, that the HyL process can be successfully and profitably operated by a society which has only in recent years undertaken to build a steel industry. The personnel requirements of the process have been demonstrated to lie within the grasp of an emerging economy. In developed regions, there will be no difficulty in obtaining qualified people, and the process offers many interesting possibilities for automation.

6. The Reduction of Ore and the Production of Steel

6a. Selection of the ore reduction process best suited to a given location has sometimes been handicapped by non-uniform bases for comparison. To avoid this difficulty, it is helpful to view the ore reduction as merely a component in a system made up of a number of related, individual processes. The choice of reduction process is then determined by the effect it has on the grand process which the whole system carries out.

6b. From this viewpoint, ore reduction is a component in the conversion of iron ore and scrap iron into finished steel. A somewhat simplified version of this is shown in figure 1. The iron ore passes through five stages, as listed below:

Process Stage	Function
1. Beneficiation	Composition changes by physical means
2. Reduction) 3. Refining)	Composition changes by chemical means
4. Casting) 5. Forming)	Producing desired shapes, sizes and surfaces

6c. The total cost of making steel in any given location is the sum of the costs of the above stages, and this cost will vary according to the characteristics of the location. For example, the extent and kind of impurities in the ore have an important bearing on the cost of steel production. In general, therefore, it is best to use high purity ores if they are available, even though low-grade ores might be slightly cheaper. The second primary raw material shown in figure 1 is scrap steel and iron. An important source of scrap is the steel works itself, where it is unavoidably formed at many places in the operation. This is reused within the works, and hence is known as "circulating scrap" or "home scrap". It amounts to about 30 per cent of the weight of the finished products.(5)

6d. If this were the only scrap returned to the steel refining furnaces, and the remaining charge were composed of iron from newly reduced ore, then the furnace would be supplied with a mixture containing about 20 per cent scrap (allowing for process losses which are not recovered). However, the various steel refining furnaces have been so designed that they can usually handle a considerably larger percentage of scrap than this. The home scrap may therefore be augmented by scrap purchased from sources outside the steel works if the price is attractive. For a specified production rate, scrap purchases diminish the capital investment needed for ore reduction, but increase foreign exchange requirements if scrap must be imported.

6c. The energy supply may be treated as a third ingredient in the grand process. This is usually a carbonaceous fuel (coal, oil, natural gas, lignite, etc.), a portion of which is chemically transformed into a reducing agent for the removal of oxygen from the ore in the reducing stage. Another portion of the fuel must be converted to steam or electricity for various power services, at a cost which must be included in the total cost of production. Finally, some fuel is burnt directly to supply heat to various furnaces in the plant. Electricity, generated from water power, may be employed if cheap enough, but must be supplemented by some carbonaceous material for making the reducing agent.

6f. The cost of the total energy demand is substantial, and it is important to select equipment and processes which can use the cheapest available source of energy. Reduction processes have been developed for each major kind of fuel, and there will often be a strong economic reason to choose the process on the basis of fuel cost.[6] The same consideration will also carry weight in selecting the optimum refining process. Other factors must be considered in making a final design for a steel installation, but the foregoing illustrates the fact that ore reduction is only one component in a complex system of energy and material processing units. The choice of a reduction process should therefore be based on a system point of view in which the total cost, reliability and flexibility of steel production are paramount.[7]

7. Uses for Sponge Iron

7a. Sponge iron is most commonly used as one of the ingredients charged to the furnace in the refining stage,[8] being employed in certain localities as part of the normal feed to open hearth and electric arc furnaces. There appears to be no serious metallurgical reason why it cannot be used in any kind of refining furnace, for all grades of steel. The principal considerations are economic, and they apply with equal force to the HyL process and to all other sources of iron. Other comparable materials in the steel furnace charge are: liquid pig iron ("hot metal"), cold pig iron, lump ore, scrap iron and scrap steel. Most furnaces possess a high degree of flexibility in the relative amounts of these materials which they can accept. The optimum feed (usually a mixture) will be determined by the product to be made and by material costs and processing times.

