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The Manufacture
of RDX in
Great Britain

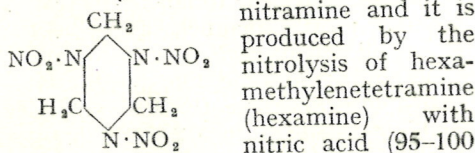
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The Manufacture of R.D.X. in Great Britain

Part I—The Historical Development

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R.D.X. is the name which has been given to a compound used as a high explosive during World War II. Chemically it is cyclotrimethylene-trinitramine and it is



per cent.). The chemistry of R.D.X. and the reactions involved in its production have been the subject of a great deal of research in Great Britain, in Canada, and in the U.S.A.

Early Production Methods

The substance was discovered as long ago as 1899 by Henning, but the high price of methanol, the starting point for the manufacture of hexamine, caused little interest to be taken in it till after 1918. Between 1919 and 1922 a batch method of manufacture was developed in America by Von Hertz. The Armament Research Department at Woolwich Arsenal commenced their investigation on R.D.X. at about the same time and found that the batch method was dangerous on account of the formation of large amounts of unstable by-products. These were identified and a process of continuous nitration followed by hot dilution was devised whereby these by-products were continuously broken down without attacking the R.D.X. and the whole process rendered safe.

The manufacture was rendered particularly difficult by the fact that the material is decomposed by sulphuric acid so that the usual means of absorbing the water produced in the reaction could not be used. In the process developed at Woolwich, hexamine was

continuously added to a large excess of 98 per cent. nitric acid maintained at room temperature, and the resultant mixture was diluted with water at a temperature of 70 to 80° C., whereby a completely stable R.D.X. was precipitated in a granular crystalline form suitable for handling.

The decomposition of the by-products produced a large quantity of NO₂ which had to be recovered as nitric acid, and there was also a considerable volume of weak nitric acid filtered from the R.D.X. to be reconcentrated. Though the acid handling problem thus presented was a large one, there is no doubt that this process of manufacture was the first to give trouble free operation on a large scale, and that in the production of this, the most powerful high explosive used in the war, the British Government was in advance of the whole world.

R.D.X. is, as has been said, a particularly powerful high explosive. When dry it is too sensitive, but when wet the material is safe to handle. It is fairly easily phlegmatised and so it is not normally used by itself, but is mixed wet with suitable material to form insensitive mixtures suitable for filling shells, bombs and other weapons, or for use as demolition charges.

Nomenclature

R.D.X. has been known by a variety of names in the different countries in which an interest has been taken in it. In Italy, where much interest was shown before the war on account of the policy of autarchy, and where a small factory had been built, it was known as T.4; in France and Belgium, where small amounts were also made, as Hexogen; and in this country, as Cyclonite. On the approach of war, it was considered that the name Cyclonite was unsuitable for security reasons, and the name R.D.X. was given to it.

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In 1922 the Armaments Research Department had started to study R.D.X. as a military explosive. The advantages of R.D.X. over explosives then in use, and over P.E.T.N., caused priority to be given to the investigation into the problems of its preparation and application. As has been said, difficulties were gradually resolved and a safe and practicable scheme for manufacture was produced.

By 1933 a small scale unit, capable of producing 75 lb. per hour without acid recovery, had been set up. This unit operated until 1939. By that time demands for R.D.X. for trials had put the plant into more or less continuous operation, and further development was prevented by the lack of spent acid recovery facilities. In these circumstances it was decided to erect a pilot plant, consisting of two Woolwich nitration units, at the Royal Gunpowder Factory, Waltham Abbey, where suitable acid recovery plant could also be erected.

This plant was installed early in 1939, and at this stage the responsibility for the plant and process development became that of the Royal Ordnance Factory organisation in collaboration with A.R.D. This plant was hardly installed before the design and layout of a factory for production of R.D.X. on a large scale had to be undertaken.

Full Scale Plant

Planning of the full scale plant began early in 1939 under the Director of Explosives, Royal Ordnance Factories (D.O.F. (X)), in collaboration with the Research Department and Chief Mechanical Engineer, Woolwich. Besides the process and acid recovery units the factory was to contain formaldehyde, hexamine and synthetic nitric acid units.

The site finally chosen on August 26, 1939, near Bridgwater seemed to offer many advantages. Methanol and ammonia could be obtained from Dowlais; T.N.T. from Pembrey and the South Wales coalfields could supply the anthracite. Sea, rail and road transport facilities were fairly favourable. A fair

quantity of water was available from the Bridgwater supply and would suffice to fill drinking water and boiler-house needs. Process water wanted in large quantities had, however, to be found.

The "rhines" or ditches draining the site flowed either west to the River Parrett and the sea, or north to the River Brue. By co-operation with the Somerset Rivers Catchment Board a new east to west channel, known as the Huntspill River or New Cut, $5\frac{1}{2}$ miles long, and something like 60 ft. wide, was dug to improve the land drainage in the area and form a 232,000,000 gal. reservoir to act as the main water supply. A similar but smaller ditch, the King Sedgmoor Drain, on the southern side of the low Polden ridge of hills, a mile or two to the south of the factory, was also called into service as a reserve supply.

Disposal of Effluent

Effluent disposal presented special problems which were eventually solved by collecting all factory effluent in a large main collecting pit 95 ft. by 47 ft. by 21 ft. deep, and pumping by means of three stainless steel unchokeable pumps into a specially cut ditch or rhine running through the factory, then alongside the Huntspill River to the outfall at the mouth of the River Parrett, four miles away.

The initial output was to be 60 tons a week, and arrangements were to be such that production could be stepped up with the minimum of disturbance as the demand increased. To cope with this output it was necessary to design units of sizes never before used for this process, and to improvise to a considerable extent methods for handling large quantities of a new and powerful explosive.

Work on the site went ahead reasonably well, and in August, 1941, the first R.D.X. was made. By that time the capacity had been increased to 90 tons a week, and it was eventually increased to 180 tons a week; a figure which was exceeded before the end of

the war as a result of improvements to plant and process made on the site.

One of the most striking features of the Woolwich process for the manufacture of R.D.X. is the size of acid plant necessary. As has been said, the plant at Woolwich had no facilities for dealing with acid at all. It had been learnt by experience that the production of 1 ton of R.D.X. required the addition of 0.86 tons hexamine to 11 tons of concentrated nitric acid. Of this 11 tons about 5 tons could be recovered as weak acid when the R.D.X. was filtered off after the dilution process, and rather more than 4 tons by absorption of the nitrous fume produced in the process. Allowing reasonable process losses, it was clear that for each ton of R.D.X. there would be about 9 tons of weak nitric to reconcentrate, and rather more than 2 tons of new strong nitric acid to produce.

In 1939 the production of 98 per cent. nitric acid in bulk was a problem only a very few plants in this country had had to solve, and Waltham Abbey was obliged to find out rapidly how to deal with the problem. From all the information available a ratio of H_2SO_4 to HNO_3 of $3\frac{1}{2}$ to 1 appeared to be good practice for the concentration of the nitric acid. It was, therefore, immediately obvious that in any large scale plant the cost of sulphuric acid concentration would be a considerable item in the cost of R.D.X.

A good deal of attention was, therefore, devoted to finding the best conditions of

operation, and seeing to what extent the ratio of nitric acid to hexamine, and the ratio of sulphuric acid to nitric acid, could be reduced. The need for installing the most efficient type of nitric acid concentration plant and working it under the best possible conditions was clear, but what type of sulphuric acid concentration plant was most suitable was not immediately obvious. An output of even 60 tons of R.D.X. a week involved the concentration of 270 tons of sulphuric acid a day. The more obvious types of concentrator for dealing with such large quantities, such as the Drum and the Gaillard, were considered unsuitable. It seemed possible that the acid might contain organic compounds of doubtful composition and stability, and it was, therefore, thought advisable to use the pot still type of plant in which the acid is maintained at a high temperature for a very much longer time.

Absorption of Nitrous Fumes

Another problem that caused a lot of difficulty was that of absorbing the enormous amounts of nitrous fume involved. In the small Waltham plant a set of eight earthenware towers 3 ft. 0 in. diameter by 18 ft. 0 in. high had proved insufficient to deal efficiently with fume from one small nitration house capable of producing 5 tons R.D.X. a week.

For Bridgwater the possibilities of both the HoKo autoclave process for direct conversion of this fume into con-

Table

	ALL TONS PER TON R.D.X.									
	Hex-amine	Gross HNO_3	Re-covered W.N.A.	Ab-sorbed fume	Net HNO_3	OVERALL LOSSES				
						HNO_3	H_2SO_4	NH_3	CH_3OH	NH_3 for hex-amine
1st Qtr., 1942..	0.930	11.616	5.563	3.219	2.832	2.999	0.78	1.026	1.836	0.479
1st Qtr., 1945..	0.833	8.779	3.482	3.429	1.868	2.139	0.49	0.664	1.436	0.423

centrated nitric acid, and of atmospheric absorption and reconcentration were considered. The balance was eventually weighed down in favour of the atmospheric process by reason of its greater simplicity and the fact that some kind of tower concentration plant would, in any case, be needed to deal with the filtrate acid. For similar reasons it was decided to install an atmospheric pressure ammonia oxidation plant and absorb the whole of the fume from nitration, ammonia oxidation and nitric acid concentration together. A set of stainless steel towers big enough to give efficient absorption was eventually erected, and it says much for the design that, when conditions were favourable, efficient absorption was obtained when the factory was running at outputs in excess of those originally contemplated, though with increasing output it was eventually found necessary to build a smaller set to deal with the fume from nitric acid concentration.

Formaldehyde and Hexamine

These remarks will suffice to show the magnitude of the problems that the planners of Bridgwater factory had to deal with in so far as the acid plant alone is concerned. The manufacture of formaldehyde from methanol and of hexamine from formaldehyde and ammonia were problems quite alien to any previously dealt with in the R.O.F. organisation. In addition the manufacture of R.D.X. had to be stepped up many times, introducing numerous problems of safety and efficiency in handling such large quantities.

As soon as R.D.X. became available to the Services the demand increased to an embarrassing extent. Even the pilot plant at Waltham Abbey was able to do very little of the investigation work planned as Service requirements necessitated it being run all out as long as possible. By the autumn of 1942 demands had risen to a point where it was clear that even the maximum capacity of Bridgwater would not meet them, and some available buildings at

R.O.F., Bishopton, were converted to R.D.X. manufacture. Experience gained at Bridgwater enabled a number of improvements to be made in this plant, which came into operation in September, 1943. About the same time erection of a second unit at Bishopton commenced in accordance with planning by the Chief Engineer, Propellants Planning Department, and this was completed by November, 1944. Each of these units had a capacity of 60 tons a week.

During the period the Bridgwater plant was running investigation work with a view to improving efficiencies was carried out continuously. The figures shown in the Table give some indication of how successful this work was.

The descriptions of plant and processes given in Parts II and III of this article will refer in the main to the Bridgwater plant, but essential points of difference at Bishopton are noted.

(To be continued)

SHALE MINING

A JOINT production committee for the shale mining industry is to be formed. This decision was made as a result of a move by the National Union of Shale Miners and Oils Works, who approached the Scottish Oils Ltd., suggesting that a good deal could be done to improve efficiency and output by the establishment of a committee of the kind for the industry.

The committee, consisting of five representatives from the employers' side and five from the Union, will be headed by a Scottish Oils nominee, and the Union hope to nominate their members as soon as possible. The activities of this committee will be confined meantime to the Westwood and Burntgrange mines, although it is hoped to include other mines after a trial period.

Monthly meetings will be held, and a regular exchange of views between the management and workers on matters relating to production and efficiency will be encouraged and recommendations made thereon.

The Manufacture of R.D.X. in Great Britain

Part II—Raw Materials and Ancillary Processes

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THE contract for the supply of plant for the manufacture of hexamine was placed with I.C.I. (Fertilizer & Synthetic Products) Limited, who, through their American contacts, were in a position to obtain design data for one or two of the sections for a plant of this type.

The hexamine section can be divided into four :—

1. Formaldehyde production.
2. Ammonia distillation.
3. Hexamine production.
4. Methanol recovery and distillation.

1. The formaldehyde plant is built in two independent units. Methanol is imported into the factory by rail and stored in suitable tanks, whence it can be fed as required to either production unit. These units comprise three main sections, in the first of which a mixture of air, methanol vapour and steam is produced by bubbling air through methanol and then injecting pure steam into the mixture. In the second section conversion takes place and the gas mixture is fed to a series of silver gauze catalyst masses in parallel where the bulk of the methanol is converted into formaldehyde, some of the methanol passing through unchanged, and the remainder being decomposed to useless by-products. The hot gases from the converters pass to the absorber system, which consists of two circulated packed towers and a third short bubble cap column with no circulation. The gases leaving the top of the third absorber contain only traces of formaldehyde and methanol and are expelled to atmosphere through an exhaustor driven by a 55 h.p. motor with a variable speed device.

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The whole of the controls and instruments for this plant are concentrated in one control room, situated between the conversion and absorption sections, which consequently forms an impressive sight. The catalytic oxidation needs careful control as the silver gauzes are extremely sensitive to changes in operating conditions, and the best results can only be obtained by continuous steady operation.

Catalyst Activity

The activity of the catalysts can be quickly impaired by the presence of impurities, in particular chlorides and iron compounds, in the steam. This steam is, therefore, supplied by three Kestner evaporators fed with steam trap condensate.

The plant is particularly sensitive to small variations in the temperature at which methanol is vaporised and the secret of steady running lies in careful control of this factor. The temperature requires to be maintained steady to within 0.1° C. and this is normally achieved by the use of a Foxboro' Stabilog temperature controller on the steam supply to the heaters. Hand control is, however, possible.

The formaldehyde solution normally produced in the plant contains 39 per cent. formaldehyde and 10 per cent. methanol by weight. It is stored in a separate building which contains 8 Pfaudler glass-lined vertical cylindrical tanks 10 ft. in diameter and 20 ft. high. The capacity of each is approximately 40 tons of solution, and pumps for circulating and for sending to the hexamine plant are installed.

2. The ammonia distillation plant produces gaseous ammonia from 28-34 per cent. ammonia liquid, which is imported into the factory by rail. The ammonia gas produced is either passed

direct to the hexamine reaction vessels or to a gas-holder.

The rail tanks arrive on a siding, where an off-loading manifold with 20 flexible hose connections is mounted between two sets of rails, and is connected below ground level to two cast iron Pulsometer centrifugal pumps, which pump the liquor to two welded mild steel store tanks 30 ft. in diameter and 15 ft. high.

Each still consists of a steam-heated boiler, stripping column and condenser, all made of mild steel. They are erected in the open with the lower part surrounded by a brick well. Controls and instruments are mounted in an adjacent building.

3. The hexamine plant proper was built to suit very stringent requirements.

The whole product had to pass a specification of quite abnormal severity, and, in addition to the more usual requirements of chemical purity and grist size, it was essential that the material should be free flowing.

The plant consists of four main sections: reaction, evaporation, centrifuging and drying. There are two reaction vessels of welded aluminium construction, 8 ft. 6 in. in diameter and 12 ft. high. In the base of each is a circular perforated aluminium pipe to act as an ammonia distributor. Each vessel has its own circulating pump and cooler and is vented to atmosphere. The heat of reaction is consider-

able and as some decomposition of hexamine takes place above 60°C ., the reacting liquor is circulated through coolers (stainless steel calandria type) by stainless steel Pulsometer centrifugal pumps. The reaction is complete when slight excess of ammonia is present, the entire cycle taking about three hours.

The charge for the vessel is 8 short tons of formalin solution, 1.2 of ammonia gas and 5.5 to 6 tons of centrifugal drain liquor. This gives a total weight of hexamine per batch of 4.9 tons, about 3 of which is new hexamine. The liquor from the reaction vessel runs to a mild steel glass-lined cylindrical receiver whence it is fed to a salting type Scott vacuum evaporator built entirely of stainless steel. The vapours from the evaporator containing 10—12 per cent.

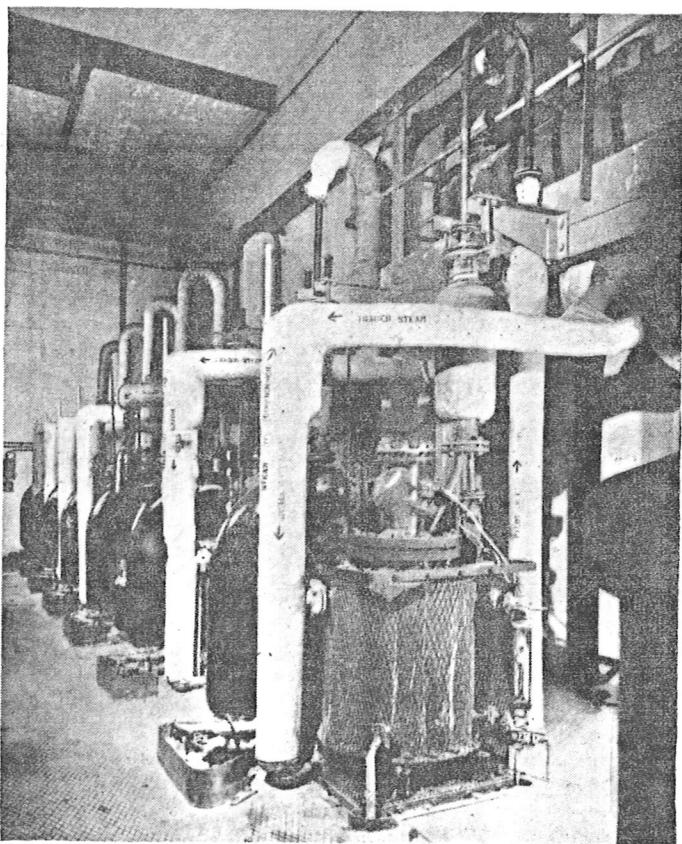


Fig. 1—Converter plant of the formaldehyde plant

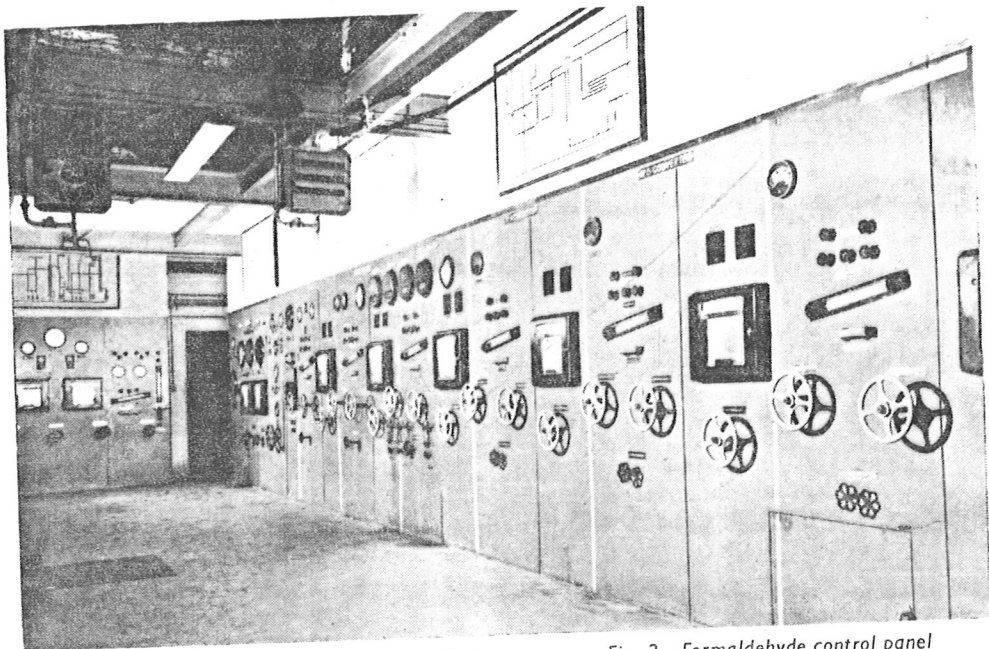


Fig. 2—Formaldehyde control panel

of methanol are condensed in Hick-Hargreaves surface condensers and pass to the methanol recovery plant. The crystals of hexamine made in the evaporator flow by gravity through a stirred salt box to overdriven Broadbent centrifugals, with baskets and casings of stainless steel and shafts of mild steel sheathed with stainless. The salt coming from the centrifugals contains about 1 per cent. water and is dried in a Simon vibrating tray drier, consisting of an enclosed shaker conveyor mounted on hickory springs and vibrated by a shaft, motor actuated through a Croft multi-speed gear with a V-rope drive. The gear enables the time of passage of salt through the drier to be controlled. The conveyor consists of an enclosed metal box with a double bottom, the upper bottom being stepped to form a number of trays with air slits between. Steam heated air is blown onto the bottom of the trays and the step plates are curved in such a way that no salt falls through the slits. The dried hexamine passes to a conveyor system and is packed for export or prepared for immediate nitration. Some 6 in. above the drier trays a row of dust

screens is fixed and through these all the air from the drier has to pass.

