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CHARCOAL BLAST FURNACES - OPERATIONS : WUNDOWIE, WESTERN AUSTRALIA

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Page

CHARCOAL BLAST FURNACE OPERATIONS

INTRODUCTION

Charcoal was the earliest fuel used in the blast furnace. It has largely been superseded by coke for various reasons thus leading to the general belief that there is some inherent weakness in charcoal-iron propositions.

It cannot be denied that one of the factors responsible for the decline was the depletion of the forests but it must be remembered that charcoal burning and blast furnace operations were very inefficient compared with today's methods.

Old charcoal burning methods required 5 to 6 tons of wood to produce a ton of charcoal while a modern retort needs only 3½ tons. In the days before hot blast and other refinements, 8 tons of charcoal per ton of iron was necessary. Today we can talk of 0.7 and less. An old time charcoal furnace probably required 10 to 20 times as much wood to produce a ton of iron as would be the case today. No wonder the forests could not stand it!

Under modern conditions, charcoal can be as economic and efficient as coke for smelting iron ore in a standard blast furnace subject only to the provisions of adequate supplies of raw materials.

Charcoal iron is still in vogue in various countries of the world. In Russia an unknown number of charcoal blast furnaces are still in operation. Japan produces some 30,000 tons of charcoal iron annually while Brasil has an integrated iron and steel industry based on charcoal believed to be in excess of 500,000 tons annually. In Sweden, which was the main stronghold of charcoal-iron, the method has declined because of competition for wood supplies by paper pulp industries. Wundowie, in Western Australia, has two furnaces producing in excess of 50,000 tons annually.

The feasibility of charcoal-iron propositions cannot be discussed in general terms but each has to be decided on its merits, having regard to all the local factors.

It is essentially an industry for relatively new and pioneer countries, where extensive forests, full of waste wood are available either naturally or by cultivation. In America and Brazil, forests are developed to provide wood in perpetuity for charcoal production while Western Australia relies on natural resources.

The Western Australian project was initiated during the war years to supply local foundries with a vital raw material and to prove the economics of charcoal-iron production thus paving the way towards a full-scale integrated iron and steel industry. Its progress can be measured by its successful and profitable expansion 5 years ago from a pilot plant to a reasonable commercial sized operation.

DEVELOPMENT OF THE PROJECT

Western Australia with an area of 975,920 square miles comprises almost 33% of the total Australian continent but has only about 8% of the total Australian population of some 11,000,000 concentrated in the temperate lower South-West.

Up till recently the economy of the State was entirely rural; its industrial development having been retarded by its isolation from other centres and its meagre population. The capital city, Perth, is some 1,500 miles from its nearest neighbour of any magnitude.

Its isolation was brought into prominence during the war years when dependence on long sea hauls for vital raw materials made supplies highly vulnerable.

Panels of business leaders and technical experts were set up during the war to determine ways and means of producing the more important raw materials locally. Pig iron and steel supplies were naturally a prime consideration.

The panel investigating iron and steel was comprised of the Director of Industrial Development, the State Mining Engineer, the Government Mineralogist, the Professor of Chemistry of the W.A. University, the Government Geologist, a steel fabricating company director, the Chief Mechanical Engineer of the Railways, and the Utilization Officer of the Forests Department.

One of the major difficulties facing the panel was the question of a suitable fuel. Although Western Australia is endowed with vast deposits of high grade iron ore, it has no known deposits of coking coal.

Attention was first directed to other relatively new processes which were designed to circumvent the need for coke in conventional furnaces, but it was soon found that either the new processes were not developed to a commercial scale or that insufficient information was procurable at that time because of the war to permit the processes to be evaluated.

As Western Australia is heavily forested in the South-West corner, the investigation turned to the possible use of charcoal in a conventional blast furnace. The forest is comprised of 4,000,000 acres of eucalypt hardwood of virtually a single species in a solid continuous belt on a relatively undulating plateau presenting no real engineering difficulties for extraction of timber. The soil is mainly laterite making excellent roads quite cheaply. The timber is all relatively near to the coast and population centres.

All natural eucalypt forests contain many trees which are not good for sawmilling and allied industries due to age, damage by fire, fallen timber, suppression or malformation. These have tended to remain standing in the forest because their removal is costly and uneconomic. But they clutter up the forest, impeding regrowth and even preventing it; they present serious fire hazards, and are a source of infection by providing a haven for insect pests, rot, fungi, etc.

Over the past 100 years, the sawmilling and allied industries have been steadily cutting these forests, removing the best logs, poles and piles and leaving the worst. The limbwood from these operations aggravate the hazards and together with unmillable trees, represent a big economic waste

The form of the eucalypt tree, with its spreading crown necessarily produces large volumes of branch wood even in good type forests. This may amount to 50% of the standing trees, even in good millable trees. Add to this the poor type trees, the dead, and the useless species and it will be evident that up to 70% and may be more of the wood produced by a natural eucalypt forest is only waste wood.

As the species present are particularly resistant to rot, fungi and borers, waste wood will last for many years when lying on the ground. There was a desperate need for an industry using vast amounts of waste wood to remove the forest debris, which is otherwise only destroyed by periodic but very damaging bush-fires.

Such an industry would necessarily open up the forest by providing roads to extract the wood leaving it to re-grow unhampered. The roads create natural fire barriers and would materially help forest fire control - now an exceedingly difficult task.

It is estimated that the forest contains a conservative 40 tons of waste wood per acre. In an area of 1 million acres of forest or a circle of 25 miles radius, the waste wood amounts to 40,000,000 tons which in turn would produce 12,000,000 tons of charcoal. With a regeneration cycle of 100 years, an industry producing 120,000 tons of charcoal annually could be sustained in perpetuity. With more modern methods of transport, a radius of 40 miles is not uneconomic today so that the scope of the industry could now reach a production of 300,000 tons of charcoal in perpetuity. With modern blast furnaces, this amount of charcoal can produce over 400,000 tons of pig-iron annually.

With the fuel problem apparently solved, the panel directed its attention to the other raw materials required. Several large deposits of high grade hematite were known to exist.

Foremost among these were Koolyanobbing and Yampi Sound (see map) each of which was known to contain over 100,000,000 tons of high grade hematite ore of over 60% metallic content. Koolyanobbing is 300 miles East of Perth but close to the East-West main railway line while the deposits at Yampi are islands just off the North-West coast.

Following the usual pattern in the steel industry, the Panel decided that the ore must be transported to the fuel and to satisfy the haulage problems of both deposits it selected the sea-board site of Bunbury, 100 miles South of Perth and connected to the East-West railway line, as the eventual location for the integrated industry. This site had the further advantage of suitable limestone deposits in close proximity.

It was realised, however, that to embark on a large scale venture during the war years with all the problems of shortages of materials and plant and most vital, manpower, would be most unwise.

As an interim measure, the panel therefore recommended that a pilot plant be constructed of sufficient size to supply the then known requirements of pig iron (6,000 tons annually) and to provide for some future expansion. At the same time it would test out the feasibility and economics of the project.

Accordingly, a decision was taken by the State Government towards the end of 1943 to erect a blast furnace and ancilliary equipment with an output of 10,000 tons annually. For reasons not defined, the site selected was Wundowie 40 miles East of Perth, in contrast to the recommended sea-board site of Bunbury.

Probably the factor influencing the decision was the presence around Wundowie of easily recoverable limonite deposits in the form of hill top caps, averaging 40 to 50% Fe and amounting to over 1,000,000 tons. In addition, Wundowie is on the fringe of the hardwood forest, in an area cut over by sawmillers many times, yet containing vast quantities of waste wood estimated to be at least 50 years supply on the scale proposed. It is adjacent to the main East-West railway line and a main water supply serving the dry inland areas. All the requisites of the pilot plant were therefore close at hand.

It was decided that the pilot plant should comprise a wood carbonizing plant capable of producing 10,000 tons of charcoal per annum; a by-product recovery plant, and a blast-furnace of 10,000 tons annual capacity.

For the purposes of comparison all cost figures appearing in this paper have been converted to present day value in direct proportion to the official basic wage (lowest wage payable to an adult worker) which was £A4.18.1. in 1943 and has increased in the intervening period to £A14.17.3. per week of 40 hours. The costs are also converted to US dollars for ease of evaluation using a factor of 2.23 US dollars to £1 Australian.

The capital cost of the pilot plant was estimated at close to $1,000,000 with an income of $680,000 made up by:

Pig Iron	10,000 tons	at $46.5	$465,000
Acetic Acid	480 tons	at $380.0	$185,000
Wood Naphtha	112,000 gals	at 39 cents	40,000
			$680,000

The annual expenditure was estimated at $510,000 leaving an anticipated gross profit of $170,000 or 25% on sales.

The pig iron cost was estimated as follows:

	US Dollars
Labour and supervision	9.8
Iron Ore 1.88 tons at 3.03	5.6
Charcoal 0.90 tons at 13.50	12.2
Limestone 0.25 tons at 5.10	1.2
Power, services, maintenance	1.2
Overhead charges	2.0
Relining fund	1.3
TOTAL	$33.3 ex works

compared with the anticipated sales price of $46.5.

Because of the shortage of materials and labour, the pilot plant was not completed until early 1948 when the furnace was finally blown-in. By this time a sawmill to recover all the building timber possible and thereby provide waste wood more cheaply, had been added to the plant. The capital cost of the plant on completion had risen steeply to $1,500,000.

In the early years of operations many difficulties were encountered mainly resulting from lack of experience in management and operational staff, aggravated by inadequate plant in certain vital directions such as blowing engines and air heaters.

These difficulties were surmounted by 1953 when the plant and labour force had settled down and the pilot plant began to pay its way without further financial assistance from the Government.

Its progress was so marked that an expansion programme was initiated early in 1957 and completed in late 1958 to bring the plant up to a commercial scale unit. This was accomplished by the addition of further carbonising plant and a second blast furnace and ancilliary equipment, bringing the rated capacity up to 50,000 tons of pig iron annually.

This second stage has proved so successful that investigation is proceeding on the possibility of advancing a step further either by the addition of a third furnace of 50,000 tons capacity or by the construction of a new integrated plant at the site originally suggested at Bunbury.

DESCRIPTION OF PLANT

The plant today consists of a sawmill, two entirely different systems of wood carbonizing plant, a by-product recovery plant and two blast furnaces with ancilliary equipment.

(a) Wood Operations

It can be safely stated that the ultimate success of a charcoal-iron operation depends almost entirely on the availability and therefore the cost of wood production.

Much investigation, research and development has gone into this phase of the operation at Wundowie. It will be self-evident that in a high cost labour country like Australia where a labourer earns $35 and the Australian average overall workers is $50 per week of 40 working hours, that cutting wood by hand would be prohibitive. The emphasis has therefore always been on mechanization to the fullest extent.

The eucalypt forest yields trees with boles up to 30 feet girth and 80 feet long. Limbwood averages 50% of the total weight of the tree. The two main species available in the proximity of Wundowie are jarrah (eucalyptus marginata) and wandoo (eucalyptus redunca var: elata) both of which are extremely dense, hard and durable. The oven dry weight of jarrah is 48 lbs per cubic foot while that of wandoo is 63 lbs per cubic foot, i.e. denser than water even in a completely dry state.

The forest is worked in three stages. Firstly, all trees with millable logs are felled for feed for the sawmill where building and joinery timbers are recovered. The output of the sawmill has not varied from inception at 1,000 cubic feet of sawn timber per day. The waste wood is cut up by slasher saws into foot lengths prior to drying and carbonizing.

In the second stage, dry limbwood from the first stage and dead wood from fallen trees etc. are recoverable after a minimum period of two years to allow the limb-wood to air dry.

In the third stage, the remaining standing trees are bulldozed or felled and allowed to dry for two years or more before recovery as waste wood.

Both species used regrow readily from coppice shoots and if the trees are cut off close to the ground these shoots will develop into good trees, growing more quickly than seedlings because of the established root systems. Therefore, there is a continuous natural regeneration of forests in areas such as the State Forests which are not being completely cleared for farming purposes.

