

THE ENGINEERING PROBLEMS ASSOCIATED

WITH THE HIGH PRESSURE SYNTHESIS

OF

AMMONIA

AND

METHYL ALCOHOL

AND WITH THE OXIDATION OF AMMONIA

TO

NITRIC ACID

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THE ENGINEERING PROBLEMS ASSOCIATED WITH THE
HIGH PRESSURE SYNTHESIS OF AMMONIA AND METHYL
ALCOHOL AND WITH THE OXIDATION OF AMMONIA TO
NITRIC ACID

INTRODUCTION.

The development of the process for the direct synthesis of Ammonia is comparatively recent. A considerable amount of research work was carried out by Haber, Nernst and others between 1900 and 1910 on the ammonia equilibrium and it was largely as a result of this work that experimental semi-technical units were brought into operation in 1910.

The first commercial plant was built at Oppau and commenced production at the end of 1913. Starting with an annual output of 7000 tons of nitrogen its capacity was successively increased during the World War to the figure of 60,000 tons by 1916. In that year a second plant was laid down at Leuna having an initial annual capacity of 30,000 tons of fixed nitrogen. This was increased to 130,000 tons per year by 1918. The phenomenally rapid increase in the size of these plants illustrates their importance to Germany during World War I. their production enabled her to withstand the Allied blockade and undoubtedly lengthened the war considerably.

Following the Armistice the process rapidly spread to other countries. In England two units were put into operation. The first an experimental unit near Liverpool; the second a large scale plant at Billingham producing 150,000 tons of Ammonia per annum.

The British re-armament programme which was commenced several years before World War II. called for additional Ammonia production capacity in areas relatively free from aerial attack. To meet these requirements a 27,000 tons per annum Ammonia plant was erected on the west coast of Scotland and a 45,000 tons per annum plant was erected in the south of Wales. These units came into production in 1939.

The history of Ammonia synthesis in Australia begins with the erection of a unit at Beer Park. This plant which has a capacity of 3300 tons was brought into operation in 1940. Since that date four additional units have been built for the Commonwealth Government bringing the total production capacity of Australia to 16500 tons/annum. of Ammonia. These units are situated at Albion, Ballarat, Villawood and Mulwala.

The development of a process for the Synthesis of Methyl alcohol was largely carried out in the years following World War. I. A plant was erected at Billingham with a capacity of 2000 tons per annum and it was brought into commission in 1930. Units of this type are normally operated in conjunction with Ammonia synthesis plants; although the recent heavy demand for the explosive R.D.X. (Cyclotrimethylene Trinitramine) has resulted in several large plants in England being converted for the exclusive production of Methyl alcohol.

The first unit to operate in Australia was completed in 1942. It came into production in that year with a capacity of 1000 tons/annum. Since that date three additional units have

been erected with the total annual output of 3000 tons.

The development of the process for the catalytic oxidation of ammonia followed immediately upon the successful synthesis of this substance. The introduction of high chrome irons and austenitic stainless steels have largely solved the difficult corrosion problems associated with the early plants. The atmospheric oxidation unit was chosen for Australia's wartime requirements owing to the ease with which the equipment required could be produced locally at short notice. The total production capacity of these units is 11000 tons per annum.

This thesis is concerned primarily with the Australian Government synthesis and oxidation plants. Section 1 covers the general description of the process used in these units and section 2 describes in detail the plant and equipment employed. The maintenance organisation and procedure relating to these factories is outlined in section 3. Section 4 which has a wider application is concerned with the design of high pressure plant and equipment. In general British practice is cited although some reference has been made to American and Continental features. Section 5 covers the specific application and scope of usefulness of the various materials of construction employed on the plants described.

As the information in certain sections of this thesis is of a secret nature it is requested that the contents be treated as confidential. In giving permission for the preparation of this thesis I.C.I.A.N.Z. Ltd. did so on the understanding that the information contained therein, either as illustrations or descriptions would not be reprinted or copied.

DESCRIPTION OF PROCESSES FOR THE
SYNTHESIS OF AMMONIA
SYNTHESIS OF METHYL ALCOHOL
AND THE OXIDATION OF AMMONIA TO NITRIC ACID.

INTRODUCTION:

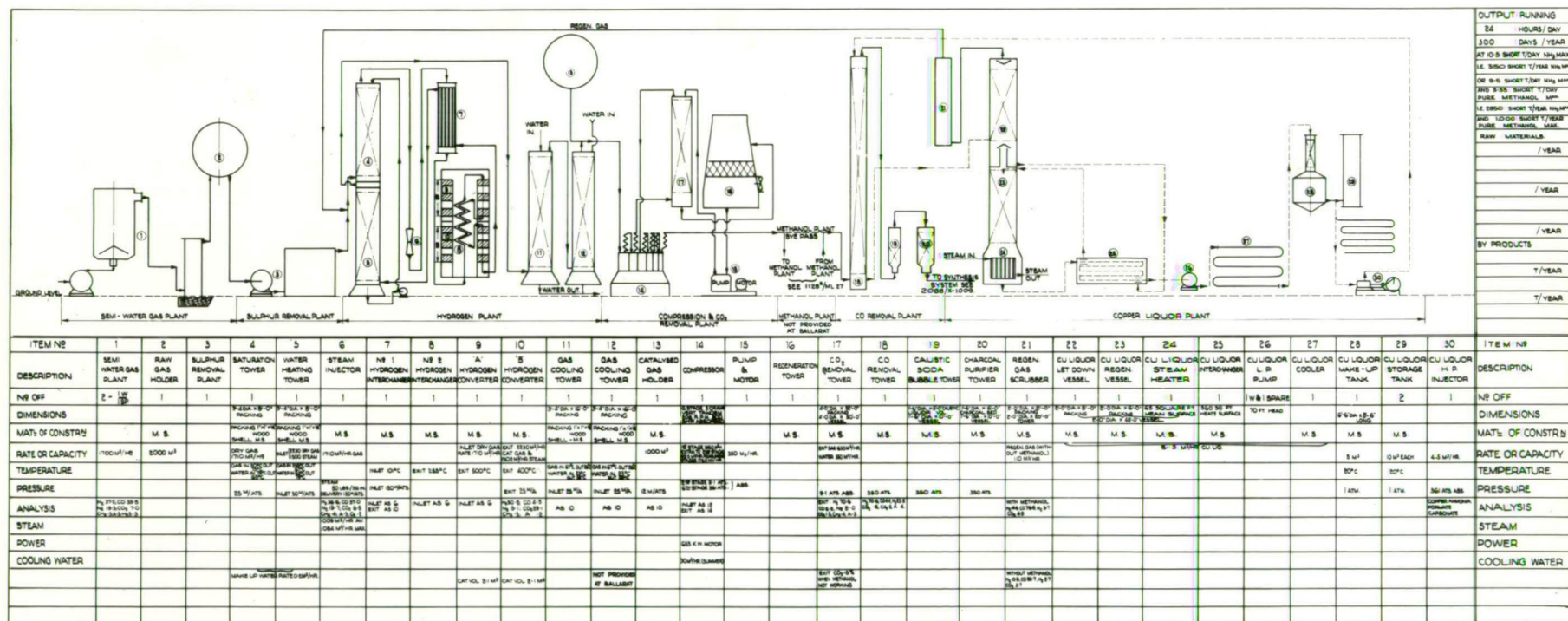
The processes described hereafter relate to plants that were designed and built in the emergency of war. This fact has materially effected the type of process chosen and the type of plant employed.

Thus under peace time conditions when operating expenses are a more important consideration than in war time more elaborate equipment would have been installed where a more efficient process or reduced supervision made the capital outlay worthwhile. An example of the former case would be the provision of a Francis turbine on the let down line from the CO₂ removal tower to recover a proportion of the power used to force the scrubbing water into the tower which operates at approximately 125 lbs/sq.in. gauge. As up to 300 tons/hour of water is circulated in this system the amount of recoverable power is appreciable; in actual fact it is found to be approximately 70 H.P. In the latter instance the strength of the nitric acid formed by the oxidation of ammonia is markedly affected by the pressure under which the reaction takes place. It is generally more profitable to carry out the reaction at 120 lbs/sq.in. gauge when the acid produced is 60% strength compared with the 50% acid produced from a plant operating at atmospheric pressure. In the case of the pressure oxidation plants a power recovery engine extracting energy from the hot exhaust gases is usually warranted. The difficulties of manufacturing a pressure oxidation plant in Australia resulted in the adoption of the atmospheric pressure unit.

Another wartime factor which influenced the design of the coke handling equipment was the possibility of irregular coke supplies. Provision for the storage and handling of approximately 700 tons of coke would not be justified under peacetime conditions but it was considered essential to have this amount of coke, which represents approximately four weeks consumption, on hand for use should enemy action restrict the normal supply of fuel to the site.

The gasholder design was to a large extent affected by the conditions and restrictions operating at the time they were designed. The possibility of aerial attack and the acute shortage of steel plate resulted in these holders being built in concrete tanks formed below ground level.

The processes have been divided into three main sections as they fall naturally into these three groups. It should be remembered, however, that the steps especially with respect to methanol and ammonia are largely interdependent.



GENERAL FLOWSHEET FOR MAKE-UP GAS SYSTEM AND COPPER LIQUOR PLANT

DESCRIPTION OF PROCESS FOR THE SYNTHESIS
OF AMMONIA.

GENERAL:

Essentially the particular process described for the synthesis of ammonia involves the generation of semi-water gas (i.e. water gas containing some nitrogen), the enrichment of the hydrogen content of this gas at the expense of the CO present by means of the iron-steam reaction, its compression and purification and finally the synthesis from it of ammonia.

The process is a continuous one and in designing the plant the assumption has been made that it would operate 300 days per year. In this period at full output rates the plant described should produce 3150 short tons (or 2850 short tons if the methanol plant is in operation).

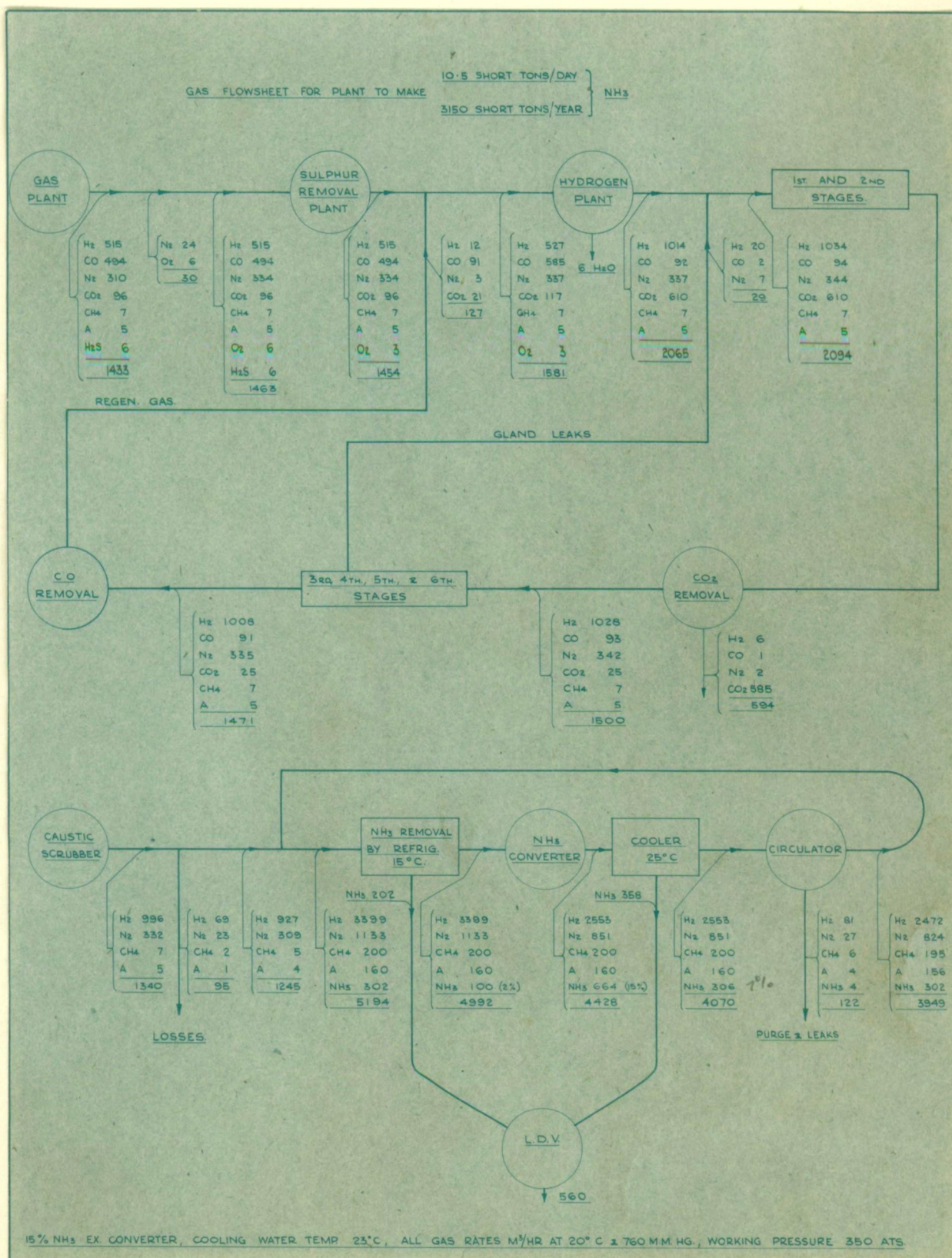
The various steps in the process are as follows:-

- (1) Gas Production. The semi-water gas is produced by passing steam and air through a bed of incandescent coke.
- (2) Sulphur Removal. Hydrogen Sulphide is removed from the raw semi-water gas by passing it through beds of hydrated iron oxide.
- (3) Hydrogen Plant. Steam is added to the gas and the resultant mixture passed over a catalyst. A large proportion of the CO in the gas is oxidised at the expense of the oxygen present in the steam to CO₂ with the formation of an equivalent amount of hydrogen.
- (4) Compression. The gas is then compressed to 350 ats. in a six stage gas compressor. It is bled off at the second stage to the CO₂ removal plant. On return from the CO₂ removal plant it enters the 3rd stage.
- (5) CO₂ Removal. The bulk of the CO₂ in the gas is removed by countercurrent scrubbing with water.
- (6) CO Removal. After compression the gas is scrubbed with a copper ammonium formate solution which dissolves out the remaining CO₂ and associates with the CO present. This solution is regenerated and subsequently re-used.
- (7) Final Purification. The gas then passes to a caustic bubbler and a charcoal scrubber for the removal of the final traces of CO₂ and organic sulphur compounds.
- (8) Ammonia Synthesis. The make-up gas is fed into the synthesis circulation system where a proportion of the gas is synthesised to ammonia by passage over a catalyst. The ammonia is subsequently precipitated by condensation and the unconverted gas is recirculated; the deficiency being made up by the new incoming gas.

These processes are described in detail as follows:-

GAS PLANT.

In this plant the production of gas is achieved by passing steam through an incandescent bed of coke situated in a water jacketed generator. As the reaction is endothermic



GAS FLOWSHEET FOR PLANT TO MAKE 3,150 SHORT TONS/YEAR OF AMMONIA

it is necessary at certain periods to restore the temperature of the coke bed by shutting off the steam and blowing with air. As there is far more nitrogen in this blow gas than is required for the production of ammonia it is necessary to pass it to atmosphere.

The cycle is further complicated by the fact that the alternate passage of air and steam through the coke in one direction only would result in the inlet section of the coke bed becoming too cold and the outlet section increasingly hot with a resultant increase in the liability of an explosion and the formation of clinker. To overcome this unsatisfactory tendency the direction of the steam flow is reversed for a portion of the cycle. This leads to the following arrangement.

- | | | |
|-----|--|----------------------------------|
| (1) | Blow - Air passed up through the coke to atmosphere. | |
| (2) | 1st up run - Steam passed up through coke | } resultant
gas to
Holder. |
| (3) | Down run - Steam passed down through coke | |
| (4) | 2nd up run - Steam passed up through coke | |

This alternating cycle is achieved by a system of valves which are described later. In practice the cycle is complicated by the necessity to purge out the base of the generator at various stages to prevent gas explosions.

The cycle normally takes six minutes which could be allocated as follows:-

1st up run	- 25 seconds
Down run	- 85 "
2nd up run	- 155 "
Blow	- 95 "

The auxiliary air required for the nitrogen content of the gas is admitted with the steam during the second up run.

Volatiles in the coke assist in the formation of methane which is not desirable. Hydrogen sulphide and organic sulphur compounds are also present in the raw gas as it comes from the generator.

The composition of the gas made is dependent on the air and steam rates employed, the relative quantities of upsteam and downsteam, the cycle timing, the generator temperature and the frequency of charging, all of which can be varied to suit the particular type of coke used and the gas composition requirements. A typical composition of the gas generated at the gas plant is as follows:-

H ₂	35.2%
CO	33.7%
N ₂	22.8%
CO ₂	6.6%
CH ₄	0.5%
Inerts	0.4%
H ₂ S	0.4%
O ₂	<u>0.4%</u>
	100%

Coke is charged into the generator intermittently at the top; approximately 30 cwt. is added at each charge.

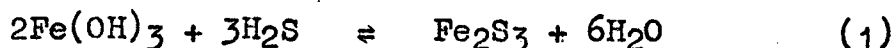
The ash and clinker are discharged through a water seal in the base of the generator.

Gas from the generators is collected in a header and piped to a raw gas holder of 2000 M³ capacity. This holder as well as providing a suitable storage to even out the intermittent rates of generation due to cyclic changes and generator conditions also acts as a convenient buffer vessel where irregularities of gas composition can be averaged to achieve a more uniform analysis. To assist in this latter object the inlet and exit lines enter and leave at opposite sides of the holder. Thus all gas made must pass through the raw gas holder.

SULPHUR REMOVAL:

The method used is that normally practised by gas works or in other processes where the percentage of H₂S in the gas is small and it is desired to completely remove this impurity.

The reactions involved may be written as follows:-



The sulphide may be re-oxidised in the presence of water thus,



These reactions are exothermic, the former is normally more rapid than the latter.

The gas is passed through beds of the iron hydroxide which is dispersed on wood chips to increase its surface area and render it porous. In practice 2% by weight of sodium carbonate is added to increase the activity of the mass. The oxide is initially installed containing 20% moisture and this amount is retained during service by means of the careful control of moisture in the incoming gas stream.

By adding a small quantity of air to the gas stream it is possible to have reactions (1) and (2) above proceeding simultaneously. The difficulties involved due to the relative slowness of (2) are overcome by having four "boxes" of oxide in series. The bulk of the H₂S is removed in the first box and revivification of the oxide proceeds in the latter boxes when the H₂S content is extremely low. The order of the boxes is changed at regular intervals in order to equalise the deposition of sulphur in the oxide beds.

Temperature control of the boxes is important as at temperatures greater than 30°C. a reaction leading to the formation of iron sulphate is liable to occur. This is undesirable as the sulphate immobilises the iron rendering it unsuitable for further use. This reaction will also occur at lower temperatures if the pH of the oxide is allowed to fall below 6.5. Should the oxide show a tendency to do this ammonia is added to the inlet gas.

Gas from the raw gas holder is passed through a centrifugal fan which is fitted with a water spray impinging onto the inlet eye of the impellor. This fan serves the double purpose of boosting the gas pressure and also washing out some of the tarry impurities. From the fan the gas passes to the oxide boxes where as well as removing the H₂S the oxide beds act as efficient filters for the removal of any entrained particles.

The H₂S in the gas leaving the oxide boxes and passing to the hydrogen plant is normally less than 1 part in 100,000.

HYDROGEN PLANT:

In this plant use is made of the "iron-steam reaction" to increase the hydrogen content of the gas at the expense of the CO present. The reaction may be written as follows:-



It is carried out over a promoted iron pelleted catalyst at temperatures ranging from 350°C to 500°C. As shown above the reaction is strongly exothermic and the heat generated is usefully employed to heat the incoming gas to the operating temperature of the catalyst by means of interchangers, and also by means of countercurrent contact scrubbing to heat water. This hot water is in turn scrubbed by the cool incoming gas thus raising the temperature of the latter and saturating it with water vapour at the higher temperature thereby supplying some of the water required for the reaction. The remainder is blown into the gas through an injector which uses the pressure of the incoming steam to boost the gas pressure sufficiently to produce an adequate flow through the catalyst.

As the reaction is an equilibrium exothermic one, the lower the temperature at which it takes place the more favourable will be the production of hydrogen; however lower temperatures reduce the velocity of the reaction considerably. In order to strike a satisfactory balance between these two opposing factors two beds of catalyst each of three trays are used with an intermediate interchanger for removing heat from the partially converted gases.

Even after passing through the interchangers and the water heating tower the converted gas is still too hot (60 - 70°C.) for compression and is thus passed through two gas cooling towers where it is cooled to approximately 23°C by counter-current scrubbing. A typical analysis of the gas passing from the hydrogen plant would be as follows:-

H ₂	-	50%
CO	-	4.4%
N ₂	-	16.3%
CO ₂	-	28.6%
CH ₄	-	0.4%
Inerts	-	0.3%
		<u>100%</u>

COMPRESSION PLANT:

On the Australian Ammonia Plants the synthesising pressure is 350 ats. This pressure is used as it strikes an economic balance between the costs of compression and the size of plants used and conversion efficiencies obtained. The original Haber-Bosch units were generally operated at pressures ranging from 200 - 250 ats, however, in recent years the tendency has been to increase this pressure and 350 - 360 ats is now commonly used. The fact that relatively few of these units are in operation or are required to be designed retards any tendency to alter factors such as the operating pressure.

The gas in the Australian Units is compressed in six stages. It is bled off to the CO₂ removal plant after the 2nd stage delivery and returns from the CO₂ removal plant to the 3rd stage suction. From the 6th stage delivery it passes to the CO removal plant or alternatively to the Methanol Synthesis plant. Gland leaks are collected and passed back to the compressor suction.

CO₂ REMOVAL PLANT:

In the CO₂ removal plant the major portion of the CO₂ is removed by counter current scrubbing with water under pressure. The pressure chosen is 125 lbs/sq.inch gauge as at this pressure the CO₂ content can be reduced to such a value that the remaining traces can be dealt with satisfactorily in the CO₂ removal plant.

This water scrubbing under pressure is also beneficial as it removes organic sulphur compounds and some of the traces of H₂S which are still present in the gas.

The water used in this process is stripped of dissolved CO₂ etc. by passing through a forced draught tower. It is returned to a sump and recirculated.

The gas from the CO₂ removal plant is returned to the 3rd stage suction. A typical composition for this gas would be:-

H ₂	-	68.5%
CO	-	6.2%
N ₂	-	22.8%
CO ₂	-	1.7%
CH ₄	-	0.5%
Inerts	-	0.3%
		<u>100%</u>

CO REMOVAL PLANT:

Gas going to the CO removal plant contains hydrogen and nitrogen in the ratio of 3 : 1 together with small percentages of CO, CO₂, CH₄ and inerts and traces of organic sulphur compounds, H₂S and oxygen.

It is not practicable to remove the methane and the inerts (which consist mainly of argon); however, as these act as diluents only and do not have any poisoning action on the ammonia catalyst their presence in small concentrations is not harmful.

It is important that all CO₂ be removed as its presence in the synthesis system would result in ammonium carbonate blockages.

CO and oxygen compounds act as temporary poisons to the ammonia catalyst and therefore must be removed as effectively as practicable before the gas enters the synthesis section. Up to 4 parts in 100,000 of CO have no appreciable effect but above this figure the activity of the ammonia catalyst is materially affected.

Sulphur compounds act as a permanent poison to the ammonia catalyst. Even slight traces have a marked effect, and it is essential that they be efficiently removed if the catalyst is to remain active for any length of time.

In the CO removal plant the gas at the full synthesis pressure (350 - 360 ats) is scrubbed with "copper liquor". Copper liquor is a solution of cuprous and cupric formate and carbonate in ammonia liquor. This liquor readily forms complex compounds with the CO thus ensuring its removal from the gas stream. The ammonia present combines with the CO₂ and the liquor also absorbs sulphur compounds which settle out from the copper liquor in the form of a sludge.

For the removal of the final traces of CO₂ a caustic bubbler is installed through which gas leaving the CO removal tower is made to pass. After the caustic bubbler the gas

enters a vessel filled with activated charcoal for the removal of any traces of sulphur compounds that may not have been removed by the copper liquor in the CO tower.

The CO removal tower operates at the highest possible pressure to ensure that the removal of the CO and CO₂ is as complete as possible. The loss of power in the form of wasted compression energy is not great as the percentage of CO and CO₂ in the gas at this stage is small.

A typical analysis of the gas at this stage would be as follows:-

H ₂	74.4%
N ₂	24.8%
Inerts	0.3%
CH ₄	0.5%
	<hr/> 100%

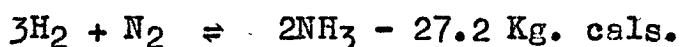
The gas at this point is still saturated with water vapour.

The copper liquor can be regenerated and made suitable for re-use by heating to 70°C. During this heating period the CO and CO₂ are evolved; they are collected and as this gas mixture is approximately 70% CO it is advantageous to return it after scrubbing with water to remove traces of ammonia to the gas stream immediately before the hydrogen plant where it can usefully be employed for the production of hydrogen. After heating the copper liquor is cooled and returned to storage.

AMMONIA SYNTHESIS:

The synthesis of ammonia is achieved by passing the compressed and purified mixture of three parts of hydrogen to one of nitrogen over a catalyst at a pressure of 350 - 360 ats.

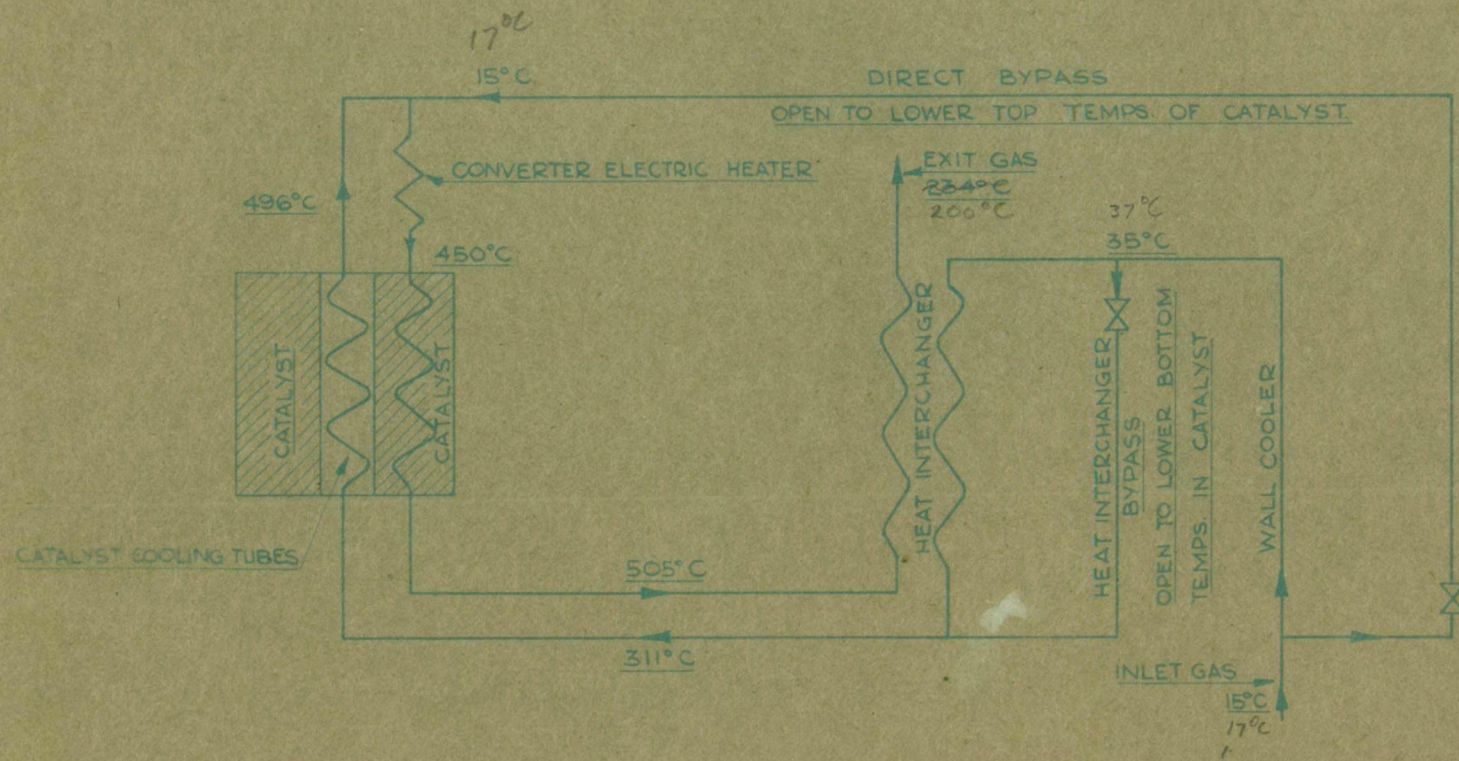
The reaction is an exothermic one and may be represented as follows:-



As the reaction is exothermic the percentage of ammonia in equilibrium is higher the lower the temperature, however the velocity of the reaction is greatly affected by temperature so that a balance of temperature must be struck at all points through the catalyst bed in order to obtain the optimum percentage of ammonia in the exit gas. These conditions require the temperature of the first layers of catalyst to be high in order that the reaction may proceed quickly at this stage and the temperature of succeeding layers to decrease in order that the reaction may proceed to the farthest extent in a direction favourable to the formation of the greatest percentage of ammonia.

The control of the temperature gradient of the catalyst in the ammonia converter is therefore important and the way in which it is achieved can be followed by means of the sketch showing the diagrammatic arrangement of controls.