4. Aqueous methanol produced in formaldehyde and hexamine manufacture is re-distilled to produce pure material for use in the formaldehyde plant. The material from the hexamine plant is considerably more in quantity than the other and is approximately 10 per cent. methanol with a little ammonia. That from the formaldehyde plant is about 60 per cent.

The 10 per cent. material from the hexamine plant is given a preliminary treatment with glue and sulphuric acid before distillation. After treatment it should contain not more than 0.2 per cent. free acid, and it is then brought up to 75 per cent. in a primary still, leaving behind a weak solution of ammonium sulphate and formate. In the secondary still this 75 per cent. methanol and the 60 per cent. material from the formaldehyde plant, are distilled to give 99-100 per cent. methanol for re-use. The primary still is of copper construction and the secondary of mild steel. Both

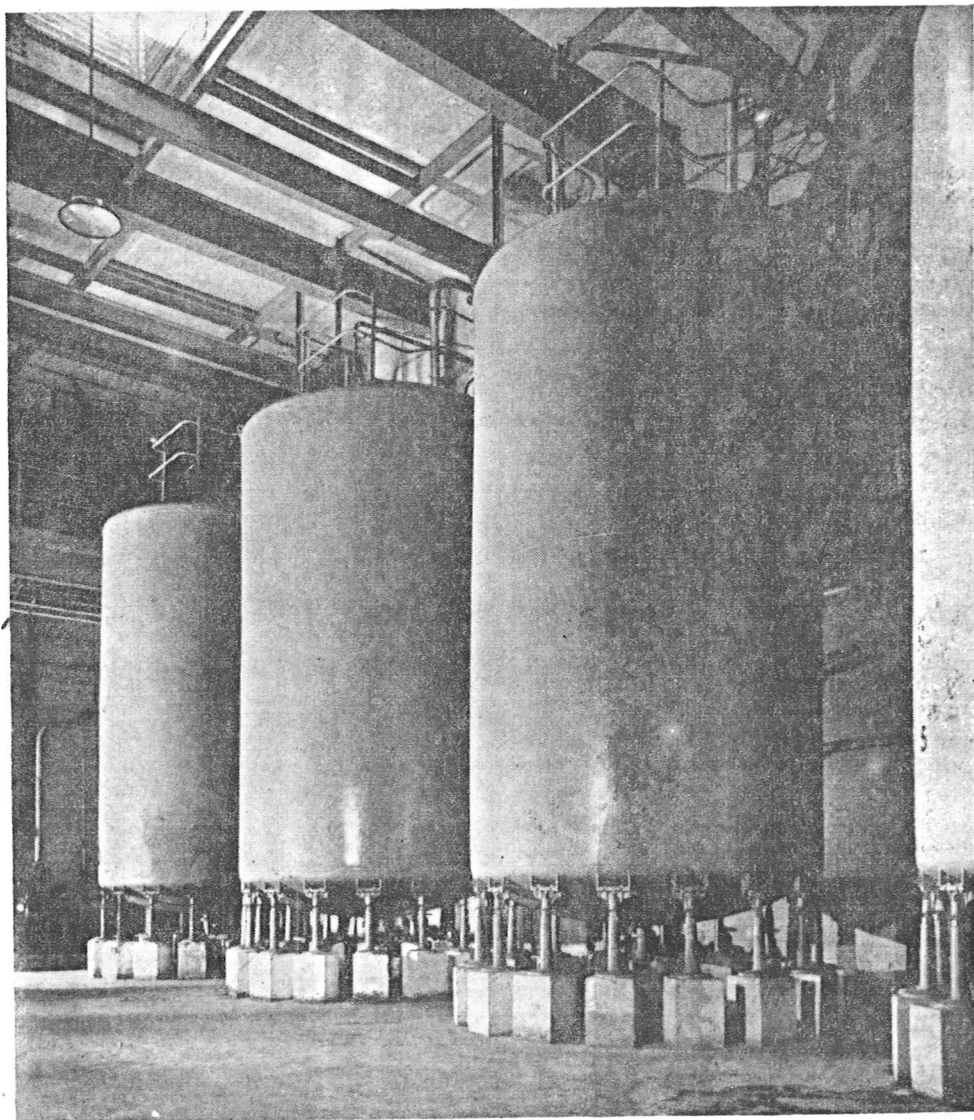
stills are controlled from a panel in one of the formaldehyde units.

Weak Nitric Acid Manufacture

This plant consists of two distinct sections, the first of which comprises towers for the oxidation and absorption of nitrogen oxides in various stages of oxidation, and the second, ammonia burners at atmospheric pressure. The absorption section deals with the gases

from these burners, and with the oxides of nitrogen coming from the R.D.X. plant. In the early days, it also dealt with the fume from the nitric acid concentration plant. When the output of the factory was increased to 180 tons a week of R.D.X. this plant had to be operated at a higher capacity than that for which it was originally designed. In

Fig. 3—Storage vessels for formaldehyde



order to reduce the extra burden placed upon it, a separate, smaller, set of stainless steel towers on similar lines was built to deal with the concentration plant fume. The following description deals only with the original plant.

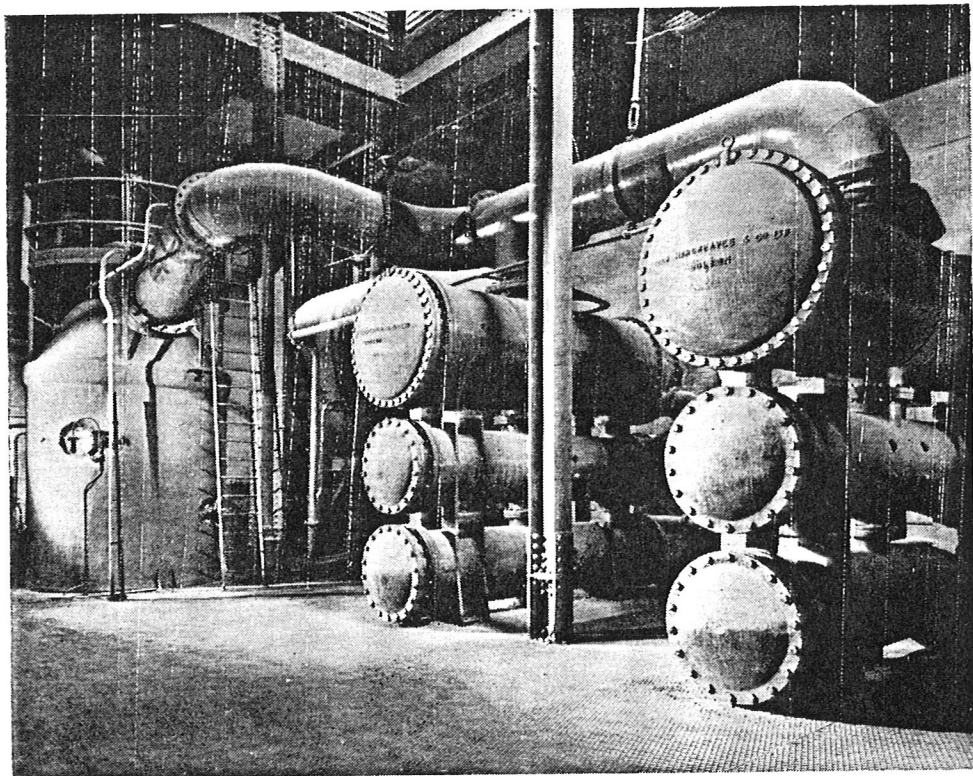
Fume Absorption.—The plant, designed and constructed by Bamag Ltd., consists of eight large stainless steel towers and two smaller ones into which the gases are fed by stainless steel blowers. The general arrangement is shown diagrammatically in the figure. The gas arriving from the R.D.X. plant is almost completely oxidised and is, therefore, taken through the reinforcing towers direct to the production tower, whereas gas from the ammonia oxidation plant goes first to the two oxidation towers.

Two of the four nitrous gas blowers are used for the R.D.X. fume and two for the ammonia oxidation fume (one running and one spare in each instance).

They are made by Keith Blackman and have each a capacity of 6,000 cu. ft. per min. at 20° C. against a total head of 62 in. w.g. and are driven by 120-h.p. motors running at 2,960 r.p.m. They are of stainless steel construction with mild steel supports for the casing. The suction opening is 12 in. in diameter and the delivery 14 in.

The reinforcing towers are the strong end of the liquid flow system and the first to deal with R.D.X. fume. They are conical ended stainless steel cylinders 10 ft. 10 in. in diameter with an overall height of 39 ft. 3 in. They are suspended from the enclosing girder structure by eight stainless steel straps, welded equidistantly round the top circumference of the cylindrical portion. Each tower is divided into two compartments of approximately equal volume by a 9ft. 7 in.

Fig. 4—Hexamine condenser and evaporator



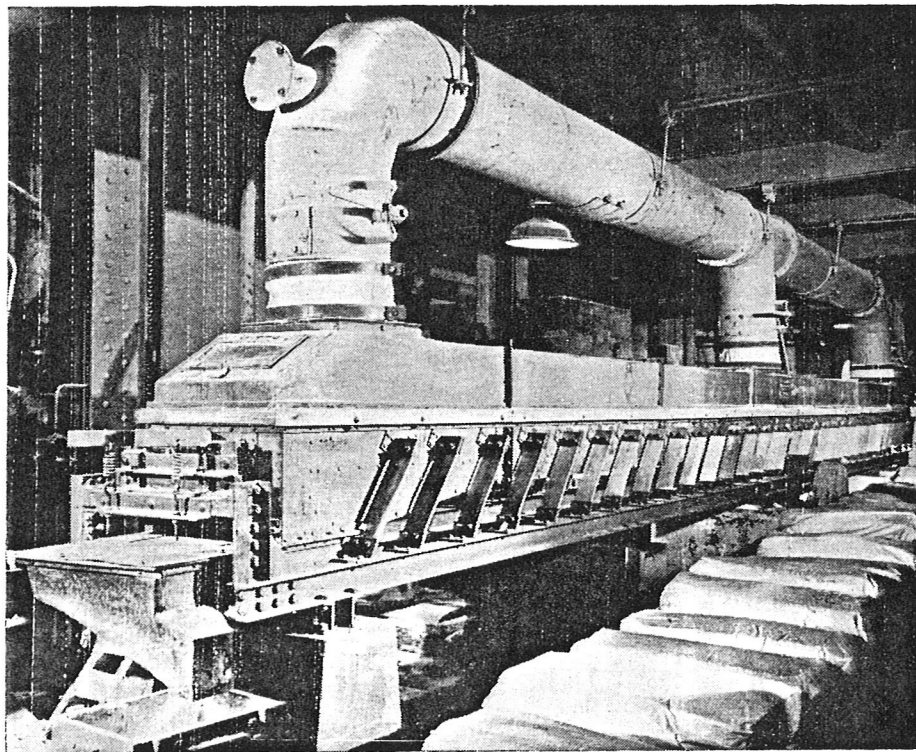


Fig. 5—The hexamine drier

dia. acid collecting tray, and each section has an independent acid circulation system. All sections are packed with 2 in. and $4\frac{3}{4}$ in. Raschig rings, but these do not occupy the whole volume.

Oxidation Towers

The oxidation towers are similar in shape to the reinforcing towers, but larger, being 58 ft. 9 in. in total height and 14 ft. 5 in. in diameter. These towers are not divided into two sections and the packing consists of $4\frac{3}{4}$ in. and $7\frac{7}{8}$ in. rings, only 25 per cent. of the space being packed. The tower suspension is of similar design to that of the reinforcing towers and acid is circulated independently in each by pump.

Nitrous gas from the top of oxidation tower No. 2 passes through 2 ft. 3 in. dia. stainless steel trunking to the bottom gas flange of the so-called production tower. Its dimensions are the same as those of the oxidation towers,

but it is divided into two sections by a 14 ft. dia. tray with a 6 ft. dia. gas uptake shielded to prevent by-passing of the sprayed acid.

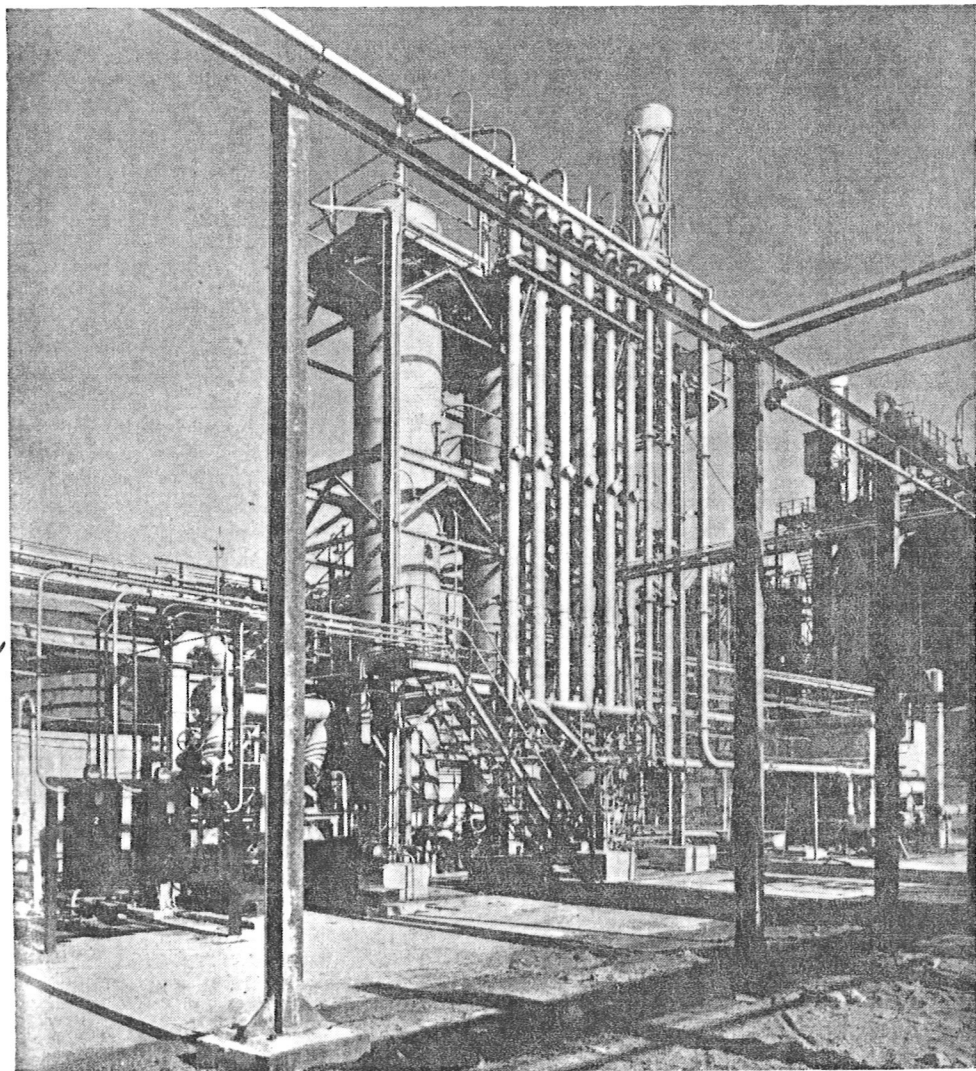
The absorption towers have the same dimensions as the oxidation towers and are undivided. They differ in degree of packing, and in the fact that the gas mains connecting them are short horizontal stretches instead of downcomers, the acid and gas flows being alternately co- and counter-current. The circulating pumps, of LaBour manufacture, draw acid by 4 in. lines from the tower bottoms and deliver it through tubular coolers to the acid distributors at the tower tops. Two sizes of cooler are installed, one with 26 and one with 52 tubes, 27 ft. 4 in. long and $\frac{3}{4}$ in. dia. Cooling is by water or ammonia brine chilled by a Sterne refrigerating plant with a capacity of 1,150,000 B.Th.U. per hour, a further

position by a perforated plate. They give a total filter surface of about 290 sq. ft. Above these filters there is another layer of $\frac{5}{8}$ in. earthenware rings to ensure uniform distribution of the gas over the whole area of the catalyst, which consists of circular sheets of 80-mesh gauze, 7 ft. 3 in. in dia. There are three of these gauzes, the first two being of platinum with 5 per cent. rhodium and the third pure platinum. The hood above has four symmetrically

disposed holes, three of which are covered with mica to form inspection windows, the fourth being a stainless steel plug for insertion of the gas torch for lighting.

The upper and lower conical surfaces of the converter body are lagged and the gases, which leave the top by a brick-lined 22 in. dia. horizontal pipe, pass to the tube nest of the air preheater, consisting of an inverted U-shaped mild

Fig. 7—Fume absorption plant



steel tube nest and plate, enclosed in an aluminium shell and mounted on a mild steel box lined with fire brick.

The converted gas leaving the pre-heaters is at a temperature of approximately 500° C., and has to be brought down to 20-30° C. before entering the absorption system. This is accomplished in two stages, the first a waste heat boiler and the second a tubular water-cooled heat exchanger. Between the two is a crash condenser for removing moisture.