In the initial stages of the plant, the wood required for carbonizing was in the form of billets up to 4 feet long and up to 7 inches maximum cross-sectional dimensions. Tree felling for the sawmill and the preparation of the waste wood was carried out by mobile circular power saws. The logs were loaded by crane and the billet wood by hand, on to suitable motor vehicles for transport to the works.

When the additional carbonizing plant was installed, the extra wood was required to be in 12" lengths and 7" maximum cross-sectional dimensions because of the feeding arrangement for the new plant. Again mobile circular power saws were used for cutting, the wood being then hand-split and loaded into portable bins of 1.1/4 tons capacity. The latter were picked up by a rubber-tyred tractor and tipped into tip-type motor trucks for conveying to the works.

Eventually, this system also became unwieldly due to the number of cutters required. As a matter of interest, the output of billet wood per cutter per day was 10 tons while that of foot wood was 7 tons.

After further experimentation, it was decided that the forest operations could only be stabilised if the wood was transferred to a cutting section in the plant in the largest form possible.

At an installed cost of $120,000 a waste wood mill was designed and constructed to reduce wood from up to 20 feet lengths and up to 4 feet diameter to small wood of up to 12" lengths and a maximum depth of 3".

The arrangement of the mill is unique. Logs of varying cross-section and lengths are loaded into a U-shaped trough by a tractor logger. The U-shaped trough is mounted on wheels and is oscillated past circular saws of large diameter. The logs are pushed forward a predetermined distance by a pusher plate and are cut into "cheeses" no more than 12" thick. The "cheeses" fall onto a cleatless raised chain conveyor, which carries them on their flats under a reciprocating vertical splitter. The forward movement of the "cheese" through the splitter is regulated by the speed of the conveyor in relation to the speed of the splitter, resulting in widths of slices being no more than 3". The output of this mill is greater than 150 tons of cut wood per 8 hour day. The labour force is only 4 men.

The all-in cost of such wood ready to go into the carbonizing plant inclusive of the cost of the standing tree, preliminary cutting, loading on to motor vehicles, transport to the plant, milling and capital charges in less than $4 per ton. This revolutionary method of preparing dry hardwoods to a suitable form for carbonizing at such a low cost per ton is probably the biggest single factor in the success of the venture.

(b) Charcoal Production

The elementary composition of dry wood varies little with the species. There is on the average 48.5% to 50.5% carbon, 6% to 7% hydrogen, 43% to 45% oxygen, the principal constituents being cellulose, lignin and semi-cellulose.

The cellulose content varies between 30% and 63% with an average of 45%. On carbonization it gives 1% to 4% acetic acid and tars containing only traces of phenols and, of course, carbon.

Lignin represents the "skin" of the wood which contains between 20% and 30% of it with an average of 25%. Its composition is not well known but on carbonization it yields besides carbon, a little acid, methanol and tar.

The semi-celluloses, 20% to 30% in the wood, serve to agglomerate the vegetable fibres. They yield on carbonization products high in carbon, tar, and traces of acid.

Ash content of wood varies with the species and with the nature of the soil. There is more ash in the bark and in small branchwood than in the trunk. Ash content will vary up to 0.25%.

The moisture content of bark is usually much higher than wood and barked wood will dry faster than unbarked wood. Drying rates are also proportionate to the size of wood which is a very poor conductor of heat. The moisture in wood is usually in equilibrium with the atmosphere at about 15% based on the ovendry weight of wood.

If wood is heated in a closed vessel and the vapours are condensed, several distinct phases are observed. Below 170°C practically pure hygroscopic water is released. From 200°C a partial decomposition takes place yielding a pyroligneous product containing acid but not alcohol. Towards 250°C - 270°C an exothermic reaction begins and continues without increment of heat from external sources to 325° - 350°C. Heating must then be resumed to drive off the remaining volatile matter.

Yields of products vary considerably with each species. Hardwoods generally yield 6 to 8.6% of acids and softwoods yield less than 4%. Methanol and tar yields vary in a similar manner.

The physical quality of charcoal varies with the density of the wood, the size of the wood, and the method of carbonization employed.

Generally speaking, dense woods will yield hard dense charcoal while light woods yield charcoal of light weight and high porosity. The yield of charcoal from all types of wood is about 40% of the ovendry weight.

Almost without exception, small wood will yield harder and denser charcoal than large wood. With small wood there is less tendency to burst during carbonisation so that shrinkage cracks are kept to a minimum. The dimension along the grain is particularly important as wood dries and carbonizes quicker along the grain. In fact, some of the best charcoal made at Wundowie has been from discs of tree boles no more than 3" thick.

The retorting process has a large influence on the size of the charcoal produced. With slow carbonization large pieces of wood tend to fracture less than in faster methods. Modern retorts carbonise in under 24 hours so that it is important for the raw material to be as small as is economically possible. In some types of modern retorts, there is also mechanical damage to contend with when the charcoal is discharged through grates and doors.

The chemical quality of charcoal can be closely controlled in modern day retorts. Volatile content remaining in the charcoal can be held at 6% maximum while absorption by water can be kept to a minimum. The fixed carbon is usually between 90 and 95%.

The distillation of the eucalypts used yields the following principal products:

	Per cent of dry wood substance
Charcoal (average 10% volatile matter)	37.10
Non condensible but combustible gas	20.45
Pyroligneous liquor	42.45
	100.00

The phyroligneous liquor which is diluted by the 25% of free moisutre contained in the wood has the following principal constituents expressed as percentages of dry wood substance carbonized.

Acetic acid	2.80
Tar (soluble & insoluble)	9.70
Methyl alcohol	1.69
Other products	4.26
Water from decomposition	24.00
Total	42.45

(c) Carbonization - Batch Process

In all methods of carbonization some external heat must be provided. Wood is self-carbonizing at 8.5% moisture content if the heat of the charcoal is recovered and 2.9% if the heat of the charcoal is not recovered. Apart from losses from furnace walls, heat must be provided to reduce the moisture to the self-carbonising level.

There is a number of different processes in use today for the production of charcoal. Wundowie uses two of these processes for an output of 120 tons daily.

Horizontal batch-type tunnel retorts were installed to supply the needs of the original pilot plant. Under this system, the wood in billet form is hand-stacked into lattice-type steel containers mounted on railway lines. Four containers each holding 4½ tons of wood at 25% moisture content based on dry wood substance (d.w.s.) are connected together and charged to each retort.

The retort is a closed vessel with two off-takes leading to condensers. It hangs in a firebrick setting and is heated externally by blast furnace gas or non-condensable wood gas. The number of retorts is seven producing 40 tons of charcoal per day.

The combustible gas yielded by the distillation and having a calorific value of up to 400 B.T.U. per cubic foot, is burned under the retorts thus supplementing and thereby reducing the quantity of blast furnace gas used for carbonisation.

The rakes of buggies are withdrawn hot from the retorts and transferred to coolers where the heat is dissipated by radiation in the absence of oxygen. After 48 hours cooling the charcoal is ready for feeding to the blast furnaces.

(d) Recovery of By-Products

Pyroligneous acid amounting to about 18,000 gallons per day is piped to a by-product recovery plant to extract the wood tar, acetic acid, methanol and ketones it contains.

Part of the tar is insoluble in the pyroligneous acid and is separated out in conical bottom settling tanks. The soluble tars are recovered at a later stage by treatment with a solvent. The tar is used as a fuel for steam raising.

Crude methanol and other low boiling products such as acetone, aldehydes and methyl acetate are separated from the settled liquors by distillation in bubble cap columns. The crude methanol is further refined to pure methanol, methyl ethyl ketone and acetone.

Acetic acid and other homologes are separated from the demethanolised liquor by an extraction process using ethyl acetate as a solvent in a counter current extraction tower. The crude acid is recovered from the solvent by distillation and the solvent is returned to the circuit. The acid is then re-distilled to yield glacial acetic acid.

In view of the small population in W.A. and the lack of industries, most of the products recovered are marketed in the Eastern portion of Australia. Methanol is highly inflammable while acetic acid is highly corrosive and must be stored and carried in stainless steel containers. Distribution of the products is therefore very expensive and has militated against the profitability of the operation.

The methanol produced is used as an aircraft fuel for boosting jets on take-off and for plant hormone manufacture. Its biggest outlet is in the manufacture of formaldehyde which could go hand in hand with wood-distillation if circumstances warrant.

Acetic acid is used mainly in the food and textile industries, but again it could well provide the raw material for cellulose acetate and rayon manufacture.

It can be readily shown that these two by-products can compete with synthetics where outlets exist close to the distillation plants.

Because of the distribution problem, this section of the plant was not expanded with the remainder, leading to the selection of additional carbonising plant which could be operated without by-product recovery in the form of chemicals.

(e) Carbonisation - Continuous Process

The plant selected was the continuous rinsing gas type in which the wood is carbonised by direct contact with hot oxygen free gases.

Two retorts each of 35 tons per day nominal capacity were installed making the total charcoal production capacity for the plant a nominal 110 tons per day which it was then believed would allow pig iron capacity of 120 tons per day.

Actually, with wood of low moisture content and small dimensions, it is found in practice that these retorts will average 40 tons per day each giving a daily output of 120 tons from old and new plant.

This quantity of charcoal will, in turn, be sufficient for a daily production of 150 tons of pig iron of about 1% silicon in properly designed furnaces having up-to-date features.

Each retort consists essentially of a vertical steel unlined cylinder approximately 110 feet high and 11 feet in diameter with a flap type valve at the top to admit the wood and specially designed valves at the bottom to permit the periodic withdrawal of charcoal. The steel used for the retorts is specially selected to withstand the conditions under operation.

The wood is skip fed into the retorts, the charge being kept at a reasonably constant level. As it descends, the rising gases gradually dry and heat it to carbonizing levels. Just below the centre, the retort atmosphere is recycled, its temperature being kept constant by the burning of part of the re-cycled gas.

The charcoal from this section is cooled as it descends by the admission of cold oxygen-free gas at the bottom. On withdrawal it is conveyed on rubber belt conveyors to storage.

The cooling gas joins with the products of carbonization at the carbonizing level and forms part of the rinsing gas. The excess rises through the wood and helps to heat it. It is withdrawn from the top, scrubbed with tar, and piped to the steam raising plant for power generation.

Normally, the products of carbonization are not combustible when wood at 25% moisture content calculated on d.w.s. is carbonized in this continuous fashion. In this instance, blast furnace gas, which is oxygen free, is used as the cooling medium. Its admission ensures the combustibility of the top gas which, when burnt, actually produces in power, a by-product far more valuable to the plant as a whole than chemical products. Industrial power is expensive in W.A. at around 2.2 cents per unit.

To make the top gas combustible without this device, it would be necessary to artificially dry the wood well below its atmospheric equilibrium which would be extremely costly both in capital and operation.

The charcoal produced in both sections can be controlled to a given analysis. It usually has 85-95% fixed carbon and down to 6% volatile matter. Free moisture is under 5%. Ash depends on the species carbonized but is generally under 1%. It is hard and lumpy with less than 5% under 5 mm. It is therefore an excellent fuel for a blast furnace.

It is of interest to note that the batch system of operation requires 3 men per shift for an output of 40 tons per 24 hours, while the continuous system, being highly automated requires only 2 men per shift for an output of 80 tons per 24 hours.

There are several methods of producing charcoal in modern type plant, but it is believed in the light of experience gained with the continuous type, that it is to be preferred when used in conjunction with blast furnaces - an operation so far unique to Wundowie.

(f) Blast Furnaces

The first blast furnace to be installed for the original plant was of the simplest construction, its purpose being purely for pilot-plant operation. It had a 5 feet hearth and a rated capacity of 25 tons daily, using the limonitic ores located in the vicinity.

It was fully lined with ceramic refractories, with four tuyeres and the simplest of top charging gear. Apart from a primary dust-catcher, no further gas cleaning was indulged. The blowers were of positive displacement with a capacity of 1500 c.f. per minute of air up to a pressure of 5 p.s.i. They became very inefficient at or over that pressure!