The entering gas may be passed directly to the top of the catalyst bed by means of the direct by-pass or it may follow the more normal route of passing down the wall cooler (used solely for cooling the containing forging) and through an interchanger. This interchanger is also provided with a by-pass. After the interchanger the gas enters a number of tubes running through the catalyst and by-



DIAGRAMMATIC ARRANGEMENT OF CONTROLS
AMMONIA CONVERTER

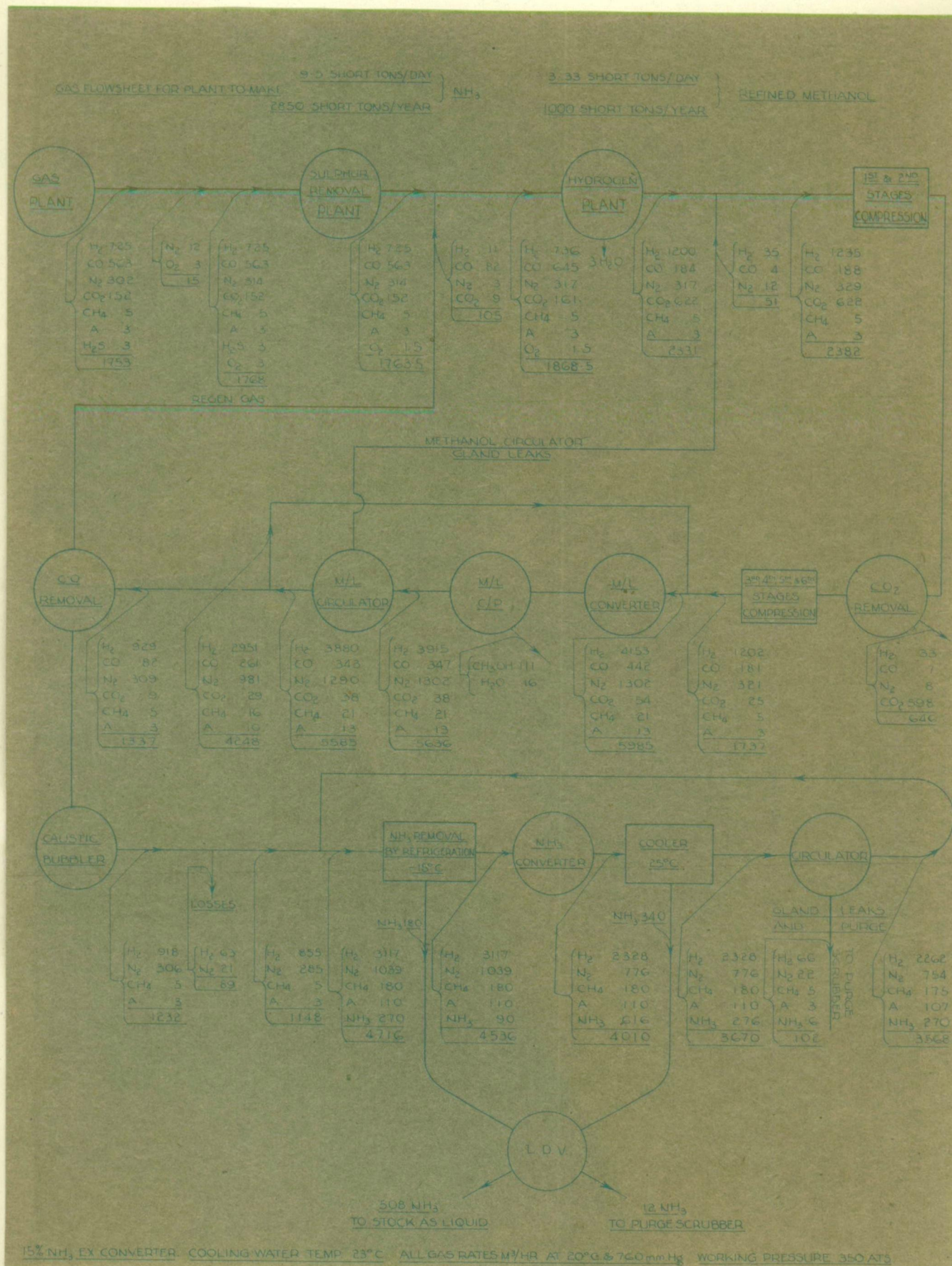
passing up through them it removes the reaction heat preferentially in such a way that the bottom or tail sections of the catalyst bed are maintained at a lower temperature than the top or inlet sections. Leaving the catalyst cooling tubes the gas passes over an electric heater used for starting up purposes and passes down through the catalyst. From the catalyst bed the converted gas passes through the interchanger and leaves the converter. Operation of the direct and interchanger bypasses and variation of the gas rate through the converter control the temperature gradient of the catalyst.

The gas leaving the converter may contain up to 15% ammonia and this is removed in two stages. First by indirect water cooling to about 25°C. and then by cooling to about -15°C. by the ammonia refrigeration. After each step the condensed liquid ammonia is collected and blown to storage. The gas leaving the final condensation contains 2% ammonia.

The unconverted gas is passed back to the converter; circulation being maintained by means of a booster pump. The deficit caused by the removal of condensed ammonia is made up by the entry of fresh gas from the purification system. The rate of this make up gas is controlled to balance the ammonia synthesised.

It is customary to bleed the make up gas into the circulation system at a point just before the ammonia refrigerator. All saturated make up gas is thus cooled to -15°C and the majority of the water it contains is thereby condensed with the liquid ammonia. It is important to remove the water vapour at this stage as it acts as a temporary poison to the ammonia catalyst.

The methane and inert content of the circulating gas tends to build up in the system and in order to keep this at a suitably low figure it is necessary to systematically purge a small proportion of the circulating gas. This is passed through a purge gas scrubber for the recovery of any ammonia it may contain. The scrubber is operated on weak liquor and serves as a useful source of aqueous ammonia.



DESCRIPTION OF PROCESS FOR THE SYNTHESIS
OF METHANOL

INTRODUCTION:

The plant for synthesising methanol is run as an ancilliary unit to the ammonia synthesis plant. Normally the methanol unit would not operate unless the ammonia plant was synthesising ammonia. It is customary to pipe gas from the compressor to the methanol circulation system and to bleed gas back from the system to the inlet of the CO removal plant.

METHANOL SYNTHESIS PLANT:

Methanol is synthesised by passing a mixture of gases consisting of two part of hydrogen to one of CO over a catalyst at 350 - 360 ats and 350 - 400°C. The reaction may be represented as follows:



The arrangement of the converter and circulation system is generally similar but less elaborate than that used for ammonia synthesis. The gas entering the converter passes through an interchanger provided with a by-pass and then down through the catalyst, back through the heat interchanger and away from the converter. Very little control is obtainable over the temperature gradient through the catalyst and this only by variation of the circulation rate. The inlet temperature of the gas going to the catalyst is controlled by adjustment of the by-pass. A conversion of up to 2% is obtained. The methanol so formed is precipitated by cooling, using indirect counter-current water coolers, and then collected in a catchpot and blown to storage. It contains approximately 20% water. The unconverted gas is recirculated by means of a booster pump.

The composition of the gas entering the system which is injected immediately before the converter is largely controlled by the requirements of the ammonia plant and the ability of the CO₂ removal and CO removal plants to effectively handle the corresponding gas rate. A normal analysis would be as follows:-

H ₂	-	70.0%
CO	-	10.1%
N ₂	-	18.2%
CO ₂	-	1.2%
CH ₄	-	.3%
Inerts	-	<u>.2%</u>
		100%

The bleed off from the system which is taken upstream from the inlet point would normally have the following composition:-

H ₂	-	69.4%
CO	-	6.1%
N ₂	-	23.1%
CO ₂	-	0.7%
CH ₄	-	0.4%
Inerts	-	<u>0.3%</u>
		100%

DISTILLATION OF CRUDE METHANOL:

The crude methanol from the synthesis plant contains up to 20% water and traces of iron carbonyl, ammonia, and organic compounds.

The iron carbonyl is removed by doping the crude spirit with 40% caustic and then blowing with air for 24 hours. This takes place in the crude methanol storage tanks. After this treatment the spirit is fed to a 48 plate still; the refined methanol is taken off at the appropriate tray (usually six from the top). Water is withdrawn at the bottom and methanol contaminated with lighter fractions is refluxed at the top. A bleed off from this reflux is taken to a second reflux still where the crude methanol from the bottom is run back to the crude methanol storage.

The refined methanol from the primary still is run through a cooler and then into batch tanks for testing. If it is satisfactory it is run to the refined methanol storage tanks and is exported from these in tankers or drums as required. Should it be found to contain ammonia when run into the batch tanks it is doped with sulphuric acid and then returned to the crude storage for redistillation.

The distillation process is continuous and with careful plant control it is possible to produce refined methanol which meets the following specification.

- (1) Specific Gravity at 15.5°C. - max. 0.799
- (2) Boiling Range - at rate of 3 - 4 mls/min., not less than 95% between 64.5°C x 65.5°C at 760 mms Hg pressure.
- (3) Methanol - greater than 99%
- Ketones - less than .05 gms/100 mls.
- Aldehyde - " " .05 " "
- Acidity - " " .004 " "
- Residue - " " .01 " "
- Total Sulphur - " " .001 " "

DESCRIPTION OF PROCESS FOR THE OXIDATION
OF AMMONIA.

ATMOSPHERIC AMMONIA OXIDATION:

The oxidation of ammonia to nitric oxide takes place as a catalytic reaction when an ammonia : air gas mixture is passed over a platinum gauze at approximately 875°C.

The ammonia : air mix is obtained by passing ammonia liquor down a stripping column up which air is blown. The air rate and the ammonia liquor rate are adjusted to give an ammonia gas strength of 8 - 10%. Steam is blown into the base of the column to assist in the stripping process. Denuded liquor and condensed steam are run out at the bottom of the column through a luted drain. The amount of ammonia left in the effluent is small and should not exceed 0.1%.

The ammonia : air mix is passed from the stripping column to the converter cold gas header from which the converter inlet mains lead off to the respective converter units. The converters are fitted with interchangers to heat the incoming gas at the expense of the converted gas. The gas reaching the gauze is usually at 200°C.

The ideal conversion reaction may be written as follows:-



A certain proportion of the ammonia and the nitric oxide degenerates into nitrogen; these reactions take place on the gauze itself and on the hot metal surfaces of the interchanger. These "degenerate" reactions lower the efficiency of the converters in some cases by up to 3%.

As the formation of nitric oxide uses only a proportion of the oxygen present in the ammonia : air mixture there is a considerable quantity remaining for the oxidation of nitric oxide to nitrogen peroxide. This takes place as follows:-



This exothermic equilibrium reaction proceeds almost entirely in the direction of the peroxide at temperatures below 150°C. It is obviously advantageous to cool the products of conversion as quickly and effectively as possible and this is done in air and water coolers of large capacity in order that the oxidation reaction may proceed as far as possible. Some of the peroxide formed will combine with the water present in the gas stream which has been derived from the conversion reaction and the breaking down of ammonia. This combination of the peroxide with water proceeds as follows:-

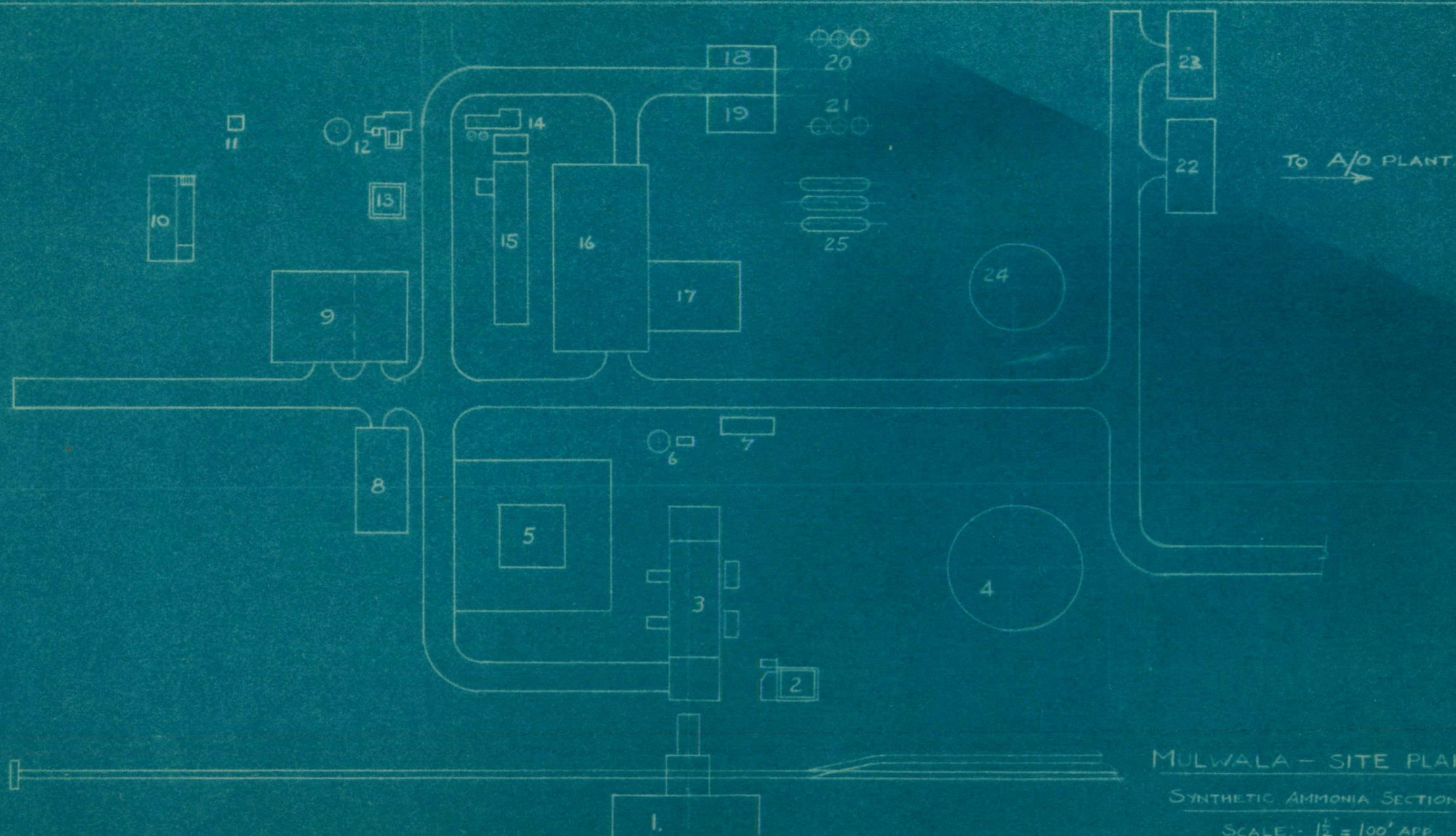


The nitric acid so formed - about 25% strength - is collected and drained off to the acid circulating system.

The gas leaves the coolers and enters the absorption system at about 25°C. In this system which consists of ten ring packed towers connected in series the gas is scrubbed with weak nitric acid and the absorption of peroxide is carried out

and the nitric oxide so formed is further oxidised. The circulation of each tower is maintained separately but water is fed into the last tower and acid from it is allowed to migrate to the next tower; this process is repeated with subsequent towers resulting in a gradient of acid strength from the first tower which is circulating at approximately 50% down to the last tower which is circulating at approximately 6%. Coolers are fitted to the first seven circulation systems to assist in the absorption process.

The volumes of the oxidiser-cooler and the absorption towers are large enough to give almost complete oxidation and absorption of all the converted nitrogen. Efficiencies of 97% are possible in this section under normal conditions. The unabsorbed gas consisting mainly of nitrogen and a small proportion of oxygen is discharged from the top of the last tower.



MULWALA - SITE PLAN

SYNTHETIC AMMONIA SECTION

SCALE: $1\frac{1}{2}'' = 100'$ APP.

ENG

DESCRIPTION OF PLANT AND EQUIPMENT REQUIRED FOR THE SYNTHESIS
OF AMMONIA AND METHANOL AND THE OXIDATION OF AMMONIA.

Introduction and General Layout.

Of the five factories built in Australia for the synthesis of ammonia etc., the Mulwala unit has been chosen as the most suitable for detailed description. All the units are essentially similar, the main differences being in the orientation of buildings to suit local conditions.

At Mulwala, the oxidation plant was located approximately 250 yards from the ammonia and methanol plants.

The location plans show the disposition of the various sections, the key to these being as follows:-

For Ammonia and Methanol Sections -

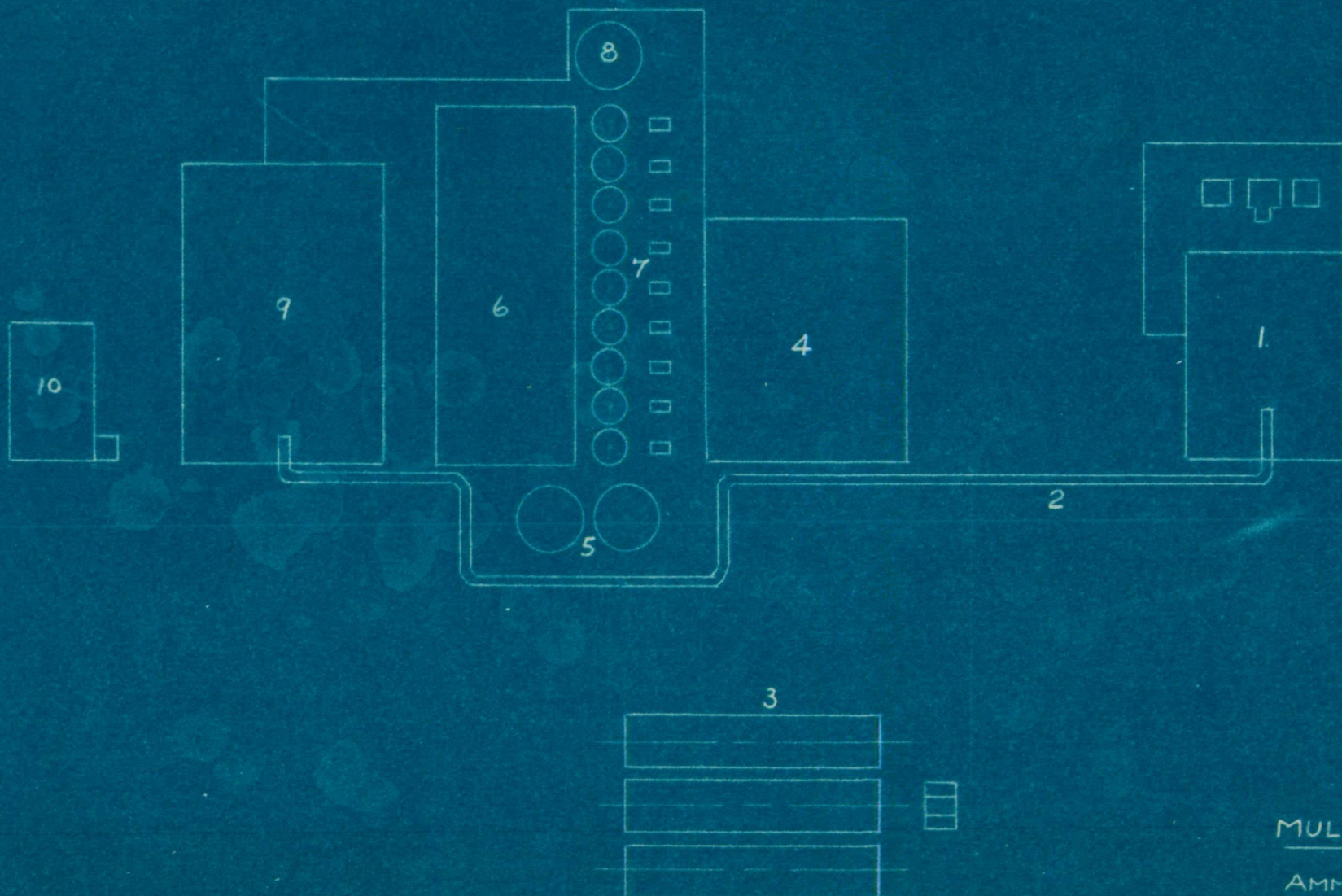
1. Coke Storage and Coke Handling Plant
2. Gas Plant Cooling Tower
3. Gas Plant
4. Raw Gas Holder
5. Sulphur Removal Plant
6. Fresh Water Emergency Storage Tank
7. Lavatory Block
8. Administrative Offices
9. Workshops and Store
10. Main Cooling Tower
11. Anti-Gas Training Test Chamber
12. Nitrogen Plant
13. Forced Draught Tower for CO₂ Removal Plant
14. Copper Liquor Preparation Plant
15. Tower Structure
16. Ammonia Plant
17. Sub-Station
18. Methanol Loading Out Platform
19. Methanol Distillation Tower Structure
20. Refined Methanol Storage Tanks
21. Crude Methanol Storage Tanks
22. Changeroom
23. Messroom
24. Catalysed Gas Holder
25. Anhydrous Ammonia Stock Tanks (foundations only).

Access to the site is provided by 18' bitumen sealed roads and a 5'3" gauge railroad for coke deliveries.

The Gas Plant is housed in a steel framed building 30' wide by 60' long by 60' high. The roof is sheeted with "super six" corrugated sheets and the walls with 3" corrugated sheets. Adequate ventilation is assured by leaving the bottom 8' unsheeted and by providing a louvred ventilator in the apex of the roof running the full length of the building. A penthouse, 30' x 23' x 20' high, for fans and blowers is built at one end of the building.

The administrative office block is a single storied building 31' wide by 60' long. A small process laboratory for plant control is built at one end. It is a timber framed building covered and lined with cement asbestos sheets. The workshop and store are combined in one building 52' wide by 77' long consisting of a timber framework covered with galvanised iron sheeting.

All the equipment for the hydrogen, compression, CO₂ and CO removal, and ammonia and methanol synthesis plants is housed in the tower structure and the main ammonia building.



MULWALA SITE PLAN
 AMMONIA OXIDATION SECTION
 SCALE: 1" = 30'

The tower structure, which carries all vessels, towers and catchpots, runs parallel to the ammonia building, being separated by 16'. It is a steel framework 21' wide by 98' long by 72' high. A 30 ton travelling and traversing hand operated crane is situated at the top of the structure. Supporting joists and access platforms are provided at appropriate levels. A stairway running the full height of the structure is supplied.

The ammonia building is a steel framed structure 53' wide by 106' long by 55' high. It is sheeted on the roof with "super six" corrugated cement asbestos sheet and on the walls with 3" corrugated asbestos sheet. A 10 ton hand operated travelling and traversing crane runs the full length of the building. Two 14' sliding doors are provided one at each end, and 5 - 3 ft. sliding doors. A continuous control panel runs down the side of the building adjacent to the tower structure and along one end of the building. All instruments and panel mounted valves are located on this panel which is 7' high and is 3'6" from the floor level; a control platform runs in front of the panel. The remainder of the building houses the main compressor, and interstage coolers, the circulators, the copper liquor injector, and sundry other equipment. The main sub-station is built adjacent to the ammonia building and the sub-station controls are located on a panel built into the ammonia building wall opposite the main control panel.

The changeroom and messrooms are wood framed buildings covered and lined with cement asbestos sheets. The former is 30' by 60' and the latter 30' by 50'.

For the Ammonia Oxidation Section -

1. Burner House and Still
2. Gas Cooling Main
3. Ammonia Liquor Stock Tanks and Pumping Station
4. Circulation Acid Coolers
5. Nitric Acid Storage Tanks
6. Absorption Towers
7. Circulating Tanks
8. Purge Tank
9. Oxidiser Cooler
10. Cooling Tower and Pond

The Burner House consists of a timber frame sheeted on the roof and two sides with cement asbestos sheets. The building is 30' wide by 40' long by 14' high to the roof truss.

The Absorption Towers and the Acid Coolers are located on either side of the Circulating Tanks and Circulating Pumps. A wooden roof over this section protects the equipment from the weather. No attempt is made to sheet in the walls of this shelter on account of the presence of acid fumes.

The Oxidiser Cooler is located alongside the Absorption Towers. The cooler coils are supported on a timber structure which in turn sits on piers in a storage pond. The pond is 38' by 54' by 5' deep. The supporting structure being 40' high, it is covered along the sides with 3" corrugated cement asbestos sheets to reduce water loss.

The two cell cooling tower is located alongside the oxidiser cooler on the same building line, the centres of the two units being 43' apart.

The Ammonia Liquor storage tanks are located 40' from the gas cooling main on the opposite side to the remainder of the plant.

EMG:OM

GAS GENERATING PLANT.

Installation:

The installation comprises :-

Two Mechanical Generators, each with Vaporiser Jacket, Wet Ash Discharge and Hand Operated Fuel Feed Gear.
Two Lynn type Washer Coolers.
Two Seal Boxes.
Gas and Blow Gas Connections.
Two Chimneys.
Two Air Blowers.
Air, Steam and Water Mains.
Operating Valves.
Two Automatic Mechanical Operators.
Generator Building.
Fuel Handling Plant.
Water Cooling System.

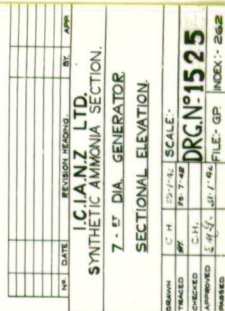
GENERATORS:

Two exactly similar semi-water Gas Generators as provided, one working and one spare when operating at normal flowsheet gas rates.

The central portion consists of a vertical cylindrical vessel, 7 ft. diameter and 13 ft. long. It is kept cool in operation by a low pressure steam raising jacket which surrounds it at the top and sides. Access holes to the central cylinder through the jacket include, at the top, four small poke holes fitted with metal plugs, the coke inlet in the centre; through the side near the top a brick lined connection for the blow gas, and a third unlined connection for the up-run steam.

At the bottom of the Generator is a rotating Meehanite Ash Bowl on which is built the Grate. The grate has eccentric sides and as it revolves, crushes large pieces of clinker and ash between itself and the sides of the Generator. It is fitted with slotted parts at the top through which air, steam and down-run gas can pass freely. The Grate and Ash Bowl are driven by a worm gear which is operated by a crank whose action can be varied to control the speed of rotation of the Ash Bowl. This is normally about one revolution in ninety minutes.

The seal between the rotating Grate and the stationary bottom gas and air lines is provided by a water lute at the circumference of a vertical pipe through which the inlet air and steam pass to the centre of the Grate, and through which the outgoing gas made during the down-run can pass from the Generator. The bottom steam, air and gas lines connect with this vertical pipe through the blast box. On the air line to the blast box, after the automatic primary air valve, there is a 3" cock to atmosphere; this admits air to the base of



the generator when it is on stand-by. The blast box itself is luted into the pit at the bottom of the Generator.

The trough, the grate and the rotating portion of the blast box lute form a rigid piece of plant, and rotate together. Ash falls from the periphery of the grate into the trough, and is scraped upwards over the outside lip of the trough by stationary but adjustable shovels.

There is a water feed to the L.P. steam jacket which can be controlled by a valve accessible from the operating platform; this jacket is also fitted with a level gauge attachment, four hand-holes and a manhole for inspection purposes. The L.P. steam from the jacket passes by an 8" diameter manifold to the steam inlet to the Generator from the H.P. steam main. The steam jacket can be vented to atmosphere, and it is also provided with a 6" relief valve which blows at 6-1/2 lbs. per sq. in. gauge. The jacket was originally designed to operate at a pressure of slightly less than 1 lb. gauge, this low pressure being sufficient to drive the steam through the coke bed for gas generating purposes. However, it was found that this operating pressure resulted in condensation of unconverted steam on the walls of the Generator adjacent to the top of the jacket with consequent corrosion. The raising of the operating pressure of the jacket to 6 lbs. gauge was sufficient to overcome this trouble.

COKE HANDLING AND STORAGE.

The coke arrives at the plant either by road or rail and is tipped into a ground hopper of 10 tons. capacity. It is elevated from this hopper by means of an overhead electrically driven travelling hoist of 3 tons capacity fitted with a bucket of 3 cwts. capacity. It can be discharged either directly to the Generators, or to a storage dump holding up to 670 tons.

The storage dump is so arranged that up to 125 tons of the coke stored therein can be rilled through discharge doors back into the ground hopper. In discharging from the ground, the coke is sieved and the resulting fines are collected in a subsidiary hopper for subsequent disposal.

AUTOMATICALLY OPERATED VALVES.

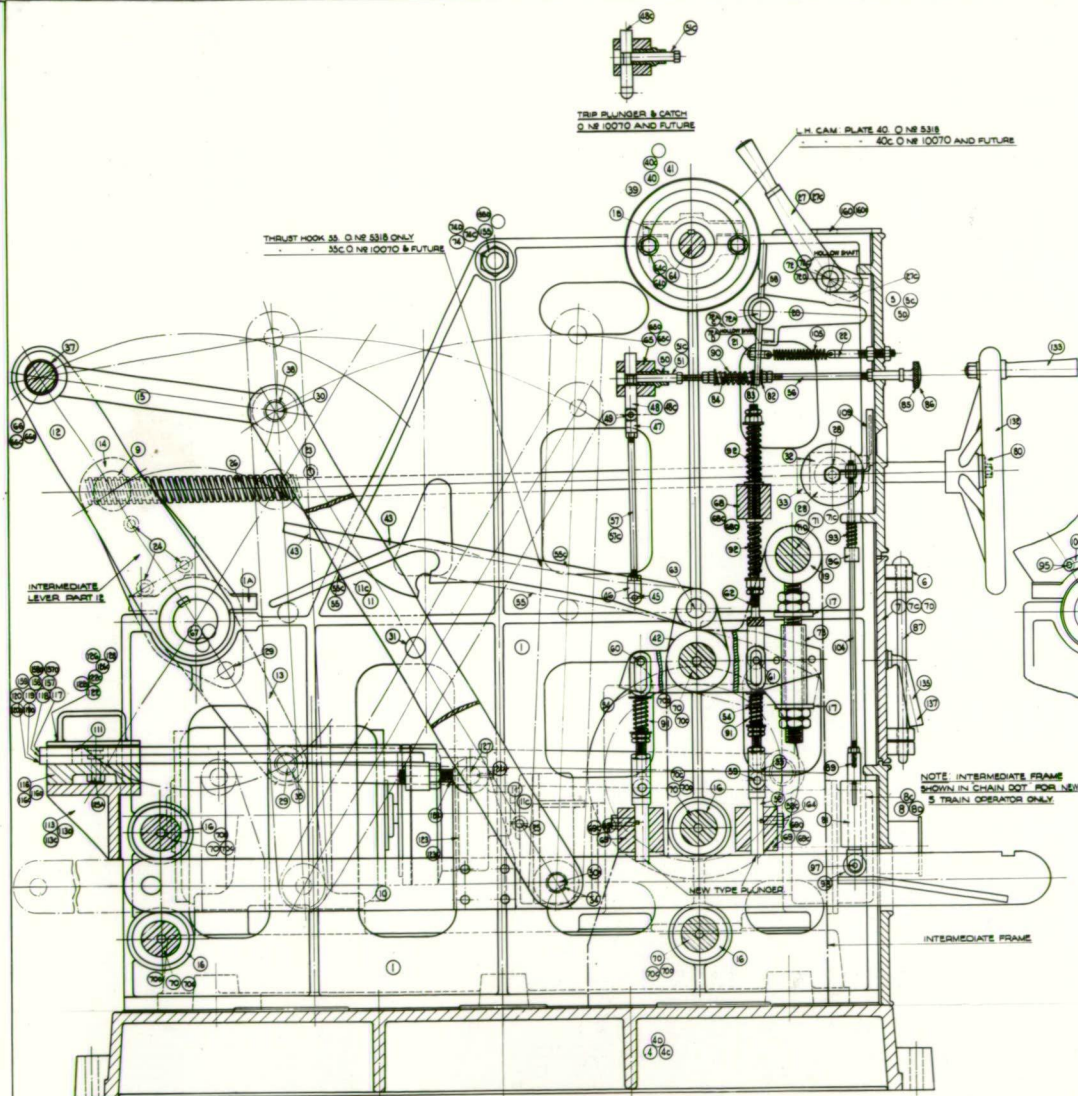
There are eight valves on the gas, air and steam lines to the Generator, which are automatically operated. These are :-

At the bottom of the Generator
and on lines going to the
blast box.