Concentration of Nitric Acid

Nitric acid is concentrated at the Bridgwater factory by seven I.C.I. stills, each complete with its own condensers, bleachers, nitric acid and weak sulphuric acid coolers. From the still tops a common fume main, draughted by three Keith Blackman blowers, conveys the fume to a set of absorption towers, very like those previously described, but smaller.

The stills are 33 in. in dia. and 44 ft. high, constructed of mild steel sections, lined with acid-resisting cement and earthenware. A cast lead saucer, mounted directly on the foundation block, forms the bottom of the still. It is enclosed in acid-resisting brickwork. The top of the still is a domed silicon iron cover with inspection holes and other connections. The stills were originally packed with graded quartz, but later various other packings, in particular steatite insulators, were used with improved results.

The nitric acid feed rate to each still is measured by a stainless steel niveau, an orifice type flowmeter in which the head of liquid above the orifice is used to indicate the flow through the orifice. This height is measured by an air-operated depth gauge whose indicator is mounted near the acid control valve. The niveau is situated just above the top of the still and acid passes from it through a lute to one arm of a silicon iron T-piece leading into the still. The other arm is used as the sulphuric acid inlet, the rate of flow being measured by a

similar arrangement. The mixed acids are distributed over the packing by a silicon iron saucer sitting on top of it. The nitric acid vapours from the top of the still are carried in a silicon iron fume main to a silicon iron pot bleacher, where the fume meets the condensed acid and reheats it, thus driving off the bulk of the dissolved oxides of nitrogen. The fume then passes through two condensers arranged in series, each consisting of a nest of water cooled aluminium hairpin elements in a stone-ware shell. The shell is 18 in. internal diameter and the eight 2 in. hairpin tubes vary in length from 8 ft. 8 in. to 10 ft. 4 in. The condensed acid from the bleachers is cooled before passing to storage.

Corrosion Problems

The weak sulphuric acid leaving the base of the tower flows into a lead lute box and then through two lead coolers away to storage. While this plant easily produced the results guaranteed by the makers, a certain amount of teething trouble was experienced with it. For example, it soon became evident that much condensation of acid vapour was taking place in that portion of fume main from the still tops situated inside the building and the temperature of the gases leaving the fans was very high. Heavy corrosion took place and the main was eventually water cooled. It was thought at first that the cause of this high temperature was lack of sufficient water through the secondary condensers and the presence of much air in the gas stream. Vigorous steps were taken to cut down air leaks in the system and it was found that extra cooling water made little difference. The feed lutes were eventually found to be the principal source of air leakage. Alterations here made some difference but not as much as had been expected.

A laboratory investigation in 1944 showed that the poor performance of the condensers was due to the presence of air which acted as a carrier gas, removed nitric acid vapour at its saturation vapour

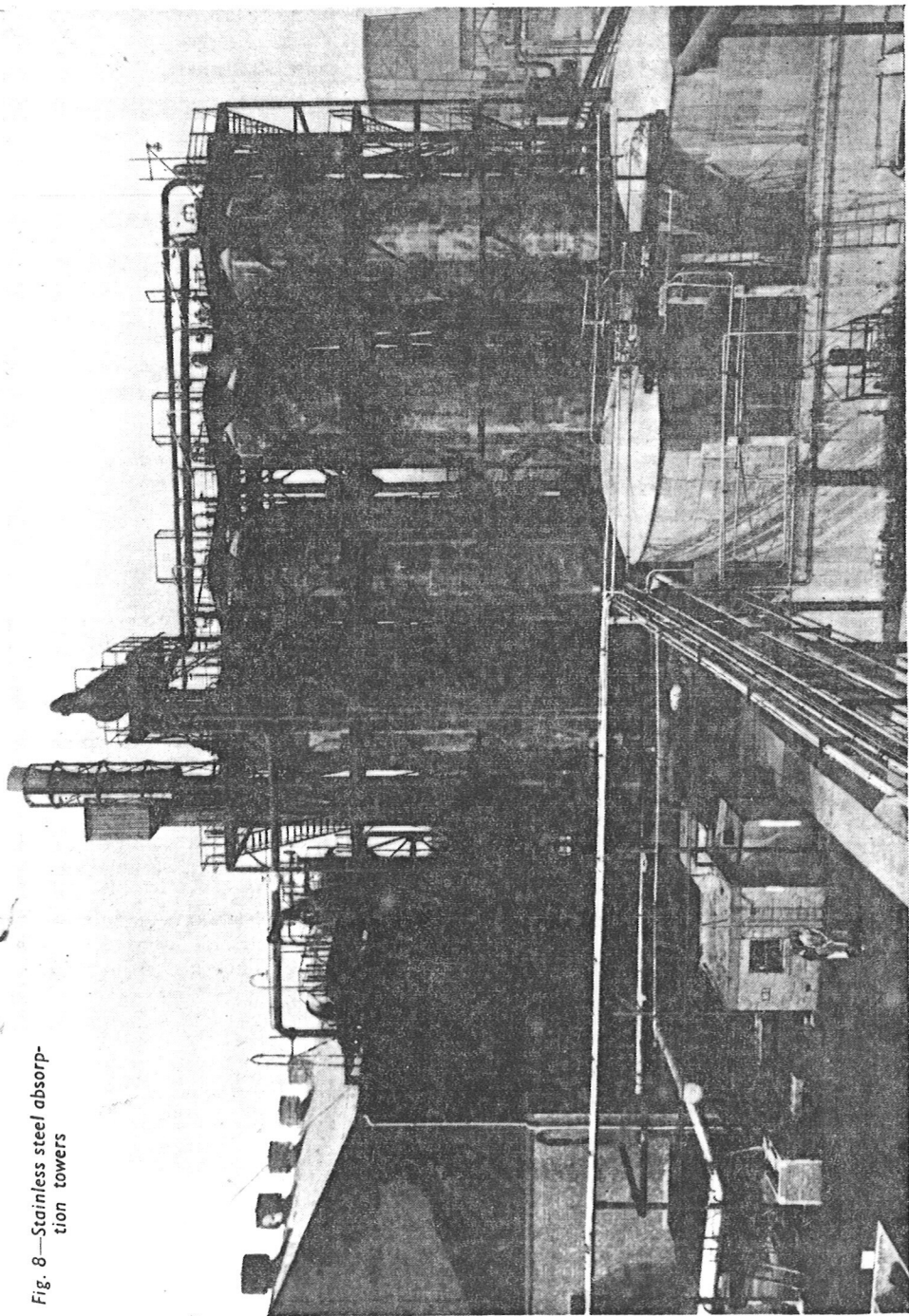


Fig. 8—Stainless steel absorption towers

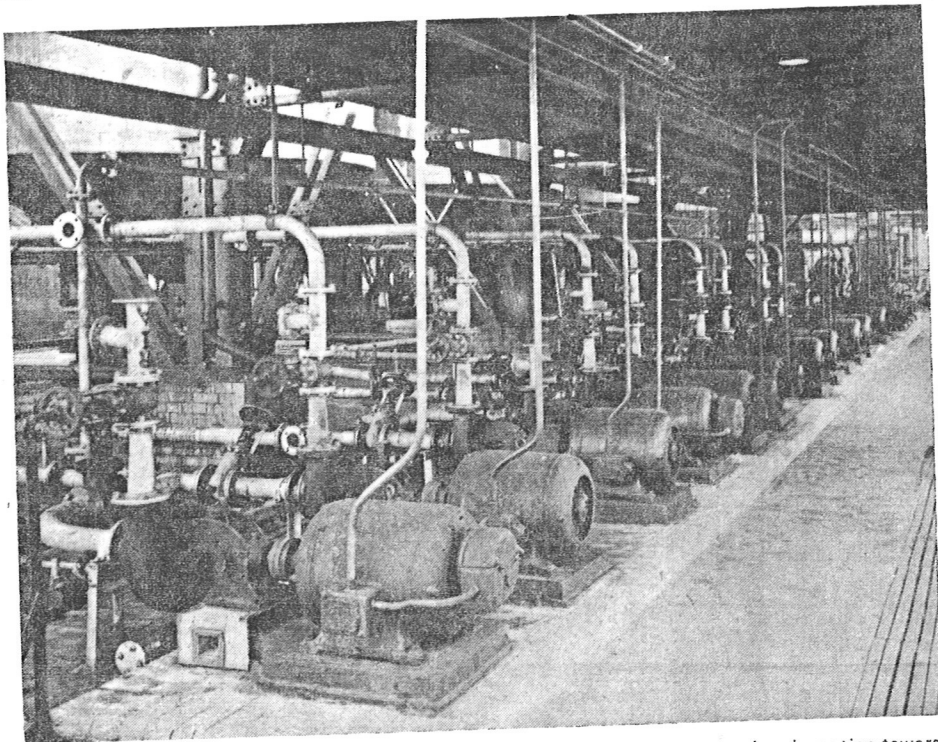


Fig. 9—Acid pumps at the absorption towers

pressure and reduced the heat transfer coefficient on the gas side of the tubes. Eventually it was decided to run the two condensers in parallel and instal an extra one in series with them. This showed an increase in condenser efficiency of several per cent.

A further important alteration was the introduction of "split feeds"; that is the introduction of the nitric acid feed on to a distribution saucer some 6 ft. below the top one which was then used for the sulphuric acid only. Many other improvements in operation were introduced as a result of experience, and whereas in 1942 the average input ratio of H_2SO_4 to HNO_3 had been over 3.5 : 1, this figure by the early part of 1945 had been considerably reduced.

Concentration of Sulphuric Acid

The concentration of sulphuric acid by the pot still process is simple in principle. Concentrated acid is boiled in a cast iron still heated by producer gas and the hot vapour passes up a

dephlegmator column down which weak acid is fed into the pot. The concentrated acid overflows at a constant level from the still pot to a double shell cooler and thence to an acid make line leading to mud settling tanks, whence it is pumped to storage.

With the exception of one or two experimental stills, all are of the standard Bamag type. They are arranged in two houses each containing twenty stills. The ten stills on each side of a central gangway are served by three Gibbons-Heurty gas producer plants. The product of each set of ten still flows into a common make line and away by gravity to a pair of mud settling tanks. The weak acid is fed to the stills through the usual type of lead feed box supplied from head tanks into which the weak acid is pumped with constant overflow.

The stills are cast iron pots about 8 ft. 2 in. in internal diameter and 6 ft. 6 in. in depth. The bottom thick-

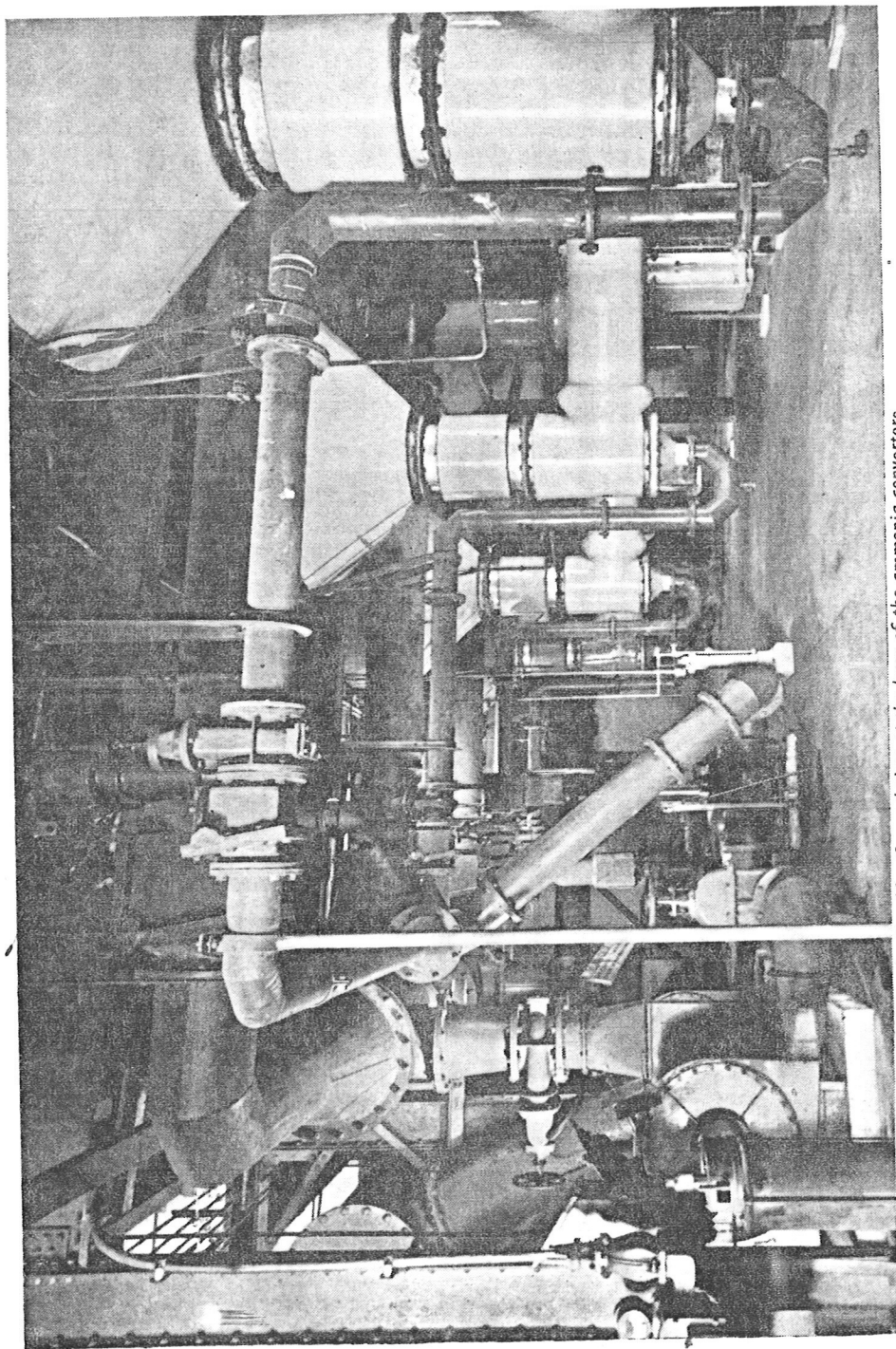


Fig. 10—General view at the base of the ammonia converters

ness was increased, as experience was gained, from $2\frac{1}{2}$ to $3\frac{1}{2}$ in. A cast iron cover with three necks is flanged on to the top of this. The three branches are:—

(a) An acid inlet 1 ft. 8 in. in diameter with a silicon iron liner and the joint between the branch and the bottom of the dephlegmating column which sits on top of it protected by tiles.

(b) A central oval branch through which the agitator passes.

(c) A manhole branch identical with the acid inlet branch. The silicon iron thermometer pocket passes through this.

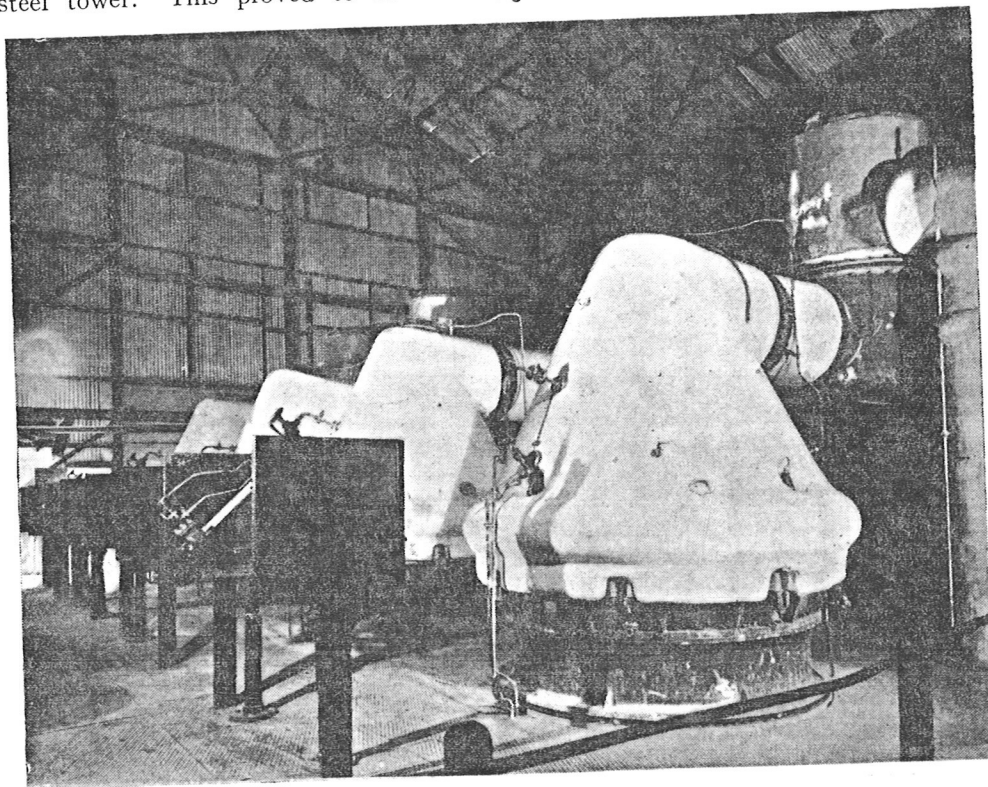
The dephlegmator was originally constructed as a silicon iron shell inside which was a set of seven silicon iron bubble cap plates. Efficient as this system was, the shortcomings of silicon iron led to its eventual abandonment in favour of a tile-lined, quartz-filled mild steel tower. This proved to be con-

siderably cheaper than the bubble cap tower and was much easier to handle when making repairs to the pot or lid.

The final design consisted of a mild steel shell lined first with lead and then with two layers of acid-resisting tiles. The quartz packing rests on silicon iron grid bars at the bottom of the tower, which is 10 ft. in height. About a foot from the top a stoneware distribution plate is fed with acid by a short length of pipe passing through the stoneware lid, which also carries a socket for the vapour connection. The short space above the distributing plate is filled with Raschig rings to act as a stripping column.