The stoves were the recuperative type, designed for blast furnace gas and built entirely of mild steel. They failed rapidly soon after commissioning. Eventually the mild steel elements were replaced by heat resisting steel elements which had a life of about 6 months.

With gradual improvements in wind capacity (by the installation of a steam driven turbo blower), stoves and other ancilliary plant, the production was increased from 5,700 tons in 1949 to the rated capacity of 10,000 tons in 1952 - a difficult initial period of 4 years.

From 1952, the output increased year by year to 14,000 tons in 1957 with remarkable improvement in the economics to the self supporting level. It is of interest to note that in the first ten years of operation, this furnace produced close to 100,000 tons on the one lining or an average of 10,000 tons annually - the output planned for the plant in 1943.

Building of the second furnace was commenced early in 1957. It was designed by Industry personnel especially to produce 1% silicon iron whereas the first furnace was planned for foundry iron, and provision was made for as many modern features as possible.

As a result, a revolving top, double bell distributor, two gas up takes, pressure type dip stick, carbon bosh and hearth walls, automatic skip and 6 tuyeres were included in the design of this 8-foot hearth diameter furnace intended to produce 70 tons per day.

The furnace was blown-in in January 1958 and at the same time, No.1 was blown out for rebuild and reline. It was increased to a 6'-6" diameter hearth by using carbon in the hearth walls and bosh and had all the features installed in No.2. It was blown-in in January 1959.

No.1 furnace will now regularly produce 55 tons and No.2 furnace 95 tons of basic iron per day with lesser outputs on higher silicon foundry irons. Both furnaces have now operated over 5 years on the carbon linings.

During the rebuild, two additional turbo-blowers were installed which with the one installed in 1954, provide for one in operation on each furnace and one standby. The blowers have a capacity of 6,000 c.f.m. and a maximum pressure of 15 p.s.i. Being steam driven, control of volume at a constant level irrespective of the furnace back-pressure was readily arranged.

The air-heaters for both furnaces - 2 off per furnace - are of the recuperative counter flow type with sufficient surface to raise the blast temperature to 1200°F when burning blast furnace gas. The elements in the high temperature section are made of 25/20 chrome nickel high temperature steel tubes. They are designed for easy maintenance particularly in tube replacements.

The gas from both furnaces, after leaving the primary dustcatchers, is joined in a common dirty gas main. It is then scrubbed in venturi type gas cleaners and distributed throughout the plant.

Each furnace is tapped alternately every 4 hours into a common 20-ton ladle, the hot metal being pigged on a two-strand pig machine with 120 moulds per strand producing notched pigs of about 50 lbs each.

Each cast is dropped off the end of the machine on to a specially designed motor vehicle for transfer to the stockpile, where it is stored separately until required for an order.

The plant has steam raising capacity of 45,000 lbs per hour, a turbo-generator of 250 K.W. which is sufficient for all the continuous power requirements of the plant, three steam turbo-blowers, a stand-by diesel generator set of 250 K.V.A. and all the necessary instrument air and compressed air services.

(g) Special features of small plant operation

The personnel employed in the various sections are as follows:

One shift operation

Sawmill Log Recovery (contract & supervision)	10	
Sawmilling & Distribution of sawmill products	64	
Waste wood recovery (contract & supervision)	66	
Waste wood log recovery (contract & supervision)	10	
Waste wood log mill - one shift at present	4	
Materials handling	19	
Laboratory	6	
Technical staff	11	
Office staff	24	
Transport maintenance	19	
General maintenance, cleaning etc. stand-bys for shift-workers etc.	106	339

Three shift operation

Batch Retorts	3 per shift	12	
Continuous Retorts	2 " "	8	
By-Product recovery	1 " "	4	
Blast Furnaces	8 " "	32	
Steam-raising plant	1 " "	4	
Power Plant	1 " "	4	
Shift Bosses	1 " "	4	68
			407

It may be of interest to record that the number of workers per shift on the continuous section of the plant including charcoal, acetic acid and methanol recovery, and blast furnaces is only 17 men including a shift supervisor.

It will also be noted that only 32 men are employed in the blast furnaces. As four shifts are worked, 8 per shift are sufficient to cover the operations of both furnaces and show the economy possible with small furnaces. Each furnace has a keeper and a scale car operator. The helpers and plant hands assist with costs from both furnaces and operation of the pig machine. The furnaces are left unattended during pigging operations but as the machines are close by, there is little danger.

Ladle temperature of the metal is between 1300 and 1400°C. Tuyeres and cooler failures are rare when linings are good but frequent failures will occur when the linings become worn.

Perhaps the most important need for any furnaces and these at Wundowie are no exception, is the maintenance of a good cooling water supply. At Wundowie water is recirculated through a cooling tower. Special precautions are necessary to ensure that flows are not interrupted through depositions in pipes etc.

Both furnaces were installed with bosh and stack spray cooling but have stave cooled hearths. In the light of experience, it would be preferred to splash cool hearths of the existing and future furnaces.

Occasionally, when wet charcoal is fed to the furnaces, clean and sticky hanging can and does occur but otherwise operation is relatively smooth and regular. Both mixed and layer charging have been tried without noticeable difference in operation. Mixed charging is preferred for simplicity in operation.

As the lines of each furnace are substantially different, it is natural that there are some differences in operation. It is found that No.1 furnace can more readily produce high silicon grades and No.2 is better burdened for under 1.5% silicon. The charcoal-iron ratio on No.1 furnace is around 0.85, while that of No.2 is around 0.70, the average overall being 0.75.

The disadvantage with small furnaces is the irregularity in grade from cast to cast, but these irregularities become less pronounced as furnace sizes are increased. For instance, No.1 furnace with a 6'-6" hearth diameter has varied by ∓ 0.5% in silicon content from cast to cast whereas No.2 with an 8'-0" hearth can be held fairly steady with a variation of ∓ 0.25% from cast to cast.

As care has been taken to ensure that wind volume is kept constant, and the iron ore, charcoal and limestone are of very uniform grade, it will be obvious that the difficulty lies in weighing out the small quantities for each skip load.

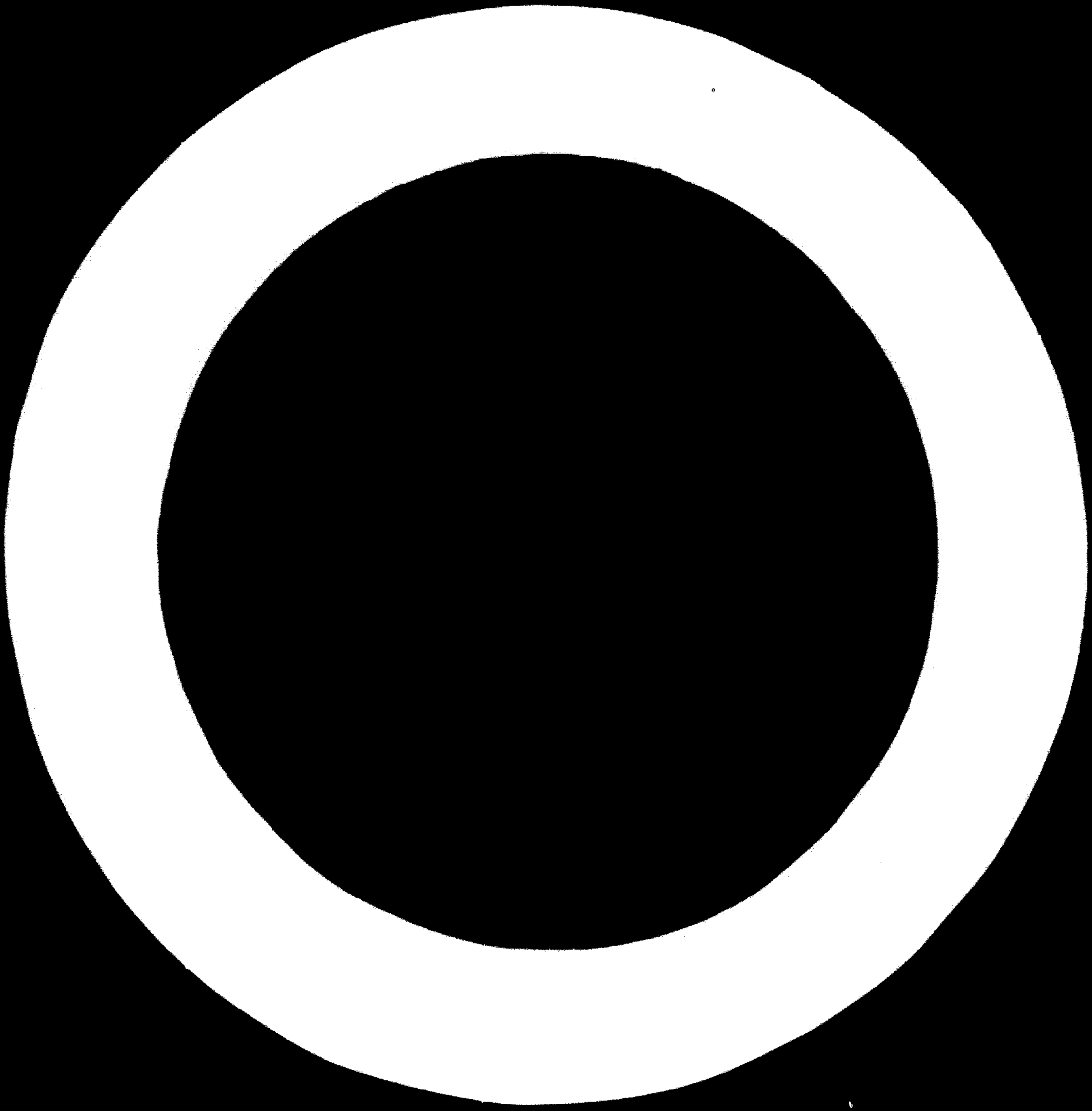
As Wundowie is only a pig iron producer, regularity of grade from cast to cast is not as important as it would be to an integrated steel industry. Casts at Wundowie are kept separate and analyzed separately and are only combined to make up orders. Customers can by this means be assured of uniformity throughout a consignment and can be supplied with iron to very close tolerances in all elements.

One feature of charcoal operations is the very low sulphur of the iron produced. Wundowie specifies and sells iron at 0.01% sulphur as a normal production. At the same time, phosphorus is low at about 0.03% while other tramp elements are virtually non-existent.

Because of the low ash content of charcoal and the high grade of ore used, the difficulty in operation is to keep slag volumes up to a workable level. Both furnaces operate with a volume of 400 lbs per ton of iron produced. This is done by adding slag formers in the form of low grade limestone which is available cheaply. If only high grade stone was available, quartz would have to be added to ensure workability of the furnace.

Again because of the low slag volume, the cinder notch, built into each furnace as an elevated tap hole, is used in emergencies only, the slag being tapped through the tap hole with the iron. The slag is run into pits adjacent to the cast house and dug out once weekly.

A typical burden for No.2 furnace is as follows:



Furnace - typical burden

S L A G

Burden Composition	lbs	SiO2 %	SiO2 lbs	Al2O3 %	Al2O3 lbs	CaO %	CaO lbs	MgO %	MgO lbs	MnO lbs	FeO lbs	CaS lbs	Total lbs
[illegible] Ore	4120	3.9	160.68	.3	12.36	.21	8.65	.19	7.83	[illegible]	[illegible]	[illegible]	-
Sandstone	520	20.5	106.60	.5	2.60	43.20	224.64	.11	.57				-
Quartz	40	95.8	38.32	2.7	1.08	.02	-	-	-				-
Manganese Ore	24	8.7	2.09	2.9	.70	-	-	-	-				-
Total in Burden			307.69		16.74		233.29		8.40	16.95	5.30	5.00	593.37
To Iron & Slag			59.61										59.61
Remaining in Slag & Iron			248.08		16.74		233.29		8.40	16.95	5.30	5.00	533.76
Composition of Slag & Iron %		46.48		3.14		43.71		1.57		3.17	.99	.94	100.00

I R O N

Burden Composition	lbs	Fe %	Fe lbs	Mn %	Mn lbs	P %	P lbs	S %	S lbs	Si lbs	C lbs	Total lbs
[illegible] Ore	4120	63.4	2612.08	.4	16.48	.02	.82	.03	1.23	[illegible]	[illegible]	-
Sandstone	520											-
Quartz	40											-
Manganese Ore	24	6.6	1.58	40.75	9.78	.08	.02	.48	.12			-
Total in burden			2615.38		26.26		.84		1.35	27.81	116.18	2788.23
To Iron & Slag			4.32		13.13		-		.96	-	-	18.21
Remaining in Slag & Iron			2611.26		13.13		.84		.39	27.81	116.18	2770.02
Composition of Slag & Iron %		94.27		.47		.03		.015		1.00	4.19	99.996

SLAG PER 1 ton of IRON 431.6 lbs.