TABLE I

Operating Cost: 165,000 tons Fe per year

	Quantity per yr	Quantity per ton Fe	Cost Per Year		Cost Per Ton Fe		Unit Cost		Unit of Measure
			Sw Fr	US $	Sw Fr	US $	Sw Fr	US $	
Natural Gas	3,465,000	21.0	4,520,000	1,040,000	27.41	6.30	1.30	0.30	1000 FT^3
Water Makeup	194,500	1.18	23,000	5,300	.14	.03	.12	0.027	1000 US gal
Catalysts, chemicals			174,000	40,000	1.06	.24			
Operating Labour	54,000	0.33	189,000	43,200	1.14	.26	3.48	0.80	Man hour
Supervision	9,000	0.055	49,000	11,200	.30	.07	5.43	1.25	Man hour
Maintenance			1,066,000	245,000	6.47	1.48			
General Overhead			237,000	54,400	1.43	.33			
Miscellaneous Supplies			131,000	30,000	.79	.18			
Royalty*			716,000	165,000	4.35	1.00			
Net Operating Cost			7,105,000	1,634,000	43.09	9.91			

* Royalty subject to negotiation

7b. At present, producers of sponge by the HyL and other processes use most of it in their own nearby steel furnaces. Some sponge is sold for use in other locations, and it is probable that a substantial trade of this sort can be developed. HyL sponge iron can be transported by ship or rail as a bulk commodity, without special packaging, and can be converted into steel upon reaching its destination.

8. <u>Typical Operating and Investment Costs for HyL Sponge Iron Units</u>

8a. Published data relate to an HyL sponge iron plant rated at 500 tons per day, or 165,000 tons per year.* The basis for calculation is drawn from actual experience at the Monterrey plant of Hojalata y Lamina.(9) Specifications are:

Ore:	60 per cent Fe; generally like the ores used at Monterrey; 6 - 9 per cent silica
Gas:	Heating value 935 BTU/ft^3 minimum; sulfur, less than 5 grains/1000 ft^3; 150 lbs/sq in pressure
Ore Reduction:	85 per cent metallization
Plant Production:	330 days per year

8b. Assuming the production of 165,000 tons per year of total iron in the sponge, the cost data are given in Tables 1 and 2 in $US and in Swiss francs (at $0.23 US), the latter being shown to conform with cost tabulations in prior UN documents:(10)

TABLE 2

Investment Cost 165,000 tons Fe per year

	Swiss Francs	US Dollars
Total	26,500,000	$6,100,000
Total per ton of annual production	161	$37.00

8c. It is particularly to be noted that these cost values do not contain a number of items whose magnitude may vary greatly from one location to another. Among these are: spare parts, warehouse supplies, land, site clearing and preparation, special foundation requirements, utility supply lines outside the site, import duties, inland freight charges, housing for personnel, etc. The costs do include gas reforming furnaces; ore reduction reactors; heat exchangers; piping; conveyors; control instruments; utilities and power distribution equipment in the sponge iron unit; suitable building and office space.

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* All "tons" are metric tons (1000 kg)

8d. Most of the pumps and other machines in the plant are driven by steam generated within the sponge iron unit itself. Indeed, the plant generates somewhat more than it requires, so that a quantity of steam (about 140 lbs per ton of iron) is available for use elsewhere in the steel works. Correspondingly, a small quantity of electricity is required for lights, control instruments, and a few motors (about 10.5 KWH per ton of iron). In Table 1, no credit is taken for steam production, and no charge is made for electricity. Both of these factors are included in the discussion of steel production costs given below.(11)

9. <u>Cost of Steel Production Using HyL Sponge Iron</u>

9a. Bearing in mind the effect of local factors on the cost of steel production, it will be helpful to consider a design for a completely new integrated steel works. This design is based on the HyL ore reduction process, followed by steel refining in electric arc furnaces, with natural gas as the primary source of energy.(12) It will use the operating and investment cost data given above for an HyL sponge iron unit. The following additional specifications apply:

Production rate:	250,000 tons per year of product
Product:	6" x 6" low carbon steel billets
Land area:	100.3 acres (40.6 hectares)
Furnace charge:	60 per cent sponge iron, 40 per cent scrap

Plant facilities in the analysis include the following:

Railroad tracks and sidings
Ore storage yard
HyL reduction plant
Melt shop - 3 17' electric arc furnaces
Continuous casting machine
Cranes, ladles, slag pots, etc.
Electric power plant - 50,000 kw
Control laboratory and office building
Maintenance shop
Water and waste treatment
Warehouse for parts and supplies
Slag and tailings dump
Area for future expansion

9b. The figures do not include the cost of land, rolling mills, site clearing and preparation, and the other items excluded from the sponge iron plant cost analysis previously given. The design is completely integrated and the power station supplies all necessary electricity. Excess steam generated at the sponge iron unit, as mentioned above, is used in the power house to supplement the natural gas energy supply. Table 3 presents the complete operating cost analysis for this hypothetical facility, in both $US and in Swiss francs. It is important to notice that this design covers only the production of a semi-finished product. This is a 6" x 6" billet, which must pass through rolling mills and processing lines before finished products emerge. These latter stages have been omitted here but it is possible to make a realistic comparison of the cost of different ore reduction processes by analyzing their effect on the cost of making 6" x 6" billets. The table does take account of ore beneficiation through the factor of ore price.

9c. The relative importance of the stages shown in detail in Table 3, is summarized in Table 4. From this it will be apparent that a change of 10 per cent in the investment required for ore reduction produces a change of only about 2.5 per cent in the total investment for the steel works. A 10 per cent change in reduction operating cost will similarly change the total operating cost by about 1 per cent. Although not directly apparent from the tables, production cost is markedly affected by the reliability of sponge iron output. If this should drop by 10 per cent (because of difficulties with untried processes, for example), the additional scrap purchasing needed to keep up steel production would increase the total operating cost by about 4.5 per cent. The importance of process reliability is therefore very great.

10. Regions and Situations Suited to the Process

10a. In well-developed steel centres the HyL process can be used to produce a cheap and dependable supply of iron free from copper and other harmful contaminants. Its sulfur and phosphorous content can be kept down by proper choice of ores and hydrocarbons. The process deserves serious consideration because of the contributions it can make to the move toward higher quality which now characterizes the efforts of many established steel producers.

10b. When a new nation begins a programme of industrialization, it must build upon the specific assets and liabilities which it has available. The infinite variety of our Earth presents each group with a problem and a situation more or less different from that of its neighbours. The development of a steel industry is one of many programmes falling into this general domain. The industrial planner, confronted with the multitude of processes offered to him by siderurgical specialists, can find his way toward a good solution by using the time-tested principle of simplicity. Do first that which is easiest.

10c. If a new nation is endowed with high grade iron ore, the grand steel making process can most easily be entered by developing ore deposits and selling ore. This at once makes foreign exchange available for importation of other goods and services. When capital accumulation permits, facilities for making iron can be installed and the product exported to established steel making centres. At that point, of course, it becomes necessary to choose among the several iron making processes. If the planner will sternly exclude all processes still in an experimental stage and restrict himself to those already operating on an industrial scale, he will soon determine which one is most suited to his requirements.

10d. The HyL process may be seriously considered in situations where good lump or agglomerated ore is available, and where natural gas or petroleum naphtha is an economical source of energy. Its special advantages are:

1. Proven commercial operation, in the world's largest sponge iron facility.
2. Labour requirements suited to emerging economies.
3. Variability in size, since plants have been constructed for 200 and 500 tons per day of sponge.
4. Ease of capacity expansion, because additional reactors and gas reforming furnaces can be added as desired.
5. A wide range of types of ore lumps and agglomerates can be converted to sponge.
6. An experienced engineering and consulting service is available for design, construction and initial operation.

10e. As more capital and experience become available, the other stages in the steel making process can be installed, until a substantial degree of iron and steel self-sufficiency has been achieved.

