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# THE ECHEVERRIA ORE REDUCTION PROCESS

by

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**Summary**

The Echeverria Ore Reduction Process was developed in Spain to produce a low cost, high grade substitute for steel scrap. It uses ores of about 60 % Fe content, in lump, sinter or pellet form and practically any solid carbonaceous fuel as reductant. The ore and reducing agent are charged in externally heated shafts of comparatively small cross section dimensions. For the heating of the shafts fuel oil, natural gas, producer gas etc. may be used. The reduction takes place in solid phase at about 1050°C. The iron product which contains 90-94 % total Fe at 90-95 % metallisation is uniform in quality and size and is an excellent charge material for electric arc furnaces, cupolas and oxygen converters.

The Echeverria Process is simple and flexible. It requires low investment costs and can operate economically on a small scale. These features make it of special interest to developing countries.

GE.63-13341

1. **Introduction**

(a) Early in the 1950's the quality steelworks of Patricio Echeverria S.A., at Legaspia in Northern Spain, found they did not have enough steel scrap. The Company decided to investigate the possibilities of building an ore reduction unit of moderate capacity in which the operation would be based on medium grade hematite and anthracite of high ash content available from deposits nearby. The unit would produce sponge iron as a high grade substitute for scrap. This lead to the design of a simple ore reduction process which proved to require low specific investment costs and to be able to operate at acceptable production costs.

(b) The classic method of reducing iron ore by means of a solid reductant is through a shaft furnace process. Echeverria chose this principle. However, adding necessary heat to compensate for the endothermic balance of the reduction reactions by direct heating of the charge would have lead to the complicated and capital-consuming blast furnace process. Instead Patricio Echeverria S.A. chose to add the heat indirectly through external heating of the reduction shaft by means of producer gas. This necessitated the design of small diameter shafts to allow heat transfer to the centre of the shaft without too large temperature difference between the wall and the centre. To further facilitate heat transfer, the reduction shaft walls were made of cast sections of heat resisting steel. As the reduction would take place without melting of the material it was necessary to avoid reoxidation of the reduced product. This was accomplished by equipping the lower part of the shaft with water cooling so that the discharge materials could leave the furnace at sufficiently low temperature. A certain surplus of anthracite had to be used to prevent the material from sticking to the hot shaft walls. This made necessary a simple magnetic separation of the discharge materials for the recovery of the reductant. A simple flotation washer was used for the separation of ashes from usable reductant.

(c) Following several years' pilot plant trials and experimentation the industrial Echeverria plant was able to start its operation in 1958. The plant had an initial capacity of 10,000 t.p.a. of sponge iron, which has subsequently been increased to 20,000 t.p.a. The iron product is used as part charge for the electric steelmaking furnaces producing high grade and alloy steels.

(d) Professor Martin Wiberg, Stockholm, reported on the Echeverria Process at the Second Latinamerican Congress of Steelmaking in Buenos Aires in July 1962.1/

1/ Wiberg Martin, Tecnicas Modernas en el Alto Horno; Revista Latinoamericana de Siderurgia, No. 29/30, p.12 (September/October 1962) and No. 31, p.23-24 (November 1962)

2. **Description of the Legaspia Plant**

(a) The Echeverria Ore Reduction Plant is a complete entity, comprising:-

Raw material stockyard

Ore crushing and screening equipment

Forty ore reduction retorts

Two gas producers

Magnetic separation equipment

Flotation washer for the recovery of excess reducing agent

General services of water, electric energy etc.

(b) Fig. 1 shows a general layout of the Legaspia plant and the more important dimensions.

(c) An outside view of the plant is given in Fig. 2.

(d) Fig. 3 shows a row of steel sheet mantled reduction shafts at Legaspia.

3. **Description of Process**

(a) A flow sheet for the Echeverria Process as practised at Legaspia is given in Fig. 4.

(b) The process is based on the reduction of iron ore through a solid reducing agent, at an elevated temperature, in a vertical retort, externally heated.

(c) The iron ore is received at the plant in unprepared state. It is off-loaded into storage bays and transferred to the ore preparation section as required.

(d) The ore is crushed by one of two 10 ton/hour jaw crushers set at 50 mm. and transferred to a rotary screen via a bucket elevator. The fines are screened out and subsequently used in the steelworks for decarbonisation in the electric arc furnace practice. The + 10 mm. fraction falls into one of the raw material hoppers. Prepared limestone and reducing agent (anthracite of 25 % ash, - 25 mm. + 8 mm. size) are received at the plant and transferred direct to storage hoppers.

(e) From these storage hoppers the prepared materials are discharged into a drop bottom bucket and elevated by an overhead crane to the respective bays on the retort charging platform. This platform is level with the top of the retorts, the raw materials being hand fed into the receiving hopper/preheater of each retort in set proportion.

(f) A small amount of limestone is mixed with the charge to prevent any sulphur pick-up by the ore from the reducing agent.

(g) Diagrammatic cross section of a retort is given in Fig. 5. It will be noted from this diagram that the retort may be divided into three zones, these being

a) Preheating zone
b) Reducing zone
c) Cooling and discharge zone

(h) Preheating of the charge is achieved by the introduction of air into the base of the preheater.

(i) Carbon monoxide resulting from the reaction between the reducing agent and ore in the hot reducing zone burns together with a small fraction of the reducing agent within the preheater. The amount of preheat is regulated by control of the air flow into this zone. As the process is continuous the material in the preheater is gravity fed into the retort proper. The retort column is some 10 metres high, circular in horizontal cross section, and is slightly tapered to permit the free descent of the material column. The retort is constructed of eight sections, each section is a casting of alloy steel suitable for prolonged operations at elevated temperatures.

(j) The retort stands within a refractory lined oven, and is externally heated by the combustion of producer gas between the retort and the refractory lining. The charge slowly descends from the preheater, down the retort shaft and into the cooling/discharge zone. This zone is divided into three sections. Firstly, there is a water-cooled jacket directly beneath the retort shaft. Secondly, there is a water-cooled double spiral discharge from the cooling zone feeding to the third section which is a lock hopper discharge.

(k) The time taken from charge to discharge is approximately forty-eight hours depending, of course, on reducibility of the ore. Each retort unit has a rating of approximately 1.4 ton of iron product per day.

(l) The lock hopper of each retort is emptied once per shift. The product is screened into three fractions 0 - 15 mm., 15 - 30 mm., + 30 mm., and is magnetically separated. The non-metallics pass to a flotation type washer where the excess anthracite used in the charge is recovered and recirculated back to the anthracite bin. The calcined limestone, ash and gangue particles are tipped to waste.

(m) It will be noted from the above description that the plant and the process are simple and straight forward. In the plant the whole operation is controlled by a minimum of instrumentation. There are two pyrometers per unit to measure the temperature of the combustion gases between the retort and the refractory casing. The burner settings are adjusted to maintain a temperature reading of between 1000°C and 1100°C. Overheating would adversely affect the life of the alloy steel castings and might cause "scabbing" within the retort. Operations of below the optimum temperature level would decrease the production rate per retort unit.

(n) The spiral discharge, at the base of the water cooled jacket, is of variable speed and is adjusted to control retort throughput and thus give the required degree of reduction in the iron product. This is usually within the 90 % - 92 % range.

(o) Typical analyses of ore regularly utilized and resultant sponge iron analyses are given in Table 1. Analyses of other raw materials are given in Table 2. Apart from the SORIA and BILBAO ores in Table 1, other iron bearing materials have been processed and relevant analyses are quoted in Table 3.