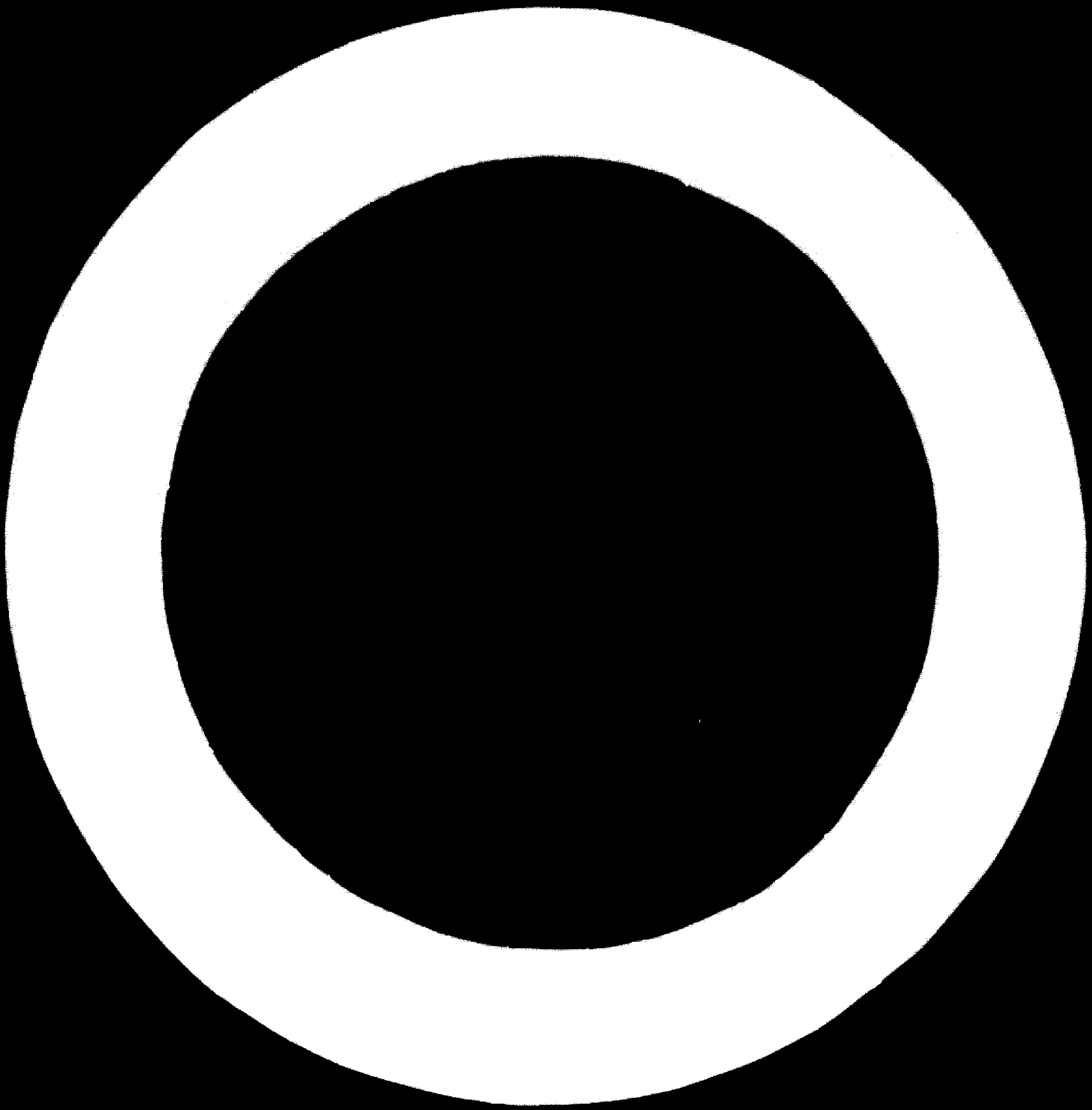
BURDEN:	[illegible] ore	4120 lbs.
	Sandstone	520 "
	Quartz	40 "
	Manganese Ore	24 "
	Charcoal	2000 "

IRON:	Si	1.00 %
	Mn	.47 %
	P	.03 %
	S	.0145
	C	4.19 %

SLAG:	SiO2	46.48 %
	Al2O3	3.14 %
	CaO	43.71 %
	MgO	1.57 %
	MnO	3.17 %
	FeO	.99 %
	CaS	.94 %

T.Alkalines

BASICITY: $\frac{CaO + MgO}{SiO_2} = \frac{45.28}{46.48} = .97$



REFINING OF PIG IRON

The pig iron as produced at Wundowie is already a high grade product being comparatively free of detrimental trace elements. It is used exclusively for special purpose castings such as ductile irons and roll-making.

The iron ore used is of such high standard that, when smelted with charcoal which is comparatively free from ash, a very pure pig iron is produced. The following are typical specifications:

	CHARCOAL IRON			BASIC IRON	HEMATITE IRON
	General Specification	White Iron	S.G. Base Iron		
Silicon	0.25 to 3.75% in 0.25% divisions	0.25% max	0.25 to 2.75% in 0.25% divisions	1.2% max	0.25 to 3.75% in 0.25% divisions
Carbon	3.5/4.5 depending on Silicon	4.0/4.5	3.75/4.5 depending on Silicon	3.75/4.25	3.6/4.5 depending on Silicon
Manganese	0.4 to 1%	0.6% max	0.4% max	0.8 to 1.0%	0.6 to 1.0%
Sulphur	0.015% about	0.05% max	0.02% max	0.04% max	.05% max
Phosphorus	0.03% about	0.03% about	0.03% about	0.1%	0.1%
Titanium	0.02% max	0.02% max	0.02% max	-	-
Other elements	nil to trace	-do-	-do-	-do-	-do-

With advancing technology, there is a growing demand for irons of even higher purity than those shown. The specification is as follows:

Silicon	0.2 maximum or lower
Manganese	0.2 " " "
Carbon	3.5 minimum
Phosphorus	0.115 maximum
Sulphur	0.01 maximum

Titanium &
Other elements - trace only

This iron can readily be produced with a new metallurgical tool called a "Shaking Ladle" which was developed in Sweden for the refining of pig iron and provided that the iron is reasonably pure to begin with, it can be further refined quite cheaply.

After being charged to the ladle, the pig iron is given a swirling motion by the movement of the ladle and all elements can be reduced by the addition of various slag formers in combination with top blowing with oxygen.

This method of refining can lead to the production of steel in a similar type of vessel. In some respects, the various operations are somewhat like the first stage of a combination L.D. and Kaldo process before the carbon blow.

A shaking ladle is being installed at Wundowie but results were not available at the time of writing.

FUTURE DEVELOPMENT

It is proposed that the next stage in the development of this type of industry in Western Australia, should be based on the construction of such larger furnaces allied possibly with alloy steel production, not necessarily at Wundowie, but more probably at the site originally chosen at Bunbury.

Although it is not known what maximum size furnace can be operated on the hard lumpy charcoals that are producible from W.A. hardboards, it is known that furnaces up to 65 feet from tuyeres to stockline have been operated successfully on hardwoods in other parts of the world.

For instance, a furnace at Nadishdrusk in Russia was erected in 1942 with a working height of 57'-5" and a hearth diameter of 11'-6". It had a working volume of 7,000 cubic feet and it had a rated capacity of 180 tons daily.

Compare this with the No.2 furnace at Wundowie with a working height of 46'-9", a hearth diameter of 8 feet and a working volume of 2540 cubic feet producing 95 tons per day. (See furnace lines No.1, No.2, 200 tons per day and 400 tons per day).

Using the constants found with the furnace at Wundowie, the Russian furnace could easily produce 300 tons per day. This remarkable difference is due mainly to the fact that European hardwood charcoals are much lighter.(12.5 lbs per cubic foot) compared with Wundowie at 19 lbs per cubic foot bulk density of lumpy charcoal, and to the quality of the iron ore used.

The furnace proposed with a 65 foot working height and a 15 foot hearth diameter, will produce at least 400 tons daily. It is not known whether this is the largest furnace that can be built on this type of charcoal but it would lead the way to larger furnaces once the results have been assessed. Two such furnaces would produce sufficient for 280,000 tons annually which with oxygen steel and continuous casting could readily be worked up to an economic integrated steel industry.

Actually, it is debatable whether there is any limit to the size of charcoal furnaces. Some authorities have now proved beyond doubt, that the softening of iron ore under the action of carbon monoxide and heat is a far more serious consideration than the softness of the fuel. Iron ore begins to soften soon after entering the furnace and this probably imposes greater limitations than the quality of the fuel.

It has been further shown that sinter does not soften as much as iron ore, and pellets react about the same as iron ore. It is therefore highly probable that with a combination of sinter and pellet burden, charcoal furnaces could approach coke furnaces in size and better them in performance because of the low slag volumes generated.

As mentioned earlier, the combination of blast furnaces with wood-distillation in continuous retorts can yield a valuable by-product in the form of a combustible gas. The projected plant would have sufficient surplus gas over and above normal plant requirements to continuously produce 5,000 K.W. It will be obvious that this would be more than sufficient for the oxygen requirement for steel manufacture and most of the power requirements of the mills. This feature alone makes the possibilities of an integrated industry attractive but it could not have been possible without the development of continuous retorts in conjunction with high top pressure blast furnaces.

The proposed plant would be comprised of the following main items:

	Capacity
Wood cutting and handling plant	1800 tons per day
Continuous carbonising retorts	600 " " "

	Capacity
Power plant including steam raising plant, turbo-blowers and turbo-generators	
Blast furnaces 2 @ 400 each	800 tons per day
Workshops, offices etc.	

The capital cost of this plant including all ancillaries to produce 800 tons per day of molten pig iron is estimated at about $10,000,000.

It might be of interest to compare the basic costs of the present and past operations with the estimated cost of the higher output.

	Pilot Plant		Commercial plant	Larger Plant
	Estimate 1943	Actual average 1948/57	Actual average 1958/63	Estimate 2 x 400 ton furnaces
Output of Iron	10,000	10,000	50,000	250,000
	- - - - U.S. Dollars per ton - - - - - - - - - -			
Operating costs including operating materials	9.8	6.51	3.05	0.60
Maintenance		2.45	1.21	1.00
Ores	5.6	16.13	12.70	11.70
Charcoal	12.2	19.84	16.35	15.00
Fluxes	1.2	2.50	1.17	1.00
Power and Services	1.2	5.33	1.68	1.00
Administration and Overheads	2.0	6.53	3.64	1.54
Relining Fund	1.3	0.58	0.58	0.58
U.S.$ ...	33.3	59.87	40.38	32.42

This comparison is based on practical experience in a plant producing 50,000 tons annually. It will be noted that depreciation and other capital charges are omitted as they are subject to domestic considerations.

In estimating the unit costs for the larger plant the following assumptions have been made:

(a) The labour for each furnace will increase by two men per shift but other services and service materials making up the operating cost are assumed at the same rate as for the present output.

(b) Iron ore is made available at furnace hoppers at $7.3 per ton compared with $8.2 in the present operation. It is assumed that 1.6 tons of ore per ton of pig iron will be required.

(c) Wood is assumed at $4 as existing but charcoal cost will reduce to $18 because of volume production.

(d) Flux cost is reduced because of volume production.