The vapours from the top of the dephlegmator pass through a silicon iron pipe to a silicon iron water ejector and thence through a de-aerating pot to

Fig. 11—View of the top of the ammonia converters



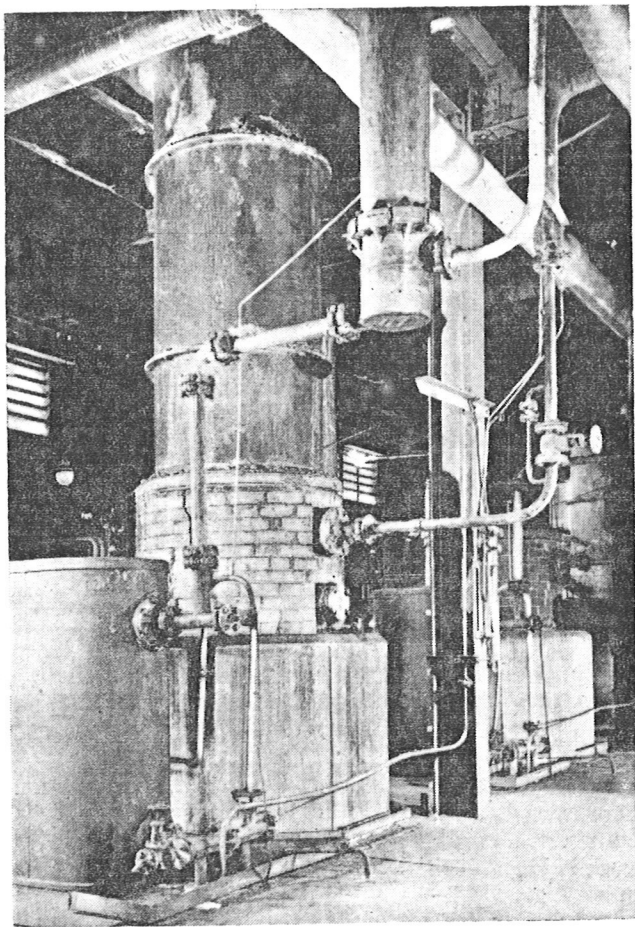


Fig. 12—Base of nitric acid concentration tower

waste. The acid loss is small, the acidity of the ejector water averaging about 0.1 per cent. The agitator is provided in order to prevent the accumulation of sludge at the bottom of the pot and is driven by an electric motor through a Radicon gear. The shaft is steel protected by silicon iron sleeves and the blade is silicon iron. The speed is 30 r.p.m. and the blade length 5 ft. 1 in.

The cooler is of the double shell type and is constructed of cast iron. The shells are of truncated conical form and connected at the base. The inner shell is widest at the base and the outer shell at the top. The inner shell is partly brick-lined and carries on its top the acid inlet pipe. Beneath the cooler and

connected with it through a 12 in. isolation valve is a sludge box.

The furnace design still follows the original lines, *i.e.*, the pot is suspended by the flanged rim in the setting and the pot chamber is separated from the combustion chamber by arches in the form of a grill. By means of two semi-circular arches the hot gases are turned round the pot before leaving the furnace. The temperature at which they leave is about 420° C. The air for a pair of furnaces is provided by a fan placed on top of the brickwork, and in some instances is preheated. The producer gas input to the furnace is controlled by a cone valve. The waste gases leave the furnace through a flue to a chimney and thence to atmosphere.

The producers are of the Gibbons - Heurty - Bamag type; the fuel is anthracite and the producer is water-jacketted to provide the steam necessary for the generation of gas. The fuel is fed from an overhead storage hopper by a revolving segmental drum, the speed of which can be varied. The internal diameter of the body is 10 ft. The cast iron grate lies on the base and is revolved with it by a variable speed pawl and ratchet drive. Each producer has its own air fan and motor situated on the platform. The air passes through a butterfly valve controlled by a variable load governor and is mixed with steam. Hand control is available in case of breakdown. There are water seals at the feeder, the ash box and the ash basin. The gas undergoes no cooling or

purification except that given by a brick-lined rectangular steel dust catcher.

For explosives work it may be stated that, in some cases, the pot still type of plant has advantages, in spite of the fact that the fuel consumption may be as much as 50 per cent. higher than that of direct fired plants like the Gaillard and the Drum. The acid from such plants is not as clean as that from pots, and it is difficult to concentrate to strengths above 93 per cent. without excessive loss of fume. With the pots continual operation at 95-96 per cent. occasions no difficulty. Acid from a pot still plant has been kept at a high temperature for such a long time that freedom from organic matter can be assumed.

(To be continued)

RESEARCH ON WATTLE TANNING

AT a meeting organised under the auspices of the South African Society of Leather Trades Chemists and the Eastern Province Branch of the South African Chemical Institute, at Port Elizabeth, Mr. D. Roux, M.Sc., a research worker of the Leather Industries Research Institute, Grahamstown, delivered a paper in which details were given on some aspects of the work being carried out on the production of light coloured leather from wattle extract.

Investigation had shown that the darkening of wattle solution was due to oxidation and that the presence of a reducing agent inhibited the colouration. Previous workers had reached the same conclusion, and it was common practice amongst tanners to add sodium bisulphite to tanning liquors to achieve the desired result. However, a fairly large quantity of the reducing agent was required. Work at the Institute was directed to producing a light coloured extract in the first instance, and it was found that the addition of a small quantity of sodium bisulphite to the solution in which the initial extraction from the bark was made produced a light coloured extract which did not subse-

quently discolour. The quantity of bisulphite required was very much smaller than that required if added to the normal extract during subsequent tanning operations. Further work is being conducted in accordance with the laboratory process with a view to overcoming the technical difficulties associated with the production of wattle extract on a large scale.

INTERNATIONAL SCIENTIFIC FILM CONGRESS

THE International Scientific Film Association was constituted last year in Paris by delegates from 22 countries who had accepted the joint invitation to the inaugural congress from The Scientific Film Associations of Great Britain and France. The primary aim of the Association is:—

“To raise the standard and to promote the use of the scientific film and related material throughout the world in order to achieve the widest possible understanding and appreciation of scientific method and outlook, especially in relation to social progress.”

The second congress of the Association will be held in London from October 4—11, 1948. This year's congress is being convened by the Scientific Film Association of Great Britain, with the help of the British Film Institute, and invitations have already been issued to countries throughout the world.

The congress will open with a formal reception to the delegates on October 4, and the following three days will be devoted to business meetings of The International Scientific Film Association. On the 8, 9 and 10 of October there will be a Festival of Scientific Films at which it is hoped to show many contributions from all the participating countries to members of the general public.

The widespread public interest in this country in the scientific film, as evidenced by over 10,000 members of local scientific film societies, makes it particularly appropriate that this congress should be held in Great Britain.



Fig. 13—A view of one of the R.D.X. "cleanways"

The Manufacture of R.D.X. in Great Britain

Part III—Production of the Explosive

By W. H. SIMMONS,* F.R.I.C., A.M.I.Chem.E., A. FORSTER,† O.B.E., D.Sc., Ph.D., and R. C. BOWDEN,‡ O.B.E., Ph.D., M.Sc., M.I.Chem.E., F.R.I.C.

THE Bridgwater R.D.X. factory is unique among British explosives factories in that the buildings are interconnected by a series of covered "clean ways." The area in which R.D.X. is made and mixed with other materials to form the finished explosives, which are exported from the factory, is fenced off as a "danger area," and all the buildings in which explosive is handled are surrounded by earth traverses.

At the entrance to the area are situated changing rooms for male and female workers. All operatives handling explosives change into "clean" clothing before starting work and put on "clean" shoes. These are made without steel nails and are exclusively worn in "clean"

areas so that they cannot become contaminated with grit and thus form a possible source of danger. The term "clean" as applied to floors, shoes and clothing in explosives factories refers solely to this condition of freedom from grit. The "cleanways" connecting changing rooms and plant are of concrete construction with a gritless asphalt carpet. The sides are open so as not to give any chance of them acting as tunnels to convey an explosion from one building to another, but they are roofed over with asbestos cement for protection of the operatives from the weather.

As many readers will be unfamiliar with explosives practice a brief review of the precautions that are taken will not be out of place, particularly when it is remembered that such safety measures, rigidly enforced,* have, in 50 years, made

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explosives manufacture one of the safest industrial operations instead of one of the most dangerous.

Safety Precautions

The elimination of all cracks, pockets and ledges in metal parts touching or near explosive and in walls and floors; the complete exclusion of striking metal to metal parts; the positioning of bearings as far as possible from the explosive are all points of design that have to be carefully watched.

All motors, shafts, plant units and building frames are earthed and motors have to be of flameproof design. In buildings containing dry explosive, or in which drying processes are carried out, motors are placed outside and only Buxton tested electrical fittings are used. All buildings have lightning conductors and special care is taken with earthing where there is a chance of generating static electricity (sieves, etc.). No iron or steel which might strike sparks from hard surfaces, possibly contaminated with explosive, are allowed. Every building has displayed in it a notice giving particulars of the maximum quantity of explosive allowed in it and the maximum number of operatives, all loose articles allowed in the building, and the Special Rules for safe operation of the process carried out there.

Comparatively small buildings, well-spaced from each other and surrounded by earth traverses with dog-leg entrances and internal dividing walls to prevent propagation of explosion from one unit to another, are among the constructional points.

Particular care is needed when cleaning out plant. Wooden implements are used for the removal of caked explosive and, before any plant can be removed from the section, it must be thoroughly decontaminated and certified clear of explosive by a chemist. A chemist, too, must pass a welding flame over all plant that has to be heated or welded, before any repairs can be done. Small steel one-man air raid shelters with eye-slits and arm-holes cut in them were

found useful for this purpose, being used with a burner with a 6-ft. extension to the jet.

The process consists essentially of the nitrolysis (commonly known as "nitration") of hexamine by the continuous addition of crystalline hexamine and concentrated nitric acid to a cooled reaction mixture resulting from the same ingredients. The resulting solution contains the R.D.X. product and various unwanted by-products, as well as much unused nitric acid. This solution overflows into a vessel where a controlled hot dilution takes place, allowing the R.D.X. to crystallize out and decomposing the by-products previously described. The residual weak acid is separated from the solid R.D.X. by continuous filtration, and is blended with the weak acid from the absorption towers before concentration.

Properties of R.D.X.

The crude R.D.X. is milled to reduce crystal size and purified by washing and boiling in water. This pure wet R.D.X. is mixed with various phlegmatizing agents before drying, according to the final product required. R.D.X. is a colourless opaque crystalline solid without odour or taste. Its melting point is 205° C. and its density 1.825. It is sparingly soluble in water (0.005 per cent. at 20° C. and 0.20 per cent. at 95° C.). It is soluble in nitric acid, the solubility rising rapidly with temperature and increase of the acid strength. It is also soluble in certain organic solvents such as acetone and cyclohexanone. It is rapidly hydrolysed by dilute caustic soda, a property made use of for decontaminating plant. Sulphuric acid of over 70 per cent. reacts violently with R.D.X. producing oxides of nitrogen and water soluble decomposition products.

The nitrating houses contain either two or three nitrators which feed two dilutors. The nitrator itself is a rectangular stainless steel vessel 3 ft. by 1 ft. 3 in. by 2 ft. 8 in. high, divided into three compartments by baffles. Each compartment contains a stirrer entering through

the lid. The first compartment also contains three concentric cooling coils ($\frac{5}{8}$ in. i.d.) having a cooling surface of 20 sq. ft. The second and third compartments each contain one coil. Two fume off-takes rise from the nitrator lid, the first carrying a cylindrical Pyrex sight-glass. Brown fumes seen in this sight-glass indicate that the contents of the nitrator should be drowned at once. In the lid over the first and second compartments there are 2 in. dia. holes, through which the hexamine feeds enter.

In the first compartment a 1 in. dia. nitric acid feed enters. The outlet is placed centrally on the end of the third compartment so as to give a 23-in. working depth.

The hexamine feeding device is placed in a compartment above the nitrator. It consists of a double hopper supplying two horizontal screw feeds. These are driven through a P.I.V. gear box and geared together so that the second delivers one quarter of the quantity delivered by the first. The rates can be varied to give a total feed from 125 to 375 lb. per hour. The regulated flow of hexamine falls through the floor by two chutes and is directed into the first two compartments of the nitrator by vertical screws. The nitric acid feed to the nitrator is through a Rotameter.

Under the nitrator is a 3-in. drowning valve which can be operated from the control panel. When this is used the contents of the nitrator fall through the floor into a tank of urea solution in a separate compartment below. Drowning into this solution reduced greatly the amount of fume produced as compared with drowning into water.

The overflow from the nitrator runs into a stand-pipe feeding a dilutor at a somewhat lower level. These vessels are similar in shape to the nitrators, but considerably larger; being 8 ft. 9 in. by

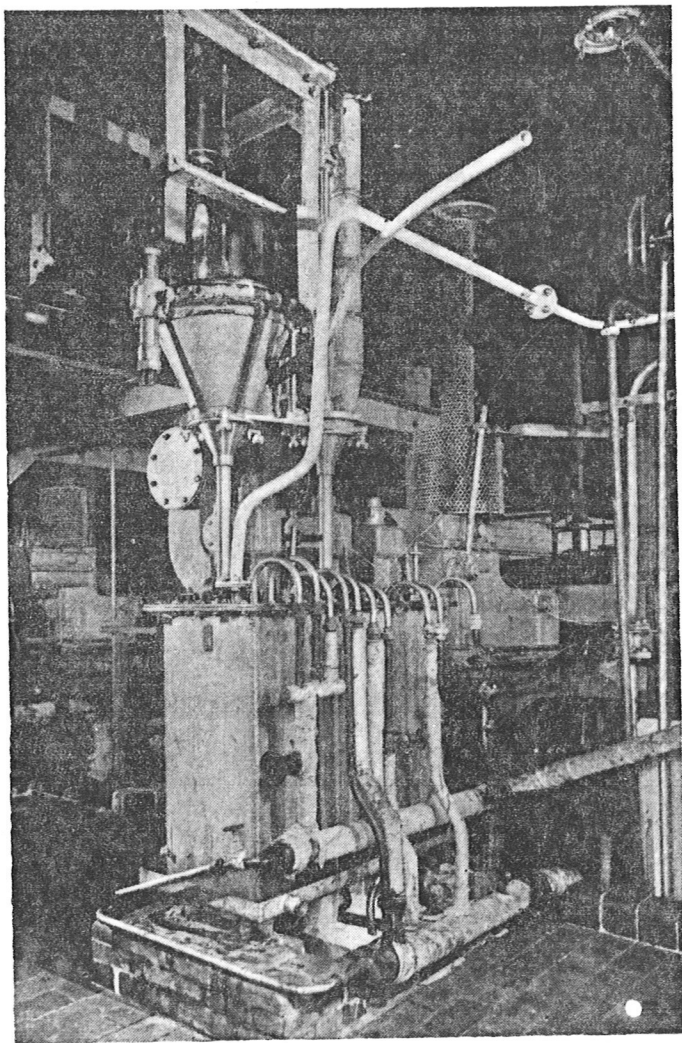


Fig. 14—A continuous nitrator for R.D.X.

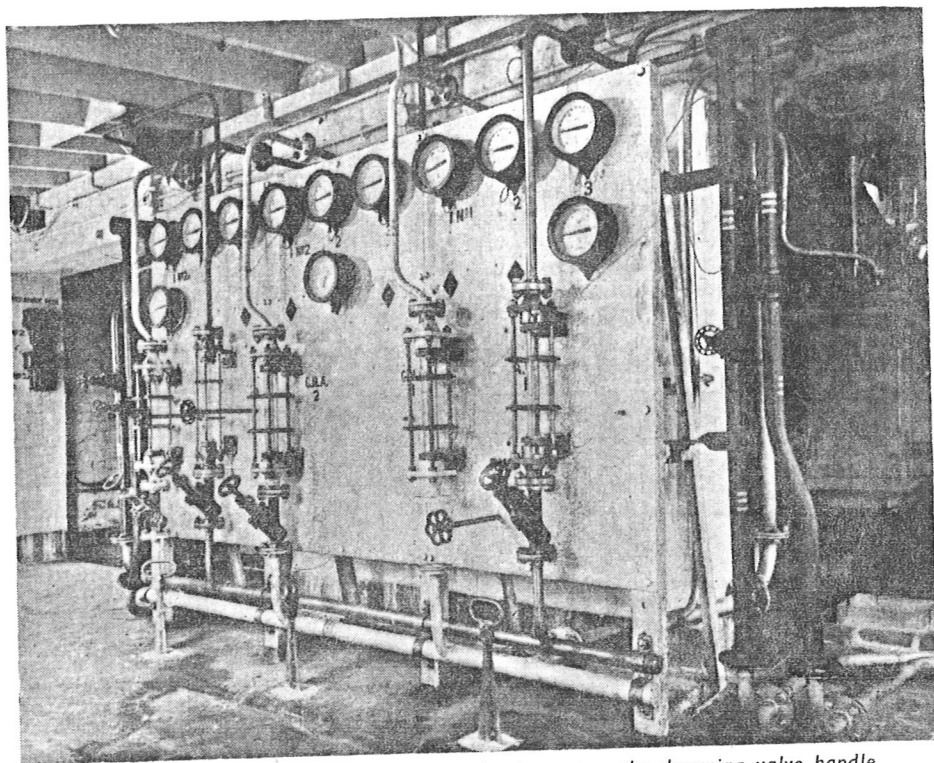


Fig. 15—Nitrator control panel, showing in the centre, the drowning valve handle

2 ft. by 3 ft. 9 in. deep. The working depth is 2 ft. 2 in.; there are four stirred compartments, each cooled by a coil, and further cooling is obtained from external sprays.

The stirrers have flat blades 15 in. by 8 in. and run at 195 r.p.m. Nitrous fume is evolved copiously in the dilutor and is removed by ducts connected to each compartment and uniting into a 15-in. main, which, in turn, connects into a 20-in. trunk leading to a fume cooler. The solution of nitrated hexamine enters the first compartment, which also has a 1-in. connection in the lid for the dilution water. This is acidulated water removed from the R.D.X. at a later stage. The quantity added is regulated through a Rotameter.

A venturi type emergency steam ejector is fitted to the fume main to cope with possible power or fan failures. The fume main falls slightly from the house to

a seal pot which collects acid condensate and returns it to the system, and then enters a fume cooler. This is 6 ft. in dia. and 11 ft. high. It contains 706 $1\frac{1}{2}$ -in. stainless steel tubes 8 ft. long arranged in three passes and externally cooled by water. Condensate is collected below and returned to the system and the fume, now cooled to 20-30° C., passes along the stainless steel mains leading to the absorption towers.