4. Process Requirements

(a) Iron Ores

(i) The readily reducible Spanish hematite and limonite ores are used for the production of sponge iron at Patricio Echeverria S.A. Experiments with more dense hematite ores and magnetites made so far were less successful due to the inherent irreducibility of these ores. No doubt crushing of the ores and sintering or pelletizing and burning would make them more amenable to Echeverria treatment through increased porosity. In the case of magnetites the sintering process should then conveniently be carried out in a way that the $Fe_3O_4$ be oxidized to $Fe_2O_3$ which would further increase the reducibility.

(ii) The iron ores utilized should also not have a low fusion point characteristic as "scabbing" on the inside of the retort column may result if softening of the particles occur at operating temperatures.

(b) Reducing Agent

Anthracite of high ash content is normally utilized as the reducing agent. High grade anthracite and charcoal have been used with success, but the higher price of these two commodities rules out their regular application in preference to the cheaper low grade anthracite.

(c) Electric Energy

Electric energy consumption for the entire ore reduction plant is approximately 110 kWh/ton iron product. This figure includes consumption for:-

raw material handling, crushing and screening, retort operation, gas production, magnetic separation, blower fans, extraction fans, washer operation, cranes - elevators, lift, plant lighting, water circulation.

(d) Water

The circulating water requirement is approximately 1 m3 water/ton reduced iron. The plant is equipped with three 10 h.p. water pumps. There are two forced air draught water coolers. Cooling of the water is, however, not usually practised as a plentiful supply of fresh water is normally available at the Spanish works.

(e) Labour

(i) The plant manning is:-

one engineer

one foreman and

30 unskilled workmen.

(ii) On each shift there are seven men. One of them handles the transport of raw materials. At the top level there are two chargers. Two men are located at the level of the burners and pyrometer panel. One man deals with the extraction and conveying of the sponge iron and one man is stationed at the gas producers.

5. Capital Cost

(a) The capital cost of the complete plant to produce 20,000 t.p.a. of sponge iron, including building and services was equivalent to $ 35 per annual ton of product.

6. Production Costs

(a) The following nominal prices may be assumed for computing approximate operating costs:

| | |
|---|---|
| Iron ore of 60 % Fe as quarried, delivered to site | \$ 8.5 per ton |
| Gas coal delivered to plant | \$ 14.0 per ton |
| Low grade anthracite delivered to plant | \$ 14.0 per ton |
| Prepared limestone delivered to plant | \$ 3.0 per ton |
| Electric energy | \$ 0.012 per kWh |
| Labour | \$ 0.7 per man hour |

(b) Using above unit costs a total cost for the production of one ton of reduced iron of \$ 44.55 may be calculated, as shown in Table 4.

(c) It is realised that the Spanish plant is not thermally efficient. Under circumstances different to those existing at the works considerable improvements could be made to improve the thermal efficiency without affecting the simplicity of the process, and with only slight additions to the capital costs.

(d) It is considered that by using the heat content of the waste gas to preheat the air for combustion a saving of at least \$ 3.5 per ton could be effected.

7. Some Theoretic Aspects of the Echeverria Process

(a) In the Echeverria Process the reactants remain in solid phase and are indirectly heated to the reaction temperature. One might fear that such a process would show a fairly slow reaction rate. However, an Echeverria shaft at Legaspia has a reaction volume of about 1m3 and produces about 1.5 tons per day of reduced iron product. This specific production figure 1.5 tons/m3 per day compares favourably with the corresponding figure for a modern blast furnace, which is about 2 tons/m3 per day. This is no doubt due to, among other things, the use of classified ore of good reducibility. By the sizing of the ore and the solid reductant the charge becomes porous, thus permitting good circulation of the CO formed during the solid/solid reduction process, with a high degree of indirect reduction as a result. In fact, the consumption of 320 kg anthracite of 62.5% fixed carbon content for the reduction of hematite ore, to yield one ton of sponge iron containing 93 % total Fe of 90 % metallisation, corresponds to an indirect reduction of 53 %. In normal blast furnace practice an indirect reduction of 30 - 35 % is obtained.

(b) On the question of possible sticking of reduced material to the hot walls of the Echeverria shafts it may be mentioned that through a slight excess of anthracite and temperature control of the reduction part of the shaft the danger of sticking has been completely eliminated at Legazpia.

(c) Another point often raised in regard to iron reduced in solid phase is the possible risk of reoxidation. As has often been quoted by authors on sponge iron manufacture; iron reduced by C and CO at about 1000°C is not subject to any noteworthy reoxidation below 200°C. The Echeverria iron is discharged from the shaft well below that temperature and any reoxidation has not been noticed at Legazpia.

8. Future Development Possibilities

(a) In order to reduce capital costs of Echeverria Plants further, it has been proposed to use silicon carbide in the retorts instead of the present sections of heat resistant steel. The increased thermal conductivity of this material and the possibility of successful operation at higher temperatures are factors conducive to raising the output per retort unit. It is anticipated that a silicon carbide retort will have an operating life at least equal to the present 15 - 18 months of the alloy steel castings. A trial silicon carbide retort has recently been installed at Legazpia and first operation results will be available shortly.

(b) The existing plant is well suited to meet the local requirements of:-

relatively small annual output
flexibility of operation
simplicity of operation.

(c) However, the low capacity of each retort unit and the space it requires is less conducive to the application of these retorts to large annual tonnage plants. Therefore, to apply the principles of this process to large production units certain modifications and improvements have been made in the design of retorts for prospective plants. Schemes have been prepared for plants to produce up to 250,000 tons of sponge iron per annum, based on the Echeverria process. These schemes incorporate several large capacity retorts of elongated horizontal cross section within a common oven, modified charging and discharging mechanisms enabling introduction of reducing gases into the retort to be effected. This would make possible a decrease of solid reducing agent consumption, if required.

These large tonnage plants have been designed so as to be almost fully automatic in operation, thereby reducing labour requirements. Capital costs of these plants based on the Echeverria process are estimated to be less than $ 30 per annual ton (see Table 5) and on the basis of the previously quoted prices it is estimated that the resultant cost of iron product would be approximately $ 35/ton. Using cheap natural gas as the thermal source it is estimated that the resultant sponge iron would cost less than $ 30 /ton.

9. **The Echeverria Process for Developing Countries**

(a) The Echeverria Ore Reduction Process shows a number of features which makes it of special interest to the developing countries.

(b) Often the creation of steel industry in a developing country is dependent on some of the following conditions:-

(1) Local deposits of ores and fuels. More often high or medium grade iron ores are available than coking coals. On the other hand, bituminous coals or low grade anthracite are available in many cases. Sometimes there are sources of natural gas in the country.

(2) A rapidly increasing need for general construction steels, concrete reinforcement bars, steels for simple tools etc.

(3) Very little steel scrap is available in the country.

(4) Availability of unskilled labour.

(5) The government and other local interests would like to start a steel industry on a small scale with possibilities of expansion.

(c) The Echeverria Ore Reduction Process fulfils the above requirements. Its advantages include:-

(1) The process is independent of the availability of metallurgical coke. It may use as reductant any solid carbonaceous fuel such as anthracite of high ash content or char from the charring of bituminous coals. In the latter case the gas from the charring operation may be used for the external heating of the reduction shafts.

(2) The Echeverria principle lends itself to the design of both small and large capacity plants. A 5,000 tons/annum plant may be operated economically. A 250,000 tons per annum project has been elaborated assuming the arrangement of the retorts in battery type furnaces.