TABLE 3

Operating Cost 250,000 tons low carbon steel 1 yr

ITEM	Quantity per yr	Quantity per T steel	Cost per Year Sw Fr	Cost per Year US $	Cost per Ton Steel Sw Fr	Cost per Ton Steel US	Unit Cost Sw Fr	Unit Cost US $	Unit of Measure
SPONGE IRON – Table 1	165,000	0.66	7,105,000	1,634,100	28.42	6.54	43.09	9.91	Ton
Melt Shop and Casting Plant									
Natural gas	775,000	3.10	1,009,000	232,000	4.03	0.93	1.30	0.30	1000 FT³
Water Make-up	125,000	.50	15,000	3,400	.06	.01	0.12	0.027	1000 US gal
Operating Labour	641,000	2.56	2,226,000	512,000	8.90	2.05	3.43	0.80	man hour
Supervision	9,000	.036	49,000	11,200	.19	.04	5.43	1.25	man hour
Maintenance			1,392,000	320,000	5.57	1.28			
General Overhead			2,275,000	523,200	9.10	2.09			
Electrodes	4,090	.00836	5,435,000	1,250,000	21.74	5.00	2,610.00	600.00	Ton
Fluxes and Alloys			4,480,000	1,030,500	17.93	4.13			
Refractories and Materials	7,370	.0295	4,639,000	1,067,000	18.56	4.27	630.00	145.00	Ton
Oxygen and Misc. Supplies			599,000	138,000	2.40	.55			
Total Steel	250,000		22,119,000	5,087,300	88.48	20.35			Ton
50,000 KW Power Plant									
Natural gas	2,350,000	11.44	3,730,000	858,000	14.92	3.43	1.30	0.30	1000 FT³
Water Make up	525,000	2.10	62,000	14,200	.25	.06	0.12	0.027	1000 US gal
Chemicals			204,000	47,000	.82	.19			

TABLE 3 (contd.)

Operating Cost 250,000 tons low carbon steel 1 yr

	Quantity per yr	Quantity per T steel	Cost per Year		Cost per Ton Steel		Unit Cost		Unit of Measure
			Sw Fr	US $	Sw Fr	US $	Sw Fr	US $	
[illegible] Power Plant (cont)									
Operating Labour	75,000	0.30	261,000	60,000	1.04	.24	3.48	0.[illegible]0	Man hour
Supervision	16,000	0.064	[illegible]7,000	20,000	.35	.08	5.43	1.25	Man hour
Maintenance			2[illegible]3,000	65,000	1.13	.26			
General Overhead			243,000	56,000	[illegible]7	.22			
Total Power	204,000,000	16.00	4,[illegible]70,00[illegible]	1,120,200	[illegible]	[illegible]			[illegible]
General Plant Facilities									
Labour	125,000	.50	435,000	100,000	1.74	.40	3.48	0.[illegible]0	Man hour
Supervision	[illegible],000	.036	[illegible]9,000	11,200	.1[illegible]	.0[illegible]	5.43	1.25	Man hour
Miscellaneous Supplies			217,000	50,000	.87	.20			
Maintenance			278,000	64,000	1.11	.26			
General Overhead			484,00[illegible]	111,200	1.94	.44			
Total			1,[illegible]63,000	336,400	5.[illegible]5	1.34			
Net Operating Cost	250,000		35,557,000	8,178,000	142.23	32.71			Ton
Iron Ore 60% Fe	275,000		14,34[illegible],000	3,300,000	57.39	13.20	52.00	12.00	Ton
Scrap	115,000		22,521,000	5,180,000	90.08	20.72	196.00	45.00	Ton
Total Direct Production Cost	250,000		72,426,000	16,658,000	289.70	66.63			Ton

TABLE 4

250,000 tons-1 year   6" x 6" billets

Stage	Capital Investment			Operating Cost per ton steel		
	Sw. Fr.	US $	%	Sw.Fr.	US $	%
Reduction (HyL process)	26,500,000	6,100,000	24.7	28.42	6.54	9.8
Refining (Elec. arc furnace) Casting (Continuous)	34,800,000	8,000,000	32.4	88.48	20.35	30.6
Power plant	28,300,000	6,500,000	26.3	19.48	4.48	6.7
General Plant facilities	17,800,000	4,100,000	16.6	5.85	1.34	2.0
Subtotal	107,400,000	24,700,000	100%	142.23	32.71	49.1
Iron ore at $12 per ton				57.39	13.20	19.8
Scrap at $45 per ton				90.08	20.72	31.1
Total	107,400,000	24,700,000	100%	289.70	66.63	100%

10f. A reverse course of development is often more suitable when local supplies of ore are not adequate. Then it may be better to begin with steel forming plant, and work backward to steel refining, using imported scrap, sponge or pig iron. Finally, complete integration is achieved by adding reduction and beneficiation equipment. This, indeed, was the procedure followed by Hojalata y Lamina S.A. in their development. It has the great merit of quickly reducing foreign exchange demands with a minimum investment.