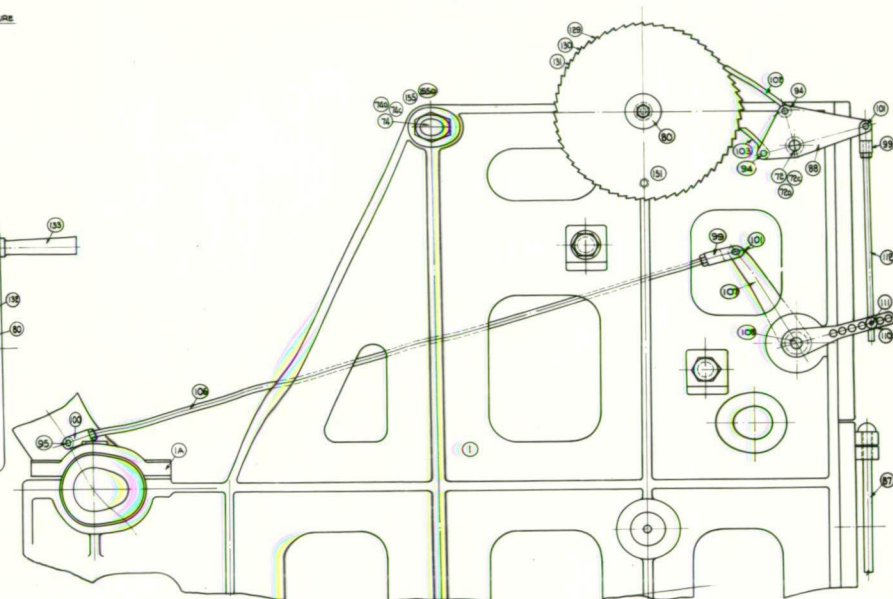
Primary Air Valve,
Secondary Air Valve,
Bottom Gas Valve (for
down-run gas),
Bottom Steam Valve (for
up-run steam; actually
a 3-way valve for up
and down steam).

At the top of the Generator
and on lines passing through
the steam jacket.

Top Gas Valve (for up-run
gas),
Top Steam Valve (for
down-run steam) 3-way,
Stack Valve.



SECTIONAL END ELEVATION



END ELEVATION SHOWING RATCHET DRIVE



LOCKING PLUNGER & GUIDE SCREW
Q NR 10070 AND FUTURE

ICIANZ LTD SYNTHETIC AMMONIA SECTION			
ARRANGEMENT OF MECHANICAL OPERATOR END ELEVATIONS			
DRAWN	M.L.C.	30-4-45	SCALE: 1/4" = 1" HIGH
TRACED	L.P.B.	1-7-44	DWG NO 0115
CHECKED			FILE GP INDEX 15
APPROVED			
PASSED			

The top and bottom steam valves, together constitute a three-way valve, and they are interlinked with the top and bottom gas valves so that whenever the top gas valve is open the top steam valve and bottom gas valves are shut, and the bottom steam valve is open. Alternatively, when the top gas valve is shut, the top steam valve and the bottom gas valves are open and the bottom steam valve is shut. The actual admission of steam is then controlled by the main steam valve. Thus either the top or the bottom gas valve must always be open, and they cannot be shut together.

AUTOMATIC OPERATING GEAR.

Each Generator has a motor-operated automatic device which controls the movement of the following valves through an arrangement of five lever and rod systems -

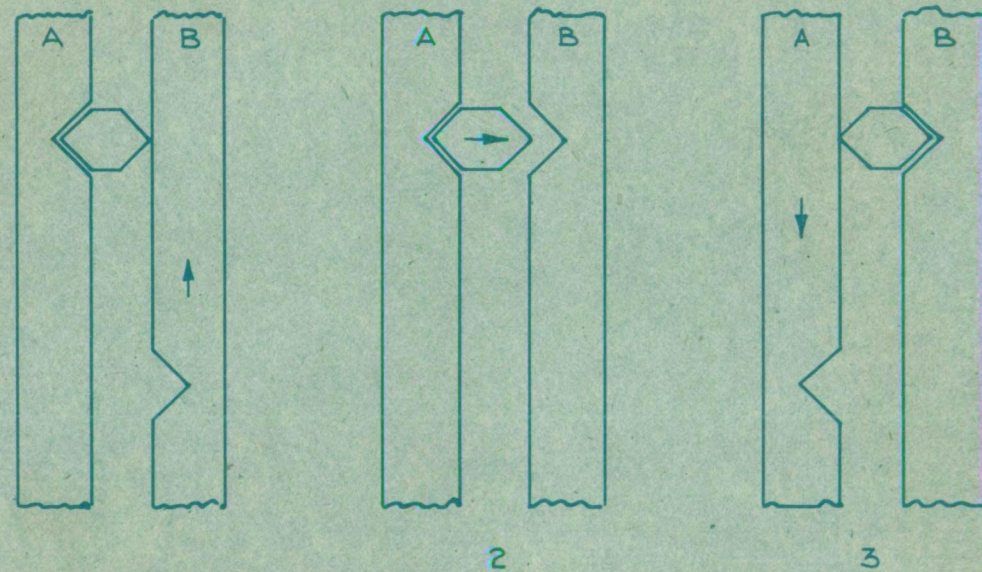
1. The stack valve, which is in effect a slide over the stack pipe, outside the building but inside the bottom cone of a draught pipe which carries the blow gases above the level of the building.
2. The primary air valve (14" diameter).
3. The auxiliary air valve (9" diameter).
4. The top and bottom gas valves and the three-way steam valve directing steam to the top or bottom of the Generator as described previously. This is known as the change-over control, and the change-over is said to be "open" or "on" when the bottom gas valve is open and the top gas valve shut.
5. The 2" valve on the H.P. steam inlet and the 8" main steam valve on the L.P. steam inlet line before the three-way steam valve. H. P. steam is used to supplement the L. P. steam supply from the Generator jacket. The mechanism ensures that the main steam valve always opens before and shuts after the H. P. steam valve.

The mechanical operator which works these five systems is shown in Drawing No. Q115/GP/115.

The driving motor (shown dotted) by means of a reduction gear, clutch, and crank connecting rod, imparts an oscillating motion to shaft (67) which runs horizontally across the back of the control board. Keyed to shaft (67) are five levers (one to each of the above rods) of which (11) is an example. The levers are connected to each of the five valve rods by link mechanism which, when a valve is not being operated, oscillate freely about the pin (30a).

Horizontally across the top of the control board there is a shaft (64) which by means of an adjustable ratchet and pawl mechanism is caused to rotate one revolution per generator cycle. On shaft (64) there are five pairs of adjustable cams, one pair of cams to each valve rod. When a valve is to be operated, the following sequence of movements takes place -

FIGURE 1.



ROD B MUST RETURN TO POSITION GIVEN IN 2 BEFORE
ROD A CAN BE MOVED AND VICE VERSA

GAS PLANT INTERLOCKS

The slot on the cam of one of the pairs on shaft (64) rotates into a position opposite rocker lever (58). This lever falls forward and withdraws pin (51) from supporting rod (57), thus allowing drop bar (55) to fall into pin (31) on one of the freely oscillating links. On the next occasion that the pin moves forward, the pin is restrained by drop bar (55) and the first effect is to rotate partially crank system (70). This raises the pin (91) which is locking draw-bar (10) and at the same time puts pressure on pin (52) so that when draw-bar (10) has moved its full traverse, it will be locked by pin (52). Further rotation of crank system (70) is prevented by the swinging stop (17) and then pin (31) acts as a fulcrum about which the link may rotate. This moves rod (10) which is connected by levers and bell cranks to the particular valve or valves which it is required to operate. Then when the link with pin (31) reverses its motion, it returns drop bar (55) back to its original position, in which it automatically is held by pin (51).

The movement of rod (10) in the reverse direction is caused in an exactly analogous manner by the other cam of the pair on shaft (64) allowing bar (43) to fall onto pin (31).

Thus all the movements of the valves in each cycle are determined by the relative positions of individual cams of the five pairs on shaft (64).

HAND CONTROLLED OPERATION.

When the Generator is to be operated under hand control, the five levers (37) withdraw the trip mechanism from the faces of the cams on shaft (64) and then pin (51) is worked by pulling out knob (85). Similarly, the reverse movement is obtained by pulling out knob (86).

ENTIRE MANUAL OPERATION.

If the motor fails, oscillation of shaft (67) can be obtained by turning the hand wheel (132). To do this, it is necessary first to disconnect shaft (67) from its motor drive by removing pin (29) from hole (35) and connecting it to the hand wheel drive by inserting it in hole (29). This can be done fairly rapidly, and the provision of one pin only ensures that the oscillating shaft cannot simultaneously be connected to the hand wheel and to the mechanical drive.

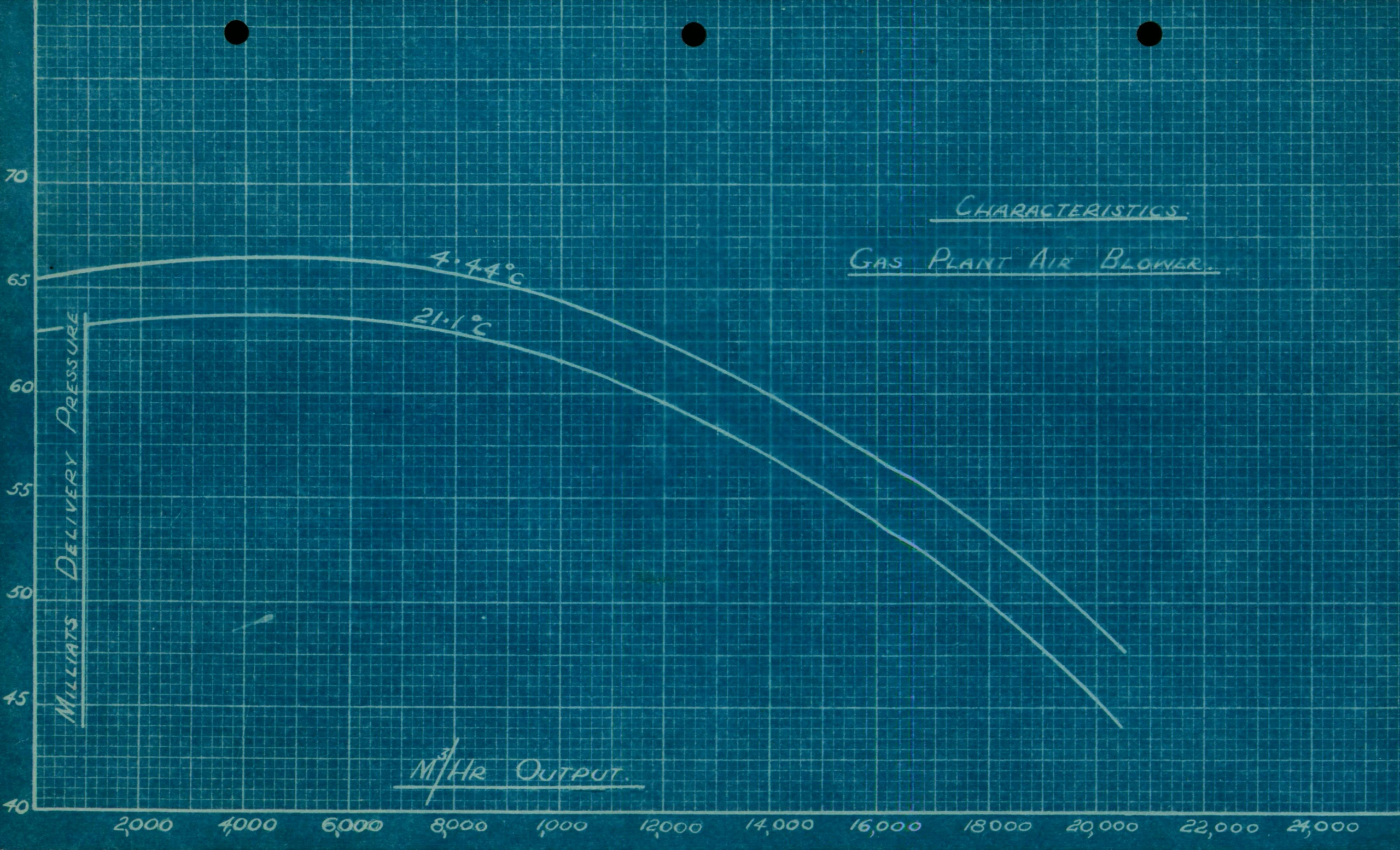
INDICATORS.

The position of each operating rod (10) is shown by a sliding strip (109) visible through apertures on the face of the control panel.

SAFETY DEVICES.

MOTOR OVERLOAD TRIP. The motor drives the reduction gear through a centrifugal clutch arranged to slip if the pull on the connecting rod exceeds 750 lbs. Should this occur, a centrifugal switch trips the motor, lights a warning light and sounds an alarm.

INTERLOCKING GEAR. The operating rods (10) are interlocked in a manner similar to that used in a railway



signal frame (see Fig. 1). The following interlocks are provided :-

- a). Interlock between Primary Air Valve (2 above) and the change-over Control (4).
- b). Interlock between Auxiliary Air Valve (3 above) and the Change-over Control (4).
- c). Interlock between the Steam Valve (5 above) and the Change-over Control (4).
- d). Interlock between the Auxiliary Air Valve (3) and the Main Steam Valve (5).

Interlock a). is required because the bottom gas valve is controlled by the Change-over Control. If the bottom gas valve and the primary air valve are open simultaneously, either air will pass into the gas main or gas into the air main. This is prevented by interlocking the Change-over Control with the primary air valve.

Similarly, interlock b). prevents the simultaneous opening of the Auxiliary Air Valve and the bottom gas valve.

In order to prevent an explosion in the base of the Generator due to air being blown into the blast box while it is full of gas, a purge of steam is applied to remove all the gas before the advent of air. To ensure that this is always done, interlock c). is provided which prevents the primary air valve opening whilst the Generator is making gas to the blast box.

The same precaution is required for the auxiliary air valve and this is achieved by interlocking the controls for the auxiliary air valve and the main steam valve.

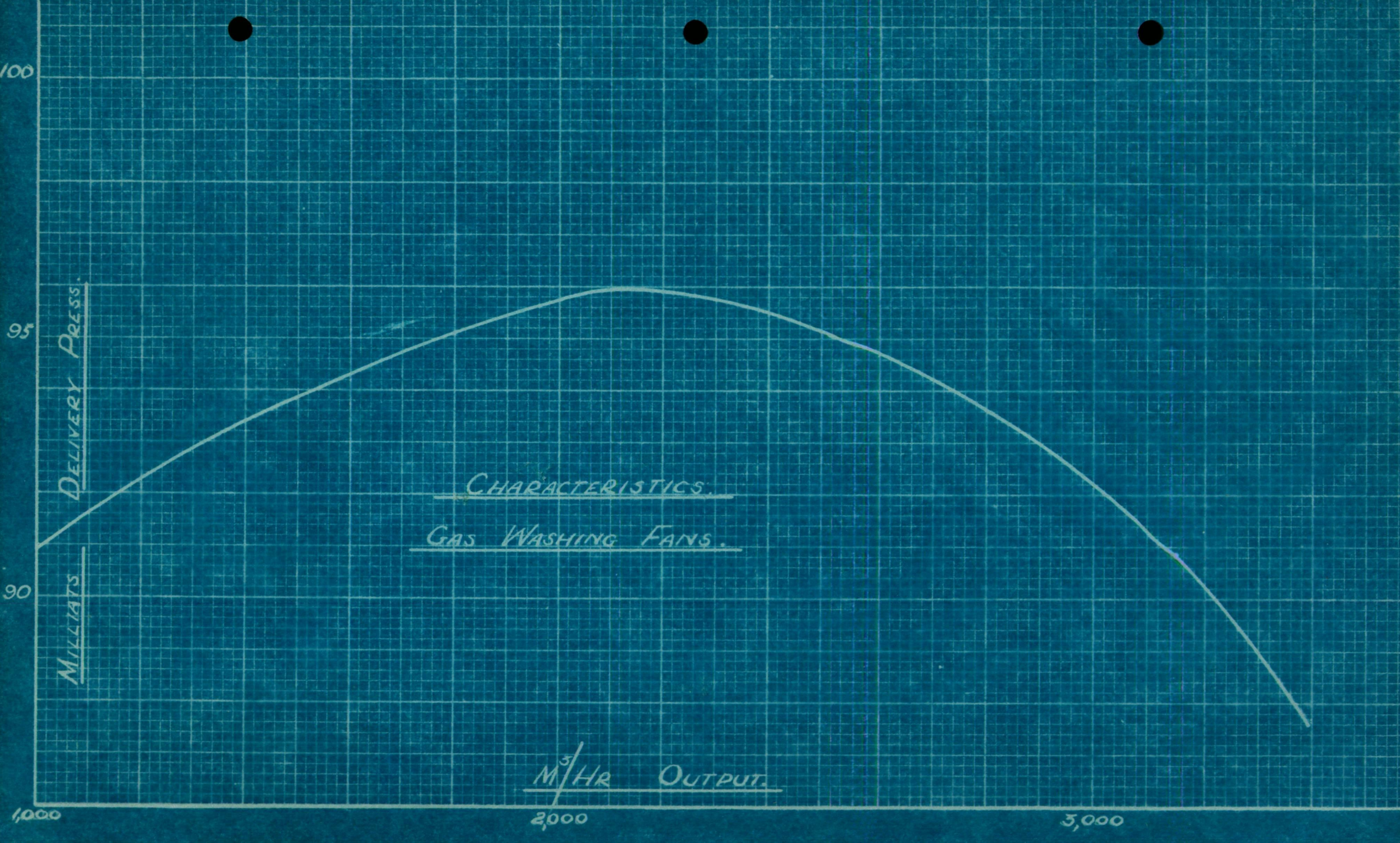
AIR BLOWERS.

To provide the air blast for the Generators there are two electrically driven blowers (one working, one spare) which feed into a 21" diameter air header, common to both Generators from which the primary air lines and the auxiliary air lines to each Generator are connected. The characteristics of the blower are shown on Graph 1. The air rate during the blast period will be approximately 9000 M³/hr. The non-working blower is isolated by a slip-plate type of goggle valve in its delivery line.

It is essential that the performance curve of these blowers be of such a shape that the operating point for all normal outputs be on a falling portion. This will prevent surging of the blower on light loads. Although several overseas units showed a tendency to surge, the Australian blowers have been free from this trouble.

LYNN STATIC GAS WASHING COOLERS.

On each Generator, the lines from the top gas valve and the bottom gas valve join and pass via a pipe into the bottom of the Lynn Washer and Cooler. This design of Washer which is housed in a cylindrical vessel 4'6" diameter and 26'



high, has a central stack carrying umbrella shaped plates under each of which is a ring secured to the shell, which passes the wash water from the circumference back towards the centre of the plate immediately below. The bottom of the washer is luted into a water pit, the lute blowing at 71 milliat. On the top of the Lynn Washer is the exit gas line of 12" diameter passing via an isolation valve into the gas collecting main. A 5" blow-off and a 5" water inlet are also located at the top of the washer.

SEMI-WATER GAS HOLDER.

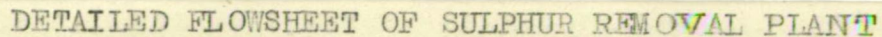
The exit gas mains from the Lynn Washers join an inlet header to the 2,000 M³ single lift, vertical guided semi-water gas holder of all-welded construction. This holder is provided with a Livesay manhole at the inlet and outlet pipes to enable these sections to be inspected without purging the holder. On the outlet gas main (14" diameter) from the water gas holder, are arranged the two inlet branches of the two gas washing fans (one working, one spare).

GAS WASHING FANS.

These centrifugal fans have an output of 1750 M³/hr saturated semi-water gas, measured at 1 at. absolute and 80%, containing 50-100 m.g./M³ coke breeze, and pressure rise of 15 milliat to 95 milliat gauge. Wash water is injected into the eye of the impellor at the rate of 0.5 M³/hr. through spray nozzles. This wash water is removed through luted drains in the base of the impellor casing. The impellor and shaft are from steel of less than 0.2% C, and 13-14% Cr. The blower characteristic are given in Graph 2.

COOLING WATER SYSTEM.

The cooling water on the Lynn Washer comes from a small circulating system comprising settling pit, open type coolers and pumps. It is kept separate from the main factory system because of its contamination with breeze. The normal cooling water rate with one Generator on line is 25 M³/hr.



SULPHUR REMOVAL PLANT.

General.

The four sulphur removal boxes are situated between the Gas Plant and the Hydrogen Plant and are connected to these units by 12" M.S. gas mains.

The boxes sit on a concrete raft, 90' x 90', which is sufficiently large to store and mix the charge of iron oxide.

Boxes.

The iron oxide is contained in four boxes arranged in square formation and encircled by the necessary gas mains. Each box is 17' 3" x 17' 3" and has four layers of oxide each 2'6" deep. Thus the total volume of oxide is 340 M³ (at normal flowsheet rates on overall space velocity of 5 hours⁻¹). Each box has four vertical internal gas ducts arranged in pairs at opposite corners of the box. One of each pair of ducts has ports opening on to the boxes above the top tray, between the second and third trays and below the bottom tray; the other duct has openings above the second and above the fourth tray. All trays in any particular box are in parallel and by use of the different ducts, the flow through the trays of a box can be reversed.

Each box has an 11 ft. opening at the top which is used for loading and discharge purposes. These openings are closed by flat covers suitably stiffened and sealed with a joint of greasy hemp 1" sq. They are held in place by holding down bolts hinged to swivel outwards spaced at 9 in. centres.

Valves and Pipe Lines.

The arrangement of valves and pipelines is shown on the Sulphur Removal Plant flowsheet.

The arrangement enables either forward or backward rotation of the boxes (i.e. 1, 2, 3, 4; 2, 3, 4, 1, etc. or 4, 3, 2, 1; 3, 2, 1, 4, etc.); in addition any box can be isolated from the other three.

The reason for valves in pairs with an intermediate blow-off is to prevent leaking valves allowing gas to by-pass the boxes completely. This would be possible with single valves in place of the pairs. When such a pair is closed, the intermediate blow-off is left open so that any gas leaking past the closed valves can escape to atmosphere.

Nitrogen and Purge Connections.

Each box has a blow-off cock in the lid and a nitrogen connection which is so arranged that it can be used on either pair of ducts.

Air Blowers.

Air to the boxes (supplied for continuous revivification) is provided by a small air blower of 30 ms./hr. capacity of the water seal "Nasch" type.

Safety Devices.

Apart from drainage lutes (which are set to blow at 100 milliat pressure) at the inlet and outlet of the boxes, the only safety device provided is a differential manometer electrical trip which is wired into the air blower motor circuit. This manometer, which is connected to the inlet and outlet mains to and from the boxes, measures the pressure drop across them. Should the pressure drop across the boxes fall due to very low gas rates, the air blower will be tripped out thus preventing the formation of explosive gas mixtures inside the boxes.

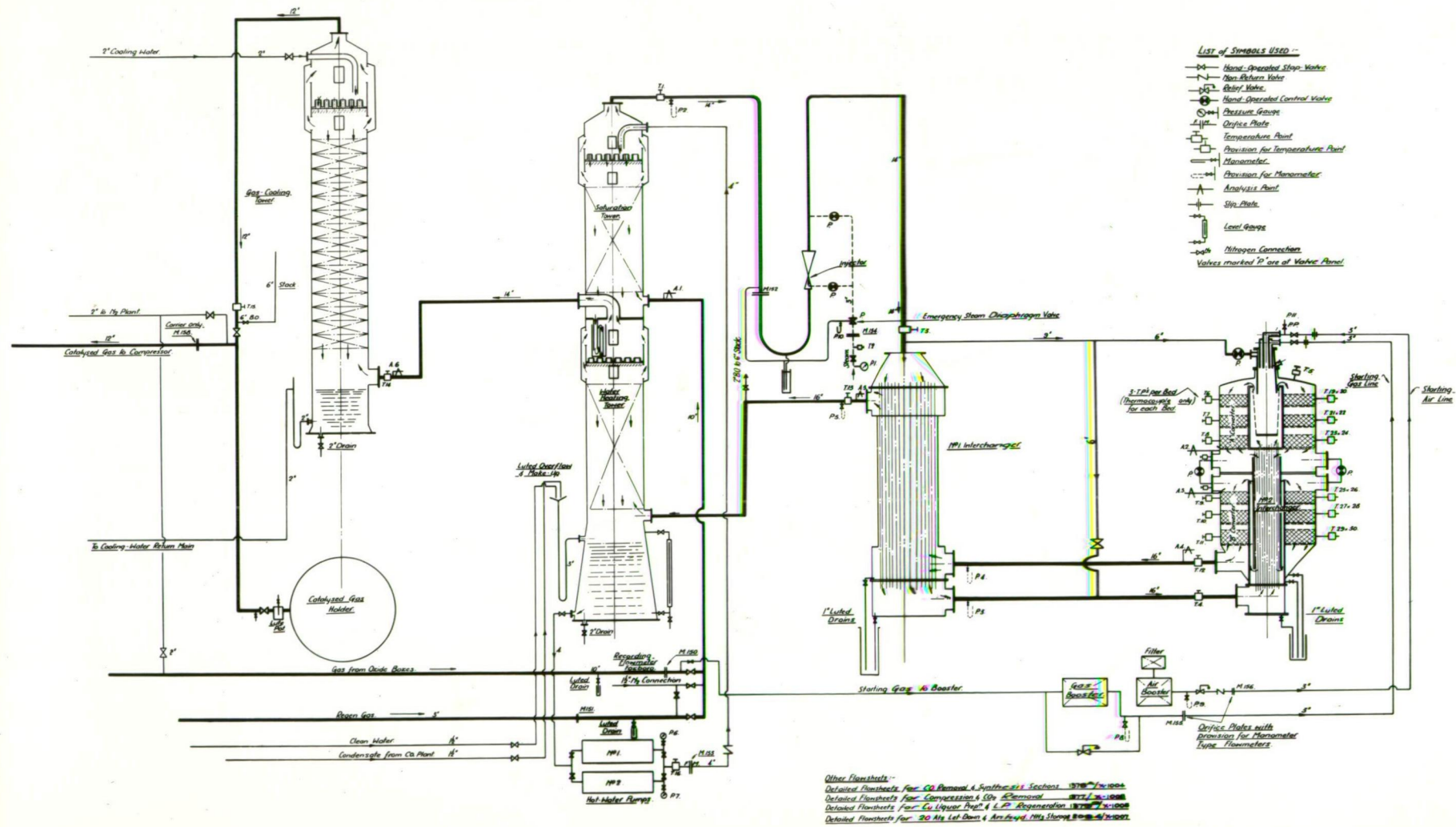
Handling of Oxide.

The oxide is handled by an inclined elevator. This is of conventional design and consists of M.S. buckets mounted on a rubber belt running in a sheet steel case. The elevator is driven by a 2 H.P. motor geared to the top shaft. A boot for loading and a discharge chute are provided. The elevator is 22 ft. long and is slung by the centre for handling purposes.

To support the elevator for charging and discharging the boxes, a 30 cwt. luffing crane is mounted at the centre of one side of the boxes; an alternative location for the hoist is provided at the centre of the opposite pair of boxes, one crane thus serves the four boxes.

To load the boxes, the elevator is located outside with its boot on the ground and the discharge chute opening into the appropriate box.

To discharge, the elevator is slung inside the box discharging out on to the concrete raft and lowered successively as each layer is removed.



DETAILED FLOWSHEET OF HYDROGEN PLANT

HYDROGEN PLANT

GENERAL

The arrangement of the equipment for the hydrogen plant is shown on the flowsheet. This is detailed below:-

Saturation Tower

Purified gas from the Sulphuric Removal Plant is piped in a 10-inch main to the base of the Saturation Tower. This tower is contained in the same shell as, and above, the water heating tower. It is of welded construction and is fabricated from $\frac{3}{8}$ -inch M.S. plate. It is designed to the following details:

Diameter	3'4"
Height	17'5"
Depth of wooden grid packing	8'0"
Type of packing	"egg-box" grids 1"x 1"x $\frac{1}{8}$ ".
Normal working pressure	25 milliats gauge
Test pressure	200 " "
Water Rate	35 M ³ /hour
Inlet Water Temperature	80°C.
Exit Water Temperature	65°C.
Gas Inlet	10" Diameter
Gas Exit	14" "

The water flowing from the Saturation Tower passes by means of a lute (set to blow at 128 milliats) to the top of the water heating tower immediately below.

Gas passing from the top of the Saturation Tower is metered and then enters a steam injector.

Steam Injector

The Steam Injector which uses the pressure of the steam required for the subsequent catalytic reaction to boost the pressure of the gas and thus maintain the appropriate gas rate, is controlled by valves mounted on the Hydrogen Plant control panel. One valve controls the rate of steam to the injector nozzle and a second supplies additional steam through a by-pass.

The design details of the steam injector are as follows:

Throat	3 $\frac{1}{4}$ " diam., 2'8 $\frac{1}{2}$ " long
Exit Cone	7" " at exit 3'3" long
Steam nozzle	0.68" diam. opening out to 0.87" in 3"

Gas from the injector passes to a heat interchanger.

No. 1 Interchanger

This is a tubular heat interchanger arranged so that the incoming cool gas passes down through the M.S. tubes and the hot gas passes across the outside of the tubes. The nest of tubes is so arranged that three passages formed by omitting rows of tubes are left to enable an equitable distribution of gas to be achieved. The dimensions of this unit are as follows:

Shell - 2' 1" diam.
 Tubes - 471 each $\frac{3}{4}$ " o.d., 17 gauge thick, 13' $8\frac{7}{8}$ " long.
 Effective surface of tubes for heat transfer purposes -
 972 sq. feet (o.d. of tubes).
 Cross sectional area through tubes - 0.995 sq. feet
 " " " outside " - 1.380 "

The Interchanger is fitted with luted drains for the removal of condensation. From the Interchanger the gas passes to the converter unit.

Converter Unit

The converter unit consists of A converter, B converter and an intermediate Interchanger (No. 2). For the control of temperatures and correct temperature gradients within the catalyst beds of both converters, three bypasses are provided.