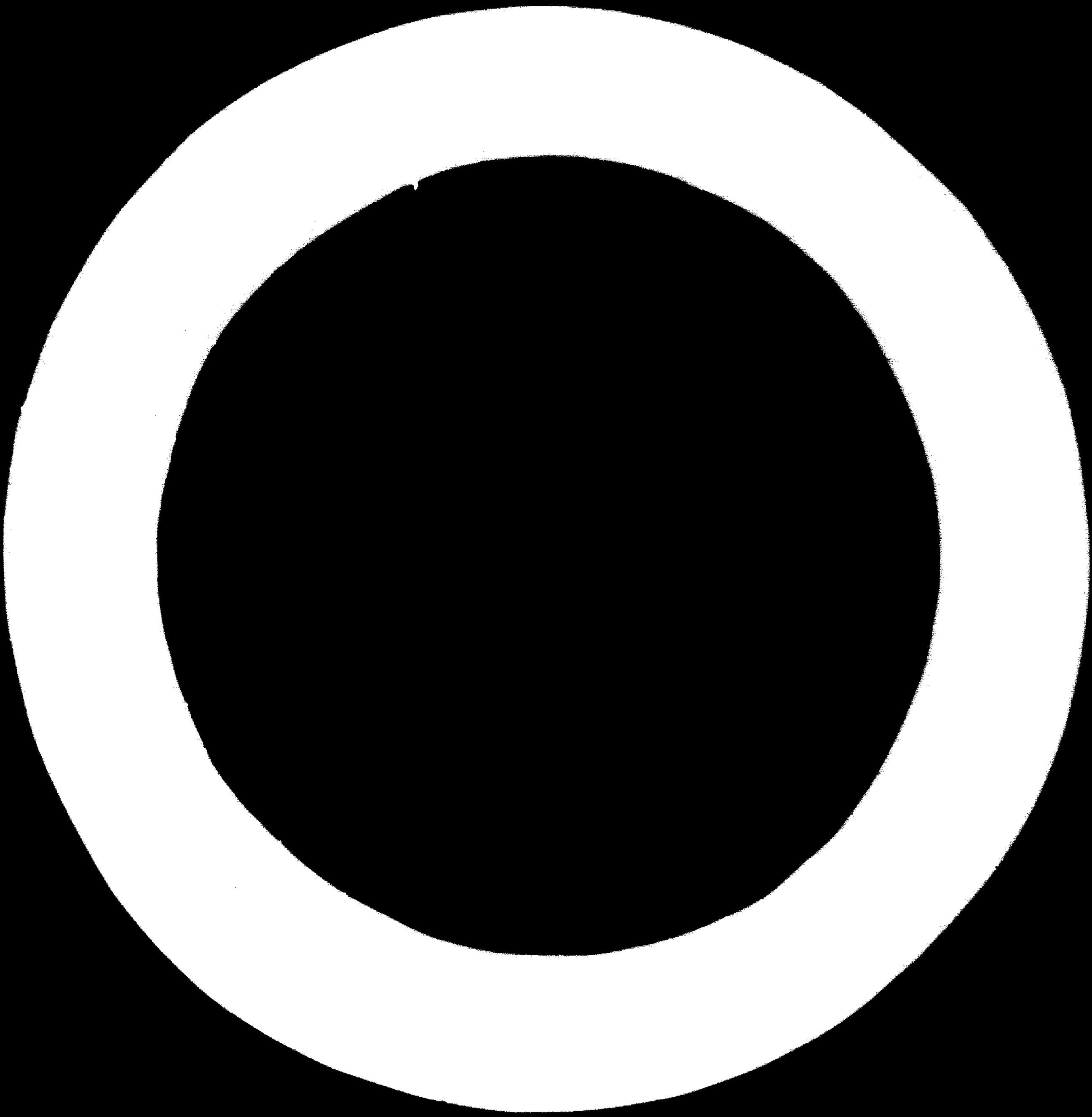
(e) Power and services are reduced because of volume production.

(f) Administration and overheads in total value is doubled for the higher output.

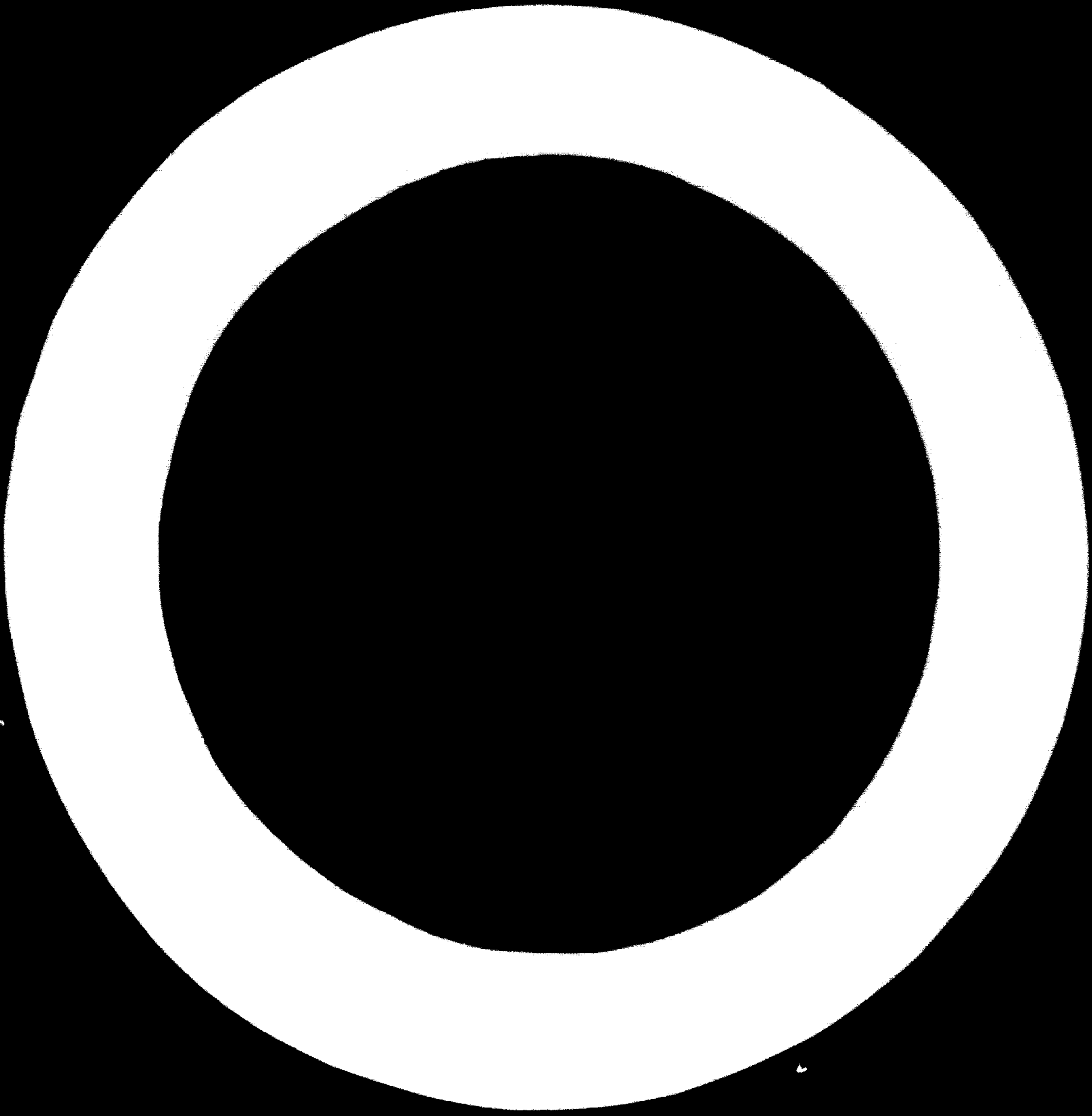
(g) The relining cost remains the same.

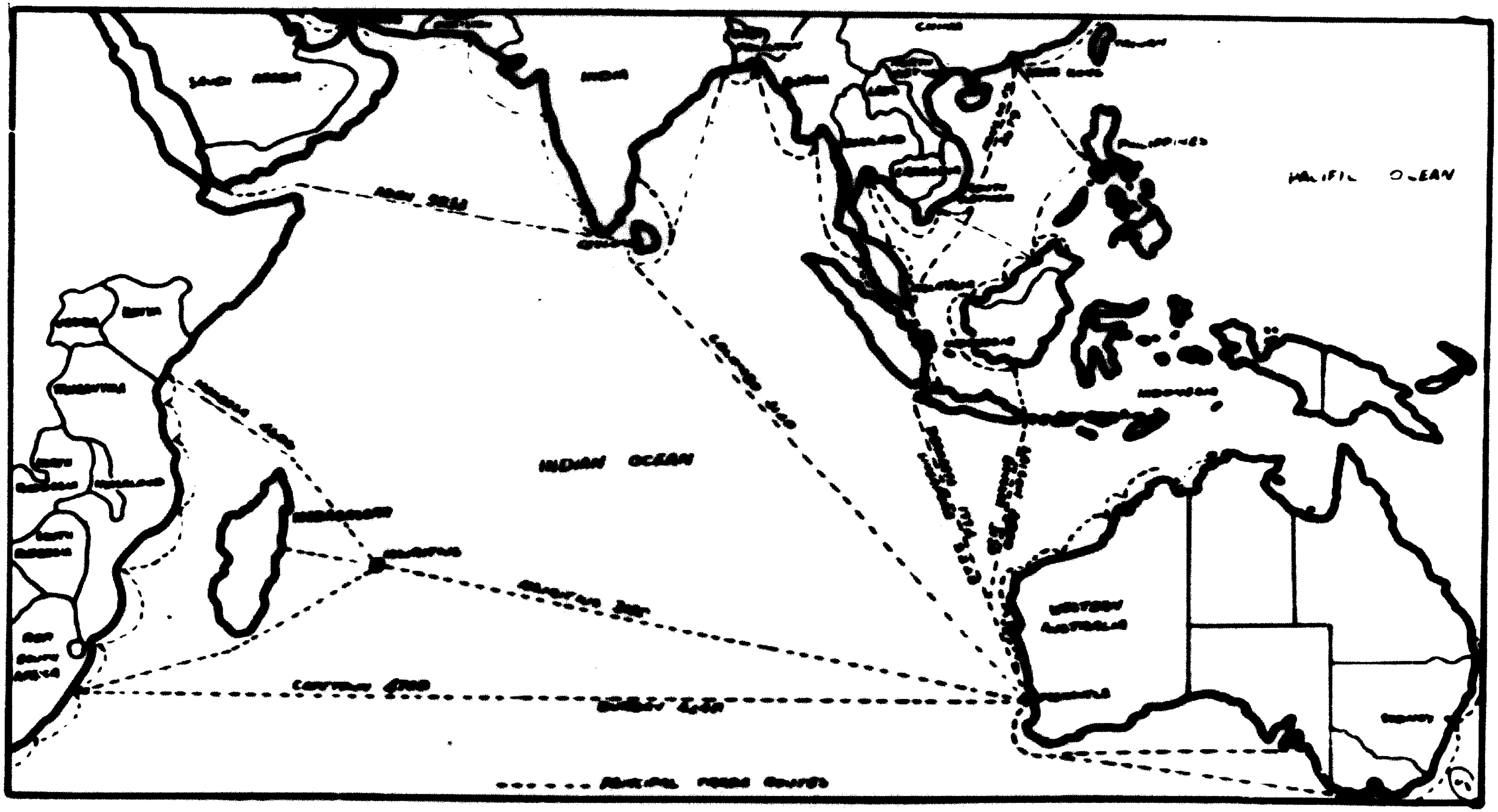
These costs clearly demonstrate the effect of volume on costs. They also illustrate the possibilities of charcoal iron as a basis for steel production in countries where coking type coal is not readily available, but where extensive forests still remain unexploited or can be developed for the purpose.

This is particularly applicable to under-developed countries where markets may limit outputs to relatively small scale operations, but which otherwise have the resources to embark on integrated steel industries without having to face up to importation of coke or coking coal.