10g. A third alternative arises when more capital can be invested. A complete steel works can be built and operated as a unified development project, based upon the sequence of process stages best suited to the local circumstances. The HyL process should receive careful consideration whenever the supplies of ore and hydrocarbon are as previously described. Its proven performance is a guarantee that it is a reliable component in the grand process of steel making.

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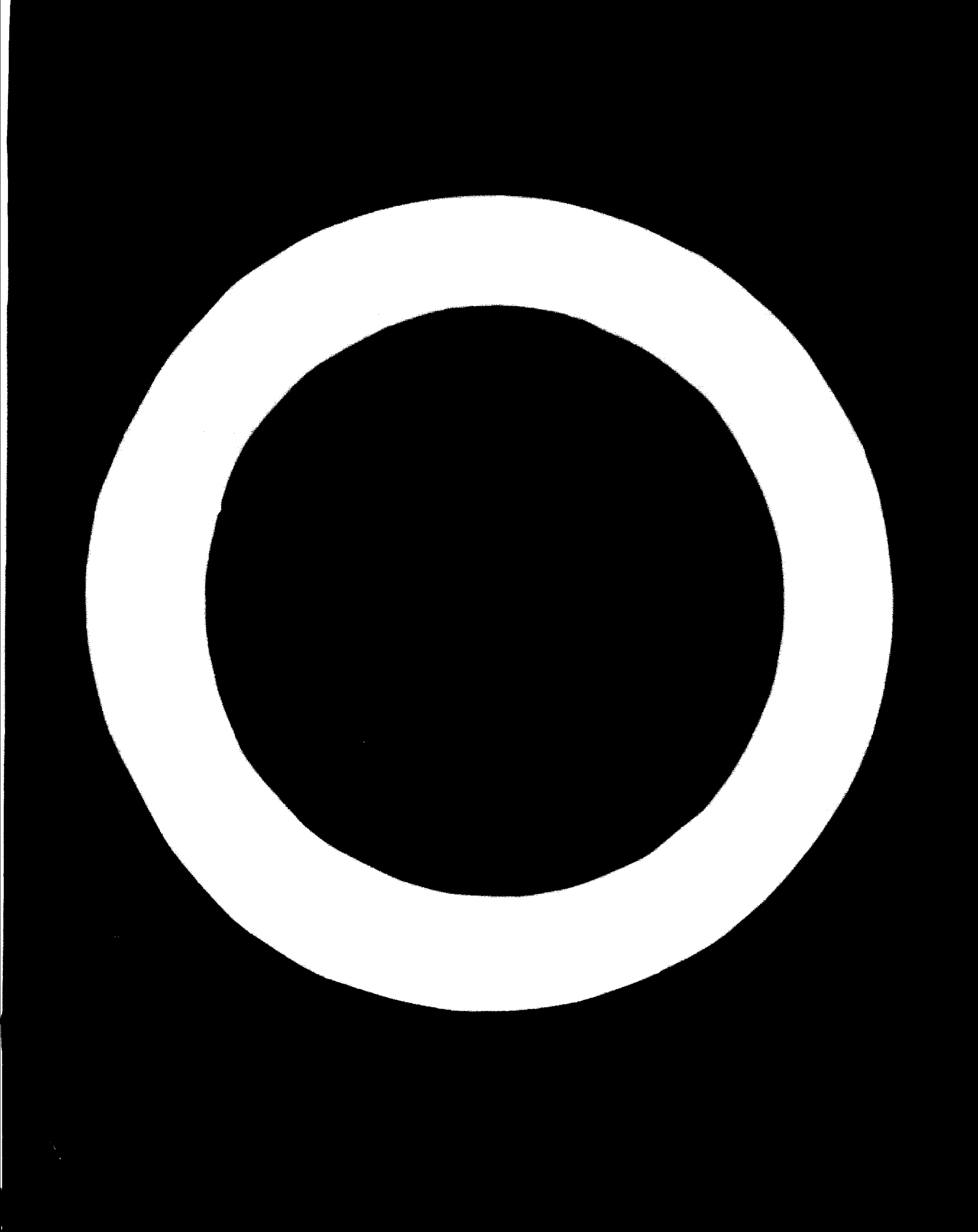
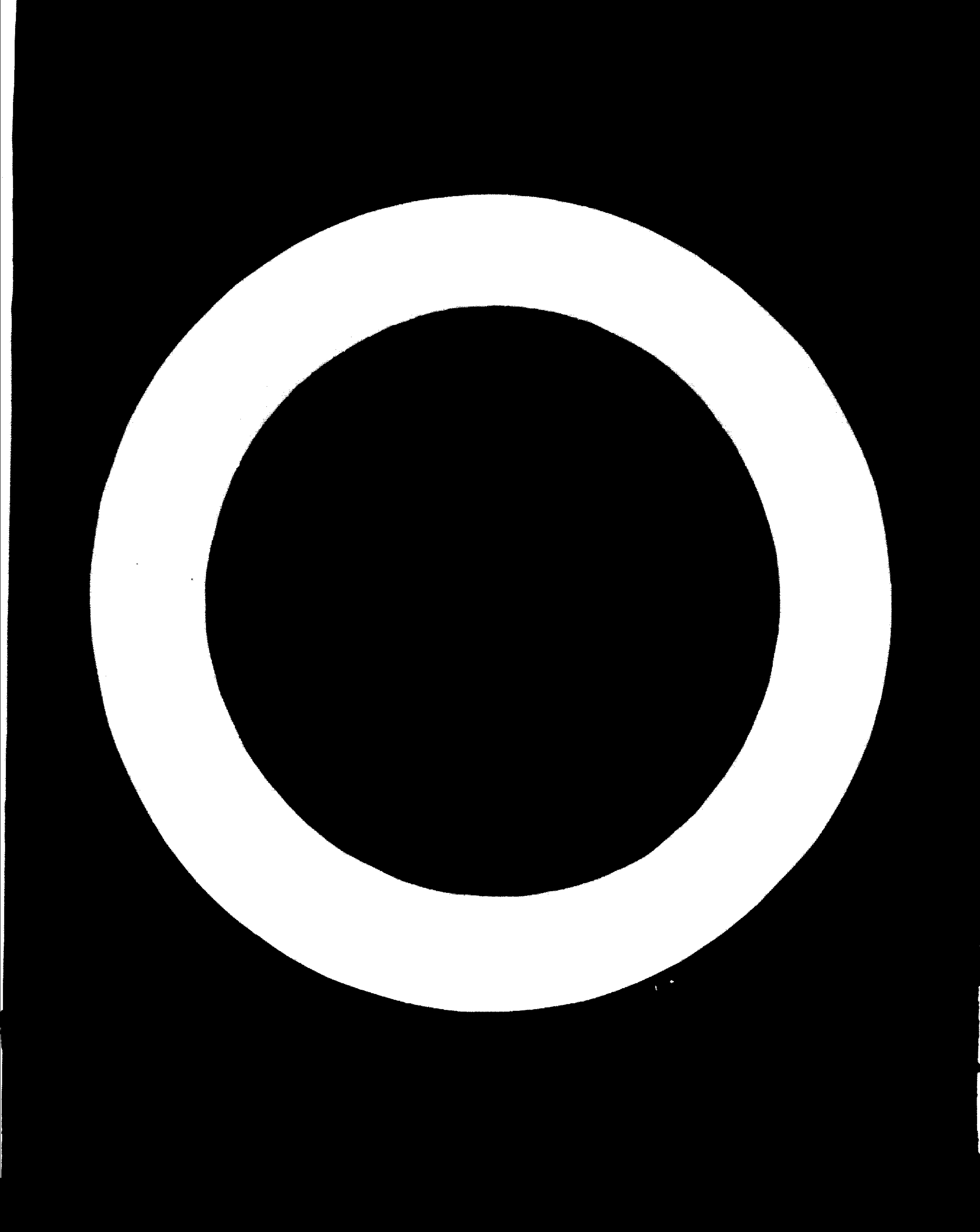