The first (No. 1 bypass) allows cold gas to pass directly to the top tray of A converter. The second (No. 2 bypass) allows gas to pass directly from A converter to B converter without negotiating the intermediate interchanger. The third (No. 3 bypass) allows warm gas from No. 1 interchanger to pass directly to A converter without passing through No. 2 interchanger. The controls for the bypass valves are located by means of geared drives on the Hydrogen Plant control panel.

No. 2 Interchanger:

Shell - 2' $8\frac{1}{4}$ " diam Welded construction
 522 tubes, $\frac{3}{4}$ " o.d. 16 gauge thick, length 9' $6\frac{1}{8}$ "
 Effective surface of tubes for heat transfer purposes
 845 sq. feet (o.d. of tubes)
 Cross sectional area through tubes 1.1 sq. feet
 " " " outside tubes 1.465 sq. feet.

From No. 2 interchanger the gas passes up into A converter.

A Converter: Built into the same shell as B Converter and No. 2 Interchanger. The catalyst is contained in three beds each 11 inches deep in an annular space of 2 feet $9\frac{1}{2}$ inches internal diameter and 6 feet 6 inches external diameter. The beds are supported by 1-inch perforated M.S. plates ($\frac{1}{8}$ -inch diameter perforations). The total volume of catalyst in A Converter is 2 M³. After passing through the three beds of the first converter the gas is cooled by No. 2 Interchanger and then enters B converter.

B Converter: This unit is identical to A Converter. From B Converter the gas passes into No. 1 Interchanger (outside tubes) and from there into the bottom of the Water Heating Tower.

Water Heating Tower

As mentioned previously this unit is located underneath the Saturation Tower. It has the following dimensions:

Diameter	3'4"
Height	25'9"
Depth of Packing	8'0"
Type of Packing	1"x 1" x $\frac{1}{8}$ " ("egg-box" grids)
Normal working pressure	30 milliats gauge
Test pressure	200 " "
Water rate	35 M ³ /hour
Gas Inlet Main	18" diameter
Gas Exit Main	14" "

A sump is situated at the base of this tower having a capacity of 2.5 M³ maximum. From this sump two hot water circulating pumps (one working and one spare) draw water and circulate it over both towers. This sump is fitted with a 2-inch purge cock and a luted overflow; the overflow also acts as a convenient point for the addition of the necessary make-up water. The pumps have a capacity of 35 M³/hour when delivering at 70-foot head and operate at 1,500 r.p.m., being driven by a 5 h.p. electric motor. The gas passes out at the top of the water heating tower and enters at the base of the Gas Cooling Tower.

Gas Cooling Tower

The purpose of this unit is to cool the gas by counter current scrubbing with water before it enters the main compressor. Details of the tower are as follows:

Diameter	3'4"
Height	29'0"
Depth of packing	16'0"
Type of packing ("egg-box" grid)	1"x 1"x $\frac{1}{8}$ "
Normal working pressure	25 milliats g.
Test pressure	200 " "
Cooling water rate	12 M ³ /hour
Gas inlet main	14" diameter
Gas exit main	12" "

Cooling water is supplied from the factory cooling water system and returns by gravity to the hot well of the cooling tower. It escapes from the base of the gas cooling tower by a 3-inch lute.

Catalysed gas from the gas cooling tower passes to the compressor inlet main. To provide buffer capacity for the compressor a catalysed gas holder is provided at this juncture.

Catalysed Gas Holder

Used purely as a buffer storage unit. Has a capacity of 1,000 M³ and is a single lift, vertically guided type. The costs for power used in the subsequent gas compressor are directly proportional to the absolute temperature of the inlet gas; to keep these to a minimum in hot climates it has been found advantageous to paint the top of these holders white to reflect the direct rays of the sun and the sides black to radiate heat.

The holder is connected to the compressor inlet main by a 12-inch connection. This main is fitted with a lute pot for isolation purposes.

Air and Gas Starting Blowers

Two water sealed "Nasch" type blowers, one for gas and one for air, are provided, each has a capacity of 50 M³/hour. Both are fitted with relief valves which lift at 200 milliats pressure.

Safety Devices

Three safety devices are installed. The first is mounted on the compressor panel and warns the compressor operator by means of a warning light and hooter when the catalysed gas holder is 90% empty. The second consists of a warning light on the hydrogen plant control panel which warns the operator when the hot water circulating pumps cut out. The third is a diaphragm controlled steam valve on the main steam line to the hydrogen plant. Should the

pressure on the upstream side of the injector fall below 10 milliat this diaphragm valve automatically shuts off the steam to the injector. This is to prevent the formation of negative pressures in the plant.

Lagging

The converter unit and interchanger with the interconnecting pipework are lagged with a 6-inch thickness of rockwool. A welded sheet steel lagging sheath is provided to retain the rockwool.

The water heating and saturation tower and the line running from this to the injector and on to the interchanger is lagged with $1\frac{1}{2}$ -inch 85% magnesia covered with $\frac{1}{2}$ -inch of hard setting compound and then wrapped with cloth to retain the lagging.

[illegible]

- OTHER FLOWSHEETS.
- Detailed Flowsheet for Hydrogen Plant
- " " " Co Removal & Synthesis Section
- " " " Co Liquor Preparation & L.R. Regeneration
- " " " 20 Hrs. Let-Down & Aqueous R.R. Stripping

DETAILED FLOWSHEET OF COMPRESSION AND CO₂ REMOVAL PLANTS

COMPRESSION PLANT.

General Layout of Plant.

The compression plant is located in the main ammonia building. Interstage and after coolers are located in a steel structure approximately 10 ft. from the compressor. The intervening space being used for the main control panel on which are mounted the control valves, the pressure gauges, indicating thermometers, alarms and manometers.

Gas Flow.

Gas enters the plant through a 12 inch diameter main passes through an isolation valve (panel operated), an orifice plate and then enters a strainer. This strainer consists of a cylinder of 1/8 inch mesh housed in a strainer box fitted with flanged cover and drain. A purging out point is located before the strainer and a panel mounted manometer is situated immediately after it. From the strainer the gas passes directly to the first stage inlet; an analysis point, temperature point, and relief valve are fitted into this section of the line.

The general flow of gas through the compressor is from the delivery of one stage to the inter-cooler through a catchpot and then to the succeeding stage. Gas after passing the second stage catchpot can be delivered to the CO₂ removal plant, by-passed directly to the third stage suction or by-passed back to the first stage suction. Panel mounted by pass valves and isolation valves to and from the CO₂ plant control the flow of the gas. A non return valve on the delivery line to the CO₂ plant prevents water being drawn into the compressor system by any tendency to back surge. Gas from the sixth stage delivery can be delivered to the methanol plant, the CO removal plant, by passed back to the third stage suction, by-passed back to the first stage suction or blown off to atmosphere. A non return valve is located on the delivery line to the methanol and CO removal plants and double isolation valves (panel mounted) on the lines leading to these plants ensure freedom from gas leaks. Relief valves are fitted after every stage, on the return line from the CO₂ plant and on the 6th. stage to 3rd. stage by-pass. Temperature points are located before and after all coolers and also on the line returning from the CO₂ plant. Panel mounted pressure gauges record pressure at the delivery of all stages, on the return line from the CO₂ plant and on the line to the CO removal plant. Pressure points are located after each cooler to which gauges may be fitted for test purposes.

The interstage piping diameters are made intentionally large to reduce pressure pulsations in the system. Pipe sizes are as follows:-

Stage.	1	2	3	4	5	6
Inlet pipe diameter.	12"	10"	4"	3"	3"	4"
Delivery pipe diameter.	14"	10"	6"	6"	3"	2"

The discharge line from the plant is 5/8" inside diameter.

Compressor.

The machine was built by Messrs. Bellis and Morcom to a design by I.C.I. Ltd. It is a three crank, six stage vertical unit; the first three stages being double acting and the last three single acting.

Bedplate, Crankcase, Entablature and Trunk Guides, are all cast in high grade close grained cast iron. Mating faces are accurately machined; the underside of the bedplate is also machined to facilitate the packing of the bedplate on supporting wedges. Large inspection doors 15 - three each side - are

provided in the crankcase these are fitted with air tight joints. Efficient wiper glands are provided where piston rods pass through the crankcase. The crankcase sump is fitted with a gunmetal drain cock.

Crankshaft. This is machined from a single steel forging. It is a three throw unit the crank angles being 120° .

Flywheel. This is of ample proportions machined from cast iron. It is spigoted into the crank; the end of the driving motor shaft is flanged and accurately machined to fit the face of the flywheel. Fitted bolts tying the motor shaft, flywheel and crank together form a rigid coupling at this point. During erection care is taken to ensure that the weight of the flywheel is equally divided between the end bearing of the compressor and the inboard bearing of the motor. If this is not done flexing of the web of the crank nearest the coupling will result.

Connecting Rods and Crossheads. The former are machined from mild steel forgings and the latter from nitr-alloy steel forgings. The pins for the top end bearings are forged integrally with the crossheads. The cross heads are fitted with double guider shoes which are white metallised on the working face and accurately machined to suit the trunk guides.

Main Bearings. There are four main bearings the centre two being interchangeable. The bearing shells are of cast iron lined with good quality white metal. The bottom halves are semi circular and arranged for easy removal without removing the crankshaft. The keeps are of cast iron and are fitted with thermometer pockets. The holding down studs are of forged steel.

Connecting Rod Bearings. The bottom end bearing, are gunmetal lined and the top end bearings are of bronze. Internal oil holes are drilled for the lubrication of the top end bearings and crosshead guide shoes from the bottom end bearing oil supply.

Bearing Pressures. The machine is designed to develop pressures in the bearings of less than the following maximum allowable pressures. These pressures are calculated on the projected area and the total resultant load

Crosshead bearings.	1344 lbs/ sq.in.
Crank pin bearings.	562 lbs / sq.in.
Main bearings.	229 lbs / sq.in.
Crosshead guides.	100 lbs / sq.in.

Cylinders, Covers and Water Jackets. The stroke of all pistons and plungers is 17 inches. The diameter of the cylinders is as follows:-

1st. stage	27 in. diam.
2nd. "	16 in. diam.
3rd. "	9 in. diam.
4th. "	6 in. diam.
5th. "	3-3/4 in. diam.
6th. "	2-1/4 in. diam.

The first and second cylinders are from close grained cast iron and are not fitted with liners. The valve chests, water jackets and stuffing boxes are cast integrally with the cylinders. The top covers are of cast iron in a double section connected to cylinder water jackets by mating parts. The 3rd. stage cylinder is of cast steel with a close grained cast iron liner. The first three stages being in line are bracketted together to ensure rigidity.

The 4th, 5th. and 6th. cylinders are attached to the top of the 1st, 2nd, and 3rd. respectively. These cylinders have nitralloy steel liners. The 4th. cylinder has a cast iron jacket while the 5th. and 6th. have cast steel jackets. The valve chests are all cast steel.

Pistons. Pistons are only used on the first, second and third stages. They are of close grained cast iron.

Piston Rods. The 1st. 2nd. and 3rd, stage rods are of forged steel provided with tapered ends for fitting to the cross head and a flanged end with spigot at the top end for fitting to the position. The 4th. 5th. and 6th. are from forged steel and are machined as plunger rods; the bottom end is flanged and spigoted for fitting and bolting to the piston of the stage below.

Piston Rod Packing. The piston rod packing is of the metallic, split ring self adjusting type. A single set is provided for the 1st. stage and double sets for 2nd. and 3rd. stages. Below the metallic packing, lantern rings and then three turns of soft packing are fitted. Leakages of gas through the metallic packing is collected at the lantern ring and bled back to the inlet of the 1st. stage.

Piston Rings: The 1st, 2nd, and 3rd. stage pistons are fitted with self sealing cast iron rings each piston having two rings. The 4th, 5th, and 6th. stage plunger rods were originally fitted with the double ring "clupet" type but they have been changed to the single ring with mitred ends. There are eighteen rings on the 4th. and 5th. stages and thirty on the sixth.

Suction and Delivery Valves. All suction and delivery valves are of the plate type. The 1st., 2nd., and 3rd. stages are supplied with the Rogler-Hoerbiger type; the 4th. 5th. and 6th. stages are supplied with the annular disc type in 15% chrome steel. The lift and gas velocities of the valves are as follows:-

Stage.	Valve lift.	Gas velocity
1st.	3/32 in.	108 ft/sec.
2nd.	3/32 in.	73 ft/sec.
3rd.	1/10 in.	60 ft/sec.
4th.	1/10 in.	44 ft/sec.
5th.	3/32 in.	82 ft/sec.
6th.	3/64 in.	71 ft/sec.

Relief Valves. These are of large capacity and are of the spring loaded type. They are designed to lift at pressures 25% above the normal working pressures. The 2nd. and 6th. stage relief valves will take full compressor rate. The discharge from all relief valves is piped back to the 1st. stage inlet.

Crankcase Lubrication. All bearings are pressure lubricated. Oil is provided under pressure by means of a double ram force feed pump located in the bedplate; it is eccentrically driven from the crankshaft and has a capacity of 2200 galls/hour at 40 lbs/sq.in. From oil strainers and twin oil coolers of the tubular "Serk" type are provided in this oil system. A second gear oil pump driven by electric motor (5 HP 1440 R.P.M.) is provided for starting up purposes. The oil level in the crankcase is indicated by a dip stick. A pressure operated diaphragm switch connected to the oil system operates an alarm should the oil supply fail.

Cylinder and Gland Lubrication. Cylinders and glands are lubricated by means of an eight point "Bosch" type lubricator driven from the crankshaft. Each oil line is provided with a non return valve and a stop valve. A spare motor driven unit (5 HP 1440 R.P.M.) is provided for starting up purposes.

Tachometer. A "Budenberg" type of tachometer is mounted on the machine being belt driven from the crankshaft.

Hand Barring Gear. The flywheel is recessed around the periphery and a set of ratchets mounted on a pedestal opposite these recesses constitute the hand barring gear. This is so arranged that the pawls are automatically thrown out should the machine start whilst they are engaged.

Indicator Gear. The machine is fitted with the necessary pressure points on all stages and indicator movement connections to fit indicator gear should it be required for testing purposes

Temperature Points. Thermometer pockets are provided for all bearings, and for the inlet and outlet pipes on the oil valves.

Access Platform and Ladders. An access platform is provided around the machine at the 8 ft. level and a smaller one on one side of the machine at the 13 ft. level. Ladders to these platforms are fitted.

Gas Density. The machine is designed to handle gases of the following density.

1st. and 2nd. stages	0.81 Kg/M ³ (1at abs. x 20°C.)
3rd. 4th. 5th. & 6th. stages.	0.41 Kg/M ³ " " "

Delivery Pressures and Capacity. The following figures give the design operating pressures and capacities of the various stages:-

Stage	1.	2.	3.	4.	5.	6.
Suction pressure (ats. abs.)	1	3.05	8.1	26.2	67.7	178.7
Delivery pressure (" ")	3.23	9.1	26.6	68.2	179.3	360
Suction temperature.	30%	30%	25%	30%	30%	30%

Capacity.	2460 M ³ /hr.	1760 M ³ /hr.
-----------	--------------------------	--------------------------

Power Consumption. At the full speed of 208 R.P.M. the compressor absorbs 800 H.P. at the coupling.

Driving Motor.

The compressor is driven by a wound rotor induction motor built by the British General Electric Co. Ltd. It has a rated continuous output of 910 H.P. when operating at full speed which is 208 R.P.M. Speed control over the full speed range is achieved by means of a liquid regulation in the rotor circuit. This liquid regulator was supplied by Metropolitan-Vickers Ltd., and is type L.R.1000. Heat generated in the regulator is removed by cooling coils built into the regulator, tank and supplied with water from the factory cooling system. The leads from the compressor motor enter the regulator through the base of the electrolyte tank and terminate on three grid electrodes. Corresponding electrodes which are capable of vertical movement are located above the stationary set and the three moving electrodes are connected together by copper bus-bar. A worm gear drive controls the vertical movement of electrodes. The tank is filled with a solution of sodium carbonate the strength being adjusted to give the required starting speed.

Power to the motor is supplied from a 1000 K.V.A. transformer housed in the factory substation. A remote controlled oil circuit breaker which is housed in the substation is located in the cable between the transformer and the motor and this constitutes the starting switch. The control start and stop buttons with appropriate indicating lights are mounted on a small pedestal alongside the liquid regulator.

A small electric fan provides cooling air to the motor slip rings. These are encased in a vapour proof C.I. housing the cooling air supply being drawn in from outside the building. This precaution is taken to prevent an explosion due to sparking of the brushes should a large gas leak develop inside the ammonia building.

The 910 H.P. motor is rigidly bolted to the flywheel of the compressor by accurately fitted bolts.

1st. Stage cooler.

This is a multitubular type having identical nests in series. The tube shells are welded from M.S. plate and are 9 in. diameter by 11ft 3in. long, they are provided with baffles to increase the velocity of the gas in the cooler and achieve a more efficient "scrubbing" action of the gas against the tubes. The cooling water flows inside the tubes which are of Alumbro being 1 in. o.d. by 18 s.w.g. 24 tubes being provided to each nest. Total cooling surface is 250 sq.ft. The gas flow is horizontal and downwards, thus assisting the removal of condensed water from the cooler. The cooling water enters at the bottom nest and flows counter current to the gas up through the three sets of tubes. This cooler is designed to operate on 8.05 M³/hr. of cooling water.

2nd. Stage Cooler.

This is similar in design to the 1st. stage cooler and consists of three multitubular coolers mounted horizontally in a vertical bank. They are connected in series. The M.S. tube shell is 7 in. diameter by 10 ft. long. 24 Alumbro tubes are provided for each nest being 3/4 in. o.d. by 18 s.w.g. by 10ft.3" long. The total cooling surface being 157 sq.ft. The gas and cooling water flow is similar to the first stage cooler. This cooler is designed to operate on 6.55 M³/hr. of cooling water.

3rd. Stage Cooler.

This is a jacketed serpentine type of cooler. Five parallel banks mounted horizontally are provided each comprising three pipes 1-1/2 in. bore by 28 ft. 4in. long; each pipe is jacketed by a 2-1/2 in. bore pipe. Welded beads on the internal pipe at regular intervals locate the external pipe. The total cooling surface is 90 sq.ft. The gas flow is horizontal and downwards the water flow is counter current. The cooling water required for this cooler is 4.23 M³/hr.

4th. Stage Cooler.

This is a jacketed serpentine cooler similar in design to the 3rd. stage cooler except that only one bank of pipes is employed. The total cooling surface is 59 sq.ft and is made up of one bank of four pipes each 1-1/4 in. o.d. by 2-5/32 in o.d. by 26 ft. 4 in. long. The cooling jackets are from 2-1/2 in bore pipe and are designed to operate on 3.46 M³/hr. The flow of gas and cooling water is counter current with the gas flow assisting the removal of condensate.

5th. Stage Cooler.

This is a jacketed serpentine cooler with two banks in parallel and its construction is similar to the 3rd and 4th. stage coolers. Each bank consists of three pipes 5/8 in bore by 1-11/32 in. o.d. by 23 ft. 6 in. long giving a cooling surface of 50 sq.ft. Counter current flow similar to other coolers is used. The cooling water requirements are 3.54 M³/hr.

6th. Stage Cooler.

This is a jacketed serpentine cooler having one bank of four horizontal pipes connected in series; they are 5/8 in. i.d. by 1-11/32 in o.d. by 23 ft. 6 in. long. They are jacketed by pipe having a bore of 1-3/4 in. The cooling surface is 33 sq.ft and the cooling water requirements are 2.44 M³/hr.

Catchpots.

Catchpots are supplied after every cooler. The gas flows through these catchpots is so arranged that the incoming gas is discharged circumferentially thus imparting spin to the gas and assisting in throwing down condensate. The outgoing gas leaves at the top of each catchpot at the centre. Drains are provided in the base of each vessel to a water and oil collecting vessel. Details of the respective catchpots are as follows:-

1st. Stage Catchpot. Of welded construction from 3/8 inch plate. It is cylindrical in shape having dished ends and is mounted vertically. It is 2 ft. 6 inches in diameter by 5 ft 6 inch in height, and is provided with a sight glass. It is subjected to a test pressure of 100 lbs/sq.in.

2nd. Stage Catchpot. Of welded construction from 1/2 inch plate. It is a vertically mounted cylinder with dished ends being 2 ft. diameter by 5 ft. 6 inch. high. It is subjected to a test pressure of 250 lbs / sq.in.

3rd. Stage Catchpot. This is made up from 10 inch bore solid drawn M.S. tube. It is 11 in o.d. by 4 ft. long. The ends are screwed to take flanges onto which the end covers are bolted. Lens rings provide the seal between the pipe and the covers. This catchpot is tested to 800 lbs/sq.inch.

4th. Stage Catchpot. This is built up from 6 inch bore solid drawn M.S. pipe 7 inch o.d. by 4 ft. long. Flanged ends sealed with lens ring joints form the catchpot. Test pressure 1500 lbs/sq.inch.

5th. Stage Catchpot. This is built up from 4 inch bore 6-3/16 inch o.d. M.S. solid drawn tubing. The catchpot is 4 ft. long and is similar in construction to the 3rd. stage unit. Test pressure 4000 lbs / sq.in.

6th. Stage Catchpot. This is identical in construction to the Methanol and Ammonia section catchpots and is fully described in the account of the former section. In passing it is interesting to note that its test pressure is 8000 lbs/sq.in.

Condensate and Oil Collecting Vessel.

Condensate and oil collected in the catchpots is blown to a cylindrical vessel which is of welded construction fabricated from 3/8 inch plate. It is 2 feet diameter by 3 feet high. It is fitted with a level gauge, pressure gauge, vent to the 1st. stage suction, and a drain line. Gland leaks from the 1st, 2nd, and 3rd. stages of the compressor pass to this vessel after being metered.

General Cooling.

The cooling water for the jackets and oil coolers on the compressor is supplied from the factory system. The compression plant is designed to operate on water at 28°C. The jackets of the machine require approximately 15 M³/hr. To prevent oil from the cylinders contaminating the general factory cooling water system a separating tank is provided in the return line from the jacket coolers. This tank which is 4 feet 6 inches by 12 feet by 5 feet high is fitted with baffles to retain oil which is removed periodically.

CO₂ REMOVAL PLANT.

General.

The CO₂ Removal Plant is situated in the process between the second and third stages of the main gas compressor. The gas is piped from the compression system after the second stage catchpot to the base of the CO₂ absorption tower via a 4" line. A non-return valve and a panel mounted isolation valve, together with an analysis point and a temperature point, are fitted to this line.

From the top of the absorption tower the gas leaves through a 4" line and after passing through an orifice plate enters a catchpot and from there returns to the third stage suction; in the return line is situated a 1" blow-off and isolation valve, a pressure gauge point, an analysis point, a relief valve (set to blow at 160 lbs./sq. in.,) a second pressure gauge connection for use of a gauge mounted on the compressor panel and an isolation valve (panel mounted). A differential pressure gauge reading the pressure drop across the CO₂ tower is fitted to the lines going to and from the tower; its object is to give warning of any hold-up of water in the tower which might eventually be carried through to the compressor.

CO₂ Absorption Tower.

This is a fusion-welded M.S. vessel fabricated according to Lloyds Rules for Class 1 pressure vessels. It is 60'1 $\frac{3}{4}$ " long by 4' diameter having dished ends of 5/8" wall thickness and sides of $\frac{1}{2}$ " wall thickness. The top of the tower is removable, being flanged to the main section and bolted in place by 40 - 1 $\frac{1}{8}$ " diameter 5 $\frac{1}{2}$ " M.S. bolts on a 4'4 $\frac{1}{2}$ " P.C.D. The flanges are 4'7" O.D. by 2" thick; they are provided with 3/8" stiffening gussets between alternate bolts. The tower is provided with central 10" water inlets and outlets at top and bottom and a 4" gas inlet 8'3" from the bottom and a 4" gas outlet in the top cover. An 18" manhole is situated 18' from the base.

Below the gas inlet pipe a series of vertical M.S. plates placed at right angles serve as vortex breakers and above the gas inlet pipe a supporting grid carries the 42' of packing. This consists of 2" x 2" x 16 S.W.G. galvanised iron rings random packed. 402 cu. ft. of packing is required providing 12,900 sq. ft. of surface.

Level gauge connections are provided 2'3" and 9'3" from the base of the tower.

The tower when empty weighs 12 tons and when full, 30 tons. Test pressure is 230 lbs./sq. in.

CO₂ Catchpot.

This is a cylindrical vessel 2'6" diameter by 11'3" long fabricated in a similar manner to the CO₂ tower. Wall thicknesses at $\frac{1}{2}$ " at sides and 5/8" at ends. The top cover is removable, being bolted to the main section by 24 1 $\frac{1}{8}$ " diameter 5 $\frac{1}{2}$ " M.S. bolts and 2'10 $\frac{1}{4}$ " in P.C.D. The flanges carrying these bolts are 3'0 $\frac{3}{4}$ " O.D. by 2" thick and are gusseted to the body in a similar manner as the CO₂ tower. Inlet and outlet pipes are 4" diameter and are situated centrally at the top of the vessel, the inlet pipe extending 5' into the centre of the catchpot.

- A OUTER CASING
- B INTERNAL CYLINDER
- C ENCLOSED CONE
- D PLUNGER
- E SEAT RING
- F OUTLET RING
- H ANNULAR SPACE
- K PILOT VALVE
- L INNER CHAMBER
- M OUTER CHAMBER
- N ORIFICE
- P CRANK AND LEVER GEAR
- Q REGULATING VALVE
- R GAS RELEASE VALVE

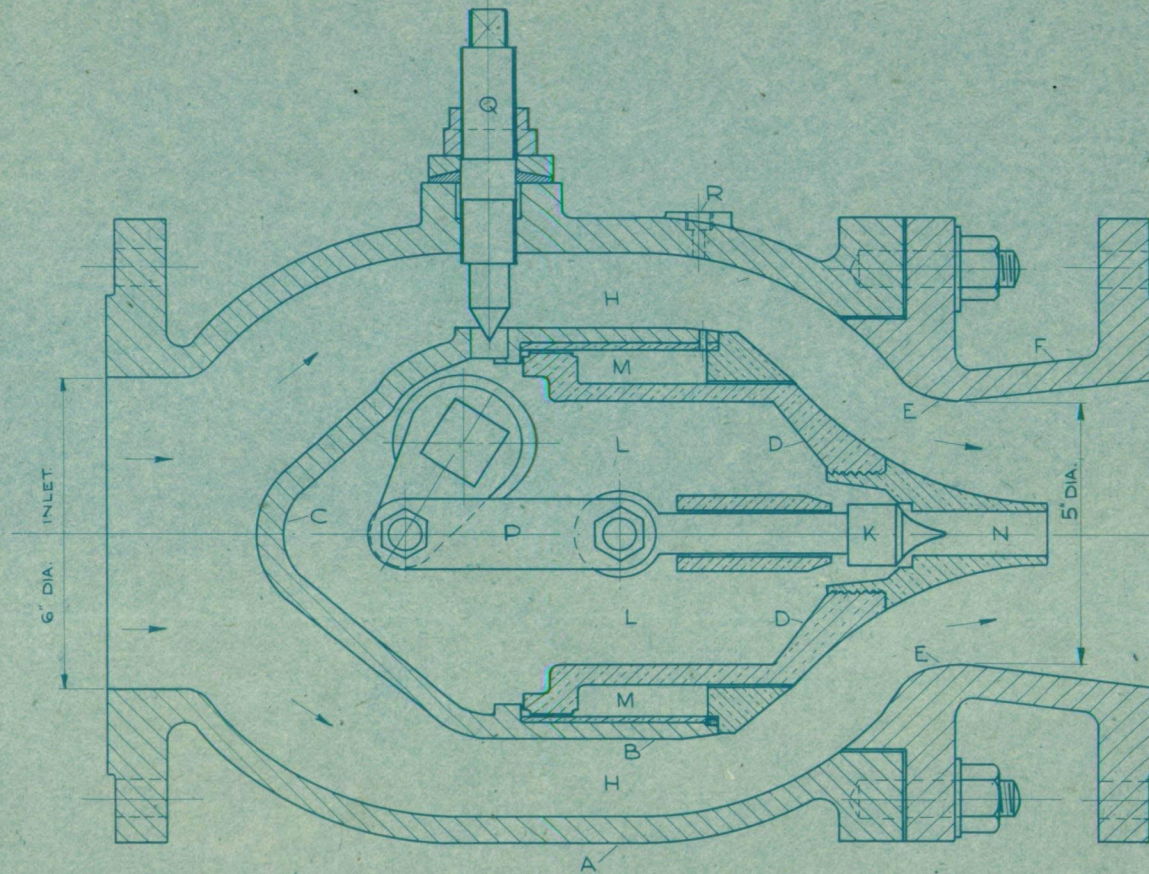


FIGURE 2
 LARNER JOHNSON VALVE 6"-5"

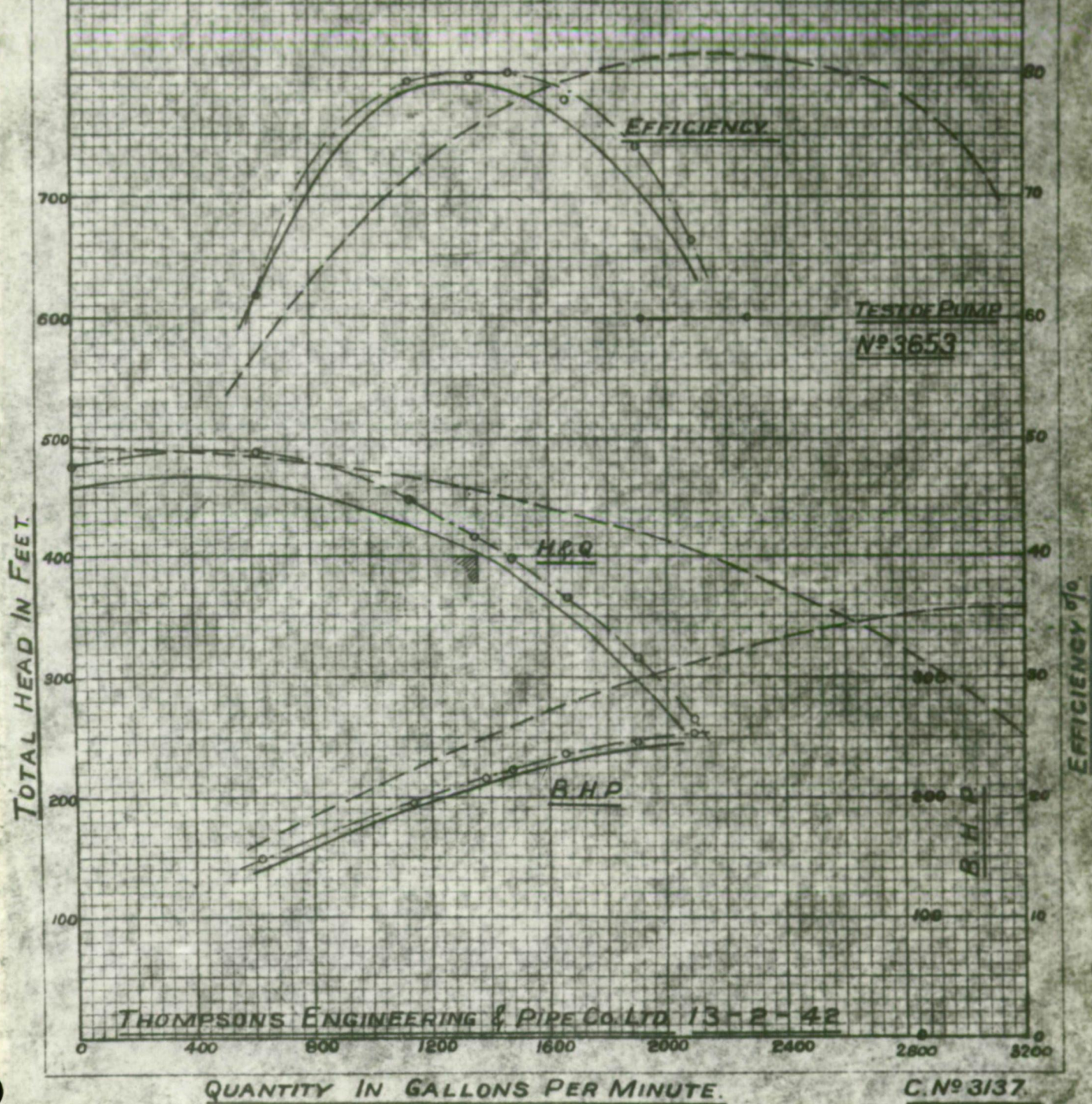
— IMPERIAL CHEMICAL INDUSTRIES OF AUSTRALIA & NEW ZEALAND LTD. —

— CO₂ TOWER — INJECTION PUMPS —

THOMPSON 8" 2 STAGE CLASS 'E.C.' PUMP

CONSTANT SPEED 1450 R.P.M.