(3) Investment costs are very low. For a conventional Echeverria plant they vary between $ 35 and 65 per annual ton of iron product depending on plant size, degree of mechanization etc., whereas for a blast furnace complex with coke ovens they are of the order of $ 90 to $ 100 per annual ton. The use of silicon carbide in the reduction retorts and the modified design using several elongated retorts in one single combustion chamber will bring down Echeverria investment costs further to the order of $ 20 to 30 per annual ton.

(4) The process is simple. There is an absolute minimum of instrumentation and the plant may be successfully operated by unskilled labour.

(5) Each retort is an independent unit. Therefore maximum flexibility is possible, and the plant capacity may be readily increased.

(6) No complex machinery is required. Most of the equipment can be obtained locally, which limits the need for foreign exchange in plant purchasing.

(7) The reduced iron product is uniform in quality and of controlled size. It is very suitable as part of the charge in electric arc and open hearth steelmaking furnaces, cupolas and oxygen steel converters.

(8) The Echeverria Process has been in successful continuous operation on an industrial scale for several years.

Acknowledgements

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## TABLE 1

### Typical Analyses of Iron Ores Regularly Utilised and Range of Resultant Iron Product Analyses.

**Iron Ore Analyses (Dry Basis)**

| | % Fe | % $SiO_2$ | % S | % Loss on Heating |
|---|---|---|---|---|
| Soria Ore | 60.3 | 11.6 | .02 | 1.3 |
| Bilbao Ore | 56.4 | 7.9 | .02 | 8.8 |

**Iron Product Analyses**

| | % Metallic Fe | % Total Fe | % Metallisation | % S |
|---|---|---|---|---|
| From Soria Ore | 80.4 | 90.0 | 89.3 | .022 |
| | 84.6 | 92.5 | 91.5 | .024 |
| | 90.0 | 94.0 | 95.7 | .020 |
| From Bilbao Ore | 75.5 | 83.1 | 90.0 | .028 |
| | 80.8 | 86.0 | 94.0 | .021 |

## TABLE 2

### Typical Analyses of Reducing Agents Utilized

| | % Volatiles | % Fixed Carbon | % S | % Ash |
|---|---|---|---|---|
| Anthracite A | 6.0 | 78.9 | 0.80 | 12.4 |
| Anthracite B | 8.2 | 62.5 | 1.10 | 27.3 |

### Typical Analyses of Coal Used in the Gas Producers

| % Volatiles | % Fixed Carbon | % S | % Ash |
|---|---|---|---|
| 37.0 | 52.6 | 1.25 | 8.5 |

TABLE 3

Analyses of Various Other Iron Bearing Materials Reduced

| | % Fe | % $SiO_2$ | % CaO | % S | % Loss on Heating |
|---|---|---|---|---|---|
| Cerain Ore | 59.6 | 0.5 | 7.0 | 0.192 | 3.3 |
| Rif Ore | 65.2 | 3.3 | - | 0.07 | 2.0 |
| Swedish Pellets | 66.1 | 2.4 | - | 0.018 | 0.3 |

Iron Product Analyses

| | % Metallic Fe | % Total Fe | % Metallization | % S |
|---|---|---|---|---|
| From Cerain Ore | 81.7 | 90.6 | 90.2 | 0.098 |
| | 82.0 | 91.7 | 89.4 | 0.095 |
| From Rif Ore | 78.6 | 91.3 | 86.2 | 0.040 |
| | 87.1 | 93.3 | 93.5 | 0.032 |
| From Swedish Pellets | 79.3 | 88.7 | 89.5 | 0.022 |
| | 85.1 | 91.8 | 92.7 | 0.019 |
| From Soria Ore Pellets | 82.9 | 91.8 | 90.2 | 0.020 |
| | 84.9 | 92.5 | 91.7 | 0.015 |
| | 86.9 | 93.4 | 93.0 | 0.012 |

The Soria Ore Pellets were reduced with Charcoal.

TABLE 4

Approximate Production Costs for Echeverria Reduced Iron.

| | |
|---|---|
| Plant capital costs | $ 700,000 |
| Annual production of sponge iron of 93% total Fe content at 99 % Fe recovery | 20,000 metric tons |

Production costs:

| Item | Units | Unit costs $ | Units per ton | $ per ton product |
|---|---|---|---|---|
| Iron ore, 60 % Fe | ton | 8.50 | 1.57 | 13.35 |
| Anthracite | " | 14.00 | 0.32 | 4.48 |
| Limestone | " | 3.00 | 0.05 | 0.15 |
| Gas coal | " | 14.00 | 1.00 | 14.00 |
| Electric energy | kWh | 0.012 | 110.00 | 1.32 |
| Operating supplies and tools | | | | 0.25 |
| Maintenance, repair plus provision for renewal | | | | 3.00 |
| Labour | manhours | 0.70 | 4 | 2.80 |
| Overheads and general costs | | | | 1.70 |
| | | | Subtotal | 41.05 |
| Depreciation and interest at 10 % | | | | 3.50 |
| | | | Total Cost of Echeverria Iron Product | 44.55 |

TABLE 5

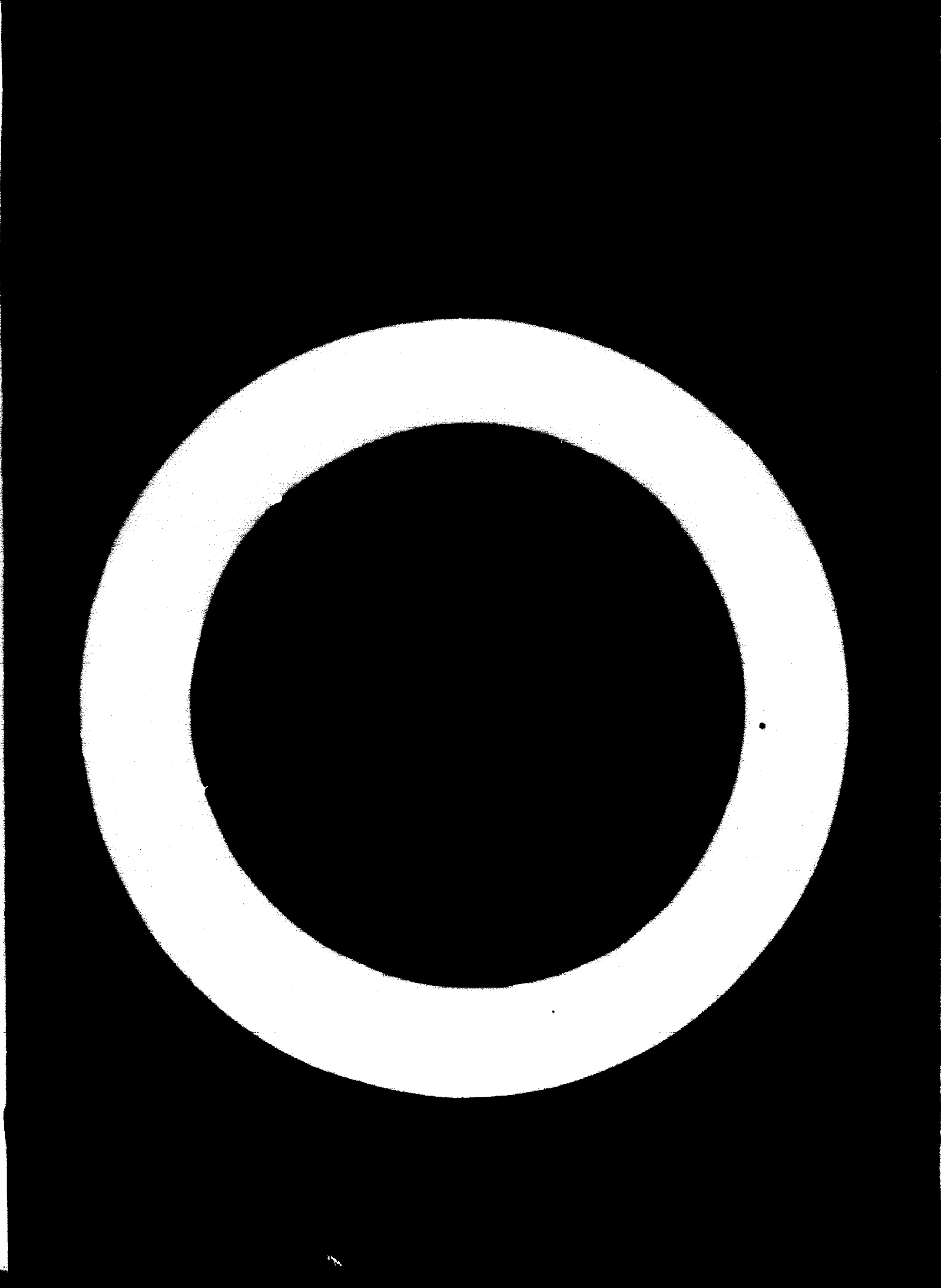
Capital Cost Estimate for a Modified Echeverria Plant with a Production Capacity of 100,000 Tons Iron Product per Annum