Classifier Filters

The R.D.X. slurry leaves the dilutor by a covered trough and enters a cooler consisting essentially of two more dilutor compartments. The cool slurry overflowing from this passes to the classifier-filters, a unique feature of the process. Before describing them, however, a brief summary of operating conditions for the nitrator and dilutor will not be out of place. As has been seen, the bulk of the

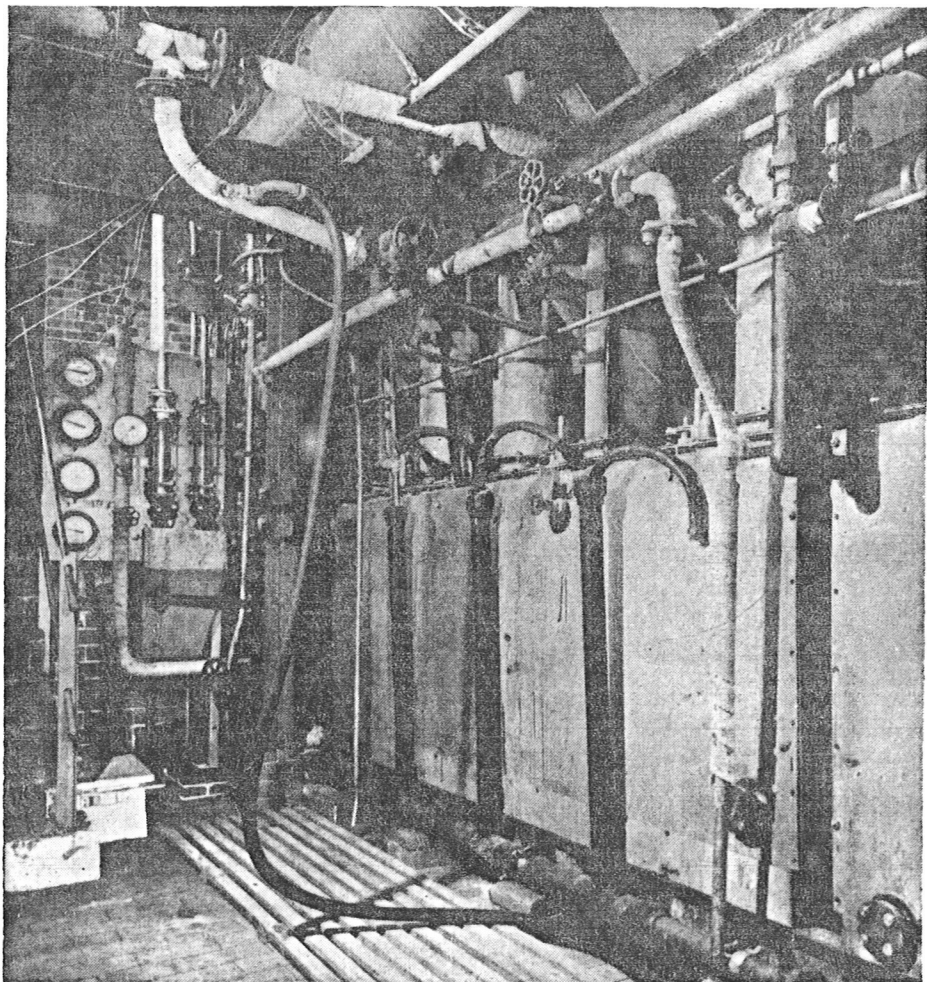
hexamine, together with all the nitric acid, is run at a predetermined rate into the first compartment of the nitrator. For each pound of hexamine 1,100 B.Th.U. are liberated. This is removed by circulating refrigerated water in the cooling coils. By this means the temperature of the compartment is maintained at a temperature not exceeding 25° C.

The plant investigation department at Bridgwater made an exhaustive investigation into the conditions controlling the efficiency of this nitrolysis. They found

that it was advantageous from the point of view of yield to add about one fifth of the total hexamine in the second compartment; the high acid/hexamine ratio obtained with the bulk of the hexamine increases the yield sufficiently to counterbalance the reduced yield on the remaining fifth. This reduced acid usage, without a corresponding reduction in yield, enabled production to be increased.

In the third compartment of the nitrator, hot water is circulated in the coil and the temperature maintained at 38° C. This increase in temperature at

Fig. 16—Dilutor with control panel in the background



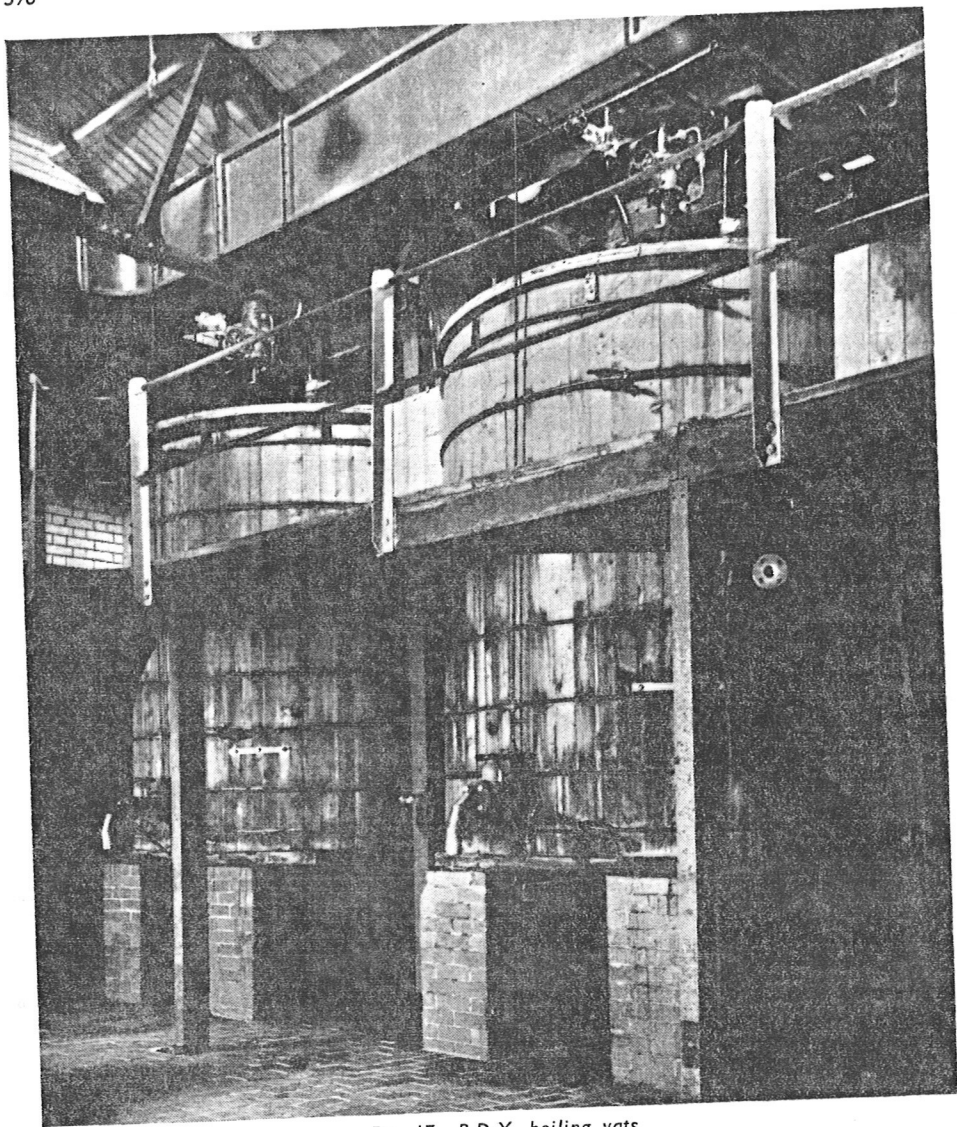


Fig. 17—R.D.X. boiling vats

the end of the nitration process is another development of the work referred to above which had a marked effect in increasing the yield.

When starting nitration, the dilutor is filled with 55 per cent. nitric acid and this is warmed to about 100°C . by circulating steam in the coils. This is gradually cut down as nitration liquor begins to circulate, and water is added

at such a rate as to maintain the strength of the outgoing acid at 55 per cent. By the time the plant has reached steady operating conditions, water is on all the coils and the external sprays, and in this way a steady temperature of 75°C . is maintained. The suction on the fume main is maintained at $\frac{1}{2}$ – $\frac{3}{4}$ in. w.g. throughout operation. Any suction failure can lead to serious results as in

normal operation each dilutor is producing NO_2 at a rate exceeding 15 lb. per minute; hence the provision of emergency fume ejectors which can be turned on from the door of the house.

Instrumentation

The control panel for the nitrating house contains dial thermometers for each compartment of the nitrator and dilutor (mercury-in-stainless-steel type); Rotameters for concentrated nitric acid and water; a cooling water pressure gauge; a cooling water dial thermometer; drowning valve control; start and stop switches for nitrator and dilutor stirrers, etc.

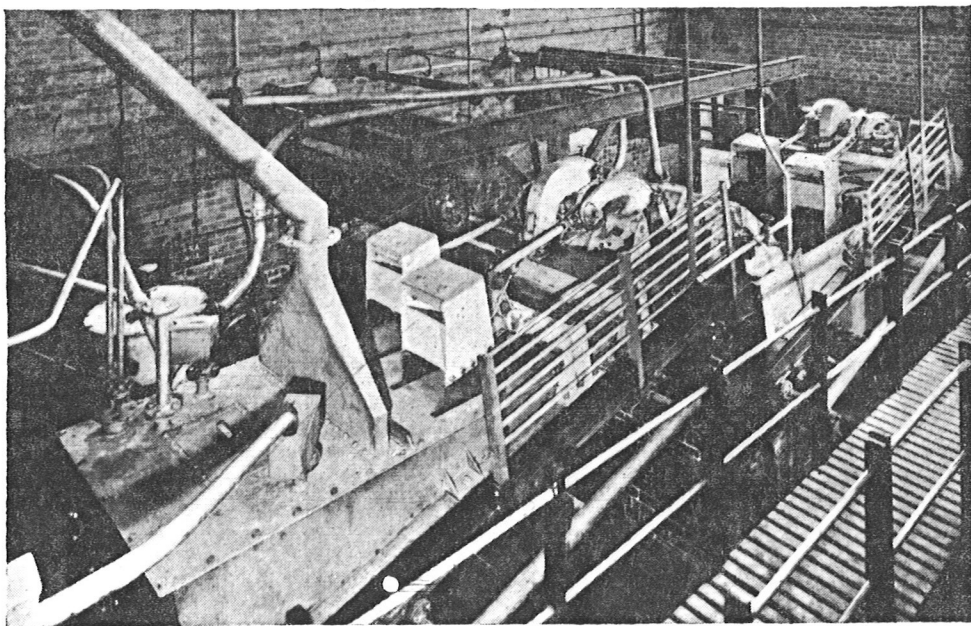
The slurry of R.D.X. and weak nitric acid leaves the cooler by a covered trough to the first filter. Intake of air which would dilute the nitrous gases going to the absorption towers is prevented by a liquid seal. There are two specially designed continuous vacuum filters (in series) to each two dilutors (in parallel).

Weak nitric acid runs off through four $1\frac{1}{2}$ -in. pipes to a 3-in. manifold. This manifold is connected to a vertical cylin-

drical separator 4 ft. high by 1 ft. 6 in. dia. to the top of which vacuum is applied. The filtrate is removed by a LaBour pump connected to the conical base of this separator, and returned to the acid factory for concentration. The first filter, in which the weak acid is separated from the R.D.X. is covered and the cover is connected to a fume off-take under suction from an air-ejector. The second filter is uncovered and the R.D.X., on its course through it, is washed with water to remove the remaining acid. The acid-water removed from the separating pot attached to this filter is pumped to a tank on the roof and used to feed the dilutor. Vacuum to both filters is supplied by a Drysdale Aquair pump made entirely of stainless steel. The crude R.D.X. coming off the end of the second filter falls into a stainless steel truck in which it is conveyed to the boiling house.

The Bishopton plant differs from the Bridgwater plant only in a few respects. Hexamine was not made at this plant but was imported from Bridgwater and from the trade. Before use it was

Fig. 18—The classifier-filters



dried in a Simon drier as used at Bridgewater. The nitrators consisted of a train of three cylindrical vessels 2 ft. 8 in. deep by 1 ft. 6 in. dia., with welded connections forming a single inseparable unit. The first compartment is thus big enough to take five cooling coils, and the necessity of using refrigerated water is avoided. Each nitration house has a separate and independent fume absorption system, consisting of five stainless steel towers in series, 32 ft. in height by 5 ft. in dia. The circulated acid is cooled before passing from one tower to another. The R.D.X. from the second filter is washed into a slurry receiver down a trough by a spray of water controlled by a Rotameter. The slurry receiver is a Columbian pine vat 6 ft. in diameter and 4 ft. high, stirred by a 14 in. impeller type stirrer working at 500 r.p.m. This vat is emptied by a steam ejector which lifts the slurry into a 2-in. line used for conveying it to the boiling house.

This system saved a great deal of handling at this factory where there were no cleanways between buildings, but at Bridgewater the stainless steel trucks, conveyed between the buildings by a Ransome battery driven lifting platform truck, were preferred.

Boiling House

The crude R.D.X. contains some coarse grist material which has to be broken down before use. Some nitric acid (0.1-0.2 per cent.) is occluded in the crystal interstices and there is also some nitric acid in the wash liquor adhering to the crude R.D.X. It is the object of the processes in this house to break the coarse grist down without producing too much very fine material, and to remove as much as possible of the nitric acid. In the Bridgewater plant, the stainless steel trucks, which hold about 400 lb. R.D.X., are wheeled into position under a steam ejector to the suction end of which a length of armoured hose is attached. The material is slurried with a water hose and the slurry is sucked up as fast as it is formed by the steam ejector. By this means one girl can empty and raise the contents of a truck in about five minutes. The delivery of this ejector is into one of two stirred stainless steel round bottomed vessels 4 ft. in dia. by 7 ft. deep. From these slurry receivers, the slurry (approx. 3:1) is fed by gravity to one of a number of British Rema disc mills. These again are all stainless steel construction. They are 18 in. in dia. and the opening can be adjusted by hand.

It is usually between 10 and 25/1000 in. Water is fed into the mill at the same time as the slurry to prevent overheating should the slurry supply fail. The milled slurry is lifted about 15 ft. above the mills through a 1-in. stainless steel pipe (the mill acting as a pump) and can be diverted to any vat by a rubber hose connection.

The vats are of Columbian pine and

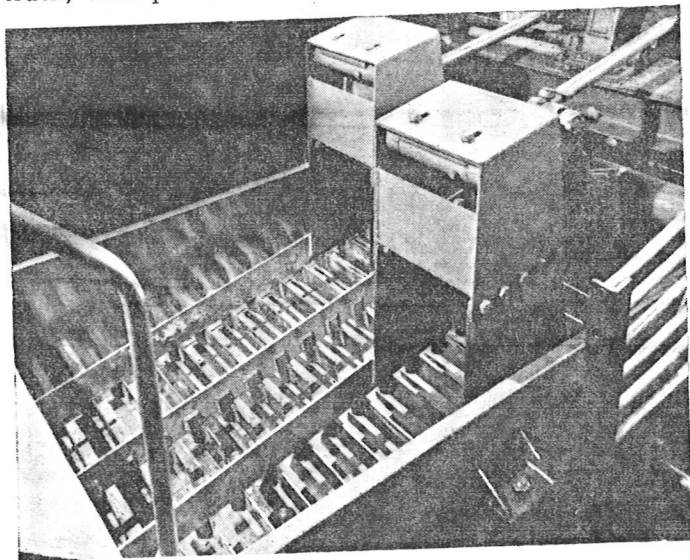


Fig. 19—An interior view of the classifier filter

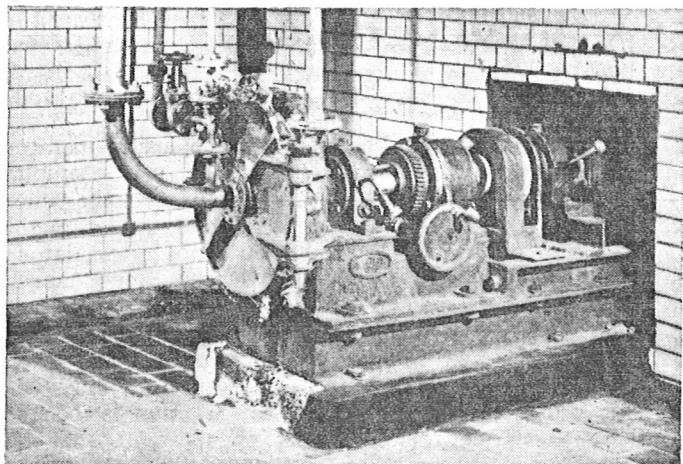


Fig. 20—Rema mill for R.D.X. slurry

are raised on brick piers 2 ft. 3 in. above the floor. They are 8 ft. 4 in. high by 8 ft. diameter with a bottom with a 1 in 10 slope to a discharge opening. The vats are $2\frac{1}{2}$ in. thick and have wooden covers venting through the roof. Through each cover passes a central stirrer shaft, a 2-in. water line, a $2\frac{1}{2}$ -in. steam inlet pipe and a 5-ft. indicating thermometer. Each vat has two $2\frac{1}{2}$ -in. enamel lined Saunders valves, one at the lowest point for discharging and one 3 ft. 6 in. above the base for decanting. The agitator is a stainless steel paddle 3 ft. 3 in long by 1 ft. 6 in. high reaching to within 2 in. of the vat bottom. It is carried by a vertical stainless steel shaft driven at 63 r.p.m.

The vats are heated by live steam through $2\frac{1}{2}$ -in. stainless steel pipes, reaching to within 6 in. of the vat bottom and terminating in fish tails pointing in the direction of stirring.

Final Processing

The vat charge is 5,000 lb. dry weight of R.D.X. As soon as this quantity has been milled in, the vat stirrers are stopped and the contents allowed to settle for $\frac{3}{4}$ hour. The supernatant liquor, which has an acidity of about 0.1 per cent., is discharged by the decanting valve through a wooden save-all to collect any fine R.D.X. still in suspension. Three similar cold water

washes are given, and after the third the steam is turned on and the liquor kept at 90-100° C. for 12 hours. After a further decantation the slurry is run off and drained down to be weighed out as damp slurry containing approximately 10 per cent. water for use in the manufacture of whatever finished product is required.