DOTTED LINES SHOW CHARACTERISTICS OF 10" 2 STAGE 'E.C.' PUMP AT 1450 R.P.M.



REFERS TO 47/SSA/D/47

THOMPSONS ENGINEERING & PIPE CO. LTD.										CENTRIFUGAL PUMP TEST LOG					Test Log No. 1230																							
CASTLEMAINE, VIC.															Pump No. 2652																							
Type of Pump		TWO STAGE CLASS "HC".					Suction Branch		3"		Discharge Branch		3"		Normal Rated Speed of Pump		1450 R.P.M.		Chart No. 2137																			
Works Order No.		200-42		Name of Purchaser		IMPERIAL CHEMICAL INDUSTRIES OF AUSTRALIA & NEW ZEALAND LIMITED.										Date		20/5/48																				
Test Point No.	Time	Speed R.P.M.	CAPACITY				HEAD								Water Horse Power																							
			Flow Meter 10" H ₂ O		Quantity Corrected to Normal Speed Gall./Min.	INLET		OUTLET		TOTAL HEAD																												
			Diff. H"	Time Sec.		Quantity Gall./Min.	Vac. "Hg. Head - 29.92"	Ft. Liquid	Head Ft. H ₂ O (Theoretical)	Ft. Liquid	Correction for Position of Gauge	Correction for V ₁ V ₂ Kg	Ft. Liquid	Corrected to Normal Speed																								
1	7.20	1460	8.7		1665	8.7	9.82		355	2.21		368.02		132																								
2	8.20	1465	6.96		1480	7.9	8.8		387	2.21		399.01		179																								
3		1466	5.72		1250	7.1	8.01		408	2.21		419.22		171.5																								
4		1470	4.0		1120	6.1	6.9		440	2.21		450.11		154.2																								
5		1484	1.22		625	4.5	5.1		482	2.21		490.21		92.2																								
6		1465	12.76		2030	11.8	12.25		248	2.21		264.56		167.5																								
7		1460	11.5		1915	10.4	11.75		300	2.21		314.96		182.6																								
8		1465	--		--	2.8	4.2		472	2.21		479.51																										
9																																						
10																																						
11																																						
12																																						
POWER & EFFICIENCY																																						
Test Point No.	Watt Hour Meter Revs. KW.	Time Sec.	Volts at Meter	Amps. at Meter	Power Factor	Electric Horse Power	Motor Eff'cy	B.H.P. Output from Motor	Gear Belt Drive Efficiency	B.H.P. Input to Pump	Pump Eff'cy	Remarks																										
1			400	230	.92		.92			229	.779																											
2			299	282	.92		.92			224	.80																											
3			400	172	.928		.919			215	.796																											
4			401	246	.924		.917			192.6	.797																											
5			402	194	.909		.91			150	.620																											
6			400	218	.92		.92			252	.665																											
7			402	209	.92		.92			246.5	.74																											
8			406	125	.80		.89			90.6																												
9																																						
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<div> <div> Drive Details Motor Type R.W. 1526 Motor Make AUST. GEN. ELECTRIC PTY. LTD. Motor Serial No. 96992 Rated B.H.P. 240 Rated R.P.M. 1465 Amps. Full Load 295 415 V. Efficiency Full 92 1 91 1 90 Power Factor Full .92 1 .92 1 .875 Drive DIRECT COUPLED. Driving Pulley Dia. In. Driven Pulley Dia. In. Belt Gearing </div> <div> REMARKS 10" H₂O. $C = 362.01 \sqrt{H_A}$ IMPELLER DIAMETER = 17-7/8" BLADES. 18-1/2" SPROCKETS. BEARING TEMPERATURES. <table border="1"> <thead> <tr> <th>Time</th> <th>Suction End</th> <th>Discharge End.</th> </tr> </thead> <tbody> <tr><td>8.00</td><td>112</td><td>108</td></tr> <tr><td>8.10</td><td>118</td><td>111</td></tr> <tr><td>8.20</td><td>120</td><td>114</td></tr> <tr><td>8.30</td><td>122</td><td>116</td></tr> <tr><td>8.40</td><td>124</td><td>117</td></tr> <tr><td>8.50</td><td>125</td><td>119</td></tr> <tr><td>9.00 to 9.40</td><td>125</td><td>118</td></tr> </tbody> </table> </div> </div>															Time	Suction End	Discharge End.	8.00	112	108	8.10	118	111	8.20	120	114	8.30	122	116	8.40	124	117	8.50	125	119	9.00 to 9.40	125	118
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Tested by E.J. ROBERTSON.										THOMPSONS ENG. & PIPE CO. LTD.																												
Witnessed & Inspected by CHAS. A. BAME.										Per John Tan																												

Level gauge connections are provided 1' and 3'6" from the base. A central 1½" diameter is fitted at the bottom end.

Water Injection Pump.

This is a two stage high head pump designed to deliver 370 M³/hr. at 400' head. It runs at 1,500 r.p.m. and is direct coupled to a 240 H.P. motor. It was supplied by Thompsons Engineering and Pipe Company, Ltd., the test log and a graph showing characteristic curves are attached.

The pump sucks water by a 10" C.I. main from the forced draught tower sump through a twin strainer set and delivers via a 10" C.I. pipe to the Absorption Tower. A panel controlled delivery valve of the Larner-Johnson type is fitted to the delivery line to control water rates to the tower.

Water Control Valves.

Due to the large quantities of water involved and the need for accurate rate control, a piston type of needle valve operated by the water pressure on the upstream side is used. Two sizes are required 6" - 5" and 6" - 3". The operation of each is the same; a cross sectional arrangement of the larger size is shown in Fig. 2.

The discharge rate from the valve is controlled by the position of plunger D which in turn takes up a position to balance the internal and external pressures. One of these internal pressures, L, will be dependent on the openings of the inlet and outlet ports from this space. Therefore, if plunger K is retracted slightly and the outlet port correspondingly increased the pressure in space L will fall and the piston D will float back thus reducing the outlet port. D will take up a new position giving a slightly greater discharge figure for the valve. Similarly advancing K will tend to close the valve. By this means fine control can be achieved. The needle valve Q adjusts the speed of operation of the valve.

These valves are situated on the pump delivery line to the tower (6" - 5"), and on the let-down line from the absorption tower to the forced draught tower (6" - 3" size).

The 6" - 3" valve operates on the same principle as the 6" - 5" unit. Because this smaller valve is in the let-down line, however, where considerable quantities of gas are liable to be evolved, a separate gas water source is required for the internal piston to prevent gas locking; this is supplied by the factory water service.

Forced Draught Regeneration and Cooling Water.

This tower which is designed to strip the dissolved CO₂ from the circulating water and also to remove the heat of solution (equivalent to 0.5°C. under normal conditions) is mounted on a concrete tank about 6' above the level of the CO₂ pump. It is packed with triangular wooden slats spaced on 9" centres in rows 15" apart. It has the following general dimensions.

Water Rate (max.)	370 M ³ /hr.
Cooling Range	0.5°C.
Tower Dimensions -	
Length	18' 9"
Width	18' 9"
Total Height	44'
Height of Packing	23'

Dimensions of Water Tank -

Length	18' 9"
Width	18' 9"
Normal Water Depth	6'
Approximate Capacity	60 M ³

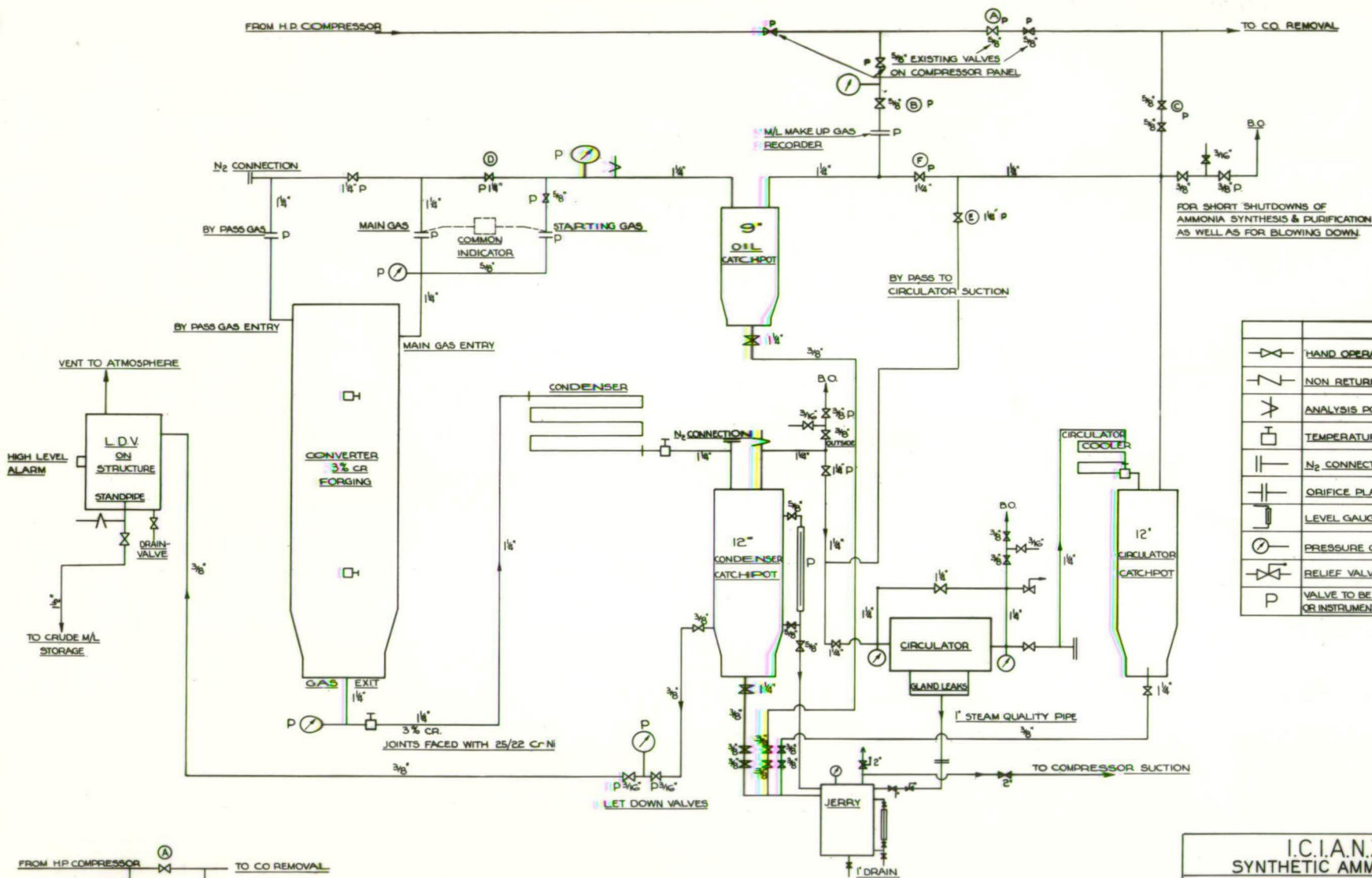
Eight rows of 1½" porcelain nozzles distribute the water on to the packing from troughs located at the top of the tower. The water is fed into these troughs from the 10" C.I. inlet main by means of a baffle box which absorbs irregularities in the water flow.

Two propellor type fans of 45,000 M³/hr. capacity each are located at the bottom of the tower immediately above the water tank. These fans supply the necessary draught to strip the descending water of any dissolved gases.

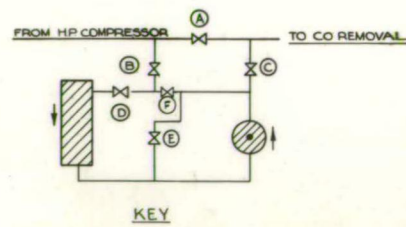
The walls of the tower are made from a double layer of tongued and grooved Murray Pine timber and a sealing layer of "Malthoid" is inserted between the planks to minimise leakage of water. A Jarrah framework independent of the external walls carries the Oregon packing slats.

Safety Devices.

The only safety device on this section of the plant is a low level alarm indicating dangerously low levels in the forced draught tower pond.



SYMBOLS	
	HAND OPERATED STOP VALVE
	NON RETURN VALVE
	ANALYSIS POINT
	TEMPERATURE POINT
	N ₂ CONNECTION
	ORIFICE PLATE
	LEVEL GAUGE
	PRESSURE GAUGE
	RELIEF VALVE
	VALVE TO BE OPERATED FROM M/L PANEL OR INSTRUMENT TO BE MOUNTED ON PANEL



NO	DATE	REVISION	BY	APP
1	18-6-48	MADE P VALVES	M.B.	
2	18-6-48	1" VALVE ON ADDO	M.L.C.	
3	12-1-49	REVISION	BY	APP

NOTE: THIS DRAWING SUPERSEDES DWG. NO 1052/M/L/23.

I.C.I.A.N.Z. LTD.
SYNTHETIC AMMONIA SECTION
REVISED FLOWSHEET
FOR
METHANOL SYNTHESIS

DRAWN	C.H.	5-3-42	SCALE
TRACED	M.L.C.	20-3-42	DRG. NO 1128/B
CHECKED			FILE: MS. INDEX 27
APPROVED			
PASSED			

METHANOL SYNTHESIS PLANT.

Gas Circulation System.

Gas from the Compression Plant is delivered to the Methanol Synthesis Plant through a 5/8" diameter H.P. line. On the compressor control panel a 5/8" bypass is provided to allow compressed gas to be piped directly to the C.O. Removal Plant. By this means the C.O. Removal Plant can be operated at any desired rate irrespective of the Methanol Plant outputs. This bypass is fitted with two panel operated 5/8" H.P. valves. One of these valves is used as a stop valve and is either always fully open or fully shut; the other is used as a control valve and is gagged to give the appropriate gas rate; operating a valve under these conditions quickly "wire draws" the seat, hence the need for the second valve for gas tight closures. The inlet line to the circulation system is equipped with two 5/8" H.P. valves and an intermediate pressure gauge. One of these valves is mounted on the compressor panel and the other on the methanol control panel. Immediately after the second valve, a recording flowmeter records the amount of gas passing to the methanol circulation system. This system which is in 1 1/4" H.P. piping throughout, runs to a 9" oil catchpot and thence to the methanol converter. Between the catchpot and the converter is an analysis connection, a pressure gauge, a 1 1/4" H.P. control valve, an indicating flowmeter and a pressure gauge (measuring the gas pressure immediately before the converter). By-passing the control valve and flowmeter is a 5/8" line also fitted with an H.P. valve and indicating flowmeter which is used to obtain fine control for starting up the converter. The converter heat exchanger bypass line with its attendant 1 1/4" valve and flowmeter is teed off immediately before the main flowmeter. This bypass line is fitted with a blank for purging out purposes. All the controls in this section are panel mounted.

From the converter, the ring main passes to the condenser coolers; this section is in 3/4" Cr. steel and is fitted with a pressure gauge (panel mounted) and temperature point. From the condenser the main passes directly to a 12" diameter condenser catchpot and from there to the suction side of the methanol circulator. A temperature point and a purging out connection are located before the catchpot and an analysis point, a blow-off station and two control valves are situated after it. The blow-off arrangement consists of a 3/8" panel operated control valve with a 3/8" isolation valve upstream; an intermediate 3/16" valve tees off for gas sampling purposes.

One of the control valves is panel mounted and the second is located at the circulator. This unit has inlet and delivery pressure gauges and a bypass fitted with control valve, relief valve and blow-off valve array. From the circulator the main runs to the circulator cooler; a circulator delivery valve and purging connections are located before the cooler and a temperature connection after the cooler, immediately before the circulator catchpot. From this catchpot the ring main completes the circuit by returning to the gas inlet point; this section contains a blow-off connection, a 5/8" branch to the C.O. Removal Plant, a bypass line to the circulator suction and a panel operated control valve. The bypass line to the circulator suction is used for starting up purposes when bringing the converter on line, it is fitted with a panel mounted control valve.

9 in. Oil Catchpot.

This is a M.S. catchpot 9" long inside diameter, 14" outside diameter by 5' long. It is fitted with top and bottom covers sealed by lens ring joints. Chrome Molybdenum studs are used for bolting on the end covers. The inlet gas is carried down to the centre of the catchpot where a spiral discharge imparts a rotary motion to the gas to assist in the precipitation of oil particles. A flat cone, below this discharge point, which reaches to within a $\frac{1}{4}$ " of the catchpot wall forms a dead space for the oil to collect. A $1\frac{1}{4}$ " connection at the bottom of the catchpot reduces after an isolation valve to a $\frac{3}{8}$ " line along which oil can be blown to a M.S. collecting pot.

Methanol Converter.

The internals of the Methanol Converter have been designed to fit the same size forging as that used for the Ammonia converter. The converter body is hollow forged from 3% chrome steel. It is 22'9" long by 4'4" outside diameter at the top reducing to 2'11" in the body. The bore is 2'3 $\frac{1}{2}$ " swaged in to 1'7 $\frac{1}{2}$ " at the base.

The bottom closure consists of a cover and lens ring, bolted in position by twelve studs. The cover is from 3% chrome steel and is 2'11" diameter by 10 $\frac{3}{4}$ " thick. The lens ring of M.S. is 22" outside diameter by 17" inside diameter by 4 $\frac{1}{8}$ " base thickness. Apex angle is 60° and radius of spherical faces is 19 $\frac{1}{2}$ ". The contact circle diameter is 19 $\frac{1}{2}$ ". The bottom studs are from Chrome Moly. steel 3 $\frac{1}{4}$ " diameter by 1'11 $\frac{1}{2}$ " long; each end is threaded 6 T.P.L. Whitworth; they are screwed 5" into the forging and are supplied with M.S. nuts. The studs are located on a 2' 4 $\frac{3}{4}$ " P.C.D.

The top closure is in two portions; the main cover has a central hole which in turn is closed by the top cover. The main cover is 4'4" diameter by 1'5 $\frac{1}{2}$ " thick forged from 3% chrome steel. The central hole is 17" diameter. It is held in place by 12 chrome Moly. studs 4 $\frac{1}{4}$ " diameter by 2'3 $\frac{1}{4}$ " long; these studs are threaded 6 T.P.L. Whitworth and screwed into the forging to a depth of 6 $\frac{1}{2}$ "; they are supplied with M.S. nuts. The main cover is reduced in thickness to 1'1 $\frac{1}{2}$ " outside a diameter of 2'9" to accommodate studs on a 3'7" P.C.D. The seal between the main cover and the body is of the Vickers-Anderson type. A recess in the top of the body takes the U shaped sealing ring which is of M.S. 2'5" outside diameter by 2'3 $\frac{1}{2}$ " inside diameter by 1 $\frac{7}{8}$ " wide. The wall thickness of the U section is $\frac{5}{8}$ ". The mean contact diameter is 2'4 $\frac{1}{4}$ ", the contact face being 3/32" wide protruding from the ring 5/16".

The top cover, which is forged from 3% chrome, is 2'9" outside diameter by 9 $\frac{3}{4}$ " thick. It is bolted into place by 12 - 3 $\frac{1}{2}$ " diameter chrome Moly. studs 2' long threaded 6 T.P.L. Whitworth located on a 2'2" P.C.D. They are screwed into the main cover to a depth of 5 $\frac{1}{4}$ "; they are supplied with M.S. nuts. The seal between the main cover and the top cover is a lens ring 25" outside diameter, 19 $\frac{1}{2}$ " inside diameter having a base depth of 4 $\frac{1}{2}$ ". The apex angle is 60° and the radius of the curved faces is 22 $\frac{1}{4}$ ". The diameter of the circle of contact is 22 $\frac{1}{4}$ ".

The internals are of the wall cooling type, i.e. all incoming gas passes spirally down the outside of the basket and carries heat away from the forging wall.

The following dimensions are applicable to the unit:-

Working Pressure	350 ats.
Test Pressure	525 ats. (hyd)
Catalyst Volume	250 litres
Catalyst depth	7 ft.
Rated Capacity	4 short tons/day
Inside diam. of Catalyst Basket	1'3 $\frac{1}{4}$ "
Length of Catalyst Basket	20'8"
Interchanger	84 coils - 1'7 $\frac{1}{2}$ " mean diam. 2" O.D. pipe x 10 S.W.G.
Interchanger area	212.4 sq. ft.
Total Weight	28 tons

Gas entering the converter at the top passes down through the wall cooler and then enters the cold side of the interchanger at the base of the converter; this is the coil-in-sheath type and is manufactured in stainless steel throughout. From the interchanger the gas passes up a central pipe to enter the heater chamber; in this is located a 100 K.W. three phase heater; this heater is fed from a transformer fitted with primary winding control which enables the output voltage to be varied from zero to one hundred volts. At 100 volts full load current is 580 amps. The heater coils in the converter are made from phosphor bronze.

The gas passes from the heater chamber directly down through the catalyst bed and from the bottom of the bed the converted gases enter the hot side of the interchanger and from there leave the converter. Two temperature points are located in the catalyst bed; and these together with those in the circulation system are read on a panel mounted multi-point indicator.

Methanol Condenser Cooler.

This is a jacketted serpentine cooler consisting of two banks of twelve tubes connected by U bends. The top tube in each bank is from $\frac{3}{8}$ Cr. steel, the remainder being ordinary H.P.M.S. pipe. The total length is 584 ft., pipe diameter throughout is 1 $\frac{1}{2}$ ins. The total cooling surface is 294 sq. ft. requiring 25 Ms/hr. for cooling purposes. If there is the slightest tendency to leak at M.S. pipe joints containing liquid methanol under pressure the methanol will quickly cut the surface of the joint. To prevent this the ends of the pipe in the cooler and on the line to the catchpot are tipped with a welded deposit of NCT₃ steel and stainless steel lens rings are used for all these joints.

Condenser Catchpot.

This is machined from a hollow M.S. forging, 8'4" long, 1'7" outside diameter by 1' inside diameter. The outside diameter is increased to 2'2 $\frac{1}{4}$ " at the top to carry a ring of studs and the inside diameter at the base is reduced to 6" for the same reason.

The top and bottom closures are covers sealed by lens rings. The top cover is 2'2 $\frac{1}{4}$ " diameter by 8 $\frac{1}{4}$ " thick, it is bolted to the body by 10 - 3" diameter chrome moly. studs 19" long screwed 6 T.P.L. Whitworth and supplied with M.S. nuts. The studs are screwed into the body to a depth of 4 $\frac{1}{2}$ " on a P.C.D. of 20 $\frac{1}{4}$ ". The top lens ring is 16" outside diameter by 12" inside diameter by 3 $\frac{1}{4}$ " base thickness. The apex angle is 60° and the radius of the contact faces is 14". The contact circle diameter is 14".

The bottom cover is 15 $\frac{1}{2}$ " diameter by 5" thick, it is bolted to the body by 7 - 2" diameter chrome moly. studs 12" long, screwed 2" B.S.F. and supplied with M.S. nuts. The studs are screwed into the base to a depth of 3" on a P.C.D. of 11 $\frac{1}{2}$ ".

The bottom lens ring is $8\frac{3}{4}$ " outside diameter by 6" inside diameter by $2\frac{3}{8}$ " base thickness. The apex angle is 60° and the radius of the contact faces and the diameter of the contact circle are both $7\frac{1}{2}$ ". The weight of the catchpot is 3 tons.

The inlet and outlet connections are through the top cover. The inlet is fitted with the spiral discharge pipe with the attendant umbrella as on the oil catchpot. A $\frac{3}{8}$ " diameter connection passes through the bottom cover and oil or other impurities can be blown through this line to the collecting pot. The catchpot is supplied with a panel mounted level gauge fitted with isolation and blow-down valves. A $\frac{3}{8}$ " branch is led from the side of the catchpot below the level gauge connection through two let-down valves to a U.S. "let-down vessel" which is mounted in such a position on the tower structure that methanol can drain from it to the crude methanol storage tanks. An analysis point and a high level alarm are provided for this vessel.

Circulator

This is a single crank vertical type machine with one double acting cylinder. A tail rod is fitted to the piston.

The output is 7,000 H^3/hour (gas at 20°C . and 1 atm.). The inlet pressure is 320 ats. and the discharge pressure 360 ats. It is driven by a 75 H.P. wound rotor induction motor; the normal running speed of the motor is 730 r.p.m., but speed control down to 370 r.p.m. is provided by means of a liquid regulator in the rotor circuit. Five Vee belts drive the circulator at 160 r.p.m. at full speed.

The design for the unit has been developed from an original design by Peter Brotherhood Ltd. A C.I. bedplate carrying the main bearings and an outboard pedestal bearing for the crankshaft also supports the C.I. entablature having built in crosshead guides and a machined seat for the cylinder.

The cylinder and top and bottom gland housings which are of forged steel, bolt together to form a single unit which is attached to the entablature by the lower flange of the cylinder. The cylinder forging is 11" diameter by 15" long having a bore of 5.633"; a pearlitic C.I. liner is fitted having a bore of 4.8125 inches. The top and bottom gland forgings are $5\frac{3}{4}$ " outside diameter by 3.063" bore and are also fitted with liners having an inside diameter of 2.25". Water jackets are provided for these three sections.

The piston rod which is 5'6" long, spigots into the crosshead and is locked with a cotter pin. Ten ring grooves are provided on the 4.75" piston and thirty eight grooves on both piston rod and the gland rods for effective sealing. The cylinder rings are 189" wide and have a gap of 0.0125" when in the cylinder. The gland rings are .155 inches wide and are fitted to have a gap of 0.006 in. when in the glands.

The stroke of the machines is $6\frac{1}{2}$ ". Lubrication is provided by two pumps driven from the crankshaft. The first is a small single acting reciprocating pump for the lubrication of the main bearings and top and bottom connecting rod bearings. The second is a three point "Bosch" type high pressure pump for the lubrication of the top and bottom glands and the cylinder.

The inlet and exit valves are of the spring loaded mushroom type. They are housed in rectangular steel blocks attached directly to the cylinder. The H.P. lines leading to and from the machine are bolted to these blocks.

The barring of the machine is carried out by hand using a lever inserted into holes drilled in the flywheel.

The auxiliaries include a second motor driven H.P. "Bosch" lubricator for starting up purposes, and a Budenburg Tachometer.

The gas leaks from the top and bottom glands are collected and piped away through a flowmeter to the oil collecting pot. The gland leaks flowmeter gives a useful indication of any breakdown in the oiling system to these seals.

Circulator Cooler

This relatively small cooler is of the water jacketted counter-current serpentine variety. It comprises 9 - 1 $\frac{1}{4}$ " H.P. pipes having a total length of 111.5 feet and a cooling surface area of 56.3 sq. feet.

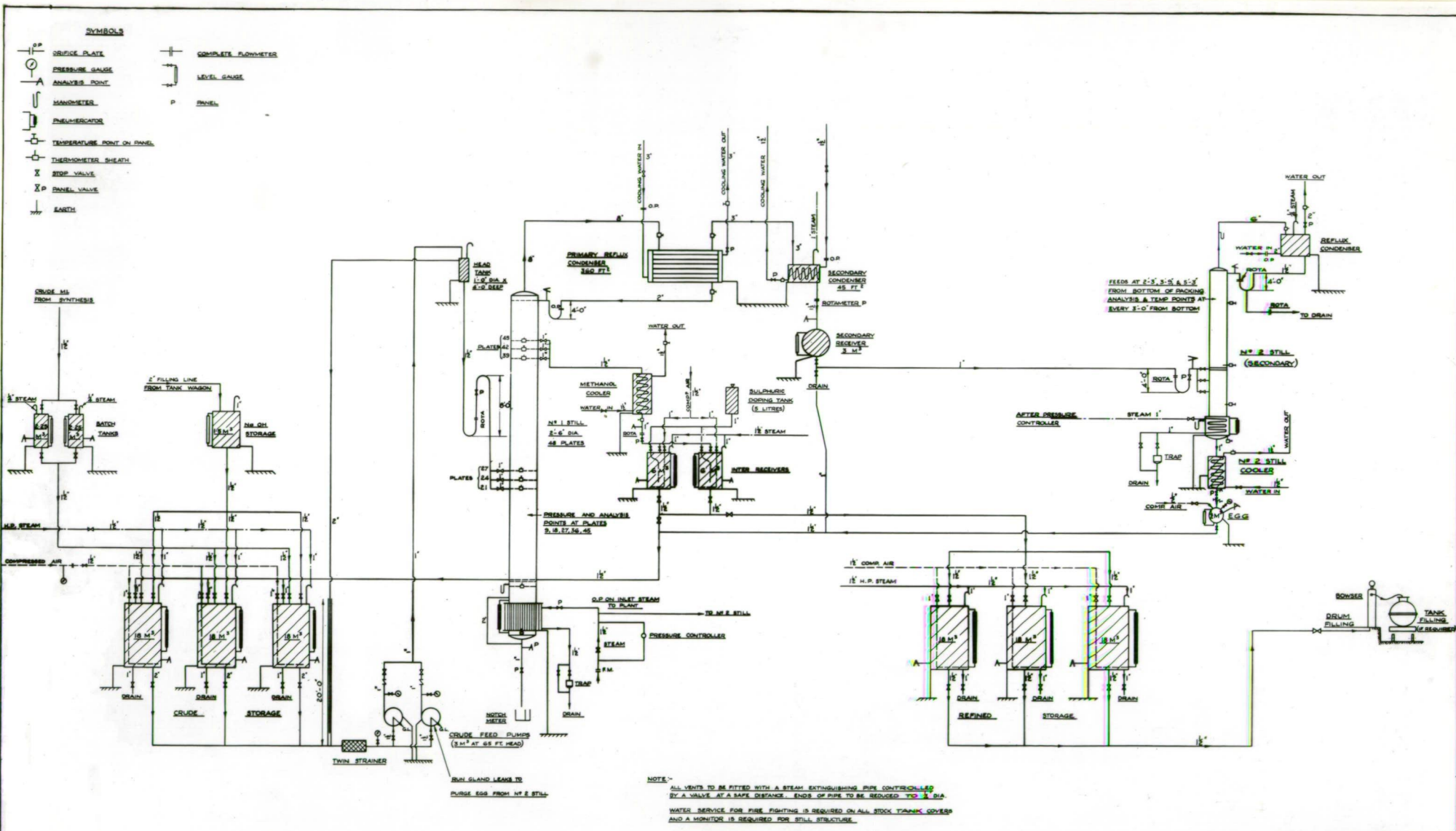
This cooler consumes 8 M³/hour of cooling water.