The plant would consist of 60 elongated silicon carbide retorts arranged in three rows of five units, four retorts per unit. Capacity of each retort = 5.7 tons of reduced iron per day.

Estimated Capital Cost:

| | | | |
|---|---|---|---|
| Equipment fob West European port | | $ | $ |
| 15 reduction units including oil burners | | 720,000 | |
| Magnetic separators, washers | | 70,000 | |
| Raw material storage and handling equipment | | 485,000 | |
| Equipment for distribution of electric energy and water | | 84,000 | |
| Miscellaneous items | | 93,000 | |
| Total equipment fob | | | 1,452,000 |
| Contingencies 10 % | | | 145,000 |
| Freight charges 8 % | | | 116,000 |
| Erection and installation 20 % | | | 290,000 |
| Building, 75 x 25 x 30 m | | | 225,000 |
| | Subtotal | | 2,228,000 |
| Engineering 20 % | | | 446,000 |
| Estimated total cost of plant | | | 2,674,000 |

Excluding: Site, site preparation, stores, spares, working capital, roads, railways, pelletizing equipment (if required), insurance charges, European supervision charges, automation of material handling, import taxes and levies.



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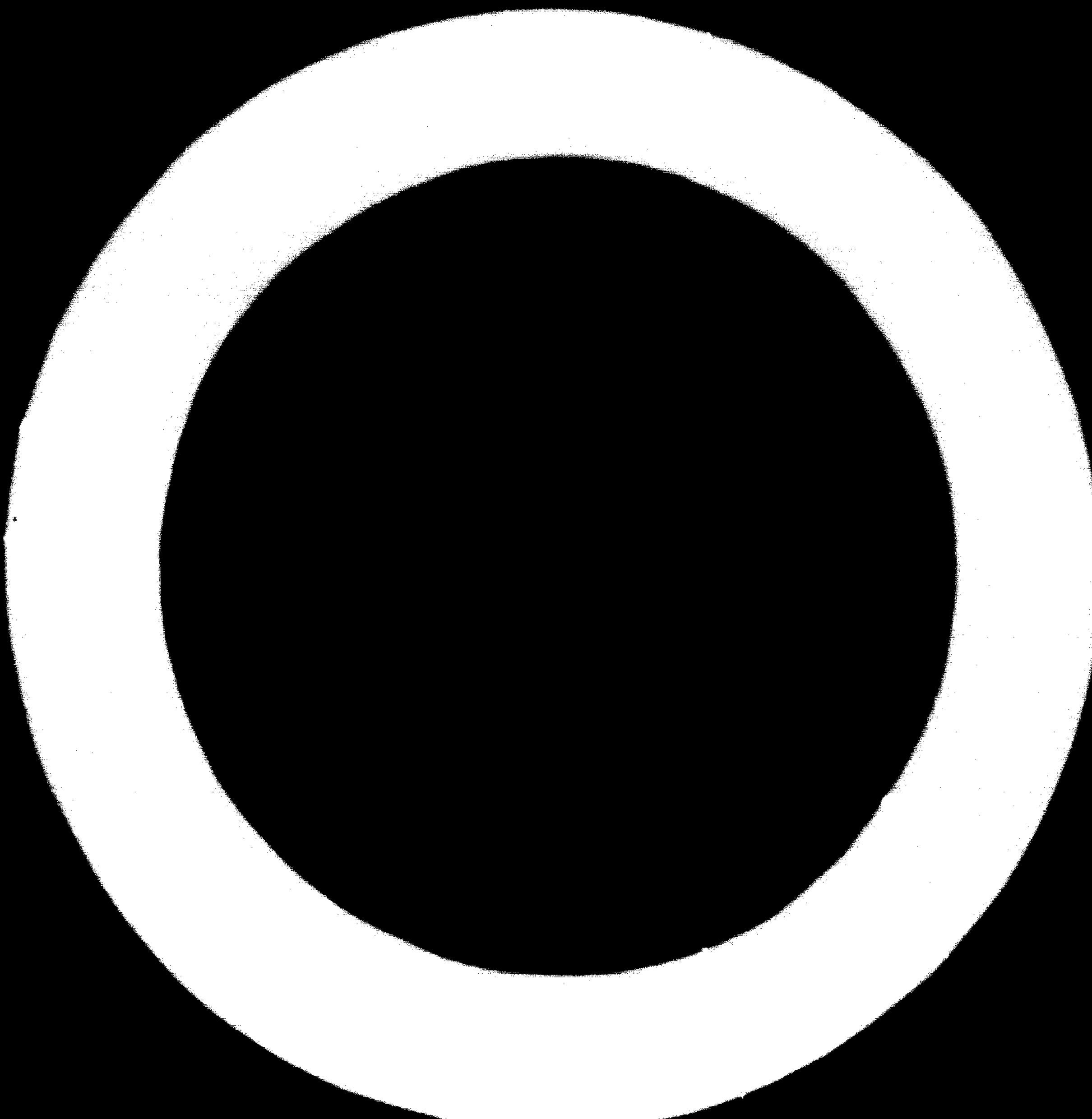
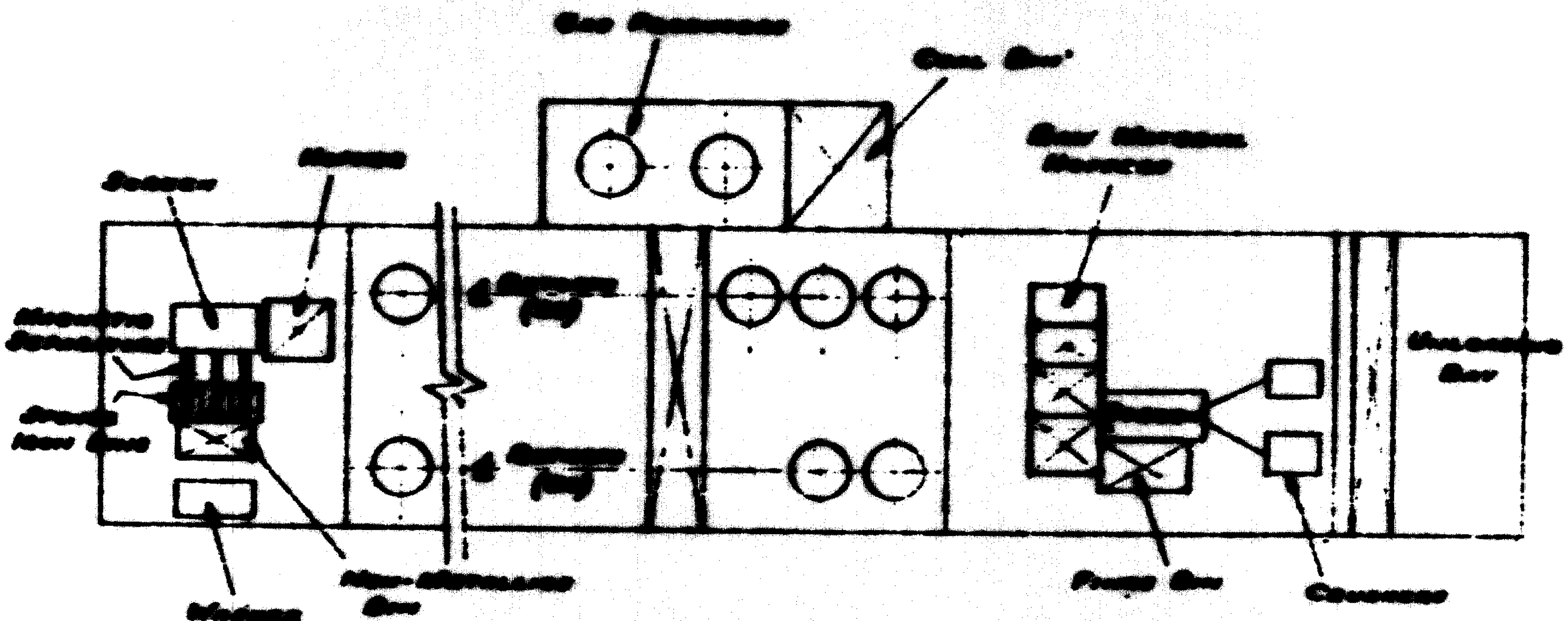