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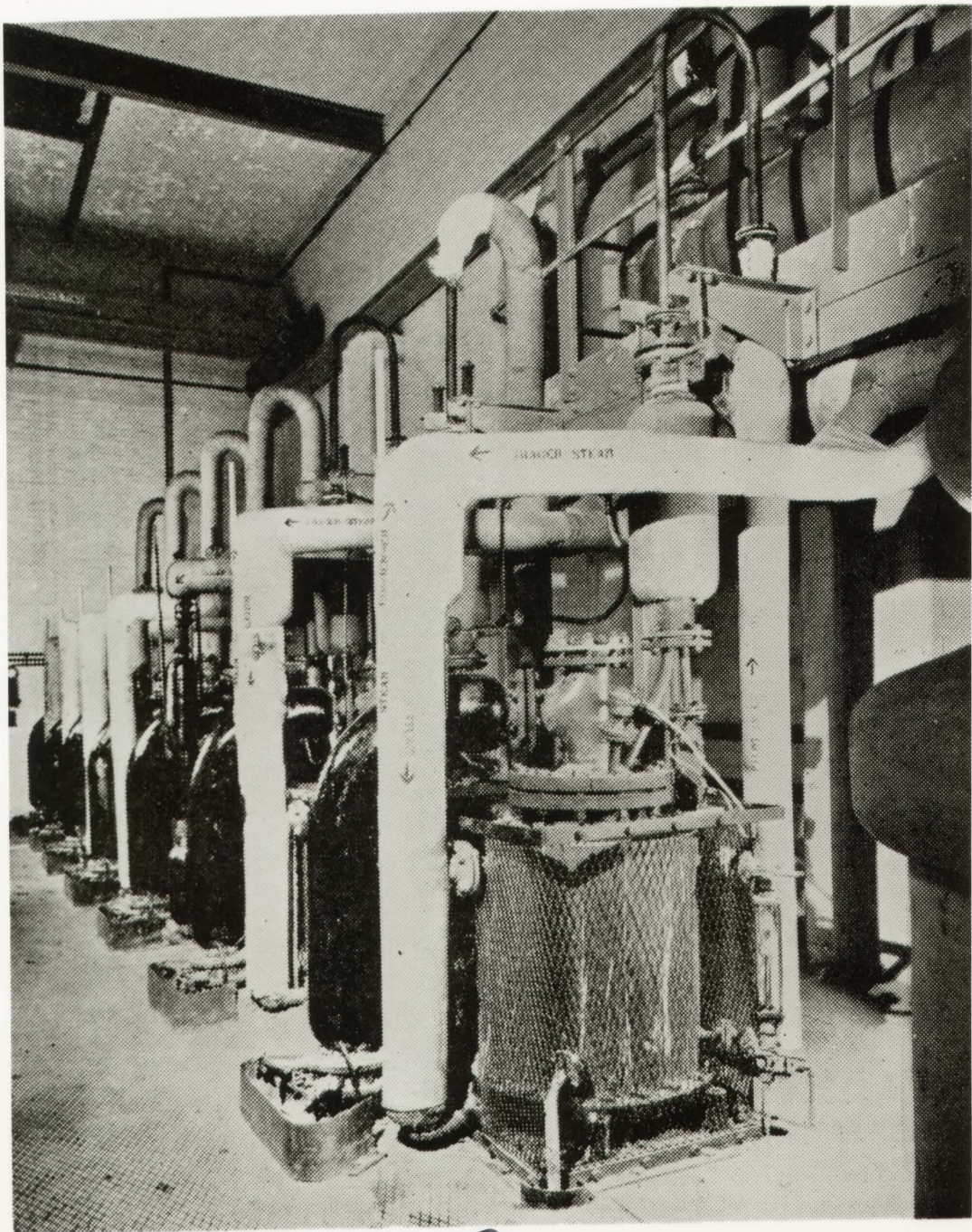
SULPHURIC ACID PRODUCTION

DURING the second quarter of 1948 the total production of sulphuric acid, by both the chamber and contact processes, amounted to 398,744 tons, counted as tons of 100 per cent. sulphuric acid, according to returns issued by the National Sulphuric Acid Association Ltd.

As 403,995 tons were produced during the preceding quarter, the new figure represents a drop in production of 5,251 tons. Percentage production for the chamber process declined by 1.6 per cent. and by 2.8 per cent. in the case of the contact method.

DIESEL POWER

THE importance of installing diesel-driven generating plant for power supply in factories, in view of the overloaded grid supply, is emphasised in information received from Davey, Paxman & Co. Ltd. The same source also discusses the characteristics of diesel sets and indicates the possibility of utilising waste heat from the engine for space heating or water supply.



Converter Platform

PTO

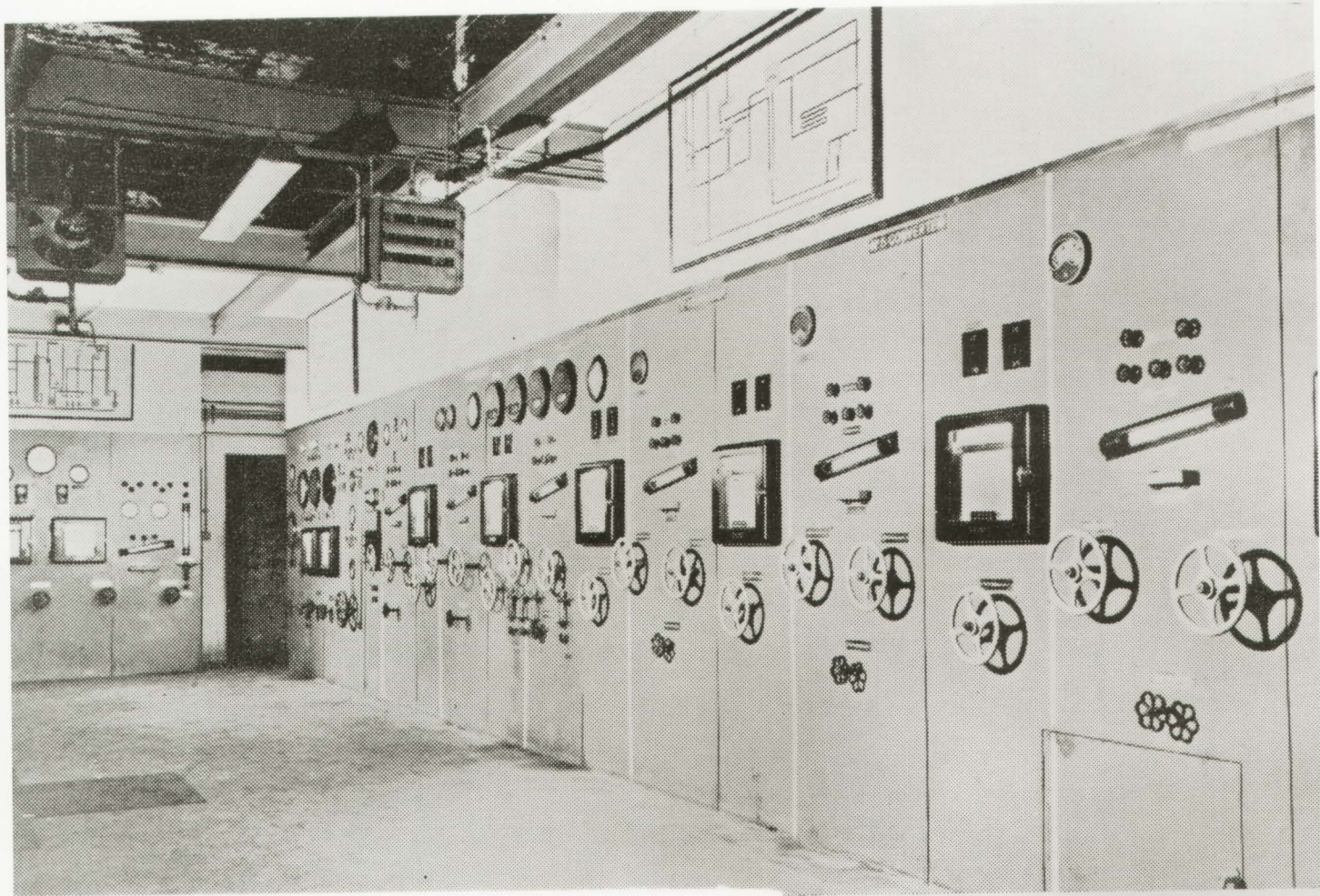


Fig. 2—Formaldehyde control panel

Fig. 3—Storage vessels for formaldehyde

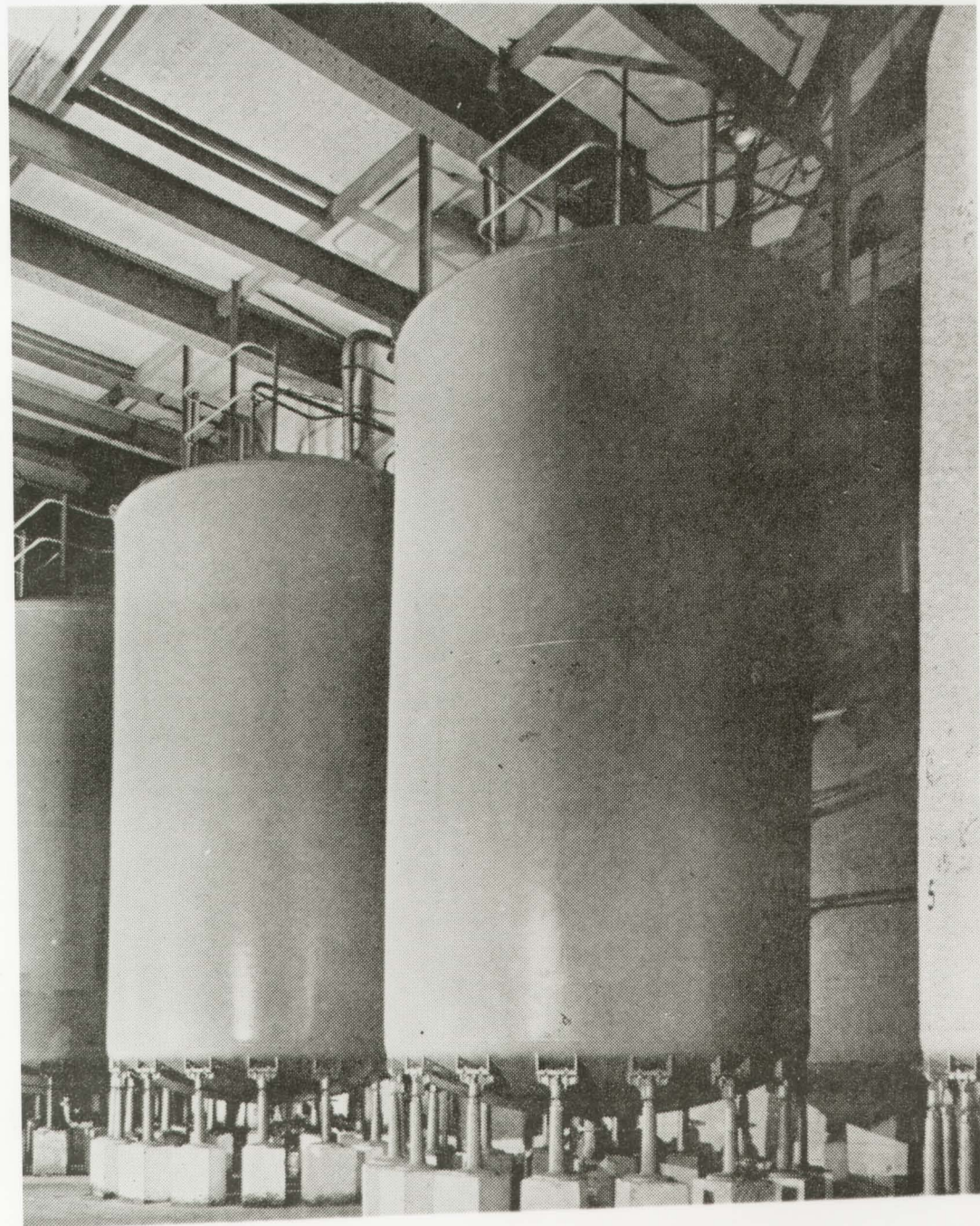
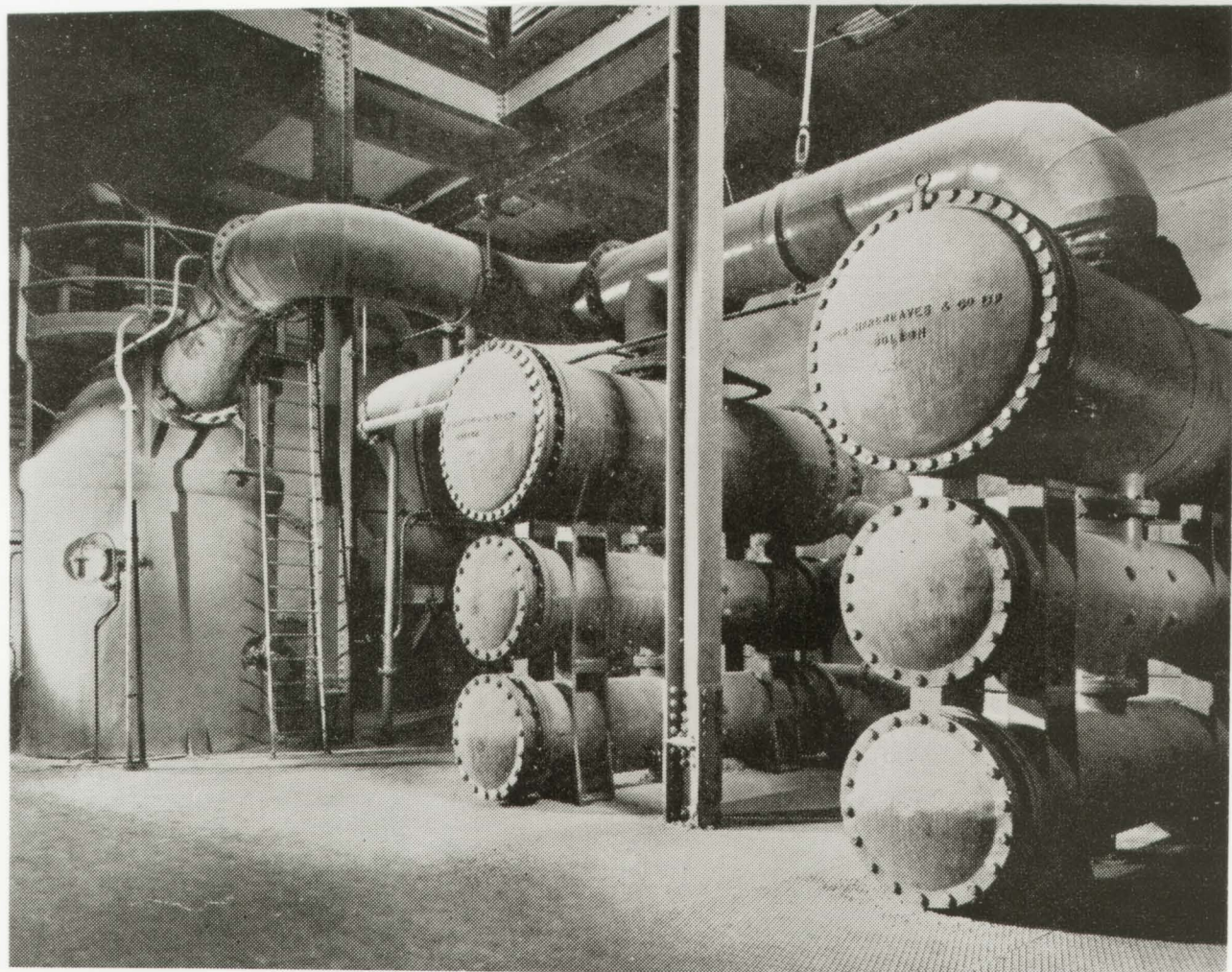