Circulator Catchpot

The circulator catchpot is similar to the condenser catchpot with the exception that no level gauge is required and that the only drain is at the bottom leading to the waste oil collecting pot.

Oil Collecting Pot

This cylinder vessel is of welded construction fabricated from $\frac{3}{8}$ " plate. It receives waste oil from the three catchpots and the gland leaks from the circulator. It is fitted with a 1" drain and a level gauge attachment, also a pressure gauge and a 2" spring loaded relief valve set to lift at 15 lbs./sq. inch gauge. A 2" line runs from this vessel to the main compressor suction line to carry away the gas evolved when oil under high pressure is let down.



- SYMBOLS**
- ORIFICE PLATE
 - PRESSURE GAUGE
 - ANALYSIS POINT
 - MANOMETER
 - PNEUMATICATOR
 - TEMPERATURE POINT ON PANEL
 - THERMOMETER SHEATH
 - STOP VALVE
 - PANEL VALVE
 - WATER
 - COMPLETE FLOWMETER
 - LEVEL GAUGE
 - PANEL

NOTE:-
 ALL VENTS TO BE FITTED WITH A STEAM EXTINGUISHING PIPE CONTROLLED BY A VALVE AT A SAFE DISTANCE. ENDS OF PIPE TO BE SECURED TO A DRAIN WATER SERVICE FOR FIRE FIGHTING IS REQUIRED ON ALL STOCK TANKS COVERS AND A MONITOR IS REQUIRED FOR STILL STRUCTURE.

I.C.I. ANZ LTD		
SYNTHETIC AMMONIA SECTION		
METHANOL DISTILLATION PLANT		
LINE DIAGRAM		
DRAWN	T.J.T.	SCALE
TRACED	P.J.B.	4-5-68
CHECKED		
APPROVED		
PASSED		
1288/MD/1		

METHANOL DISTILLATION PLANT

INTRODUCTION

The Distillation Plant is separated from the remainder of the equipment on account of the highly inflammable nature of refined methanol. The crude and refined storage tanks are located at ground level approximately 50 feet from a tower structure which carries the remainder of the equipment. This structure, which is 15 feet by 25 feet at the base by 75 feet high, has decks at appropriate levels. (approximately every 12 feet) A stairway runs up one side of the structure and an overhead gantry beam at the top of the structure is provided to facilitate the handling of the still sections and other equipment.

The structure is unsheathed but all controls, i.e. panel valves, flowmeters, temperature recorders, etc., are located on a panel situated in a control house at the base of the structure.

An elevated loading out platform for the storage and filling of drums is located on the plant. This platform is fitted with an automatic "Bowser" for measuring methanol exported from the plant. This loading platform is covered in on all sides except that facing the road which is used for loading out purposes.

BATCH TANKS

Crude methanol from the Let Down Vessel (located on the methanol synthesis bay of the main tower structure) flows by gravity to one of two batch tanks. These are of m.s. welded construction capacity $2\frac{1}{2}$ M³ fabricated from $\frac{1}{2}$ inch plate and cylindrical in shape. They are fitted with level gauges, sample points for analysis and are efficiently earthed. A 1" standpipe 6 feet high from each tank provides a vent; these are fitted with a "snuffer" for use in case of fire. These "snuffers" consist of a $\frac{1}{2}$ -inch steam jet set across the mouth of the vent. All vents on vessels in the distillation section are similarly treated and the steam to them is controlled from a common valve. In the event of a fire the steam supply to these extinguishers is turned on and this prevents the firing of any vents as well as extinguishing any that are already alight.

The batch tanks are located on a steel trestle structure above the crude methanol storage tanks.

CRUDE METHANOL STORAGE TANKS

There are three of these, each of 18 M³ capacity, situated at ground level. The various services feeding them are piped from headers above the tanks and an operating platform runs along the top of the tanks for the control of these services.

The tanks are cylindrical in shape, are 12 feet high by 8 feet diameter, and are fabricated from 5/16 inch m.s. plate. They are provided with level gauges, drain lines, vents, sample points, air connections and are efficiently earthed.

Crude methanol is fed to these tanks from a $1\frac{1}{2}$ -inch m.s. header pipe. The air connection (1 inch diameter) is connected to a perforated ring at the base of the tank for blowing purposes.

Caustic soda can be fed to these tanks by a $1\frac{1}{2}$ -inch line from the caustic soda storage tank.

A $1\frac{1}{2}$ -inch line from the 6 M³ Inter receivers the $\frac{1}{2}$ M³ egg runs back to the crude storage tanks.

PRIMARY STILL SYSTEM

The primary still, having a capacity of 0.23 tons/hour, is built up of 4-foot welded m.s. sections bolted together. It is 60 feet high and 2'6" in diameter.

The internals consist of forty-eight bubble cap plates of c.i. construction, accurately levelled. Below the plates is a callandria with a total heating surface of 430 sq.ft. This is achieved by means of 164 Alumbro tubes 10 ft. long by 1 inch O.D. The callandria operates at 15 lbs. per sq. in. pressure and a motor operated steam control valve maintains the pressure at this figure within close limits.

Vapour leaving the still passes out through an 8-inch m.s. main to the primary condenser.

Crude methanol is fed to the still at one of the following plates - 21, 24 or 27; and the refined methanol is taken off at either plates 39, 42 or 45.

Pressure and analysis points are provided at every ninth tray and eight temperature points are provided; one immediately below the callandria and one immediately above it and the others at the feed and take-off points.

The feed to the still comes from a constant head tank, 1 foot diameter x 4 feet high which is maintained by one of two Thompsons pumps (one working, one spare) with a capacity of 3 M³ per hour against a total head of 80 feet with liquid of 0.9 specific gravity. The overflow from this tank returns to the suction line via a 20-foot lute.

The 1½" m.s. line from the head tank to the still is fitted with a Rotameter for flow measurement and a control valve, both of which are mounted on the control panel.

The tails from the still are controlled by a panel valve and are measured by means of a notchmeter.

The steam supply to the callandria is metered and controlled by a panel valve; the condensate being led away through a 1½" trap to drain.

The still is lagged with 85% magnesium lagging to a thickness of 2".

PRIMARY CONDENSER

This is of the multi-pass type having an 8 in inlet and a 3-inch vapour outlet. It is of welded construction and has a condensing surface of 360 sq. ft. made up by 160 Alumbro tubes 9'6" long, 1" O.D. x 14 S.W.G.

Condensate drains through a 2" line back to the top of the still (plate no. 48) through a lute. A flowmeter, analysis point and temperature point are provided in this line.

Cooling water is supplied through a 3" line fitted with a flowmeter and isolation valve on the inlet side and a panel mounted control valve and a temperature point on the exit side.

Both the vapour lines have temperature points mounted in them.

Care is taken to ensure that this reflux condenser is efficiently earthed.

REFINED METHANOL SYSTEM

Refined methanol from one of trays 39, 42 or 45 runs via a 1½-inch diameter line to a cooler. This cooler is of the annular type, having a 1-inch diameter Alumbro coil set in an annular m.s. tank 6 feet high 4 feet 6 inches outside diameter and 4 feet inside diameter. The methanol is cooled by counter current action, the water being let into the tank at the base and overflowing from the top. Cooling water is supplied through a 1½-inch diameter line; a temperature point is located in the 1½-inch outlet line. The cooled methanol discharges from the bottom of the cooler through a 1-inch m.s. line fitted with a temperature point, an analysis point, a rotameter and a panel control valve to one of two inter receivers. These inter receivers, which serve as intermediate storage vessels for testing, are of welded construction being cylindrical in shape and fabricated from ½-inch plate being 6 feet diameter by 7 feet 6 inches high. They are fitted with level gauges, analysis points and vents. A 1-inch compressed air service is also provided to each tank which connects with a perforated ring at the base of the tank for agitation purposes. A 1-inch line runs to either tank from a 5-litre sulphuric acid m.s. container for doping the methanol.

From the inter receivers the methanol is run via a 1½-inch m.s. line to either the refined storage or back to the crude storage for further retreatment.

REFINED METHANOL STORAGE

This section consists of three cylindrical m.s. tanks of similar construction to the crude methanol storage tanks. They are located at ground level and are fitted with level gauges, drain lines, analysis points, vents and air agitation arrangements. A 1½-inch line from each tank connects to a common header feeding to a metering bowser which is electrically driven.

SECONDARY METHANOL SYSTEM

Vapour from the primary reflux condenser passes to a secondary condenser.

The secondary condenser is of the "trombone" type. The 3-inch vapour line enters the top of a horizontal cylinder; and condensate drains out the base. Cooling is provided by means of three sets of circular coils made up of galvanised ¾" I.D. piping. The cooling surface is 46.5 square feet. A 2-inch vent is located in the centre of this cooler to remove any uncondensed vapour. Cooling water is provided by means of a 1½-inch line with a flowmeter and orifice plate on the inlet side and a temperature point and panel control valve on the exit side.

Condensate from the condenser passes through a rotameter to a secondary receiver of 3 M³ capacity. This receiver, which is a cylindrical tank of welded construction from ½-inch m.s. plate, is fitted with a level gauge connection and an analysis point. It is connected by a 1-inch drain to either the feed for the secondary still or the line to the crude methanol storage.

The secondary still, which has a capacity of 0.1 tons/hour, consists of a 20-foot high 12-inch diameter m.s. column packed with 1-inch m.s. rings to a packed height of 19 feet. The feed enters through a rotameter and panel valve to one of three feed points located 2 feet 3 inches, 3 feet 9 inches and 5 feet 3 inches from the base of the packing. Analysis point is situated in the feed line. At

the base of the still a callandria heater consisting of a triple coil of 1-inch diameter Alumbro tubing having a total heating surface of 49 square feet is supplied by steam from the same system that feeds the primary still. A level gauge is fitted to the callandria. Temperature points are located at 3 foot intervals up the packed portion of the still and at the base of the callandria.

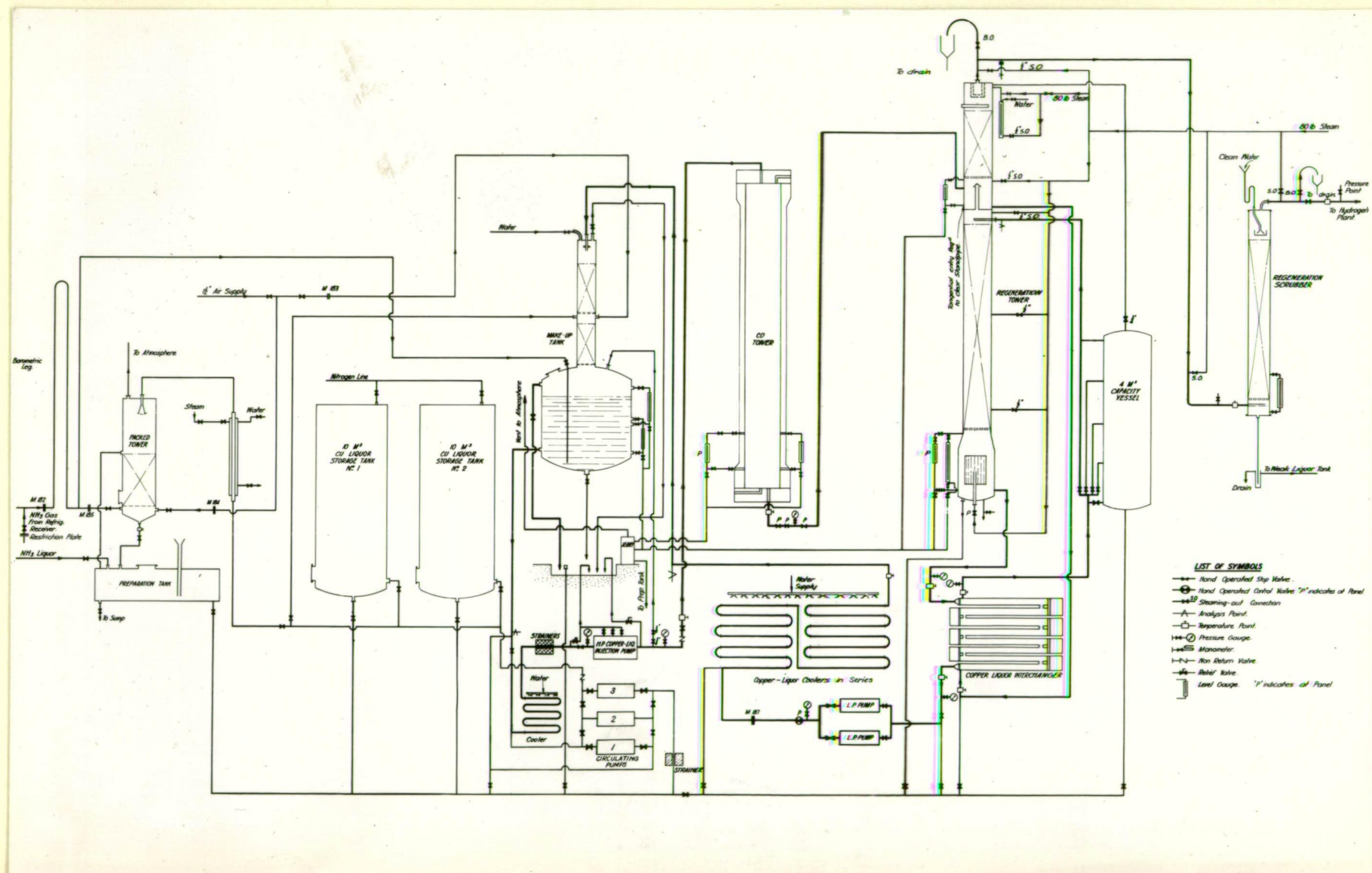
A 6-inch vent with a manometer connection and temperature point leads to the reflux condenser. This is identical in construction to the secondary condensor with the exception that the water line is 2 inches diameter in place of the 1½-inch diameter line on the latter vessel. Isolation valve and flowmeter on the inlet line and panel control valve and temperature point on the exit line are provided for this water service.

The condensate from this unit flows through a 1½-inch reflux line back to the top of the still. A rotameter and analysis point are located in this line. A drain through a rotameter is connected to this line for purging purposes.

The bottoms from the still run through the secondary still cooler to a ½ M³ pressure egg. The cooler is identical to the methanol cooler for the primary still.

The pressure egg is a m.s. cylindrical vessel with dished ends. It is fitted with a level gauge, a pressure gauge and an analysis point. Air is supplied from a "Nasch" type compressor which services the whole plant at 30 lbs. per square inch gauge pressure.

Crude methanol collected in this egg is blown back to the crude storage tanks via a 1½-inch m.s. line.



DETAILED FLOWSHEET COPPER LIQUOR PREPARATION AND REGENERATION SYSTEMS

CO REMOVAL AND FINAL PURIFICATION PLANT.

High Pressure Gas Lines.

Gas from the Compression plant enters the CO Removal plant via a 5/8 in. H.P. line; an orifice plate is fitted into this line and a panel mounted pressure gauge is connected to it. Before entering the base of the CO removal tower a 5/8 in. line from the Methanol Synthesis plant tees into the system. A purging out connection is provided immediately before the tower.

The scrubbed gas leaves the top of the tower through a 5/8 in. line which conveys it to the base of the caustic scrubber, a purging out connection, a blow-off arrangement, an isolation valve and a non-return valve are located in this section.

From the top of the caustic scrubber a 5/8 in. line runs to the top of the charcoal catchpot. A blow-off arrangement, a pressure gauge a purging out connection, and orifice plate, a branch leading to the CO and CO₂ estimators, an isolation valve and a second blow-off after the isolation valve are incorporated in this line.

Gas leaves the base of the charcoal scrubber passes through an isolation valve in the 5/8 in. line, a 3/8 in. branch for the make up gas katharometer and a panel mounted blow-off arrangement is fitted in this section; the gas then passes through a panel mounted control valve before entering the circulation system of the Synthesis plant. A by-pass taken from before and after the isolation valve preceeding the charcoal catchpot and re-entering the system immediately after the isolation valve on the line leaving this vessel allows it to be isolated for short period without shutting down the plant. This by-pass is fitted with a 5/8 in. isolation valve.

Copper Liquor Lines.

For the sake of clarity the copper liquor lines are considered under the copper liquor regeneration system.

CO Removal Tower.

This tower is made up of two equal M.S. hollow forgings bolted together to form a tower 38 ft. high; it is 13 1/2 in. inside diameter by 20 in. outside diameter. Each end of the two halves carries 10 in. of R.H. buttress thread, 1/2 in. pitch by 3/8 in. tooth face, this thread stands proud of the forging.

The two central flanges and the two end flanges are 2 feet 3-3/8 in. outside diameter by 9 in. thick and are recessed to carry a 60° lens ring.

The studs for the central joint are 2 ft. 3-5/8 in. long by 3-1/4 in. diameter. They are made from Chrome Moly. Steel and are screwed 6 T.P.I. Whitworth; 10 are provided. They are screwed into one flange and carry elongated cap nuts 11-1/4 in. long screwed for 6 - 1/2 in; the position of the hexagonal faces alternating to allow operation by a spanner.

The studs for the end joints are similar to those already described except in their length which is 2 ft 2-1/8 in. The nuts are 5-1/2 in. long and although they are not cap nuts the same staggering of the faces as used on the mid joint is necessary for spanner clearance.

The three lens rings are similar and are machined from M.S. forgings. They are 17-1/2 in. outside diameter by 13-1/2 in inside diameter with a contact diameter of 15-1/2 in a face radius of 15-1/2 in. and a base width of 3-1/2 in.

TYPICAL ARRANGEMENT OF H.P. HYDRAULIC PUMP
CYLINDER SECTION PLUNGER AND VALVES

A	-	Cylinder Body
B	-	Suction Valve Cover
C	-	Delivery Valve Cover
D	-	Delivery Valve Lift Restrainer
E	-	Suction Valve Lift Restrainer
F	-	Delivery Valve Locating Ring
G	-	Suction Valve Locating Ring
H	-	Suction Valve
J	-	Delivery Valve
K	-	Suction Valve Seat
L	-	Delivery Valve Seat
M	-	Delivery Valve Lantern Ring
N	-	1½" Plunger
P	-	Delivery Header
Q	-	Plunger Access Port
R	-	H.P. Gland Cover
S	-	L.P. Gland Nut
T	-	H.P. Lantern Ring
U	-	Plunger Locating Ring
V, W, X, Y.	-	Studs
Z, A ¹ , B ¹ , D ¹ .	-	C.A.F. Sealing Ring
E ¹	-	H.P. Packing
F ¹	-	L.P. Packing.

The end covers are 2 ft. 3-3/8 in. outside diameter by 9 in. thick and one recessed to carry the lens rings. They are drilled on a 24 in. P.C.D. to carry the 10 - 3-1/4 in. studs.

Level gauge connection holes are drilled in the wall of the tower at 1 ft. 2 in. and 5 ft. 2 in. from the bottom end, two at right angles at each distance.

The tower is random packed with 20 ft. of 1-1/2 in. by 1-1/2 in. by 16 S.W.G. M.S. rings supported on a grid 9 ft. from the base of the tower. A stand pipe with protecting umbrella at the top is provided for the gas inlet at the base of the tower; gas leaving the top of the tower must pass through a series of baffle plates to eliminate entrainment. Copper liquor is conveyed onto the packing through distributing box. To prevent escape of gas through the copper liquor outlet at the base of the tower, baffle plates are fitted to break up any incipient vortex.

Copper Liquor Injector.

This is a three-throw, single acting horizontal ram pump. It is driven by a 100 H.P. 730 R.P.M. wound rotor induction motor fitted with speed control. The drive is through a single reduction double helical gearing.

The motor and injector are mounted on a common base plate which covers the bearings for the crank shaft and to which the cylinder blocks are bolted on 15-1/2 in. centres

The driving D.H. pinion is forged integrally with the driving shaft from 0.55% C steel. The shaft is 1-1/2 in. dia. x 3 ft 5 in. long. The pinion has 26 teeth 3 in. D.P. 22-1/2 helix angle on an 8 in. face, being 8.746 in O.D. The driven wheel is 64.587 in O.D. and carries 192 D.H. teeth 3 in. D.P. 20° P.A. The teeth are machined on a 0.4 C. Steel tyre shrunk on to a C.S. spider which is keyed to and 8-1/8 in. dia. crank shaft.

The 3 throw 120° crank carries four main bearings of 6 in. dia. The cranks are at 15-1/2 in. C.R.S. The crank shaft is drilled to supply forced lubrication to all bearings.

The connecting rods are articulated to the cross heads by ball and socket joints. The cross heads slide in spun C.I. guides and are attached to the rams by means of rings fitting into recesses on the latter.

The rams are 1-7/8 in. diameter by 26 in. long and chrome plated. A case hardness of 950 - 1000 S.C. is necessary to give satisfactory life. Rams are normally case hardened when new and then ground and built up with hard chrome plating as they wear.

The cylinders are machined from forgings 6 in. square by 2 ft. 3-3/8 in. long. This unit also carries the suction and delivery valves. The cylinders are 2-7/8 in. dia. and are sealed at the ram entry end by a stuffing box packed with alternate turns of greasy hemp and woven cotton.

The valves are of the dead weight poppet type. Lift 1/8 in. seat diameter 1-15/16 in. The seats are 2-7/8 in. O.D. by 1-3/4 in. I.D. and fit snugly into the valve housing being sealed with two fibre rings let into the outface of the seat ring. Both the valves and the seats are from 12% Cr Steel. The valve recesses are sealed by covers held in place by 6 - 3/4 in. bolts.

V Q B' G Y B E H K Z F Y C D A' M J L D' P W

MAIN GLAND PACKING TO BE ALTERNATIVE
TURNS OF LIGHTHOUSE & DRY COTTON
PACKING E'

1/4" SQ SOFT PACKING

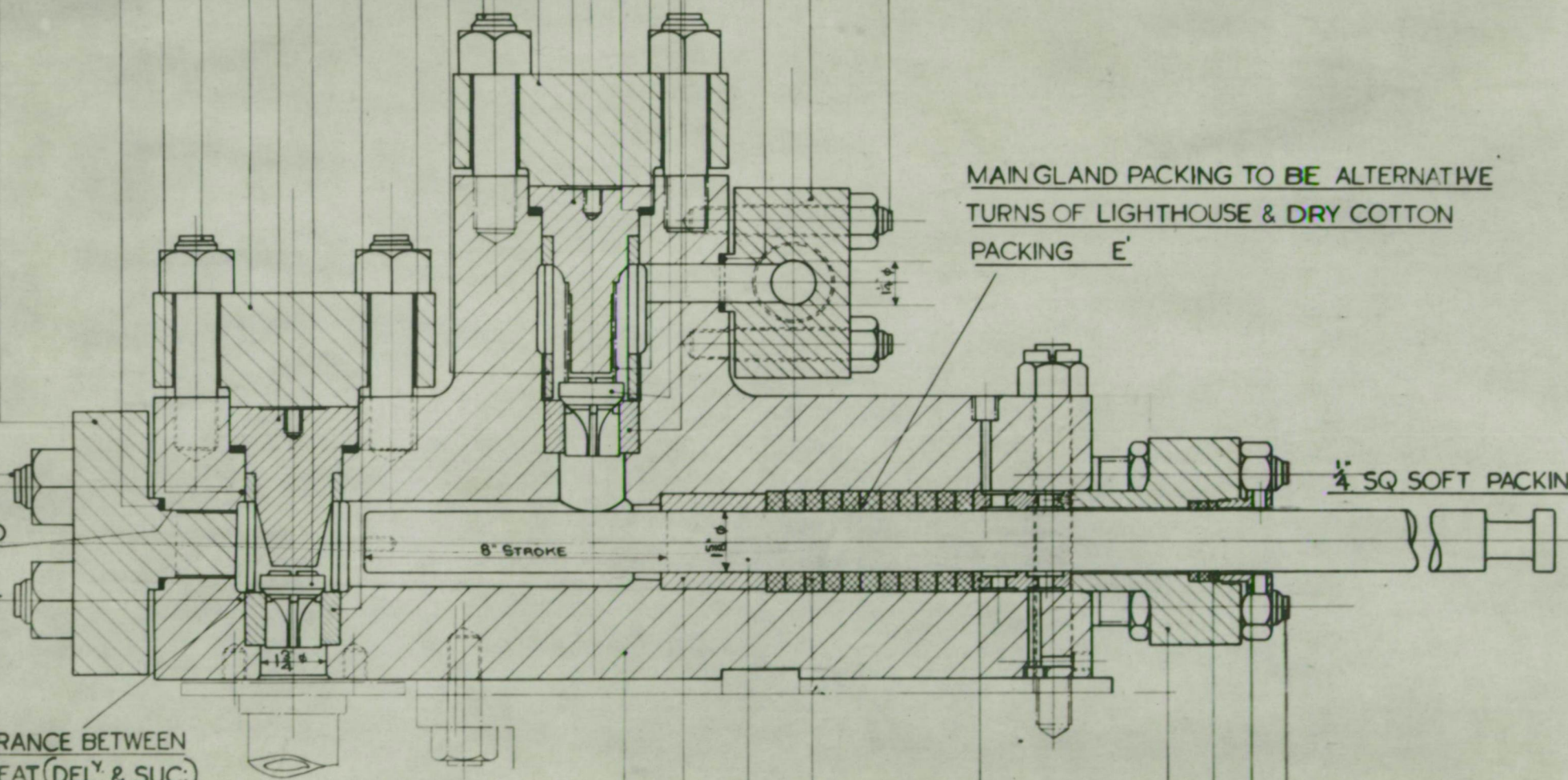
COVERS TO BE A GOOD
FIT HERE TO PREVENT
JOINT SQUEEZING OUT

.003" CLEARANCE BETWEEN
VALVE & SEAT (DEL. & SUC.)

1/8" LIFT ON VALVES

8" STROKE

A U N E' T R F S X



Inlet and outlet headers connect the cylinders.

A direct driven gear pump supplies oil from the sump in the crankcase to all bearings and guides.

Caustic Scrubber.

This is machined from a M.S hollow forging. It is 18 in. inside diameter by 28 in. outside diameter by 10 ft. long. The top is swaged in to give 12 in. inside diameter and 26-1/4 in. outside diameter and the bottom is swaged in to give 9 in. inside diameter and 21 in. outside diameter.

Covers are bolted to each end and sealed with lens rings. The top cover which is 26-1/4 in. diameter by 8-1/2 in. thick is recessed on the underside to accommodate the lens ring. It is bolted to the body by 10 chrome moly. studs 3 in. diameter on a 2-1/4 in. P.C.D. the studs are threaded to Whitworth form 6 T.P.I. they are 19 in. long and are screwed into the body to a depth of 4-1/2 in. The bottom cover is 20 in. diameter by 6-1/2 in. thick, it is recessed in a similar way to the top cover. It is bolted to the body by 8 chrome moly. studs 2-1/2 in. diameter on a 15 in. P.C.D. the studs are threaded 2-1/2 B.S.P., they are 15-1/2 in. long and are screwed into the body to a depth of 3-3/4 in.

The lens rings are turned from M.S. forgings. The top one is 16 in. outside diameter 12 in. inside diameter by 3-1/4" thick at the base, in profile it approximates to an equilateral triangle, the two inclined "sides" having a radius of 14 in. The circle of contact are each face is 14 in. diameter. The bottom lens ring is similar to the top in profile, it is 12 in. outside diameter by 9 in. inside diameter. by 20 1/2 in. maximum thickness. The radius of both faces is 10-1/4 in. and the diameter of the contact circle is 10-1/4 in.

The scrubber is mounted in a vertical position and supported in the structure by a ring projecting 1/2 in. located 6 feet from the bottom of the vessel. It is tested to 525 ats.

The scrubber is packed with approximately 4000 M.S. rings 1-1/2 in. diameter x 1-1/2 high made from 16 S.W.G. sheet. A level gauge is fitted at the side and a 5/8 in H.P. blow down line is located in the base. Caustic is injected into the side of the vessel through a 3/8 in. H.P. line leading from the caustic egg.

Caustic Injection System.

Caustic for use in the caustic scrubber is mixed in a small tank 3 ft. diameter by 3 ft. high. It is run from this tank by gravity into a caustic egg through a 5/8 in. H.P. line fitted with two isolation valves in series. The egg is made from 4 in. solid drawn pipe; it is 7 in. outside diameter by 3 ft. long. Flanges 11 in. O.D. by 2-5/8 in. thick are screwed to the ends and 6 - 1-1/2 in. studs screwed 8 T.P.I. Whitworth bolt on the covers which are the same diameter and thickness as the flanges. Pressure is supplied to the egg by a branch line running from the H.P. gas line having the CO. tower, two isolation valves and a blow-off for pressure release are fitted to this 3/8 in. line.

Charcoal Scrubber.

This is a vessel similar in dimension and construction to the caustic scrubber. The only difference between the units being the omission of a level gauge and side entry pipe on the charcoal scrubber.

Copper Liquor System.