Fig. 1.



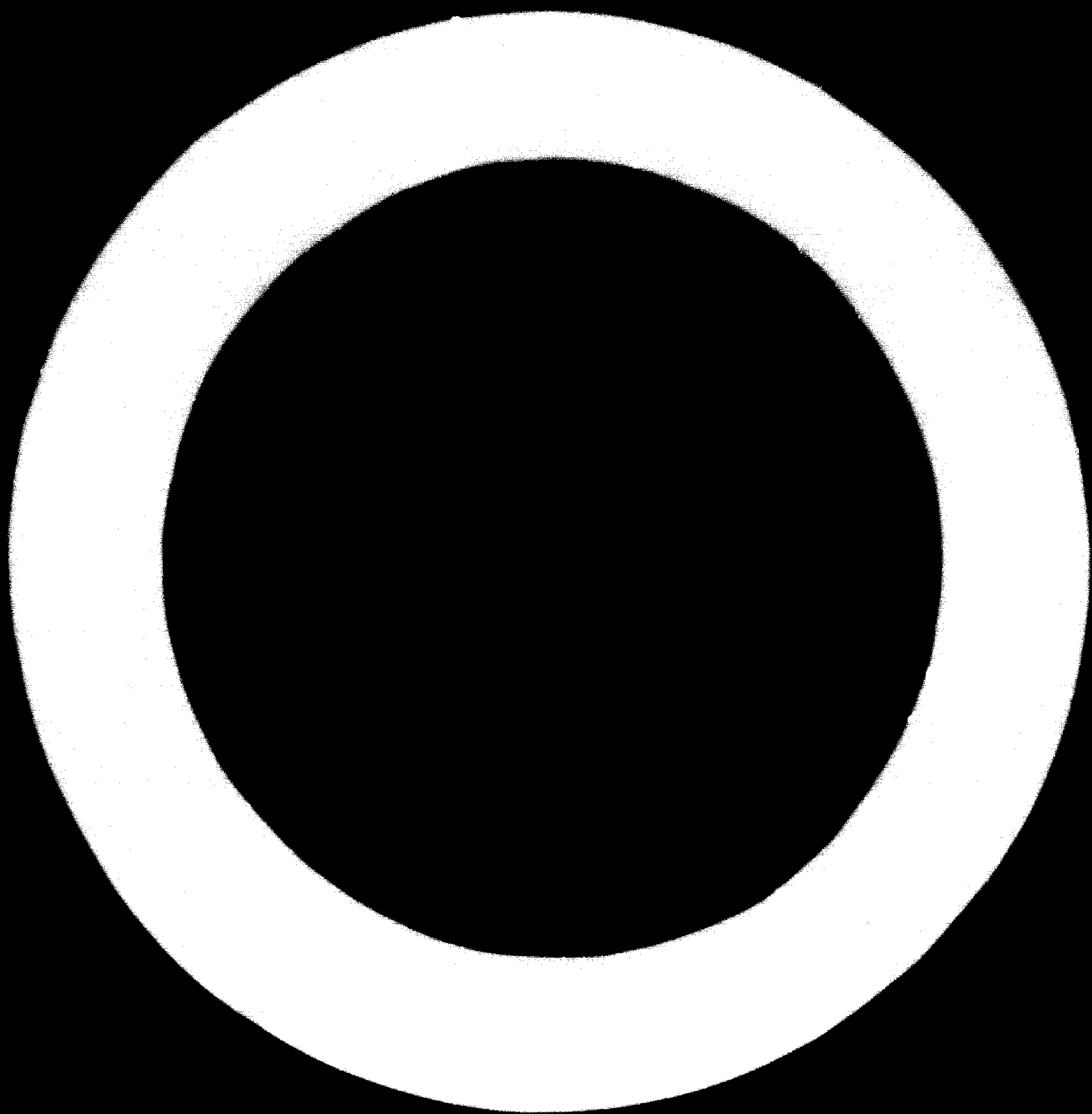
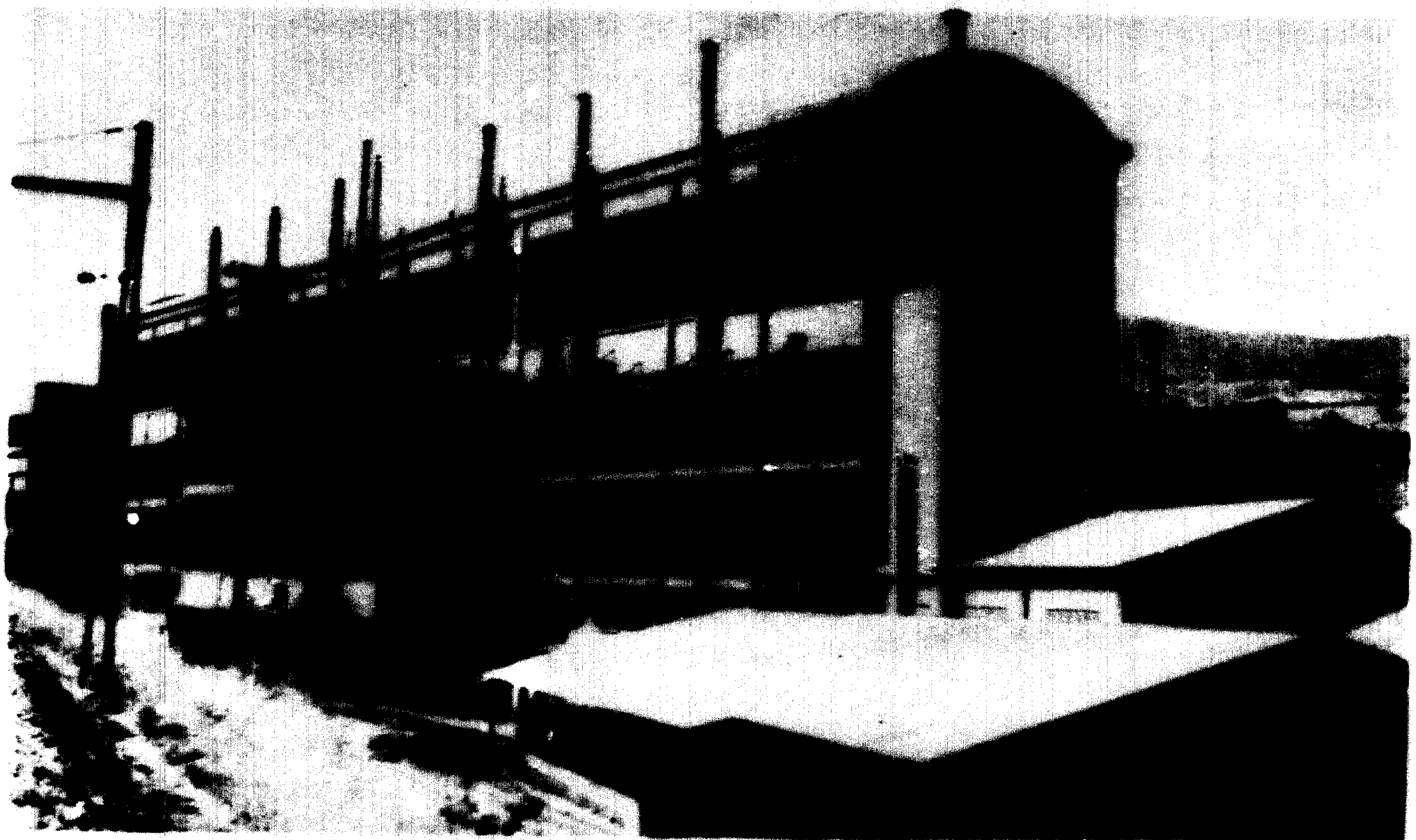