FIGURES




SAUDI ARABIA
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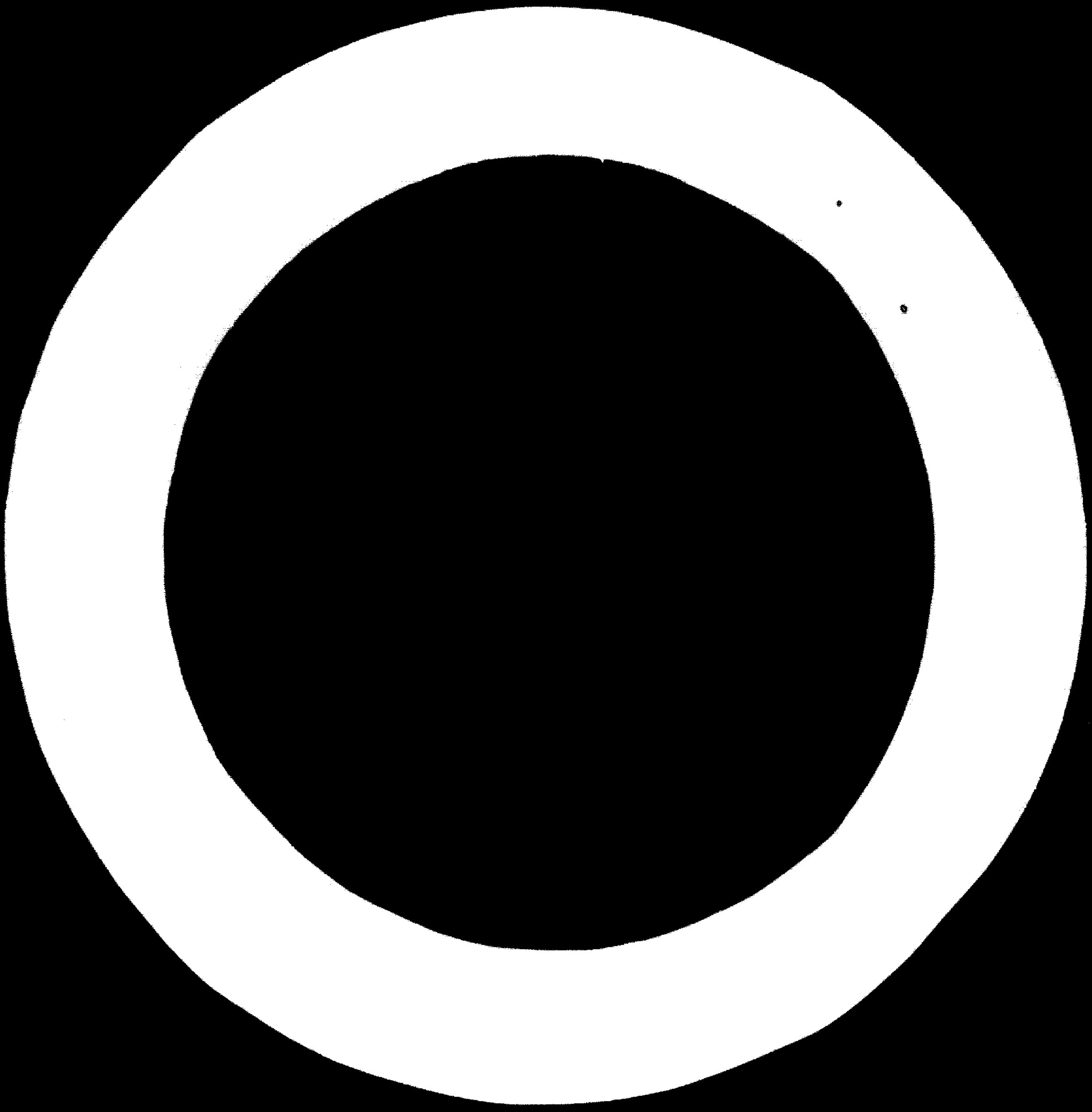
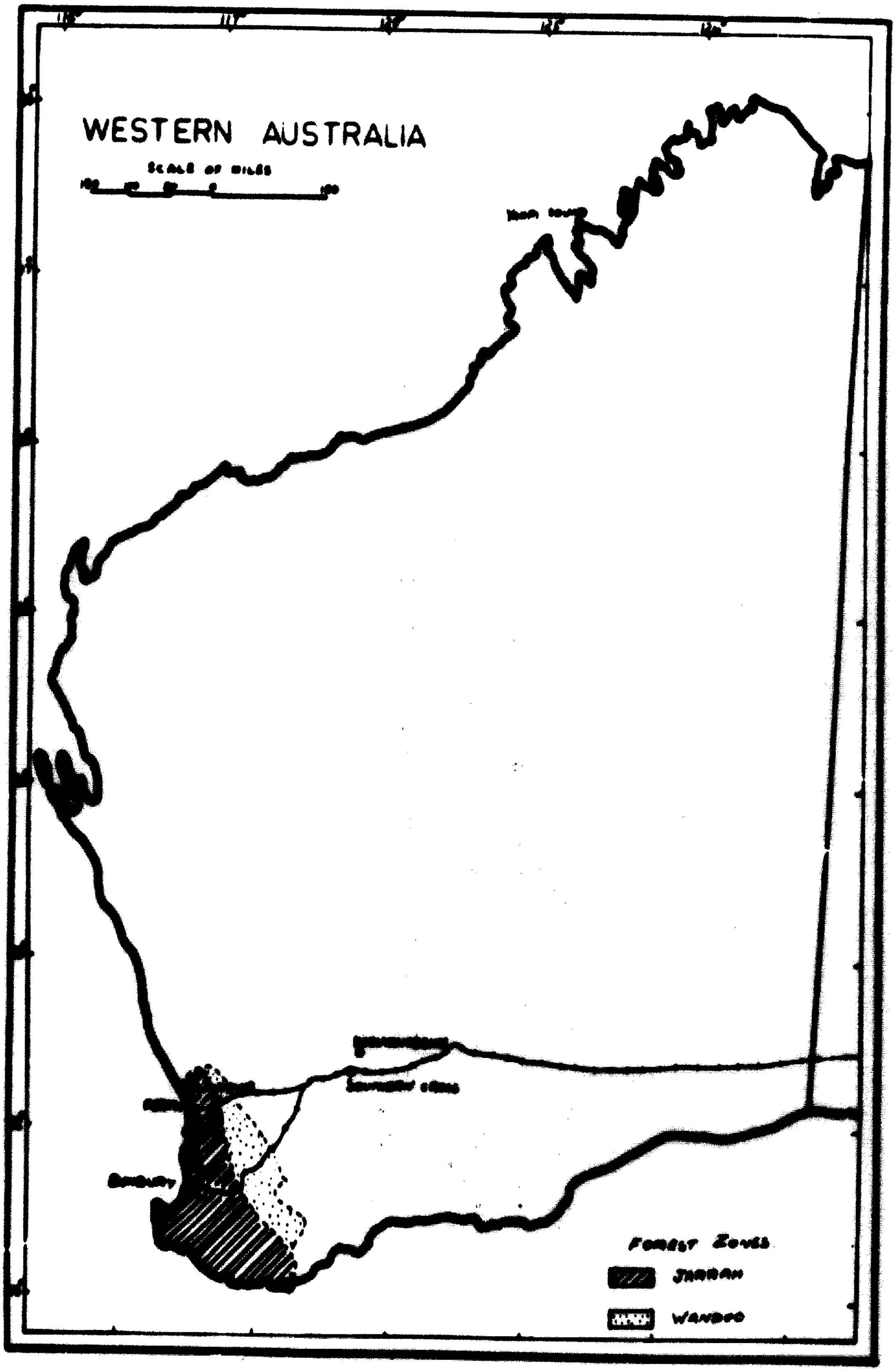
WESTERN AUSTRALIA




WESTERN AUSTRALIA
SCALE OF MILES
FOREST ZONES
JARRAH
WANDOO

General view of the plant.

No.1 furnace is on the extreme left behind the steam-raising plant.

No.2 furnace is in the centre. The continuous retorts are to the right.

In the foreground are the dust-catcher pits for the venturi scrubbers.

LOG DOCKER

The size and shape of the raw material can be seen on the extreme right where the tractor logger is charging the log carriage and on the left foreground.

The product is on the extreme left under the conveyor.

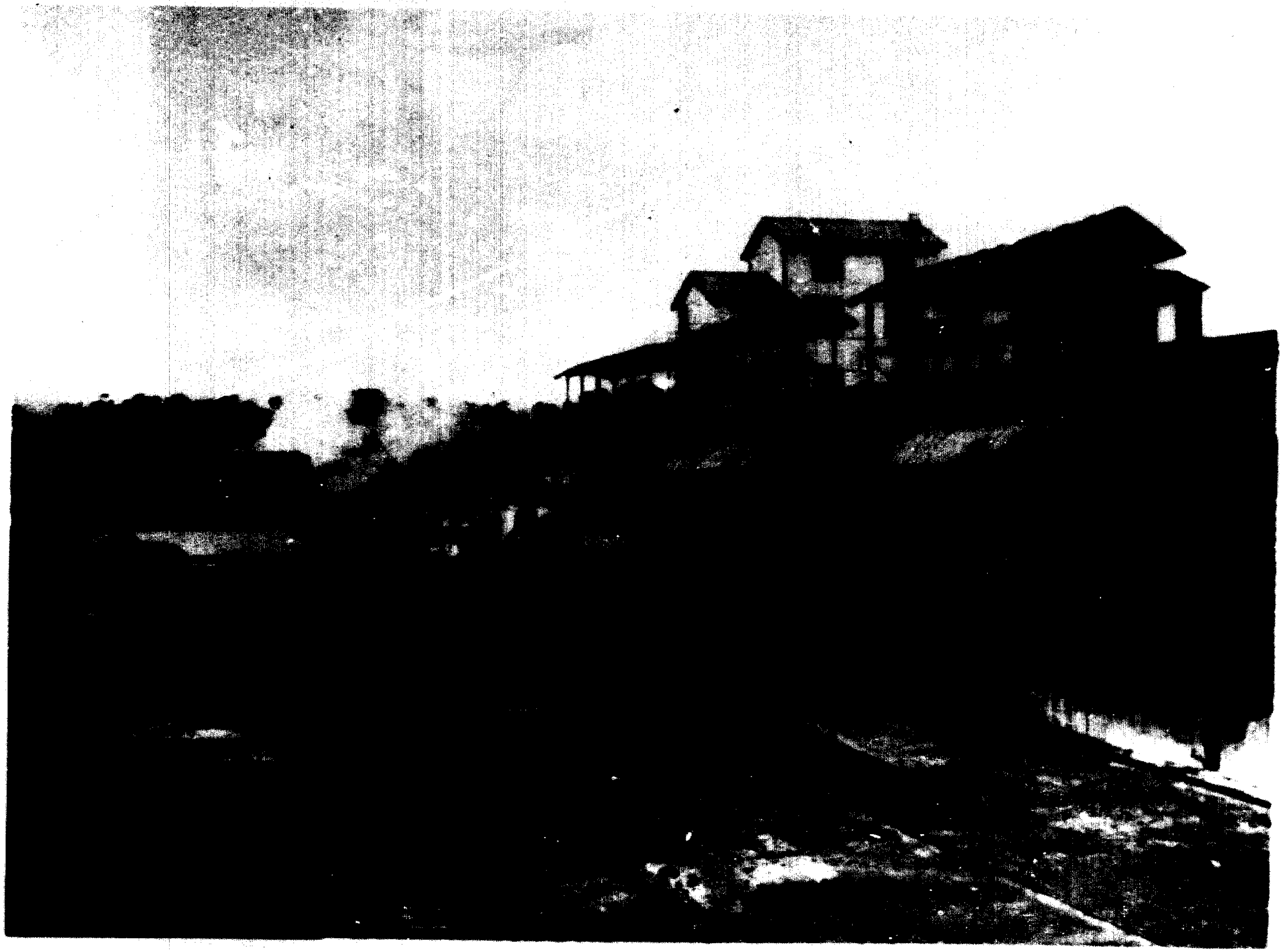
Output of the mill is 150 tons per 8 hour shift with a labour force of 4.