Copper liquor is stored in a cylindrical make up tank when in circulation, and surplus copper liquor is contained in two 10 M³ storage tanks. A 2 in. outlet from the make up tank runs to the 1st. copper liquor cooler. A by pass is provided for use on high rates to allow the liquor to be boosted in pressure by one of the three circulating pumps before passing to the cooler. After leaving this unit the liquor passes through a duplex strainer into the copper liquor injector, all lines up to this point are 2 in. diam. From the injector the liquor is delivered via a 1-1/4 in. H.P. line to the top of the CO removal tower. In this section a non-return valve, a control valve and a temperature point are located. The liquor is let out the base of the tower through a 5/8 in. line past a temperature point and to the let down panel. This let down arrangement consists of two 5/8 in. isolation valves with a third intermediate 3/8 in. valve - all panel mounted, a pressure gauge is situated between the second and third valve. When letting down copper liquor from the tower the 5/8 in. valves are normally fully open, control being obtained by operation of the 3/8 in. valve, these valves are located within sight of the panel mounted CO Tower level gauge. From the let down panel the liquor is forced up to the let down vessel situated in the top section of the regeneration tower. It flows out of this section of the tower, down through an interchanger and back to the top of the scrubbing portion of the regen tower. In this section of the circulation system a 4 M³ capacity vessel is connected in such a way that the liquor can be made to pass through a quarter, half, three quarters, or the full volume of the vessel or alternatively it may be passed completely. An analysis point is located in the line just before entering the top of the scrubbing section of the tower.

From the base of the tower the liquor returns to the interchanger and then enters one of two booster pumps. Temperature points are located on each side of the interchanger and pressure gauges are fitted to all lines to and from the unit with the exception of the initial inlet line. From the booster pumps the liquor is pumped through two coolers in series and then enters the top of a small absorption column mounted on top of the make up tank. A pressure gauge connection, panel operated valve, and flowmeter are in the line before the coolers and temperature point and an analysis point are in the line after the cooler.

Regeneration Tower.

This is a cylindrical tower of welded construction 2 ft. diameter by 43 ft. high. The tower contains a number of separate sections which perform inter-related functions. A 2 in. blow off is situated at the top of the tower. The top 2 ft. are left empty to act as a gas separating space; the next 8 ft. are packed with 1-1/2 in. x 1-1/2 in x 16 S.W.G. M.S. rings supported on a M.S. grid. Below this is another empty section 9 ft. high containing a diaphragm at the base on which is supported a 3 in x 8 ft. 3 in. standpipe; this standpipe has a cowl over the top. A level gauge fitting is provided in this section of the tower. Below the diaphragm is an empty 5 ft. 6 in. section and then 16 ft. of 1-1/2 in. by 1-1/2 in by 16 S.W.G. M.S. rings supported by a M.S. grid. The remainder of the tower is taken up with a steam heating unit. This is in the form of a callandria of 41 M.S. tubes 1 in bore by 3 ft. long enclosed in a 3 ft diameter shell. Two level gauges, one of which is visible from the operating platform inside the ammonia building are fitted to this section of the tower. The whole of the regeneration tower is lagged with 86% Magnesia lagging to a thickness of 1-1/2 in. and finished off with 1/2 in of hard setting compound and cloth wrapping.

Interchanger.

This comprises 10 horizontal banks of 12 tubes each 7/8 in o.d. by 22 ft. long packed inside a 5 in. M.S. tube. The total interchange surface is 605 sq.ft. The cold liquor passes outside the 7/8 in. tubes and the hot liquor passes through the tubes in a counter current direction.

Copper Liquor Coolers.

The large set consists of two banks of cooling coils and the small set consists of one bank of coils; all banks are identical. They consist of 32 - 12 ft. lengths of 1-1/2 in. diameter pipe containing approximately 160 sq. ft. of cooling surface. The pipe runs are horizontal on 4-1/2 in. centres. Cooling water is fed from C.I. launders above the coils, and wooden slats bolted between the launders cause the cooling water to film down over the pipes.

Make up Tank.

This is a M.S. welded cylindrical tank 6 ft. diam. by 8 ft. high with dished ends having a capacity of 5 M³. It is mounted on a steel structure 6 ft. above a concrete sump which also has a capacity of 5 M³. At the top of the vessel is mounted an 8 ft. by 18 in. scrubbing tower packed with 1/2 in. by 1/2 in. x 16 S.W.G. M.S. rings in two sections. Connections are provided so that air or ammonia gas may be blown into the base of this tower for controlling the composition of the liquor. The make up tank is fitted with level gauges manhole, drain and overflow connections.

Copper Liquor Drainage System.

All points in the copper liquor lines where liquor would collect when the lines were drained are connected by 2 in. lines to a header which in turn is connected to the suction side of the circulating pumps via a strainer.

Similary all level gauge drains run to a collecting pot from which copper liquor can be run to the preparation tank.

Booster Pumps.

Two are provided (1 running and 1 spare). They are Thompson B.G.M. 1-1/4 in - 1-1/2 in types delivery 6 M³/hr. against a total head of 75 ft.

Copper Liquor Preparation Plant.

This unit comprises the following equipment:-

Preparation Tank: Horizontal cylindrical welded tank 2 ft 6 in. dia. x 10 ft. long.

Copper Liquor Heater - Cooler: Vertical, jacketted 10 ft. length of 1-1/2 in M.S. tube. The jacket is fitted with steam and cooling water connections for temperature control purposes.

Copper Liquor Preparation Pumps. 3 are provided similar to the Booster pumps.

Air Blower: This is a positive type L2 Nash - Hytor of 70 M³/hr. capacity at 16 lbs/sq. in. It is (directley coupled to a 3 H.P. 1000 R.P.M. motor.

Copper Liquor Preparation Tower: This is a welded M.S. vertical cylindrical vessel 2 ft. 6 in. diameter by 10 ft. high. A supporting grid 18 in. from the bottom is provided to carry copper

turnings. Ammonia gas and air connections are provided in the base of this tower.

Copper Liquor Preparation Pipework. 1½-inch H.S. lines connect the circulating pump deliveries to the preparation tower through the heater cooler. From the bottom of the tower a line runs to the preparation tank, the base of this tank is connected to the pump suctions.

AMMONIA SYNTHESIS PLANT

GAS CIRCULATION SYSTEM:

The system whereby gas for synthesising is circulated through the converter, the precipitation and the condensation sections is all carried out in 1-1/4" H.P. tubing.

Hot gas leaving the converter passes to the converter coolers. This line is in 3% Chrome tubing; the flanges are in 0.4% Mo steel, the bolts are from Chrome-Molybdenum steel and the lens rings are of 3% Chrome Steel. These special materials are used as the gas in this section of line may be at temperatures exceeding 250°C. A temperature point, pressure gauge connection and an analysis point are located in this line.

From the converter cooler the gas and condensed ammonia pass to a 12 in. catchpot; for temperature control in the cooler a temperature point is located in this M.S. line. It is important that this portion of the system should have a downward slope to the catchpot for drainage purposes.

From this catchpot gas passes to a second of similar design whose function is to prevent anhydrous ammonia being carried to the circulator. On this section a panel mounted pressure gauge, an analysis point, a purging out connection, a panel mounted isolation valve and a standard blow-off connection are located.

Leaving the second catchpot the circulating gas enters the gas circulator control section. The control of gas passing through the boosting circulator is achieved by having isolation valves on the suction and delivery of the machine; a 1-1/4 in. circulator bypass line between the valves fitted with a control valve and a blow-off connection immediately before the circulator delivery valve. In this section are located purging out points on either side of both isolation valves, pressure gauges on the circulator suction and delivery and a temperature point on the circulator delivery line.

After the circulator delivery isolation valve the gas passes to a 12 in. oil catchpot and from there to the inlet of the cold exchanger. Leaving the cold exchanger the cooled gas passes to the ammonia condenser and thence to the condenser catchpot. From the condenser catchpot the gas re-enters the cold exchanger from whence it passes on to the ammonia converter. Temperature points are located on the two inlet lines and two exit lines of the cold exchanger and pressure points on either side of the condenser.

A plant bypass connecting the line immediately before the converter controls to the circulator suction line is provided to assist in controlling gas rates through the converter when it is being brought on line. This bypass has a panel operated control valve.

The line before the compressor inlet system is fitted with a blow-off arrangement and a branch leading to a Katharometer for automatically and continuously sampling the circulation gas. A purging out branch and a pressure gauge connection are located before the main isolation valve to the converter after which is an orifice plate and purging out branch, the line bifurcates at this point into two 5/8 in. inlet lines, one on each side of the top of the converter. To facilitate control at low rates during starting up periods a 5/8 in. branch with control valve, orifice plate, pressure point, and blow-off connection is provided to bypass the main inlet valve and main inlet flowmeter.

AMMONIA CONVERTER:

The internals of the ammonia converter are housed in a forging identical with the methanol converter forging in every way except for small differences in the top and bottom outlets to accommodate the more elaborate bypass arrangements of the ammonia converter. The internal arrangement is however, considerably different as shown by the following details:-

Working Pressure.	350 ats.
Test Pressure.	525 ats. (hyd.)
Catalyst Volume.	290 litres.
Catalyst Depths.	15 ft.
Rated Capacity.	10 tonnes/day.
Inside Dia. of Catalyst Basket.	12 ins.
Length of Catalyst Basket.	20 ft 8 ins.
Interchanger Area.	56 sq.ft.
Catalyst Cooling Tube Area.	53 sq.ft.
Total Weight.	30½ tons.

A general arrangement drawing of the ammonia converter is shown and also a line diagram to illustrate the gas flow in the unit.

The incoming gas all passes spirally down the outside of the lagging sheath just inside the converter wall; it then leaves the converter through two 5/8 in. connections in the side wall, of these lines combine to form a 1½ in. line which re-enters the converter at the base and passes to the outside tube of the interchanger. An interchanger bypass with panel operated valve and orifice plate for flow measurement branches from this line and enters the converter by a separate connection in the base taking the bypassed gas directly to the catalyst cooling tubes.

The interchanger is fabricated from two U.S. tubes threaded through one another and bent to form a double start spiral of eleven turns, the top ends being connected so that both hot and cold gases pass up and down the spiral. The incoming gas after being heated in the interchanger passes up the converter through the catalyst cooling tubes. From these tubes it passes over the three heater coils and enters the catalyst bed. On leaving the bed at the bottom of the converter the hot converted gas enters the internal tube of the interchanger and from there leaves the converter. A direct bypass is provided to carry gas directly on to the top of the catalyst bed; this consists of a 5/8 in. connection entering the top cover, a panel operated control valve and an orifice plate for flow measurement are provided in this line to give adequate control.

The temperature of the catalyst is ascertained by means of a central pyrometer sheath in which are located six thermocouples at points equidistant down through the bed.

The three phase heater has coils of nichrome. Power is supplied from a 125 K.V.A. transformer fitted with a motor operated voltage regulator; a panel mounted "raise and lower voltage" switch operated this regulator. The power enters

the converter through three water cooled Luntz metal electrodes.

Heat is retained in the catalyst basket and prevented from reaching the converter walls by means of a lagging sheath of asbestos cement $2\frac{1}{2}$ in. thick. The space outside the basket above the interchanger and the space around the electric elements is similarly protected.

The catalyst cooling tubes, the tube support spiders and the catalyst basket housing are all made from 18/8/1 stainless steel. All nuts, bolts and studs used in the converter are from 6% chrome steel.

CATCHPOTS:

There are four catchpots in the system. The forgings for these are all similar and identical to those used for methanol synthesis. There are two types of internals for these catchpots. The inlet spirals and their attendant umbrellas for preventing entrainment being located higher up the catchpot in those cases when ammonia liquor is being thrown down. Where large quantities of liquor are not likely to be present i.e. before and after the circulator, the umbrella and spiral pipe is moved farther down the catchpot thereby increasing the precipitating space. The two catchpots collecting ammonia are fitted with connections for visual level gauges and panel mounted induction coil level gauges. These catchpots also have $\frac{5}{8}$ in. connections for piping the ammonia to the let down system. All the catchpots have $\frac{3}{8}$ in. drainage lines from the bottom fitted with three isolation valves in series leading to an oil collecting pot.

CONVERTER COOLER:

This is similar to the methanol converter cooler in so far as it consists of two banks of twelve water jacketed tubes connected by U bends. The total length is 584 ft. with a cooling surface of 294 sq. ft. Cooling water required is 25 M³/hr. and this is supplied through a 3" line. The top (inlet) four lengths of pipe and corresponding lens rings are in 6% chrome steel. The remainder of the H.P. pipes in the cooler are from normal M.S. piping. The water jackets which are held in the concentric position by beads of weld metal "tacked" on to the H.P. pipe are jointed with the semi flexible rubber joint ring of the "Victaulic" type. Cooling water is counter current to the gas flow.

CIRCULATOR:

This is an identical unit to the Methanol Circulator. The output is smaller being 6000 M³/hr. (measured as gas at 20°C and 1 atm.); this is achieved by operating the machine at a slower speed i.e. 142 R.P.M. max. A comparison of the drives for both machines is as follows:-

	Ammonia Circulator	Methanol Circulator
Driving Motor H.P.	60	75
Max.Speed of Motor.	730	730
Motor Pulley. O.D.	14 $\frac{1}{2}$ ins.	16 $\frac{1}{4}$ ins.
Max. Speed of Circulator.	142 RPM.	160 RPM.
Circulator Pulley. O.D.	71"	71"

The drive in each case is by means of 8 - $1\frac{1}{2}$ in x $\frac{3}{4}$ in. D section V ropes. As on the Methanol converter speed control is provided down to 360 R.P.M. Designed inlet and discharge pressures are 320 ats and 360 ats respectively. Cooling is provided for the glands cylinder by water jackets.

COLD EXCHANGERS:

The cold exchanger consists of a 37 ft. length of 5" bore H.P. tube (jointed in centre) carrying a nest of 55 tubes 1/2" O.D., 16 S.W.G., 36 ft. long. The heat exchange surface is 260 sq. ft. The incoming gas to be cooled flows outside the 1/2" tubes, and the outgoing gas from the ammonia cooled coils flows inside the tubes. Temperature points on both inlet and outlet lines allow the performance of this unit to be continually checked. The whole of the condensation section consisting of the cold exchanger, the ammonia condenser, the condenser catchpot and all interconnecting pipes are ~~core~~ lagged to a thickness of 3". The lagging consists of slag wool mats held in place by wire mesh; the surface being finished with a mixture of bitumen emulsion and cement.

AMMONIA CONDENSER:

This consists of a Class 1 fusion welded pressure vessel constructed to Lloyds Rules. It is 3 ft. 6 ins. diameter by 12 ft. long, and is fabricated from 3/4" M.S. plate. It has dished ends which are bolted to the body of the vessel. Two banks of hairpin cooling coils are arranged in this condenser; they are each 150 ft. long and are fabricated from butt-welded 1-1/4" H.P. piping, the total cooling surface being 100 sq. ft. On the top of this vessel is a gas collecting chamber 6 ft. 8 ins. long by 9 ins. diameter; it is inclined to the condenser and connected to it at either end. To this header are connected two 2" branches, one 4" branch and a pressure gauge (panel mounted) connection. One 2" branch has a 1/2" purge connection and a 2" Cockburn type spring loaded pilot operated relief valve; the second 2" branch has a 2" Cockburn relief valve and a 2" blow off connection. The 4" branch has a 2" connection to the purge gas scrubber, a 2" Cockburn relief valve and a 4" connection to the Ammonia Oxidation plant (connection at top of stripping still); this 4" line, in addition to an isolation valve, is fitted with a katharometer alarm whose purpose is to close a solenoid operated valve in the line at the Ammonia Oxidation plant should any hydrogen be detected in the ammonia gas in this line.

The condenser itself is provided with an oil and sludge drain line, a 1" ammonia inlet line - both at the bottom of the vessel - a temperature point and two level gauges, one the visual sight glass type and the other of the automatic panel mounted induction coil type.

The test pressure for this vessel is 450 lbs/sq.in. (hyd.).

The oil drain runs to the Purge Evaporator which is a cylindrical vessel fabricated from 1/2" plate 1 ft. 6 ins. diameter by 3 ft. high. It is fitted with a 1" steam coil, visual level gauge, relief valve, 3/4" drain and a 2" line to the copper liquor preparation plant.

AMMONIA AND OIL JERRY:

This is a small cylindrical vessel into which are blown the drainings from the four catchpots and the gland leaks from the circulator. It is 20" in diameter by 30" high and is of welded construction. It is fitted with a pressure gauge, visual level gauge, drain, 1" steam coil (for evaporating purposes), a relief valve and a blow off line running to the purge scrubber.

LET DOWN SYSTEM:

Ammonia from the converter and condenser catchpots

is piped to the let down section in two 5/8" diameter lines at 350 ats. pressure. It is let down in each line through two panel mounted valves in series, the first being 3/8" and the second 5/8". A pressure gauge is installed for indicating the pressure between these two valves. The anhydrous ammonia is let down to approximately 20 ats. and discharges into a common 5/8" line leading to the 20 ats. let down vessel.

This is a cylindrical vessel 3 ft. diameter by 8 ft. 9 ins. long having a capacity of 1.5 M³. It is fusion welded from 7/8" plate to Lloyds Rules for Class 1 welded pressure vessels. It is fitted with a visual sight glass level gauge and a panel mounted induction coil type level gauge; a low level alarm is also supplied.

Gas released during the letting down process is further reduced in pressure by passage through a panel controlled 1-1/4" let down valve and is piped through a 2" line to the purge gas scrubber. In parallel with this let down system is a 3/8" spring loaded gas release valve which automatically releases the pressure in the let down vessel. Pressure gauges before and after this system indicate the pressure of the vessel and that of the main to the purge gas scrubber. An analysis point is also provided in this line. A 3" relief valve of the "Cockburn" spring loaded pilot operated type is fitted and a purging out connection is provided.

Liquid Ammonia is taken from the 20 ats. let down vessel through a 1-1/4" line through two panel mounted control valves to a distribution header. One branch from this header leads back to the ammonia condenser through two panel mounted control valves, a small 3/8" expansion valve with isolation valves on either side of it is provided in parallel with the second of these valves for semi-automatic operation under steady conditions. A second branch from this header leads to the ammonia liquor storage. Under normal conditions the ammonia synthesised would be stored as anhydrous liquid in stock tanks under pressure. At the time of construction of these plants the facilities were not available for the manufacture of large storage tanks for this pressure storage. An alternative arrangement of storing the product as a solution of 25% ammonia liquor was adopted as a temporary expedient until such time as the pressure storage tanks were available. The ammonia is therefore let down through two panel mounted valves, the first an isolation valve, and the second an expansion valve, and the gasified ammonia piped to the ammonia liquor storage. A pressure gauge is fitted immediately after the expansion valve and a barometric leg with surge tank is provided to prevent liquor being drawn back into the header.

The storage tanks used are those at the Ammonia Oxidation plant. The 2" line from the Ammonia Synthesis plant runs into a header above the stock tanks from which branches lead to the three tanks. Each of these branches divides into three 1" lines which lead to the base of the tank. A shielded jet is fitted to these distribution lines to facilitate the dissolution of the ammonia into the liquor. The object of the cylindrical shield is to promote the circulation of the liquor and thus reduce water hammer. Control valves are provided for each of these lines.

PURGE GAS SCRUBBER SYSTEM:

Gas from the 20 ats let down vessel, the oil collecting pot and (occasionally) from the ammonia condenser is

scrubbed with weak ammonia liquor in the purge gas scrubber. This is a 10" diameter x 26 ft. high M.S. tower of welded construction. It contains 16 ft. of random packed rings. The gas enters the base of the tower through a 2" line and discharges to atmosphere through a central exit of 3" diameter in which is located an orifice plate for flow measurement.

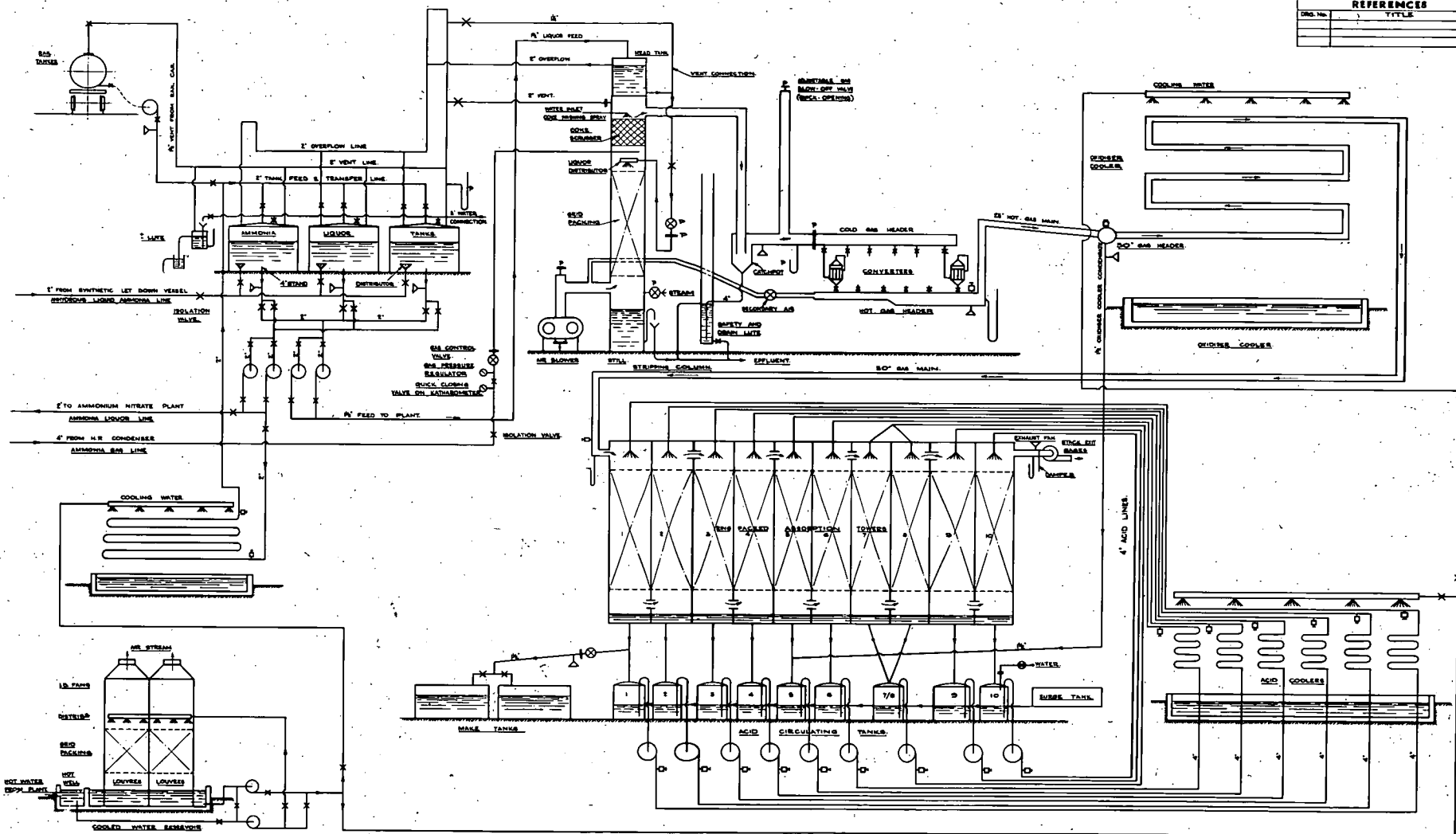
The circulating scrubbing liquor enters the top of the tower through a 1" line, is discharged over the packing by a pot type distributor and leaves the base of the scrubber through a 1-1/2" line running to a weak liquor storage tank. This tank is 1 M³ capacity, it is cylindrical in shape, and is fabricated by welding from 3/8" plate, and is 3 ft diameter by 5 ft. long. It is fitted with a visual level gauge, a temperature connection, a vent and overflow. Liquor flows from this tank through a 1" line (in which is fitted a drain) into one of two weak liquor pumps (one working, one spare).

These pumps discharge into a 1" line, fitted with an orifice plate, leading to the weak liquor cooler. This cooler consists of 235 ft. of 3/4" diameter M.S. pipe wound in a spiral 3 ft. diameter. The coil is set into an annular M.S. tank 3 ft. 2 in. outside diameter by 2 ft. 10 ins. inside diameter by 5 ft. high. The tank is open at the top; cooling water enters at the base and overflows at the top.

From the cooler a 1" line running to the purge gas scrubber completes the circulation system; in this section of the line a discharge branch is provided for bleeding off weak liquor to the storage system. To prevent excessive pressures being formed in the scrubber a 4 ft. lute is provided at the base of the scrubber.

The operating level in the weak liquor storage is set by the overflow pipe, and as this is coupled to the regen. gas scrubber lute any make up required is derived from this source.

REFERENCES	
REF. NO.	TITLE



WATER COOLING SYSTEM

- LIST OF SYMBOLS**
- X— VALVE
 - O— CONTROL VALVE
 - |— FLOWMETER
 - P— PUMP
 - M— MANOMETER
 - Δ— TEMPERATURE POINT
 - ▽— ANALYSIS POINT
 - P— PUMP
 - P— NOTE OR CONTROL ON PANEL

WATER UNIT 1,000 TONS PER ANNUM
 AIR UNIT 1,000
 BALLAST
 FILLING

I.C.I.A.N.Z. LTD. SYNTHETIC AMMONIA SECTION			
FLOWSHEET			
ATMOSPHERIC AMMONIA OXIDATION UNIT			
DRAWN	N.C.	8-8-48	SCALE
TRACED	M.P.	8-8-48	Dr. No. 2077
CHECKED			
APPROVED			
PASSED			FILE A.O. INDEX 198

NO.	DATE	REVISION	REMARKS	BY	APP.

ATMOSPHERIC AMMONIA OXIDATION PLANT.

General.

The plant as described, has a rated output of 3,000 tons per annum of nitric acid (as 100% acid) which is produced at 50% strength.

The ammonia consumption for full plant output being 8.45 short tons per day. It is supplied as an aqueous solution at 25% strength.

Ammonia Liquor Supply and Handling.

The Ammonia Liquor is delivered to the site in rail tanks, capacity 8 tons, which are fitted with a spring loaded relief valve which limits their internal pressure to 25 lbs. square inch gauge.

An unloading station consisting of one, 1½" in all iron centrifugal pump of capacity 8 M³ per hour at 80 ft. total head, driven by a 3 H.P 2880 revs. per minute motor is provided for unloading the tankers and pumping the liquid to storage through a 2½" pipe line. A 2" line connecting the tanker to the storage system serves as a vent. Flexible hoses are provided for connecting the liquor and vent lines to the tanker. A ½" sampling connection is provided near the tanker.

Ammonia Liquor Storage.

There are three 100 M³ storage tanks each 20' diameter and 12'6" deep. They are mounted above ground in a mounded compound. The height of the mound being sufficient to retain the liquor of one tank should a serious leak develop. Each tank has a depth pneumacator indicating on the control panel, and is fitted with a dip rod as well for accurate measurements.

There are three main pipelines above the tanks, all 2" diameter. The feed and transfer line is for filling the tanks from the tankers and for transferring liquor from one tank to another by means of the transfer pump which is a 2" all-iron centrifugal capacity 24 M³ per hour at 22½' total head driven by a 2 H.P 1440 revolutions per minute motor. The vent line permanently connects the gas space of all tanks, and carries a double lute which blows at 12" H₂O positive pressure or admits air at 3" H₂O negative pressure to protect the tanks. The overflow line is for returning excess liquor from the head tank in the stripping column, and it normally runs full while the stripper is operating.

A manometer (-3" to 12" water gauge) reading on the control panel is fitted to indicate the gas pressure in the storage tanks.

Two pumps, one of which is spare, are provided for keeping the head tank full from storage. They are 1" two stage all-iron centrifugals with a capacity of 2 M³ per hour at 80' total head, driven by a 2 H.P 2880 revs. per minute motor. The capacity of each of these pumps is greater than the highest liquor rate required by the stripper so that during the operation, the head tank is constantly overflowing. This serves to maintain a constant feed to the stripping column. Indicator lights are mounted on the plant control panel to show pump stoppages.

Air Blowers:

Two blowers of the positive Roots-type are provided. Both are required for full plant output. They were supplied by "Alldays and Onions" and are a low pressure Thwaites type high speed machine. They have a volumetric displacement of 4,000 M³ per hour at 750 revolutions per minute. The power requirements are 6.4 H.P at 14" water gauge. The motor fitted is a 10 H.P 1420 revolutions per minute squirrel cage machine and the drive is through 5 B-section belts.

The blower inlet is fitted with 3 "Richardson" type No. R6 viscous filters. The outlet is 10" bore. A combined relief and blow-off control valve of the weighted mushroom type is fitted to protect the blower against excessive load and to control the air rate to the plant. Before the delivery line enters the base of the stripping column, a 6" diameter branch is tapped off for the secondary air supply.

Stripping Column.

The stripping column consists of a M.S tower 4' internal diameter by 56'9" high. It is lagged with 2" thickness of "Solomit", sheet metal covered for the first 28' from ground level. It is fitted with access manholes above the liquor distributor and in the head tank. A safety ladder is also provided. The column is divided into four main sections.

The top 6' is completely closed off to form the head tank supplying ammonia liquor to the stripping section. A 2" line from the bottom of the head tank runs through an isolation valve to the control panel, on which are mounted a needle control valve and a rotameter flow indicator. The line then returns to the distributor in the stripping section.

The stripping section comprises the main portion of the column. At the top of it, is a 2-tier perforated channel distributor which distributes the liquor over the grid packing. The latter consists of 15'3" depth of wooden grids made from $\frac{1}{4}$ " hardwood 2 $\frac{1}{2}$ " wide standing on edge, with $\frac{3}{8}$ " spaces between. There are 145 layers each at right angles to the one above. The packing rests on a steel grating 7'3" above base level.

Immediately above the stripping section is another steel grating carrying a 9'6" depth of coarse coke packing comprising the gas scrubbing section. In the 1'9" space between the top of the coke and the bottom of the head tank, the main gas exit pipe 15" diameter is taken off. A temperature point is also fitted in the gas space here, connected to a Cambridge dial recorder (0-50°C-) on the control panel.

The space below the grid packing comprises the fourth section of the column. It is fitted with an effluent outlet luted to maintain a depth of 3'6" of hot effluent in the base of the column. The main air inlet from the blower enters in the space between the effluent levels and the grating carrying the grid packing. Two 1 $\frac{1}{2}$ " inlets for live steam are fitted, one entering the air space directly and one dipping to the bottom of the effluent.

Ammonia Air Gas System.

The 15" diameter gas exit drops vertically into a catchpot to remove any further condensed moisture. The catchpot condensate is drained off through a luted line.

From the catchpot the gas passes into a 15" diameter header. A gas sampling point is fitted in this header just before a 6" diameter vertical gas blow-off 12' high. This blow-off is fitted with a flap valve at the top by which blow-off rates can be controlled while the plant is starting up. A trip catch is provided for the immediate release of this blow-off should an emergency warrant its use. A manometer connection and an orifice plate with a flowmeter indicating on the control panel are in the header immediately before the inlet valves distributing gas to the convertors.

Convertors.