**Fig. 2.** Outside view of the Echeverria Plant at Legazpia, Spain



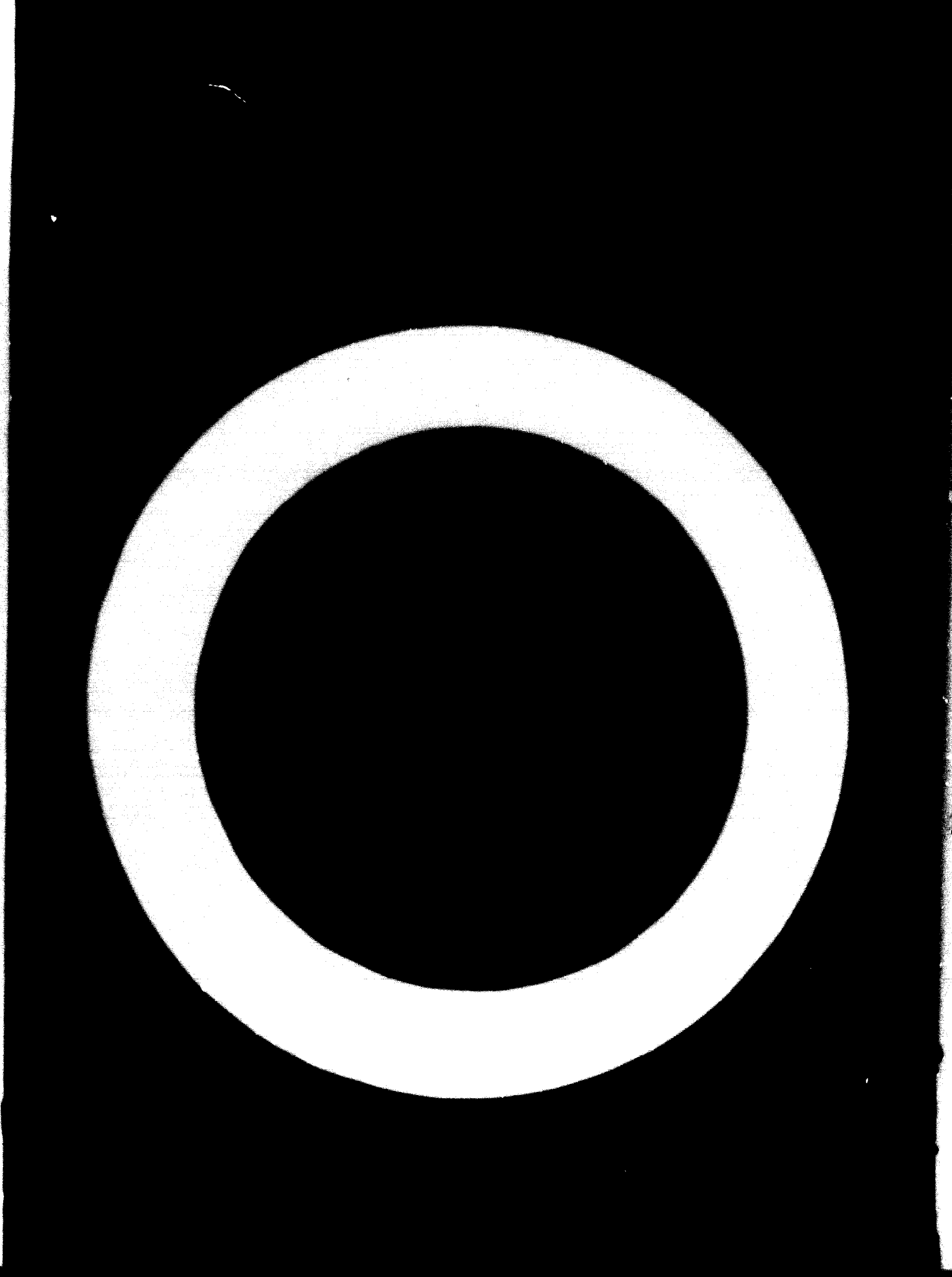
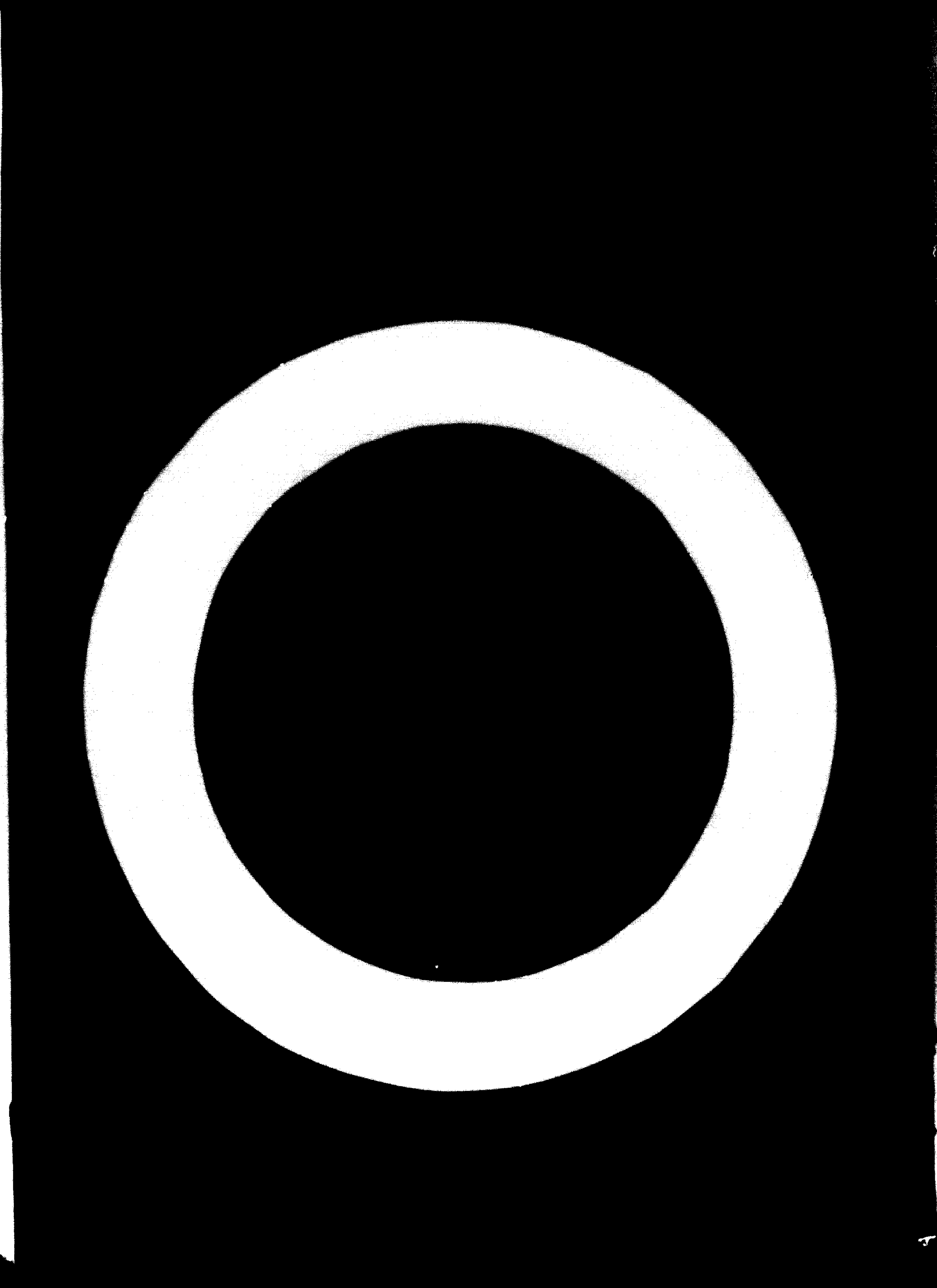