BATCH RETORTS

The retorts are on the right - coolers to the left.

The latticed steel wagons shown - each holding 4½ tons of wood are subjected to carbonising temperatures of up to 500°C. They have been in operation since 1948.

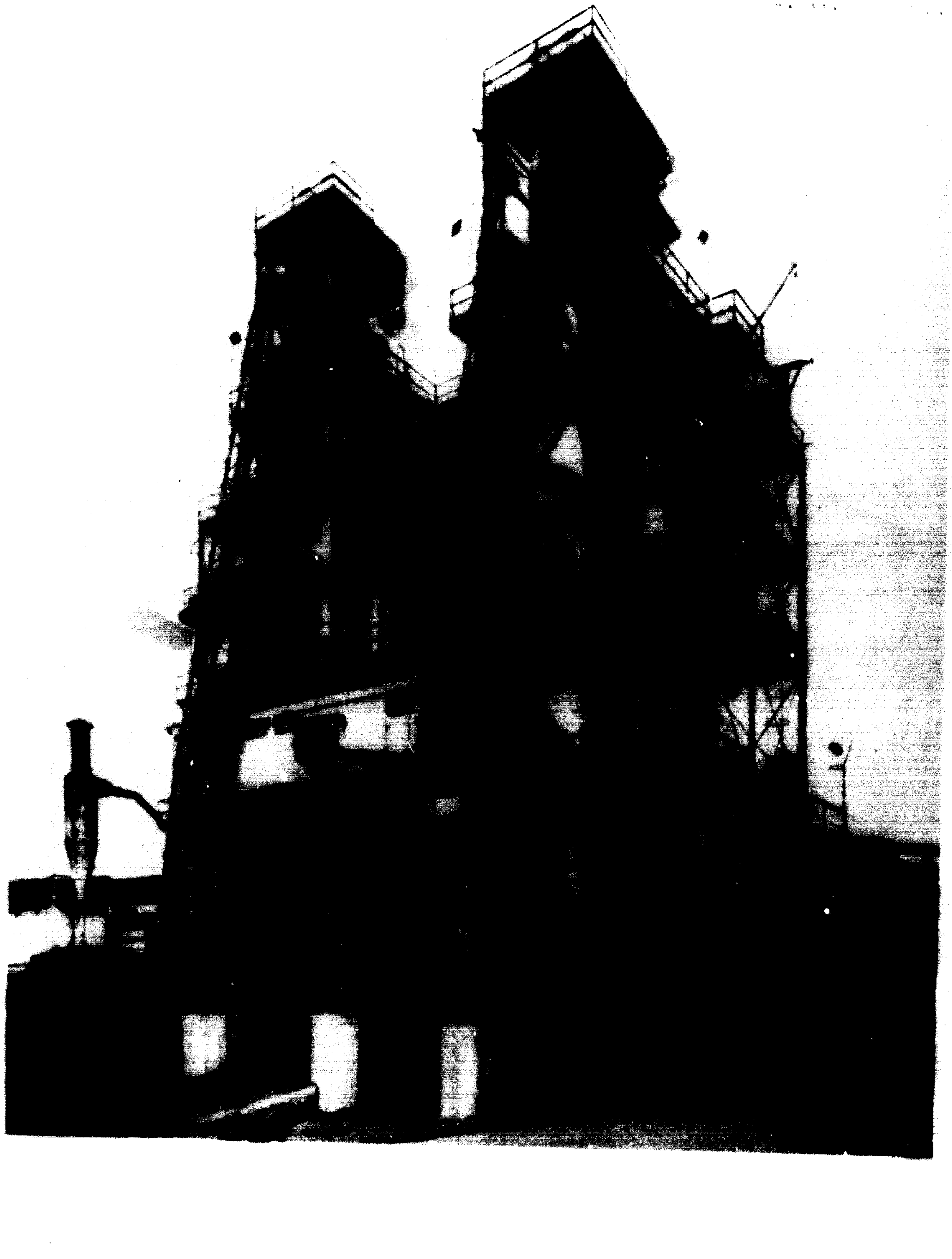
The 7 batch type retorts in this section produce 40 tons of charcoal per day.



Continuous Rinsing Gas Retorts (2)

Capacity 40 tons of charcoal each per 24 hours

Wood charging is by skip and charcoal extraction by rubber belt conveyor.



No. 2 Furnace being tapped into 20 ton Ladle.

The finished product.

SPECIFICATION

Silicon
0.25 max or 0.25/2.75% in 0.25% divisions

Manganese
0.4% max or 0.4/1% higher if required

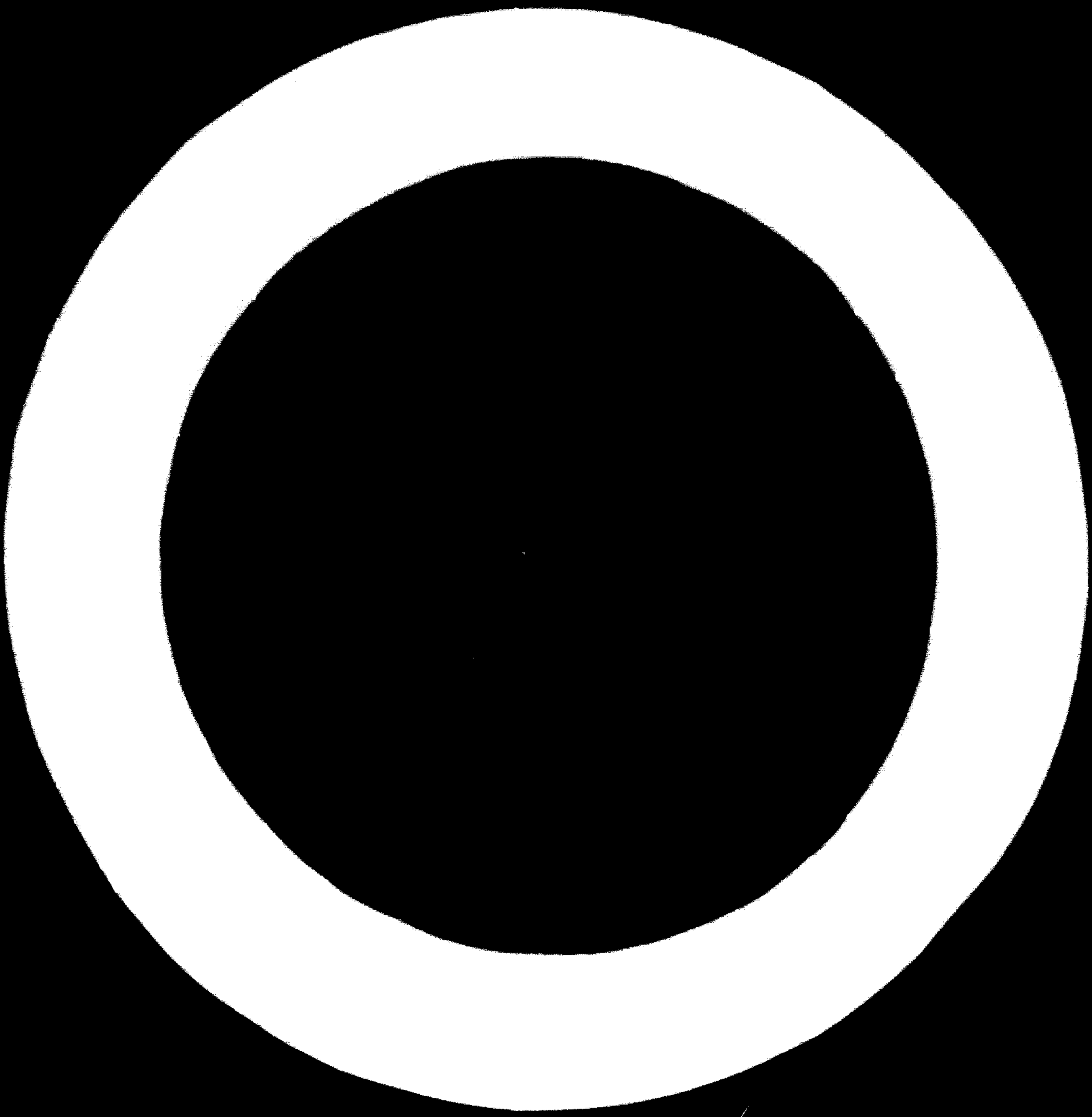
Phosphorus
0.03/0.05%

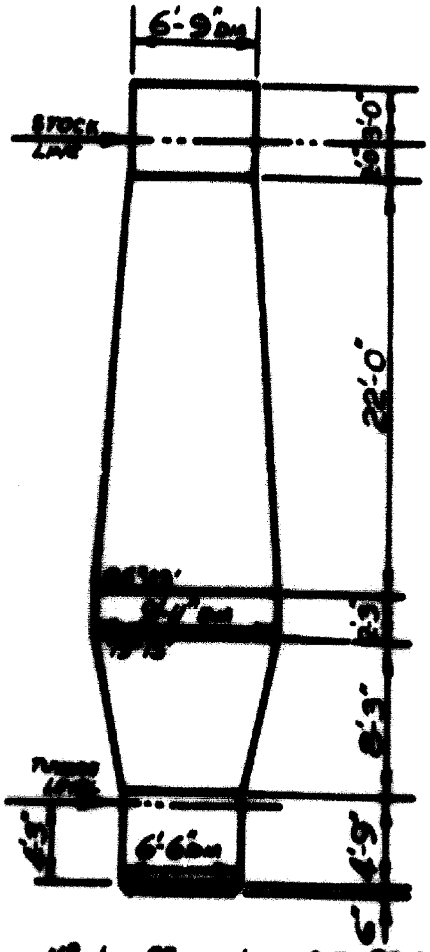
Sulphur
0.02% max.

Titanium
0.04% max.

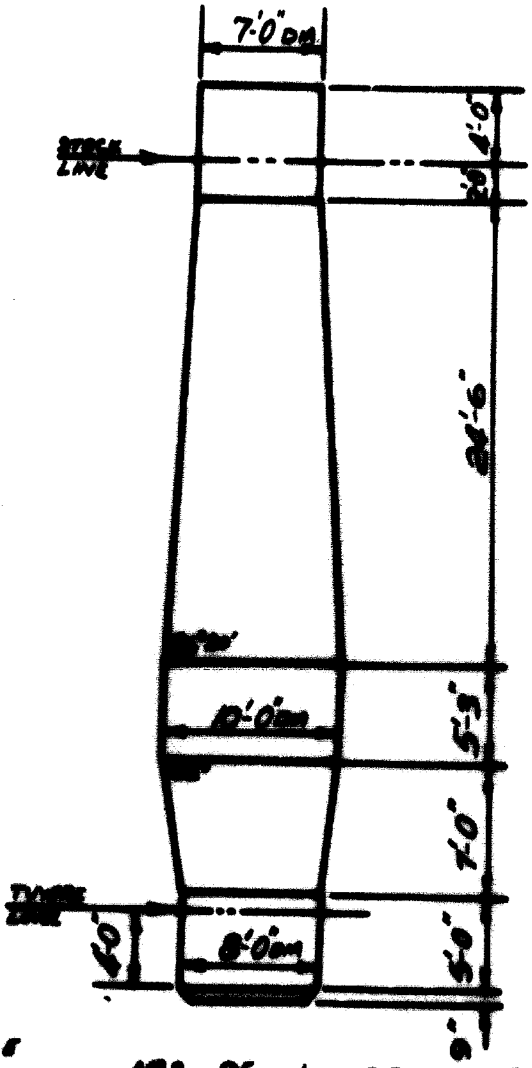
Carbon
Up to 4.50%

Interfering Elements
Nil.