FIGURES



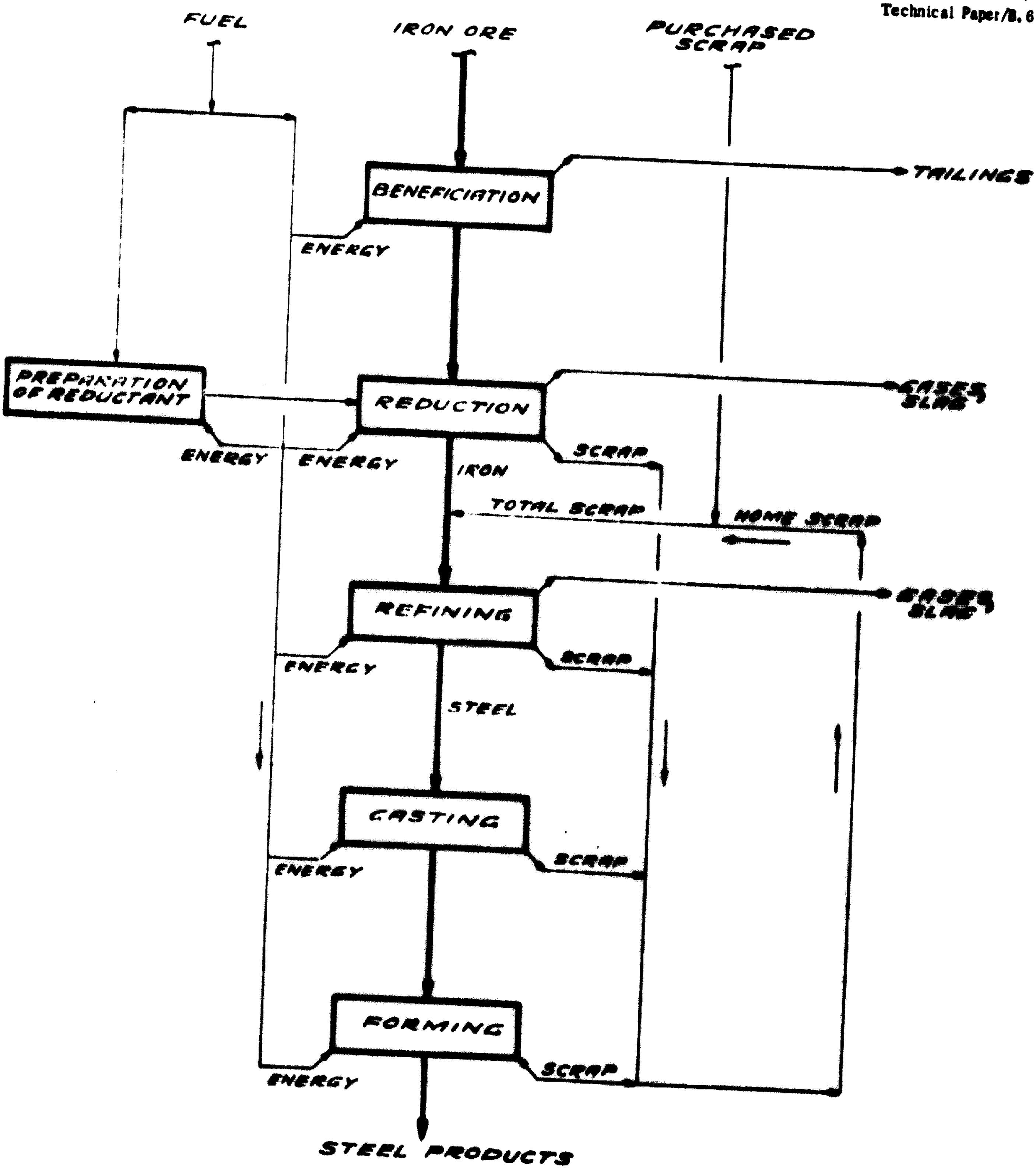


FIGURE I
THE GRAND PROCESS OF STEELMAKING

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