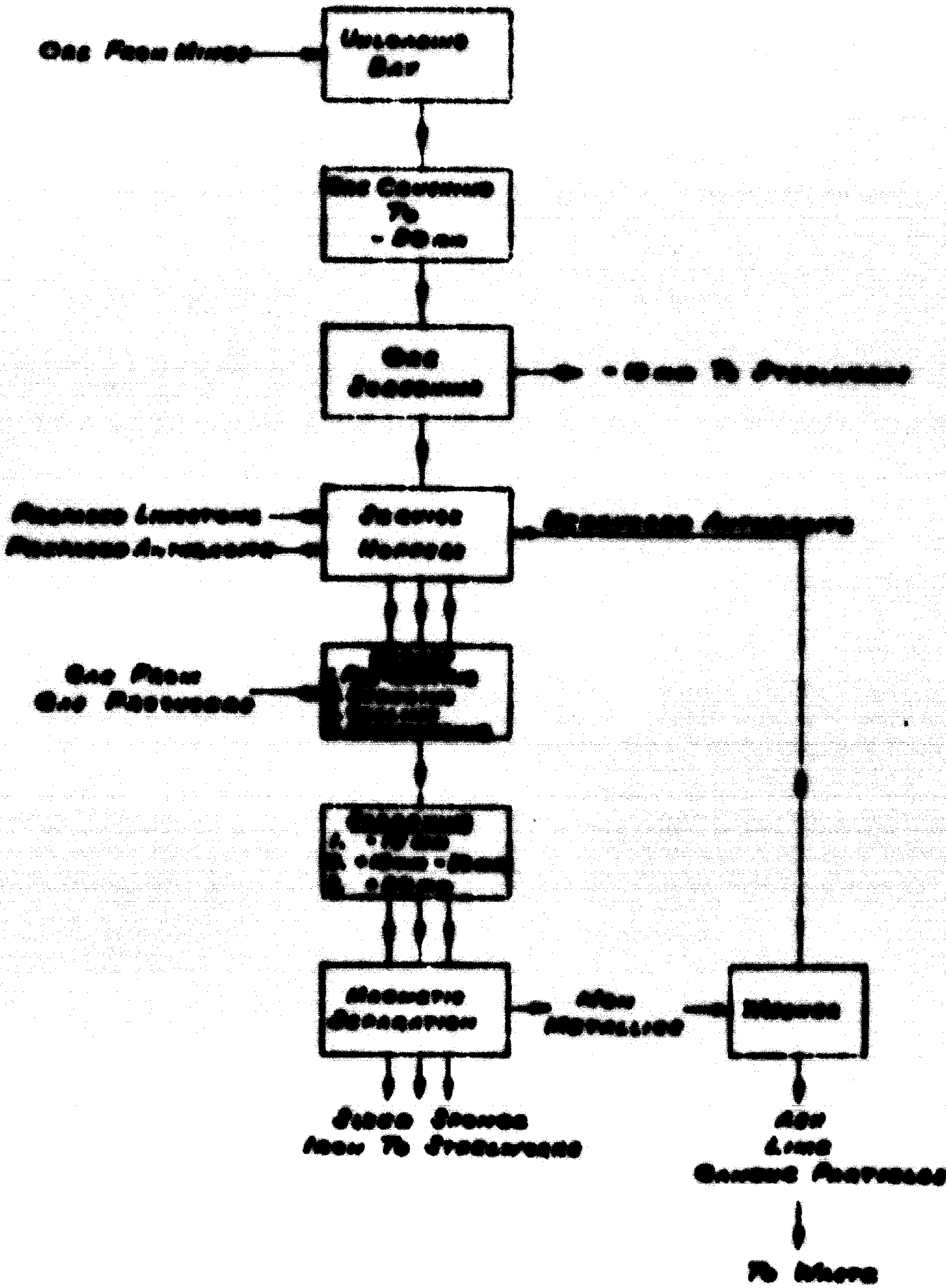


Fig. 3. A row of steel sheet mantled Echeverria shafts at the Legazpia plant.