Fig. 4—Hexamine condenser and evaporator



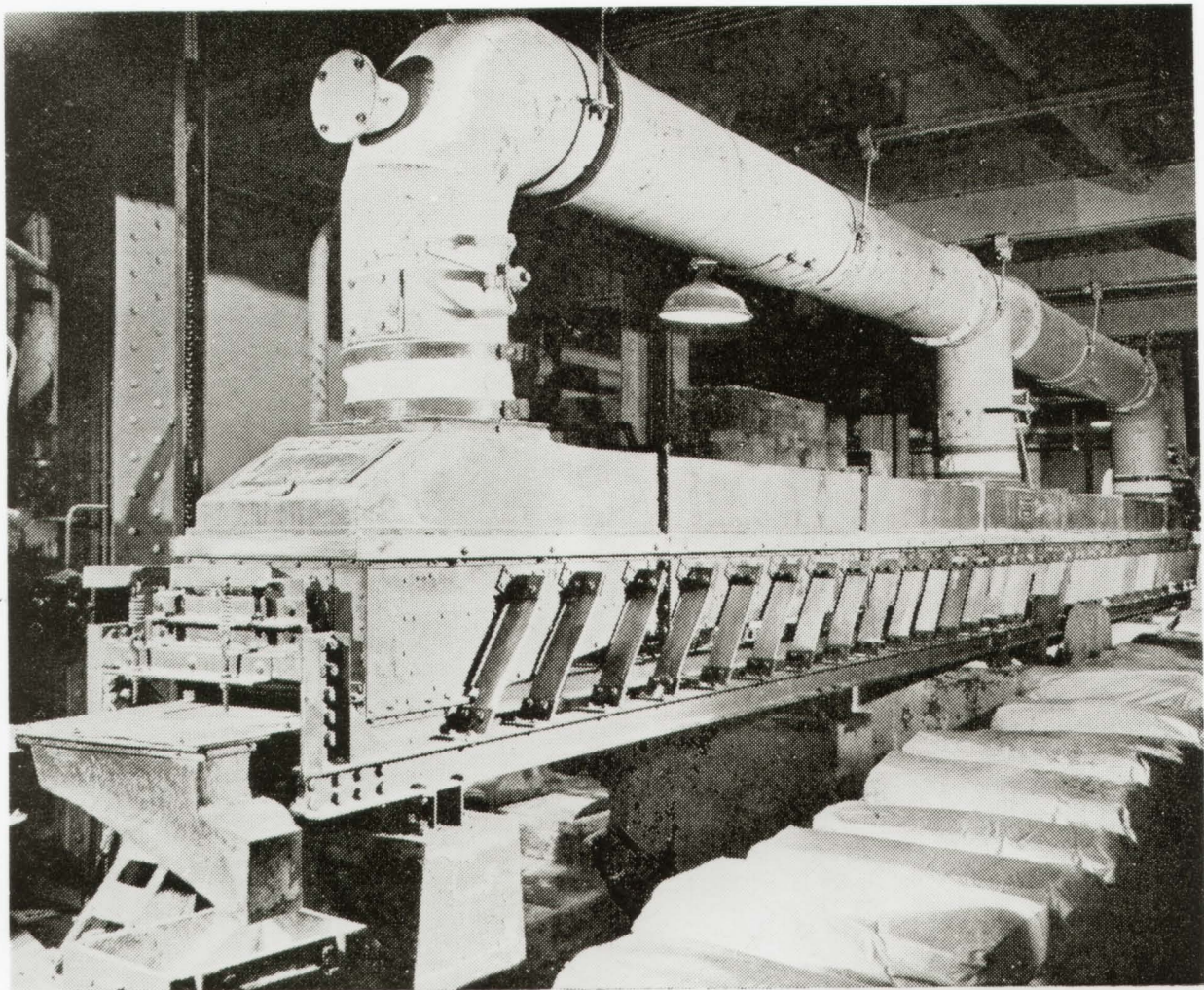


Fig. 5—The hexamine drier

Fig. 7—Fume absorption plant

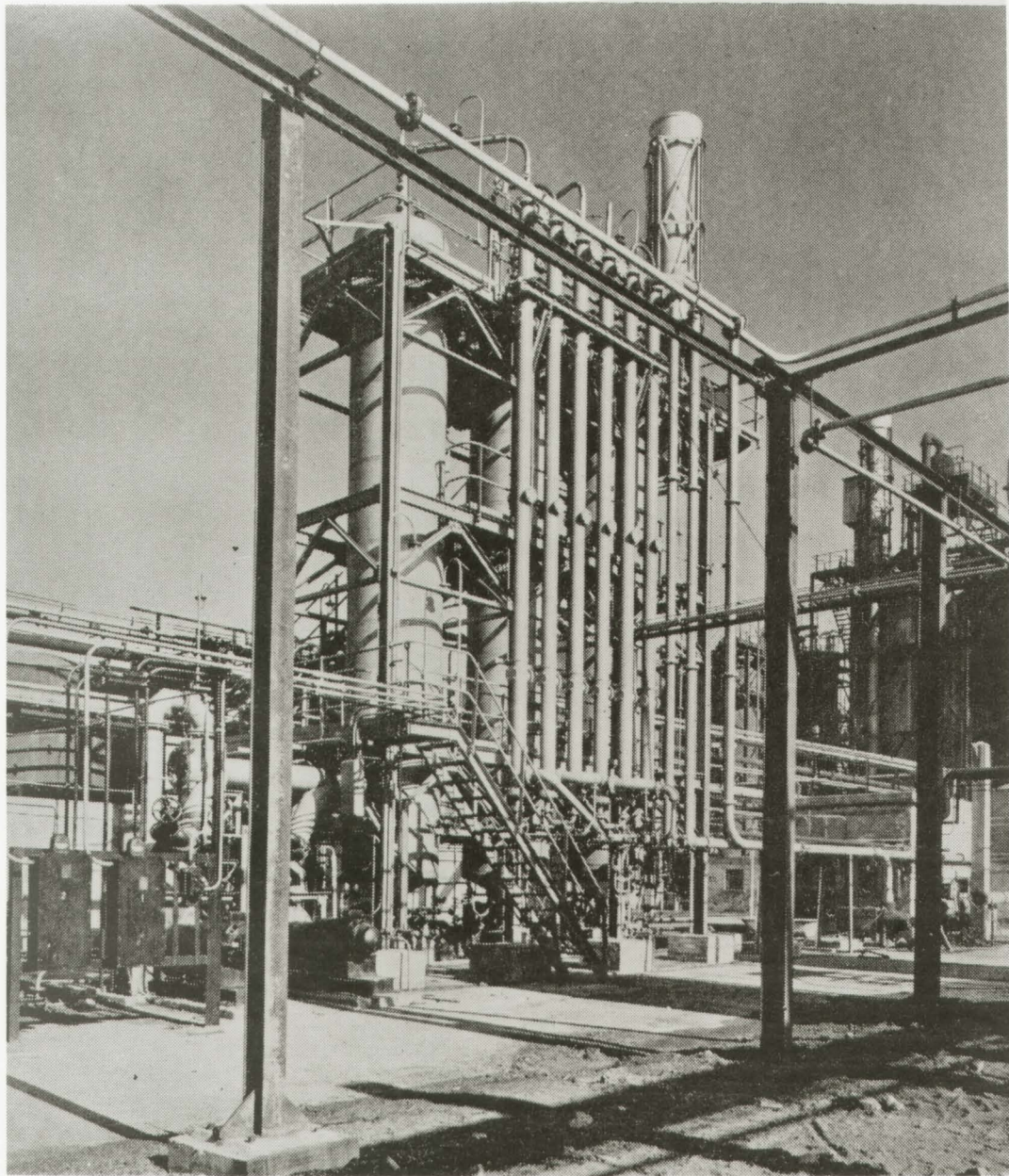
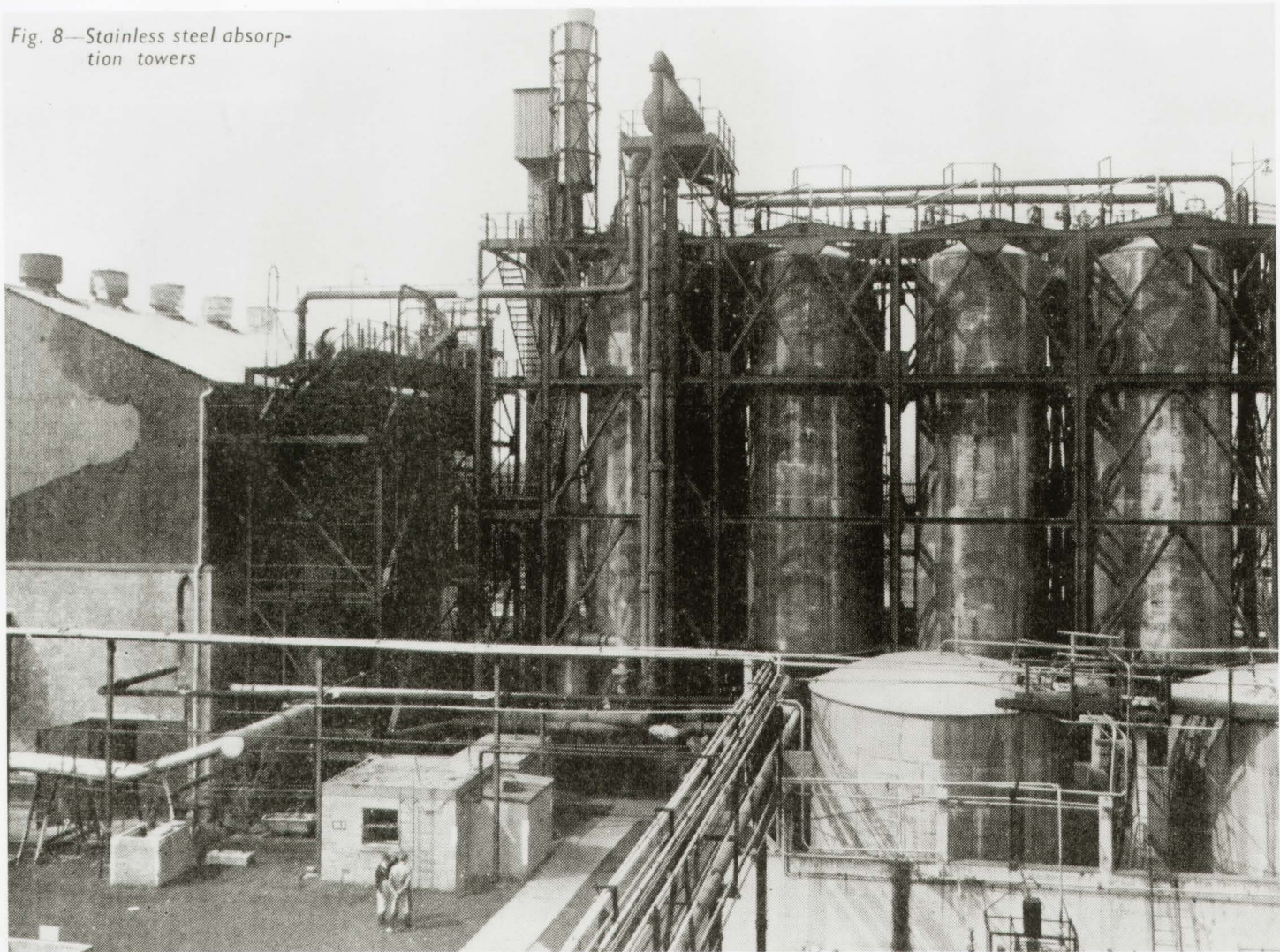


Fig. 8—Stainless steel absorption towers



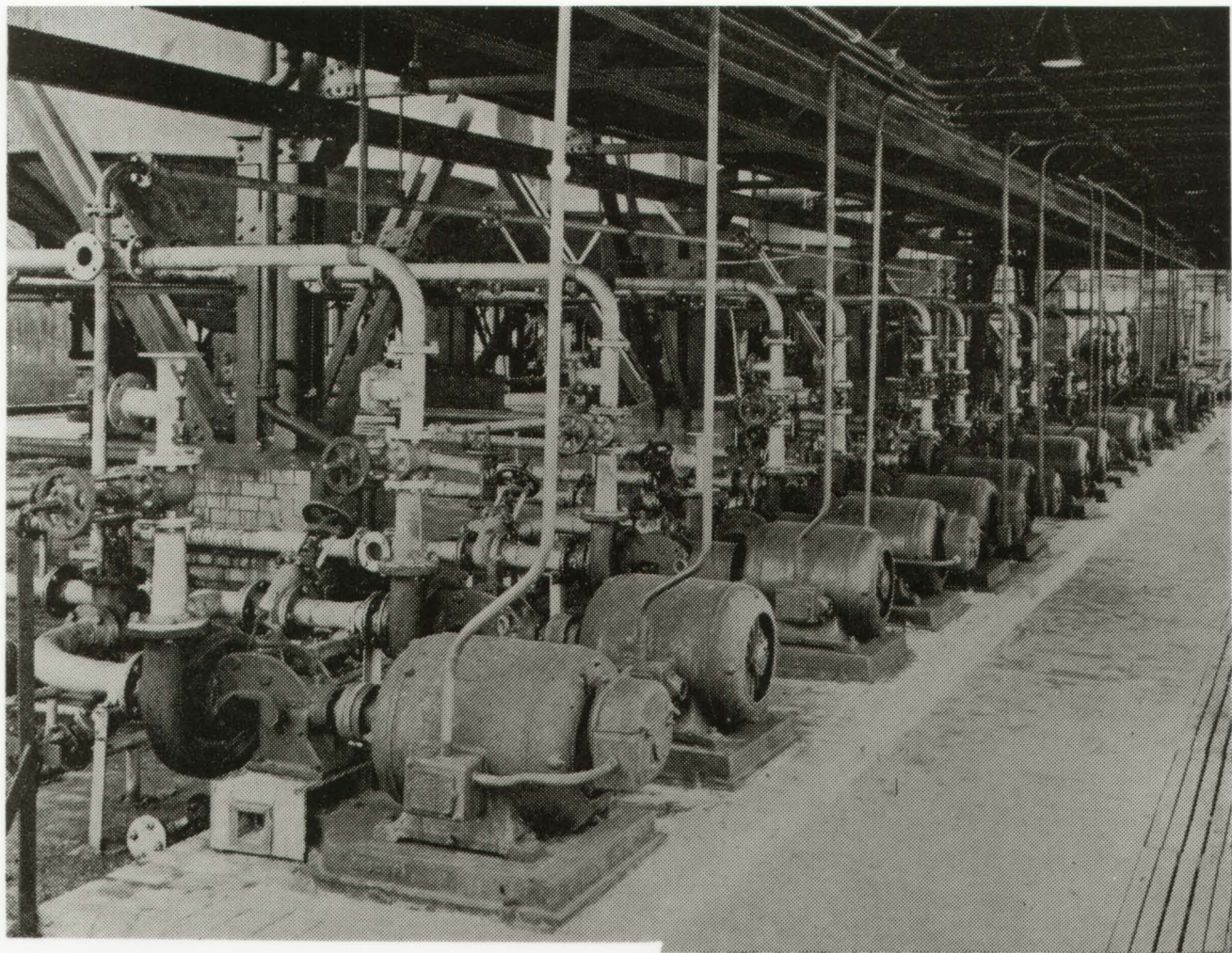


Fig. 9—Acid pumps at the absorption towers

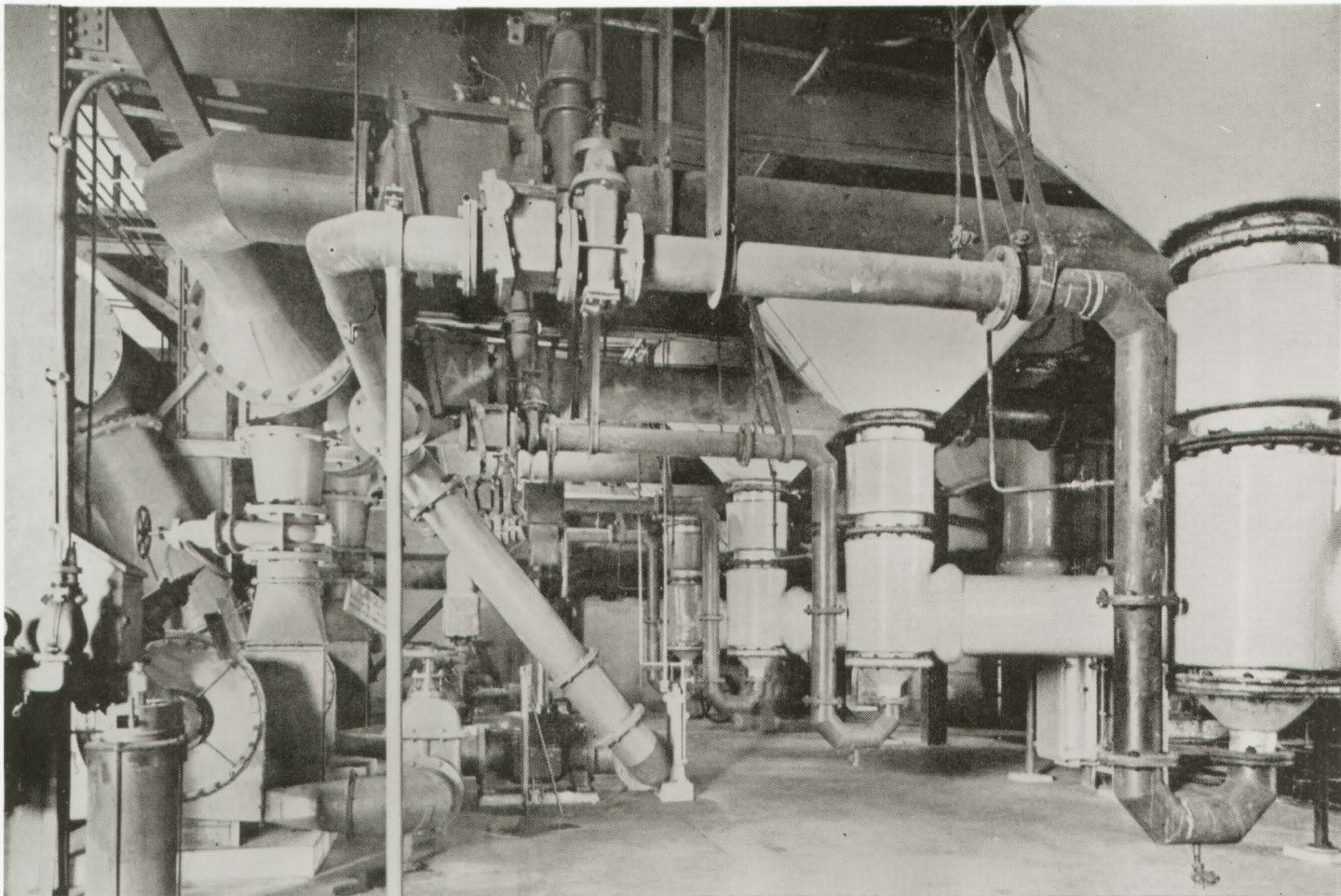
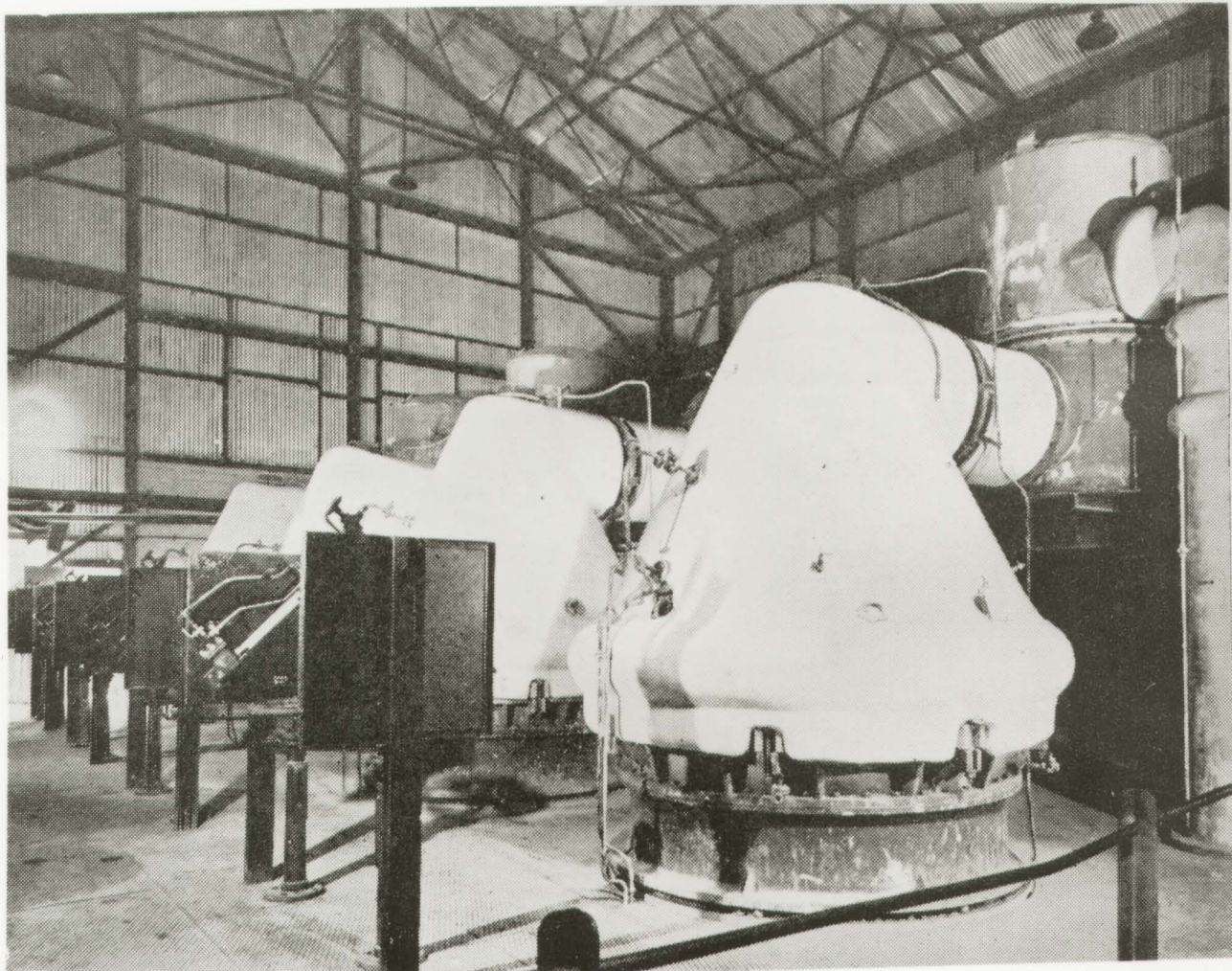