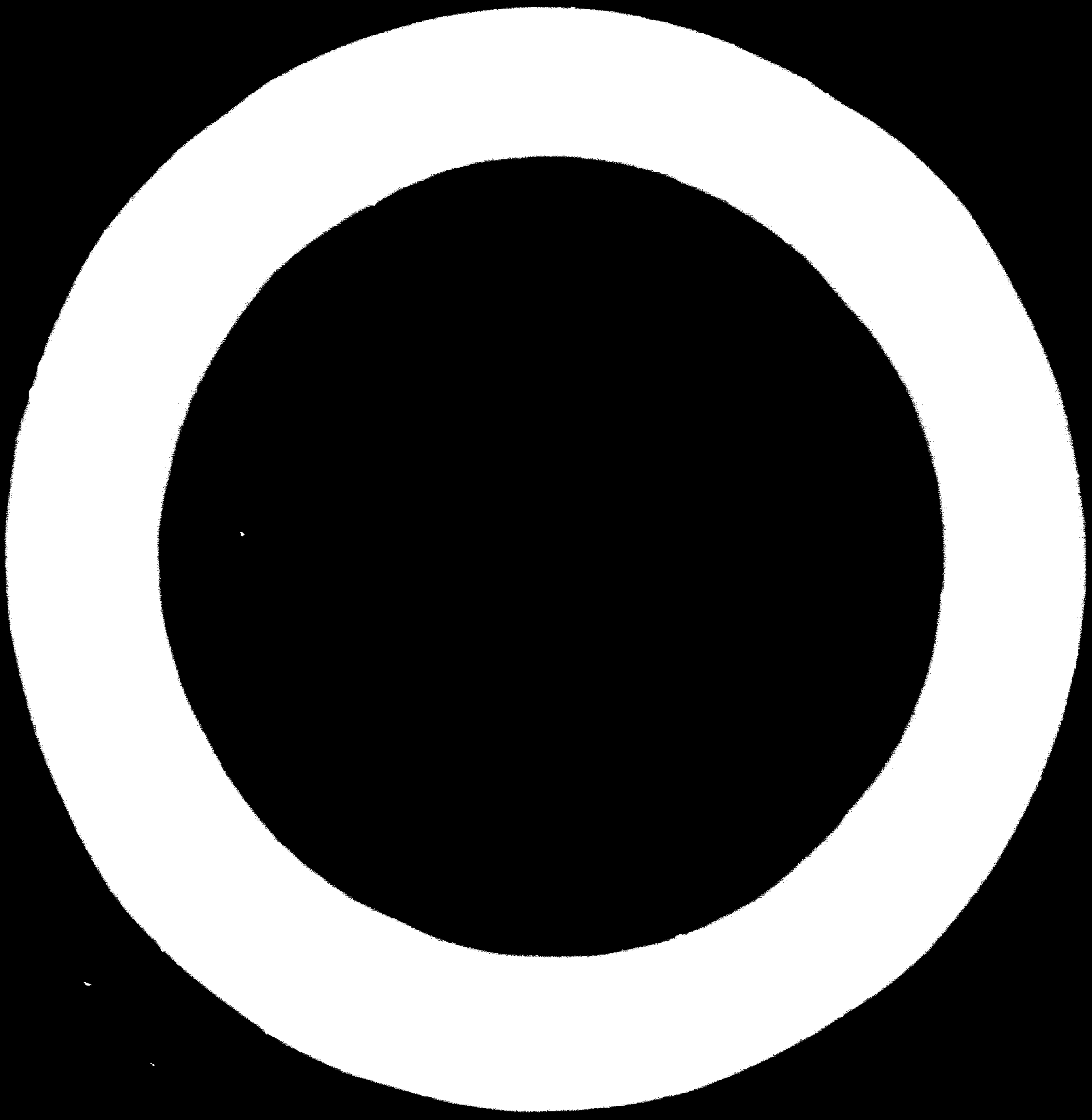


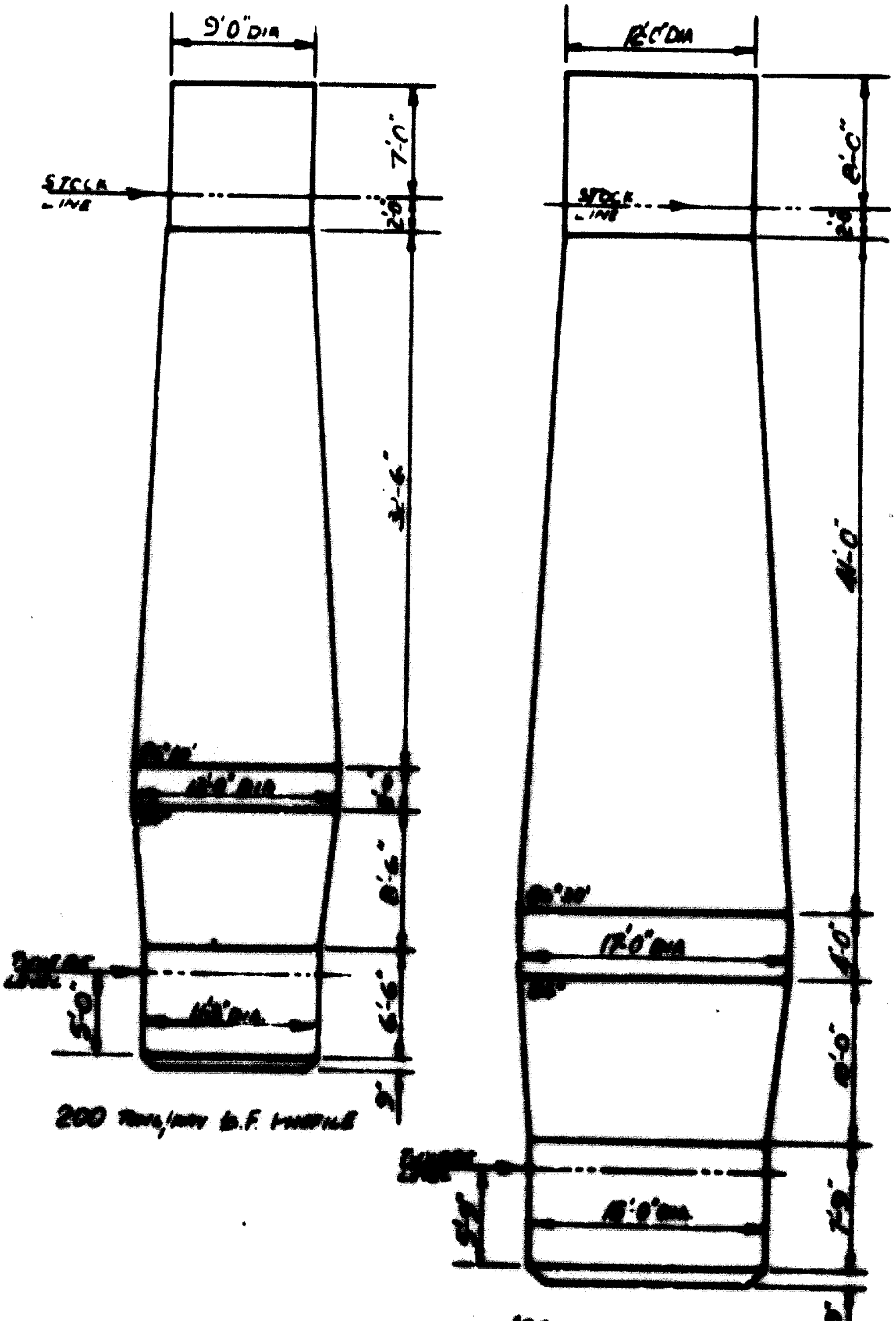
N° 1 85 tons/day B.F. PROFILE



N° 2 95 tons/day B.F. PROFILE

	[illegible]	N° 1 B.F.	N° 2 B.F.
[illegible] VOLUME	[illegible]	[illegible]	[illegible]
[illegible] VOLUME	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

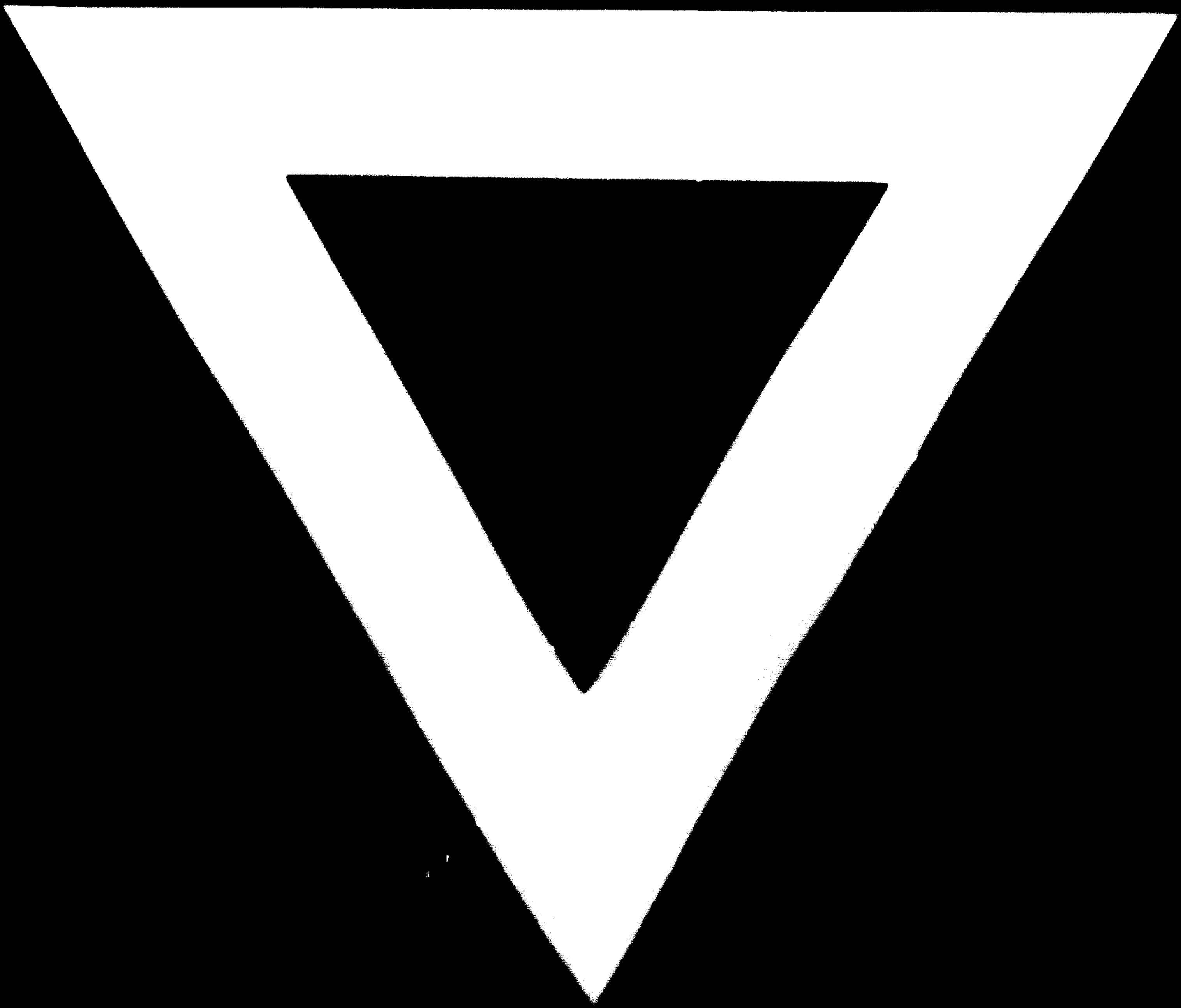




200 TON/DAY B.F. PROFILE

400 TON/DAY B.F. PROFILE

	DIMENSIONS	200 TON	400 TON
TOTAL VOLUME	FT³	[illegible]	[illegible]
WORKING VOLUME	FT³	[illegible]	[illegible]
H/D RATIO		[illegible]	[illegible]
COMBUSTION INTENSITY	[illegible]	[illegible]	[illegible]
THROUGH PUT	Hrs.	6.75	6.5
CAPACITY	TONS/DAY	200	400



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