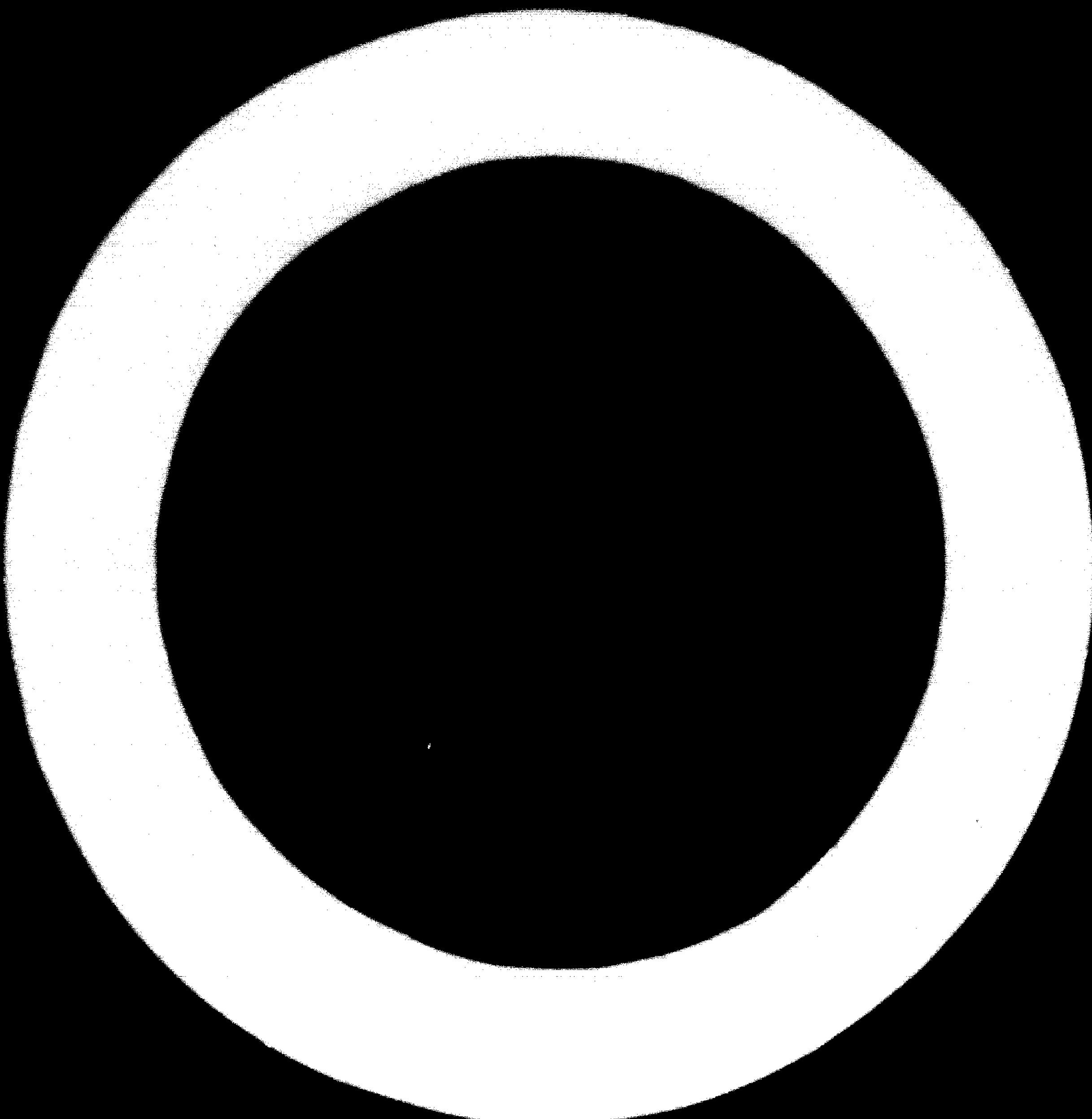
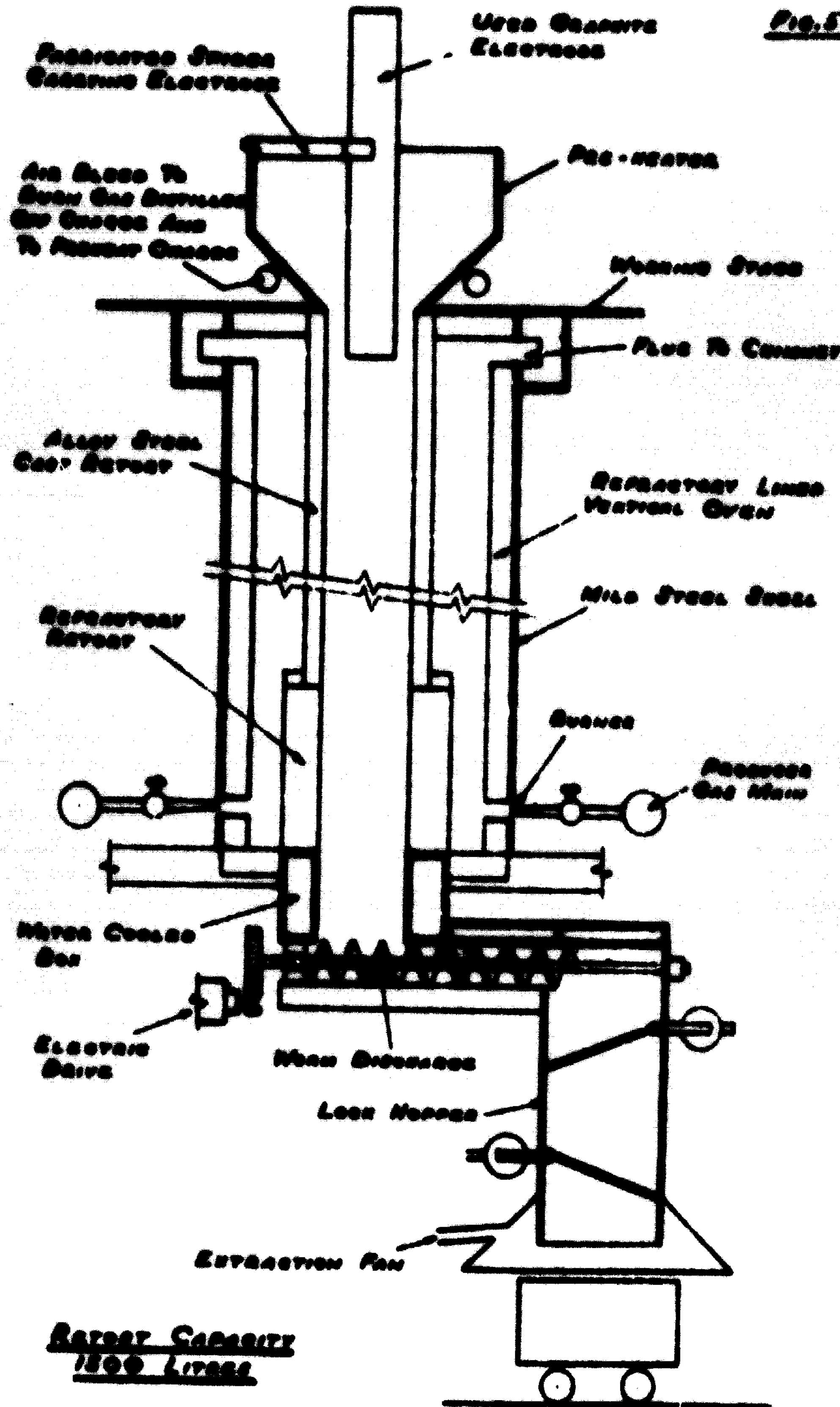


Fig.5.




Retort Capacity
1800 Litres

4. 4. 74