Fig. 10—General view at the base of the ammonia converters

Fig. 11—View of the top of the ammonia converters



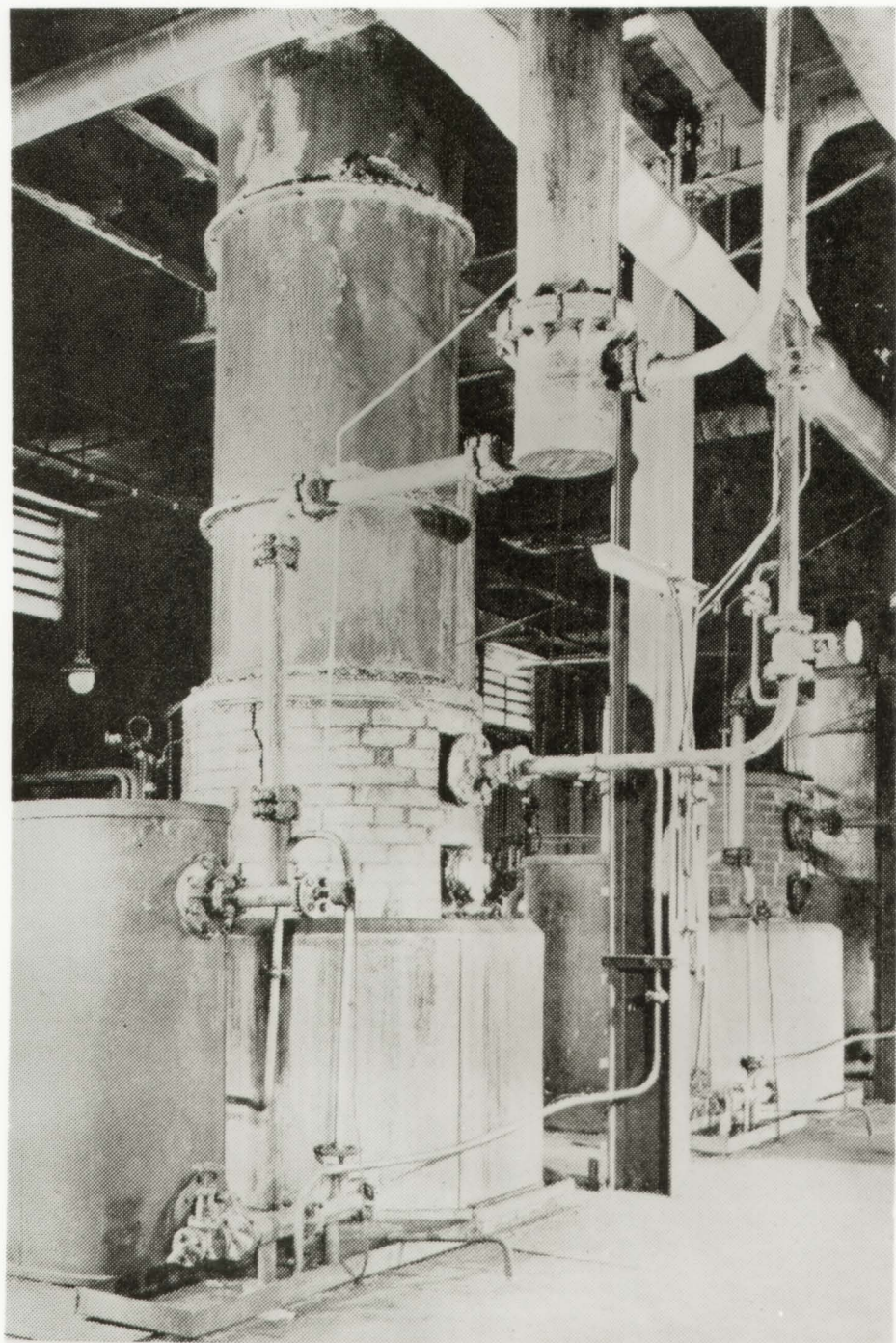
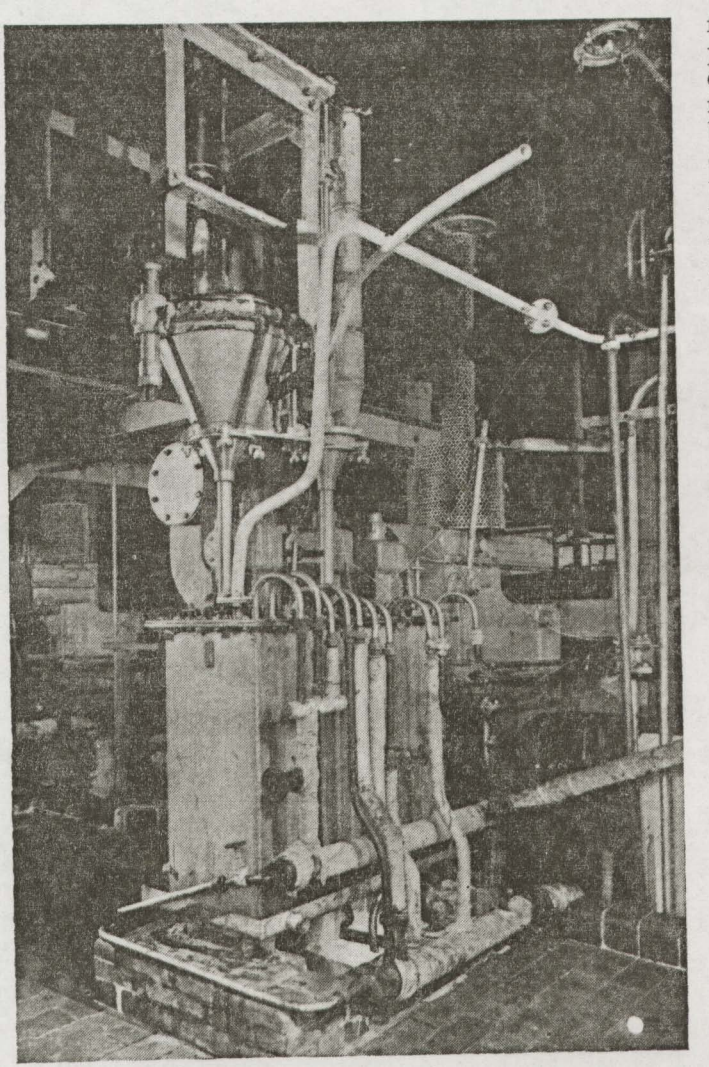




Fig. 13—A view of one of the R.D.X. "cleanways"



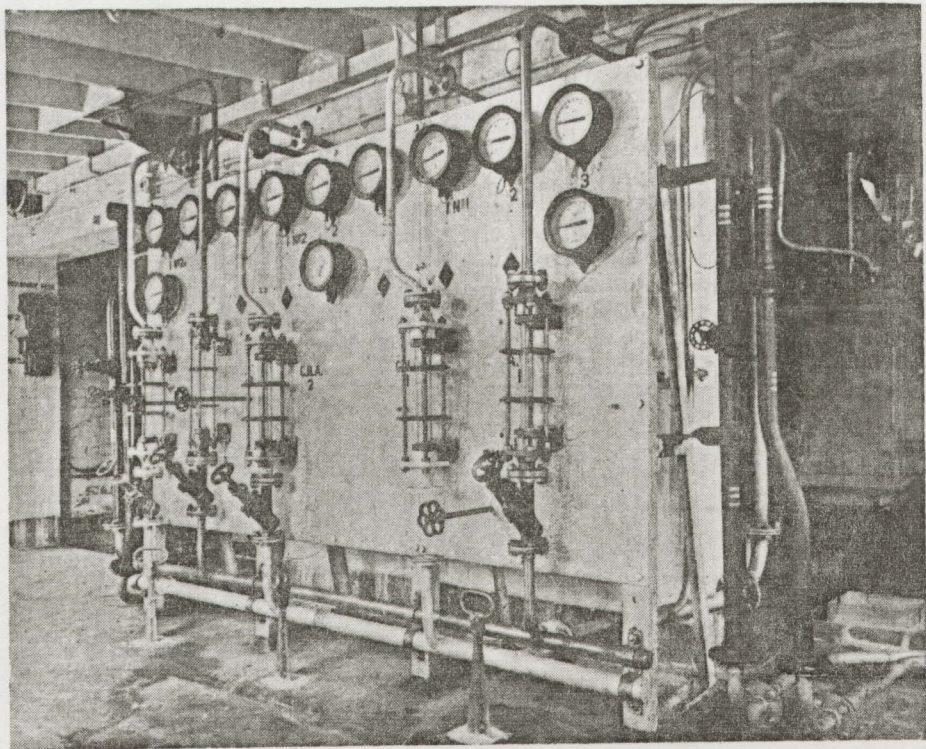
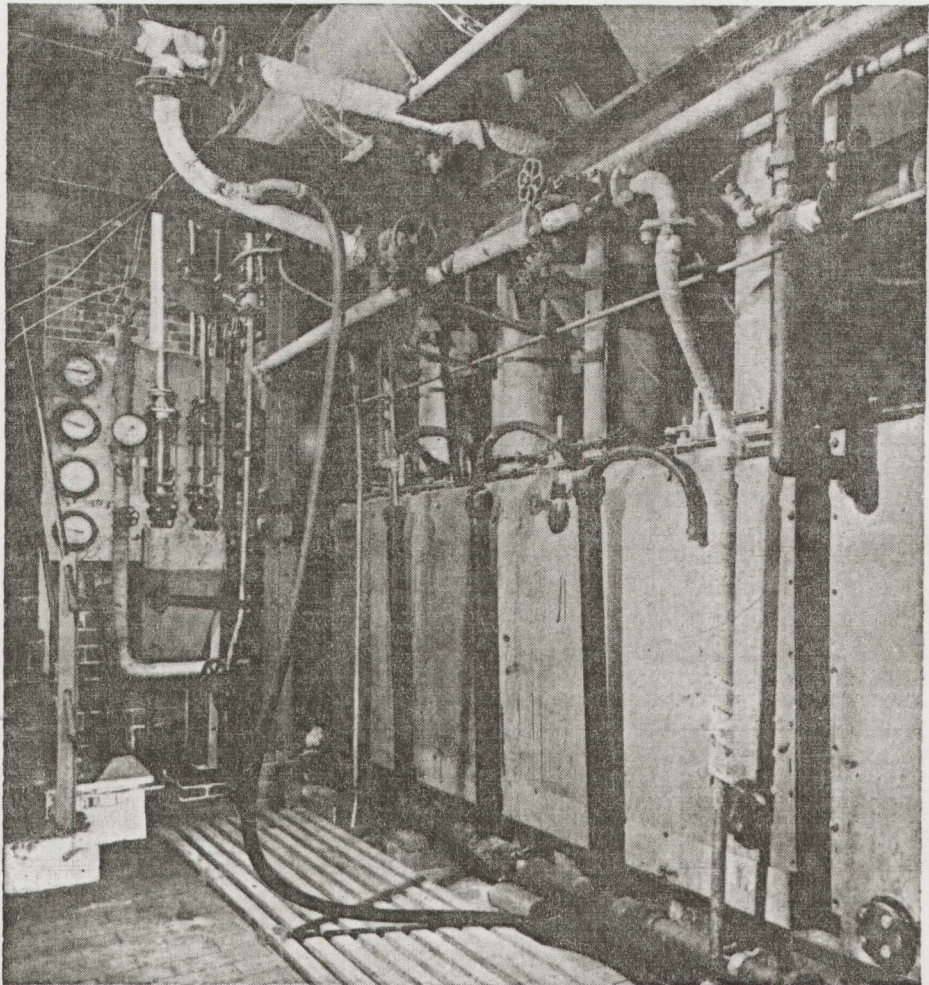


Fig. 15 - Nitrator control panel, showing in the centre, the drowning valve handle

Fig. 16—Dilutor with control panel in the background



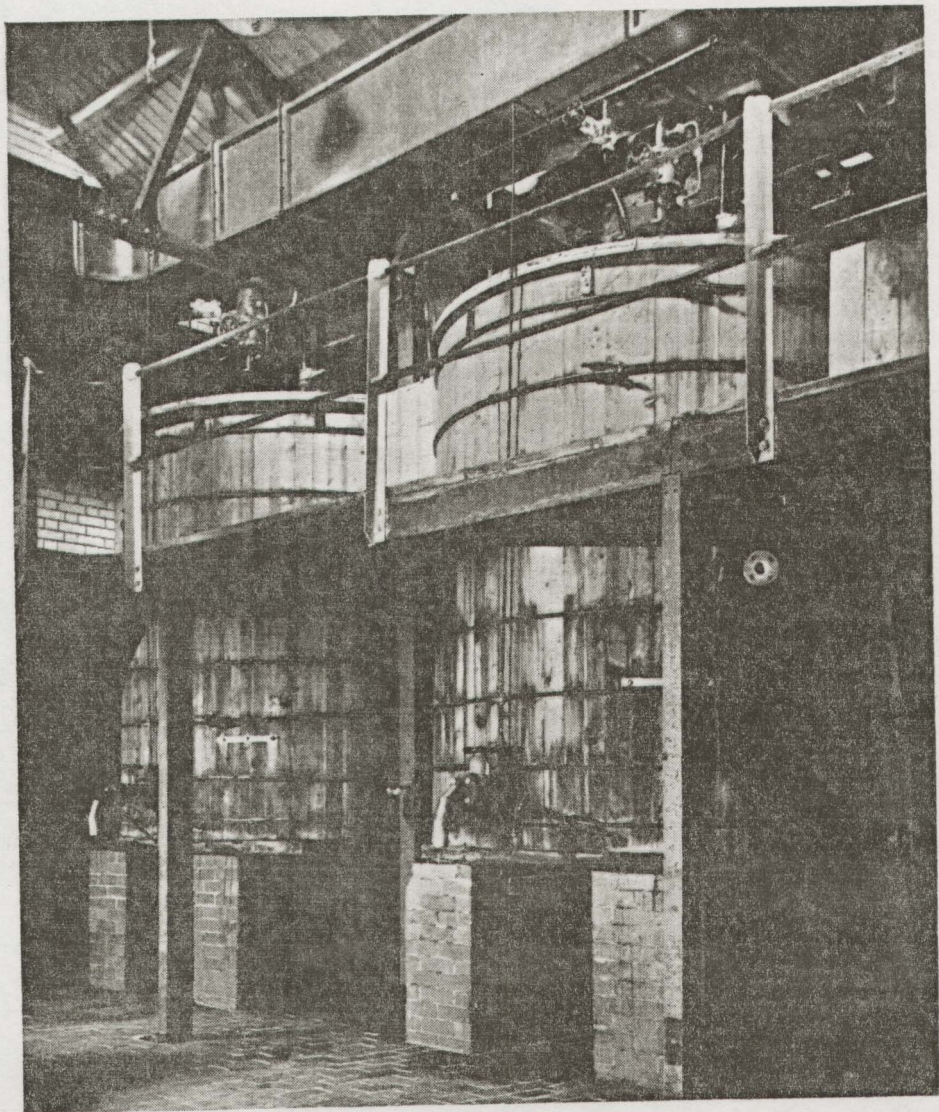
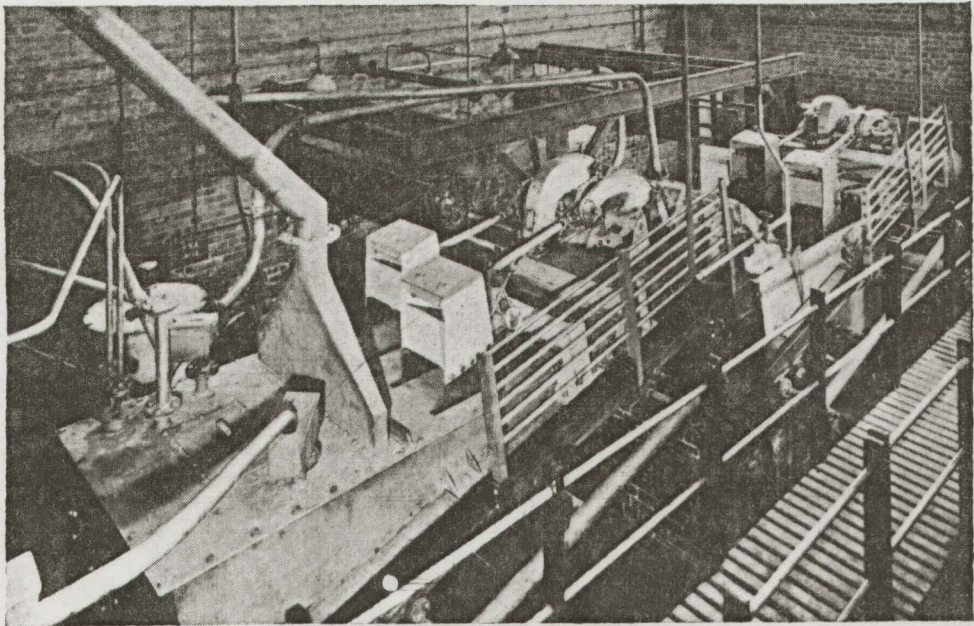
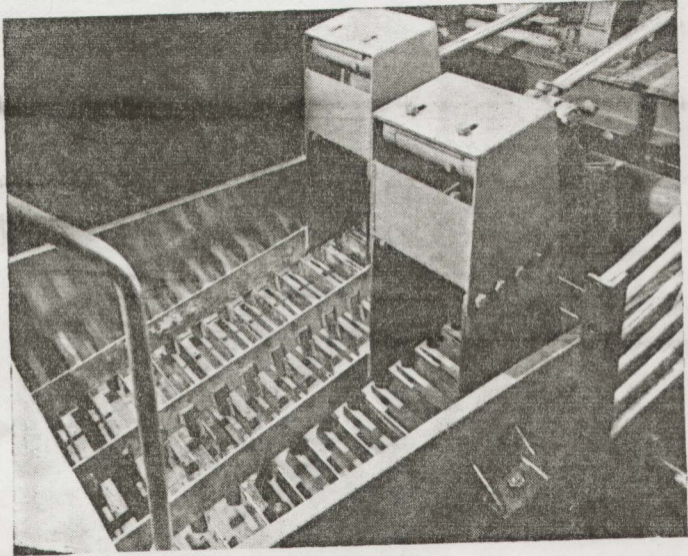


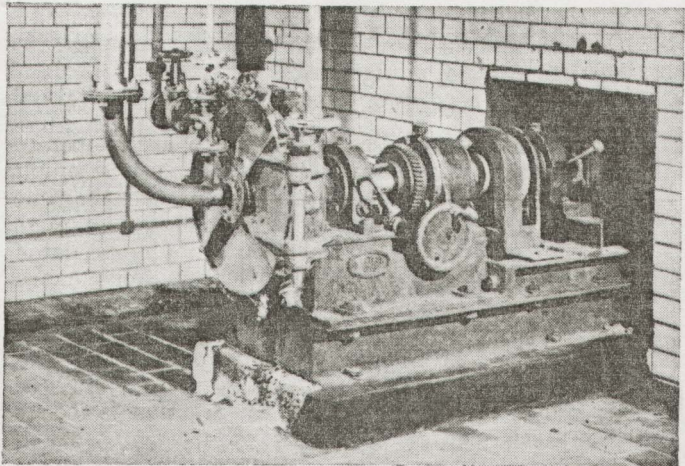
Fig. 17—R.D.X. boiling vats

Fig. 18—The classifier-filters





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ALL TONS PER TON R.D.X.

	Hex-amine	Gross HNO ₃	Re-covered W.N.A.	Ab-sorbed fume	Net HNO ₃	OVERALL LOSSES				
						HNO ₃	H ₂ SO ₄	NH ₃	CH ₃ OH	NH ₃ for hex-amine
1st Qtr., 1942..	0.930	11.616	5.563	3.219	2.832	2.999	0.78	1.026	1.836	0.479
1st Qtr., 1945..	0.833	8.779	3.482	3.429	1.868	2.139	0.49	0.664	1.436	0.423