The fourteen convertors are arranged in two parallel lines with the gas inlet header placed centrally above and the gas exit header centrally below them. The convertors are supported on brick piers with their long axes horizontal 4'9" above ground level, and are spaced to give easy access between them. Stainless steel (18/8/1/1 type) is used throughout in their construction.

The cold ammonia air mix leaves the top header through stainless steel mushroom valves which are fitted with a lever enabling them to be operated from the front of the convertor. The inlet branch is 4" diameter. The mixed gas passes immediately into a horizontal tubular interchanger 3' long by 1'4" diameter consisting of 19 tubes each 2½" diameter and 1/16" wall thickness giving 37 square feet interchange surface. The casing and tube plates are also of this thickness. The heated gas leaves the interchanger by a 5" diameter 16 gauge stainless steel branch which carries a 60 mesh stainless steel conical straining screen. This outlet pipe is also fitted with a thermo couple pocket. The preheated gas line discharges into a cast stainless steel chamber in which the frame carrying the platinum gauzes, is mounted in the centre. Two inspection holes 2" diameter are provided and are so arranged that both sides of the gauzes can be viewed. Pyrex glass is used for these inspection windows. A thermo couple pocket is fitted to the downstream side of the gauze. The Chromel-Alumel thermo couples used in the two temperature points of each convertor are coupled to two "Siemens" 18 point indicators mounted on the control panel.

The gauze holder consists of two cast stainless steel square frames screwed together, between which the square gauzes are clamped in asbestos millboard packing. Support for the gauze is provided in the form of nichrome wire ⅜" mesh, which in turn is supported by 5 horizontal fused silica rods ⅜" diameter.

The gauze pad consists of four layers of 0.003" woven wire into 80 mesh, the upstream gauze is 90% platinum, 10% rhodium and remaining three are pure platinum. They are 13" square with an effective area of 144 square inches. The total gauze weight is approximately 250 grams.

The downstream end of the gauze chamber is bolted to the interchanger. The hot gases after conversion pass through the interchanger tubes and out by means of a conical connection through the mushroom exhaust valves to the hot gas header. The exhaust valves are of stainless steel and are similarly controlled by a lever system from the front of the convertor.

Exit Gas Header.

The hot gas header collecting the converted gas from the fourteen convertors is of 16 gauge stainless steel. It is tapered from 15" diameter at the inlet end to 23" diameter at the last convertor. An angle iron framework anchors it securely at the centre allowing expansion in either direction.

The outlet end of the header is fitted with a temperature pocket, a manometer point, a luted drain and a sample point.

The secondary air inlet is situated at the inlet end of the hot gas header and adjustment of the secondary air rate is made by the means of a calibrated slide valve.

Hot Gas Main.

The hot gas main which is a continuation of the hot gas header is fabricated from 16 gauge stainless steel and is 23" diameter. It rises vertically from the hot gas header to a height of 15' and runs on wooden supports at a downward slope of approximately 1 : 40 to the oxidiser cooler. The total length of this main is 235'.

Gases enter the main at approximately 500°C and discharge to the oxidiser cooler at approximately 150°C. The space velocity in this section is 180 hours⁻¹ at full plant rates.

A temperature point is fitted at the outlet of the hot gas main.

Oxidiser Cooler.

This cooler which is fabricated by welding from 16 gauge stainless steel consists of a number of hairpin bends over which cooling water is cascaded.

Gas from the hot gas main enters a 23" diameter header at the base of the oxidiser cooler. This header which is 14'6" long is fitted with a 1½" luted drain which carries the condensate formed in the cooler to No. 5 circulation tank in the acid circulation system. A sampling point is also provided in this header.

Six 11½" diameter tubes each 210' long, branch off from the header and rise in four parallel horizontal hairpins to a second horizontal header similar to the inlet header. From one end of this a 30" diameter serpentine cooler rises in staggered coils. This cooler containing a total pipe length of 900' discharges into a 30" main carrying the gas to No. 1 absorption tower.

A thermometer pocket is fitted to the gas main before entry to the absorption system.

The stainless steel cooler system is mounted on a hardwood structure built over a collecting pond. Wooden launders above the main 30" pipes and also above the 11 $\frac{3}{8}$ " pipes serve to distribute a film of water over the outside surface of these coils. Connecting slats collect the water from one coil and transfer it to the coil immediately below.

The total volume of the condenser coolers is 5,500 Cubic feet and at full plant rate the space velocity of the gas passing through them is 23 hours.⁻¹

Absorption Towers

There are ten absorption towers ; five being operated by counter current scrubbing and five by co-current scrubbing. Each tower is 12'6" square and 42' high internal dimensions and they are built into one structure of two rows of five towers having an overall length of 69'6" and an overall width of 28'6".

The towers sit on an 11" reinforced concrete slab mounted on brick piers 9' above ground level.

The towers are built in acid resisting bricks from Illawarra and Newbold . The acid resisting cement used in the construction was made by mixing silica flour (200 mesh) silica sand (80 mesh) and sodium silica fluoride powder in the ratios of 20 : 10 : 1 by weight. 60° TW sodium silicate was used to give a mix of suitable consistency.

Four courses of brick, the first three laid on their flat and the fourth laid on edge, form the base of the towers. The first three courses have vertical joints of R85/40 mexphalte and horizontal joints of acid resisting cement. The fourth course is jointed throughout with acid resisting cement. The bricks in these four courses and also those in the external walls of the towers were coated with 30° TW sodium silicate.

Outside walls are 24" thick for the first 2'9" and 14" thick thereafter. A vertical membrane 1" thick of R85/40 Mexphalte is built into the thick section of these walls 9" from the outside face ; it connects with the similar jointing in the floor.

The transverse internal walls (four in all) are 23" thick for the first 2'9" and 14" thick thereafter. The longitudinal internal wall is 14" thick throughout.

The flow of gas which is downwards in No. 1 tower , alternates with each succeeding tower till the exhaust gas finally passes out of the top of No. 10 tower. Transmission of gas from one tower to the next is made through ports in the internal walls.

All towers are packed with glazed acid resisting earthenware Raschig rings 4" long, 4" external diameter and $\frac{1}{2}$ " wall thickness.

The packing is stacked to a height of 29' and 6' of "random" packed rings are placed on top. The rings sit upon acid resisting bricks stacked in open formation to facilitate gas passage to a height of 3'. The total height of the supporting brickwork and the ring packing is such that a space of 4' is left at the top of each tower. Over 1,400,000 rings are required for the ten towers.

A 10 gauge stainless steel lid acts as a closure for the tower tops. A manhole is provided in these lids which are sealed at the edges with acid resisting putty made from African blue asbestos. Manometers are provided at the first and last towers.

A stainless steel gutter runs round the base of the towers to catch any seepage that may occur ; this is fed back into No. 7 tank of the acid circulation system.

The exhaust gas from No. 10 tower enters a stainless steel exhaust fan manufactured by Richardsons. This unit has a capacity of 5,000 M³ per hour against a static head of 6" water gauge. Operating rate is adjusted by means of a damper slide on the discharge side. The fan is driven by a 7.5 H.P 1460 revolutions per minute T.E motor through 4 V-belts.

The fan discharges into a stainless steel column 6' high which is random packed with 1½" earthenware rings to a height of 3'6". This column acts as a spray arrestor.

A sampling point is provided at the inlet to the discharge fan.

Acid Circulation System.

Each absorption tower has its own acid circulation system, with the exception of towers 7 and 8 which have a common system.

Circulating capacity for these systems are provided by nine tanks 6' diameter by 6' high of welded construction from 16 gauge stainless steel. Conical covers are welded on to the tanks and manholes (18" diam.) are fitted to the covers. Acid circulation pumps connected to the tanks by 3" diameter stainless steel suction lines, deliver through 4" diameter stainless steel pipes to the tops of the towers. The pumps are 2/3 Thompson B.G direct coupled units running at 1440 revolutions per minute and driven by 7.5 H.P totally enclosed motors. They deliver 30 M³ per hour against a total head of 55' when operating on a liquid with specific gravity 1.2.

Coolers are provided on systems 1-6 ; these are located after the pumps and consist of horizontal banks of 4" pipes 24' long containing 21 runs in three six length banks and one three length bank. Thermometer pockets are fitted to lines after all pumps and all coolers. Cooling water is fed into launders above the coolers and cascades down over the pipes to a catchment pond below.

The circulation lines enter the top of the towers and discharges into a distributor box formed from an 18" length of 6" stainless pipe. This box has a 1" bottom outlet and several ½" diameter holes in the sides ; four 1½" diameter pipes radiate towards the tower corners from the box and discharge downwards on to flat tiles packed up 6" above the packing rings at a point midway between the corner and the box. The object of this system is to ensure uniform acid distribution. The line to towers 7 and 8 bifurcates at the top of the towers and feeds to both units.

From the bottom of the towers, a 4" stainless steel line drains the acid back to the tanks. Adjacent tanks are connected by 4" connecting pipes 18" from the bottom. The level of the tanks is so arranged that acid tends to flow slowly from tank 10 to tank 1 gaining in strength at each step. A surge tank (12' diameter by 3' high) is connected to tank No. 10 at 2'6" from the base. The object of this tanks is to handle excess acid during power failures. It normally runs empty.

Water is fed in from a constant head tank through a needle valve and a notch metre into No. 10 tank. Acid at approximately 50-54% strength is bled off from No. 1 circulation system through a notch metre into one of two acid storage tanks 13' diameter and 6' high. These tanks are of welded construction from 16 gauge stainless steel and are fitted with conical covers. They each have a capacity of 30 tons of 50% nitric acid.

Two delivery pumps are connected to each tank by 2" syphon lines and are installed for exporting the make. These units are 1" Thompson B.G.L stainless steel pumps capacity 1.5 M³ per hour against 40' total head with liquid of 1.2 specific gravity. They are direct coupled to a 1 H.P 1440 revolutions per minute totally enclosed motor.

The acid circulation and storage tanks are all connected at the apex of their conical covers to a common fume line which feeds into No. 7 tower. The slight suction under which this tower normally operates is sufficient to extract the fumes from these tanks.

SERVICES - NITROGEN PLANT

INTRODUCTION

It is necessary to have a supply of inert gas available for use in purging out vessels and pipe lines in order that explosive mixtures of air and process gas will not be formed when bringing units on or off line. This gas is also used for keeping catalysts in an inert atmosphere during the changing period as they are pyrophoric after use.

This purge gas is obtained by the controlled burning of a combustible gas - normally catalysed gas drawn from the catalysed gas holder; semi-water gas may be used but this has the disadvantage of containing sulphur compounds which are undesirable in purge gas when used for certain purposes.

EQUIPMENT

Gas Flow

Catalysed or semi-water gas enters the burner via a 2-inch M.S. line in which is fitted an orifice plate. From the burner the hot products of combustion pass directly to a water scrubbing tower and then to a caustic scrubbing tower to remove CO₂. The purge gas is drawn from the top of the scrubber by means of a centrifugal gas blower and is discharged into a small gasholder; an orifice plate is fitted in this line for plant control. Gas may be discharged directly from the holder into the purge gas reticulation system or it may be boosted in pressure by a two stage reciprocating gas compressor for use on occasions when higher rates are required. The reticulation system takes purge gas to a series of key points in the ammonia building, the tower structure and the oxide boxes. All gas lines in the nitrogen plant and the reticulation system are 2 inches diameter.

Burner and Gas Cooler

These two units are built integral with one another.

The burner consists of a horizontal cylindrical tube 12 inches diameter by 10 feet long. It is fitted with an open trough water jacket and has a jet type burner with attendant controllable air ports at one end. The other end opens directly into the base of the cooling tower.

The cooler is a 2 feet diameter by 14 feet high tower which is luted into a water seal at the base. The tower is fitted with a supporting grid carrying 12 feet of 1½-inch x 1½-inch x 16 S.W.G. M.S. rings random packed. A perforated plate type distributor conveys the cooling water on to the packing.

Caustic Scrubber

This is a M.S. tower 1 foot 9 inches diameter by 8 feet high carrying 6 feet of 1-inch x 1-inch x 16 S.W.G. random packed rings. A small centrifugal pump - 2 M³/hour capacity - circulates a sodium hydroxide solution over this tower from one of two cylindrical tanks 3 feet diameter by 3 feet high, used for preparing and storing the solution.

Nitrogen Blower

This is a centrifugal single stage machine of 50 M³/hour capacity at 35 millibars boost.

Nitrogen Holder

This is a vertical lift roller guided, water sealed holder of 50 M³ capacity. It is housed in a concrete tank built below ground level.

Nitrogen Compressor

This is a two stage reciprocating compressor supplied by Ingersoll-Rand. It has a capacity of 50 M³/hour at 100 lbs/sq. inch delivery pressure and has a built in receiver of 0.5 M³ capacity.

SERVICES - STEAM

The steam required for the plants is supplied from an external boiler station. It is reticulated to the section at 120 lbs/sq. inch gauge in a saturated condition.

The steam used on the ammonia oxidation unit is reduced to 40 lbs/sq. inch before use on the plant.

Steam required for the Ammonia and Methanol plants is used at fully supply pressure, except for the methanol stills where it is reduced to 15 lbs/sq. inch.

Estimated usages on various sections are listed below:

<u>Section</u>	<u>Consumption</u> <u>Tonnes/hour</u>
Gas Plant	1
Oxide Boxes	0.05
H ₂ Plant	1
Regeneration Tower	0.15
Ammonia Storage	0.1
Methanol Stills	0.7
Ammonia Oxidation	0.5

SERVICES - ELECTRICAL

Synthetic Ammonia and Methanol Section

A 6.6 kV 3-phase overhead feeder running from the main district substation enters the factory substation which is situated alongside the ammonia building. Four sets of leads are tapped off the main feeder, each set runs through isolating links and carbon tetrachloride immersed fuses to four transformers. The first pair are 1250 kVA units stepping the pressure down to 415 volts. The outlets lead through individual isolating links and oil circuit breakers to the 415 volt bus bars. The second pair of transformers have a capacity of 1,000 kVA and reduce the pressure to 2.2 kV; the outlets of each of these units is fitted with isolating links and lead via 0.15 sq. inch 3C PILCSWA cable to the 910 h.p. oil circuit breaker and thence via similar cable to the motor.

The electrical load is such that one 1,250 kVA and one 1,000 kVA transformer can be isolated and maintained as spare units.

Four feeders from the 415 v bus system lead through individual isolating links to four O.C.B.'s. The first O.C.B. feeds the distribution panel for the ammonia building via 2 - 0.250 sq. inch 4-core PILCSMA cable. The second O.C.B. feeds the distribution panel for the tower structure via 2 - 0.25 sq. inch 4-core PILCSMA cable. The third O.C.B. feeds the 240 h.p. motor for the CO₂ removal plant through a 0.250 sq. inch 3-core PILCSMA cable. The fourth O.C.B. feeds the gas plant distribution board through a 0.250 sq. inch 4-core cable of the same type.

The ammonia building distribution panel is fitted with 4 - 200 amp, 2 - 100 amp and 1 - 30 amp, 8 - 10 amp tapplings fitted with appropriate fuses, also "flip-on" connections for single phase lighting, power and instruments requirements. A 3-phase 7/.064 V.I.R. cable runs from a panel mounted 60-amp switch fuse on the ammonia synthesis panel to the methanol distillation panel which contains 1 - 30 amp, 4 - 20 amp, 3 - 10 amp 3-phase circuits and "flip-on" connections for single phase lighting, power and instrument requirements.

The tower structure distribution board contains 4 - 200 amp, 1 - 60 amp, 1 - 30 amp, 2 - 20 amp and 12 - 10 amp circuits, together with lighting and power outlets. One 200 amp circuit runs via a switch-fuse through a .250 sq. inch 4 C PILCSMA cable to the nitrogen plant board. The 60 amp circuit leads through a switch fuse and 7/.064 4C V.I.R. cable to the tower structure subdistribution board. The nitrogen plant board contains 1 - 150 amp, 1 - 30 amp, 3 - 20 amp, 3 - 5 amp and lighting and power circuits. The 150 amp circuit, which contains a panel mounted fuse, runs via a 0.15 sq. inch 4C PILCSMA cable to the pump house board which contains 3 - 120 amp, 6 - 30 amp and lighting circuits. The tower structure sub-board contains 1 - 30 amp, 2 - 20 amp and 6-10 amp circuits.

The gas plant distribution board contains 2 - 150 amp, 3 - 60 amp, 1 - 30 amp, 3 - 20 amp, 3 - 10 amp, 6 - 5 amp and single phase circuits for lighting. One of the 20 amp circuits runs via a 7/.064 4C V.I.R. cable to the cooling tower board which contains 4 - 10 amp and lighting circuits.

The transformers are mounted on a concrete raft inside a fenced enclosure. Bus bars run from the L.T. side of the 1,250 kVA transformers to the O.C.B.'s which are housed in a brick pent house built alongside the ammonia building. The seven O.C.B.'s are all panel mounted and built so that the controls face into the ammonia building, the panels being built integral with the ammonia building wall.

The distribution cubicles are of sheet metal weatherproof construction; each contains a panel of 3/4" "zelemite" on which are mounted the porcelain fuses of the totally enclosed type.

An emergency lighting system is installed in the ammonia building. It consists of twelve 40 watt lamps mounted at suitable points in the building. These lamps are powered by a bank of storage batteries, a relay operated switch wired into the normal 4C supply ensures that the emergency lighting system will operate in the event of a power failure. A small charger is installed for maintaining the batteries in good condition.

Ammonia Oxidation Section

This section, which consumes only 415 V power, is supplied from a separate substation. One cubicle only is installed; this is the sheet metal, weatherproof type and is located adjacent to the absorption tower. It contains outlets for 14 - 30 amp, 2 - 30 amp and 8 - 10 amp circuits, together with lighting and power single phase connections.

Reticulation is by V.I.R. cable run in black water piping for all underground and overhead work.

SERVICES - COOLING WATER

Owing to the large quantities of cooling water required in various sections of the plant it is economical to provide facilities for cooling the hot used water and returning it to the process for further use.

Three separate systems are installed. The main cooling water system serves the ammonia plant with the exception of the gas unit. Due to the contamination of cooling water with tarry matter and coke breeze on the gas plant this unit has its own separate cooling water system. The cooling water at the ammonia oxidation plant is liable to become contaminated with acid if leaks occur; a separate system is therefore used for this unit to avoid damage to ammonia plant equipment. All three systems are similarly arranged. The hot return water flows by gravity into a comparatively small well; it is picked up from this well by the hot water pump and discharged into distributing louvres at the top of a cooling tower; leaving the base of the cooling tower it falls into a cold well which is of sufficient capacity to supply plant requirements for a considerable period, i.e. 6-8 hours, with the losses usually sustained under normal working conditions. A cold water pump draws water from the cold well and discharges it into the cooling water supply system. A third pump is connected to the system in such a way that it can be used as a common spare for either the hot or cold water pumps.

Ammonia Plant Cooling Tower

This is of the induced draught type. The shell consists of two layers of Murray Pine tongued and grooved boards with Malthoid sealing between; it is 44 feet long by 11 feet wide by 21 feet overall height. The shell is divided by three partitions to give 4 similar compartments.

Each compartment is packed with 8 feet of serrated timber grid packing $1\frac{3}{4}$ inches by 0.19 inches thick by 2 inches pitch of King William pine. The packing is situated above 4 feet of louvres running round the shell. Above the packing louvres nozzles and splash plates serve to distribute the hot water. Venetian blind spray arrestors consisting of two horizontal rows of 6-inch by $\frac{1}{2}$ -inch planks at 5-inch centres set at 45° to the vertical are located above the water distributors. The top of each section is tapered in to carry a 48-inch axial flow fan running at 780 r.p.m. and having a capacity of 40,000 cu. feet/minute at 0.375 inch H_2O static head. These fans are each driven by a 10 h.p. 1440 r.p.m. totally enclosed motor by V-belt drives.

The tower is located over the cold well which is 47 feet long by 14 feet wide by 8 feet deep having a storage capacity of 150 M³.

The tower is designed to handle a maximum water rate of 250 M³/hour at a return temperature of 37°C. under the following atmospheric conditions:

Dry Bulb	25°C.	(77°F.)
Humidity	75%	
Wet Bulb	22°C.	(71.5°F.)

The design conditions stipulated that the maximum water temperature of the water leaving the tower be 27°C.

The following details relate to the packing used:

Free Space A 90.6%
Superficial Area = 10.4 feet²/feet³
Periphery/feet² cross section = 144 inches
Maximum Ratio Air/Water Rate = 1,590.

The use of this type of packing which is capable of a high loading results in a tower of relatively small dimensions, an important factor where large volumes of water have to be handled hourly. The designed water loading is 0.5 M³/hour/sq. foot cross sectional area.

The pumps installed were supplied by Thompsons of Castlemaine and are a standard 6" - 7" G.M. machine running at 1450 r.p.m. They are direct coupled to 60 h.p. totally enclosed, squirrel cage motors supplied by A.G.L. Ltd.

Ammonia Oxidation Cooling Tower

This is similar in construction to the Ammonia Cooling Tower. It is smaller, having only two sections each 10 feet square. Other details are identical.

The cold well is directly connected to the ponds under the oxidiser cooler and the acid circulation coolers; the total water capacity is approximately 200 M³.

The water circulation pumps are 80 M³/hour capacity giving a tower loading of 0.40 M³/sq. foot/hour.

Gas Plant Cooling Tower

This is a cross draught type of tower. It is 24 feet high by 9 feet 6 inches square. The packed height is 20 feet and the packing consists of 13 sets of arrestors spaced at 20" crs. Each arrestor consists of two staggered sets of 3"x 1" planks nailed at 5 1/2 inch crs. to either side of a 4"x 2" bearer; the staggering ensures that descending water does not bypass an arrestor. The tower is louvred on all sides by 12"x 1" slats set at 45° on 10 inch crs. Water distribution is achieved by 16 - 1/2 inch nozzles equally spaced and set in 4 troughs. The water discharging from the nozzles impinges onto porcelain splash plates.

The designed water load on the tower is 0.2 M³/sq.ft./hr.

This type of tower is particularly suitable for the gas plant cooling water system where a close approach to the wet bulb temperature is not required. It is relatively cheap to construct and with designed louvres the water loss due to spray formation is low.

MAINTENANCE ORGANISATION AND TECHNIQUE

INTRODUCTION

The satisfactory operation of the plants discussed largely depends upon the efficiency of the organisation for the maintenance work to be done. In continuous processes of this nature, where a number of single units are interdependent, the period between shutdowns is controlled by the reliability of all the units. Even in stages where spare equipment is provided there may not be time to bring the second unit on line without shutting down the whole plant. As the time required to bring the plant on and off line is approximately eight hours for even the shortest maintenance job, it is essential to reduce the number of shutdowns to a minimum.

The first consideration in the carrying out of any work is the safety of the maintenance team and the operatives who will subsequently control the plant. On account of the presence of many sources of danger - toxic and asphyxiating gases, combustible gas, gas and liquids at high pressures and corrosive liquids - there is need for exercising great care not only in handing jobs over to the maintenance section but also receiving the finished jobs from maintenance. For this reason a definite routine is followed for handing over of work and a clearance certificate is issued to the tradesman carrying out any maintenance job. This clearance is cancelled on the completion of the work and when the equipment concerned is handed back to the process operators.

In addition to the protection afforded by the clearance certificate system there are safety rules both general and sectional which are important necessities to ensure the safety of the engineering staff.

The routine laid down in these rules may often appear unnecessarily elaborate for small jobs, but it is only by careful attention to them that accidents, especially lost time accidents, can be kept down to a satisfactorily low level.

CLEARANCE CERTIFICATE SYSTEM

Introduction

In plants such as Synthetic Ammonia and Methanol plants a system of Clearance Certificates for maintenance work has been found to be particularly effective as a means of reducing accidents. Due to the corrosive nature of the substances handled the maintenance work comprises a high proportion of the total work carried out. In order to avoid any uncertainty as to who is in charge of sections of plant while this maintenance is being done it is essential to have a definite handing over of the appropriate plant by the process staff to the maintenance staff for all jobs which affect or are affected by the process operations.

Clearance certificates are used for this purpose; a separate certificate is issued for each job and is cancelled on completion of the work when the plant or equipment is handed back to process control.

This system has been found so effective on Synthetic Ammonia and Ammonia Oxidation plants that it has recently been enlarged to cover all I.C.I.A.N.Z. requirements and has been installed in all their factories.

Its primary object is to increase the safety of workers; it also reduces waste due to damage to plant and property and lost production time in accidents.

There are three types of clearance certificates. They are:

- (1) Standard (White job copy)
- (2) Closed Vessel (Blue job copy)
- (3) Restricted Area (Yellow job copy).

Samples of the job copies of each type are included in this thesis and their respective uses are described below.

Standard Clearance Certificates

The Standard Clearance Certificate is the type most commonly used as it is applicable to all jobs except the comparatively small number requiring one of the four special certificates.

Before any part of a plant is handed over for adjustment, repair, alteration, etc., a responsible person of the process staff, at least a foreman, must first put the plant in as safe a condition as possible. The same person must then make out a Standard Clearance Certificate describing the job to be done, the condition of the plant and the special precautions (if any) necessary to ensure safety in carrying out the job. It is this person's responsibility to see that the certificate is correct and that all possible dangers have been anticipated and provided for in the precautions described.

The person filling in the certificate signs it and hands it to the person taking over; normally the tradesman carrying out the job, who must read it and sign it to indicate that he understands both the job and the safety precautions required. He carries the certificate with him on the job and it forms his authority for working on the plant.

Immediately the job is finished the process representative examines the work and, if satisfactory, the certificate is signed off by both persons at the same time.

IMPERIAL CHEMICAL INDUSTRIES OF AUSTRALIA & NEW ZEALAND LIMITED

Synthetic Ammonia Section, Deer Park, Victoria

STANDARD CLEARANCE CERTIFICATE

Not to be used for work in Closed Vessels, Restricted Areas, or Danger Areas; Special Certificates are provided for these.

SECTION OF PLANT.....

DETAILS OF JOB: *(More than one job may be specified provided no special precautions are required and no flame is to be used)*

SPECIAL PRECAUTIONS:

It is hereby certified that the item of plant concerned IS / IS NOT isolated from every dangerous source of gas, liquid, and motive power. IF NOT, the special precautions detailed above must be taken.

Signed..... Date..... Time.....
Responsible person handing over

Signed..... Date..... Time.....
Person taking over

REMARKS ON JOB DONE:

Signed..... Date..... Time.....
Person handing back

The item of plant concerned has been examined and is now in satisfactory condition to be returned to service.

OTHER REMARKS:

Signed..... Date..... Time.....
Responsible person taking back

IMPERIAL CHEMICAL INDUSTRIES OF AUSTRALIA & NEW ZEALAND LIMITED

Synthetic Ammonia Section, Deer Park, Victoria

CLOSED VESSEL CLEARANCE CERTIFICATE

SECTION OF PLANT.....

CLOSED VESSEL CONCERNED.....

DETAILS OF JOB :

SPECIAL PRECAUTIONS:

It is hereby certified that:

(1) The vessel IS / IS NOT isolated from every dangerous source of gas, liquid, and motive power. IF NOT, the special precautions detailed above must be taken in addition to those below.

(2) The air in the vessel IS / IS NOT free from toxic, asphyxiating, and inflammable gas.

Result of air test.....

Time of taking sample..... Signed.....

Tester

(3) It IS / IS NOT necessary to wear Breathing Apparatus.

If so, the following must be worn.....

The person standing by will be.....

(4) It IS / IS NOT necessary to wear Safety Belt and Lifeline.

If so, the person standing by will be.....

(5) The use of a naked flame or heated object IS / IS NOT permissible inside the vessel.

If so, the following Flame Equipment may be used.....

(6) The vessel is safe for entry to carry out the job described above provided the safety precautions detailed on this certificate are fully observed.

Signed..... Date..... Time.....

Superintendent or Authorized Deputy

I have read this certificate and am fully aware of the precautions to be taken.

Signed..... Date..... Time.....

Person entering vessel

REMARKS ON JOB DONE:

Signed..... Date..... Time.....

Person handing back

The item of plant concerned has been examined and is now in satisfactory condition to be returned to service.

OTHER REMARKS :

Signed..... Date..... Time.....

Responsible person taking back

IMPERIAL CHEMICAL INDUSTRIES OF AUSTRALIA & NEW ZEALAND LIMITED

Synthetic Ammonia Section, Deer Park, Victoria

RESTRICTED AREA CLEARANCE CERTIFICATE

To be used only for work in the "Restricted Areas" defined in the Factory Rules.

SECTION OF PLANT.....

BUILDING OR PLANT ITEM CONCERNED.....

DETAILS OF JOB :

SPECIAL PRECAUTIONS:

It is hereby certified that:

- (1) The building or plant item described above IS/IS NOT isolated from every dangerous source of gas, liquid, and motive power. IF NOT, the special precautions detailed above must be taken.
- (2) The building or plant item described above HAS / HAS NOT been cleaned and rendered free from explosive and inflammable material.
IF SO, the person who carried out the cleaning was.....
- (3) The use of a naked flame or heated object IS / IS NOT authorised.
If so, the following Flame Equipment may be used.....
- (4) The person authorised to proceed with the job is.....
- (5) The building or plant item described above has been examined by me, and is in my opinion, in a safe condition for the above job to be carried out INSIDE/OUTSIDE the Restricted Area provided the special precautions detailed above are fully observed.

Signed..... Date..... Time.....
Superintendent or Authorized Deputy

Signed..... Date..... Time.....
Person taking over

REMARKS ON JOB DONE:

Signed..... Date..... Time.....
Person handing back

The job described above has been examined by me and found satisfactorily completed.

Signed..... Date..... Time.....
Inspector

The building or plant item concerned has been examined by me, and is in my opinion in a clean and safe condition to be returned to service.

OTHER REMARKS :

Signed..... Date..... Time.....
Superintendent or Authorized Deputy

Closed Vessel Clearance Certificates

The Closed Vessel Clearance Certificate is used for all jobs where any person is required to enter an enclosed vessel or space which may be rendered dangerous by gases, liquids or movement.

The procedure in the case of this certificate is similar to that for a Standard Clearance with the additional restrictions named on the form.

Restricted Area Clearance Certificates

The Restricted Area Clearance Certificate is used for all jobs carried out in a defined "Restricted Areas". This is an area where the fire hazard is higher than in normal working places. A Superintendent normally makes out one of these certificates.

The procedure in the case of this certificate is similar to that for a Standard Certificate with the additional restrictions named on the form.

GENERAL SAFETY RULES FOR MAINTENANCE

Entry into Closed Vessels

The appropriate clearance certificate details the steps to be taken to ensure that all possible precautions have been carried out to render the job safe.

Isolation of Plant

1. Driving Machinery: Where machines are driven by electric motors the main switches in the substation must be opened, or the fuses withdrawn and the starter tried. Alternatively a notice may be hung over the starter instructing operators not to operate the unit.

2. Pressure and Dangerous Liquids: Before assuming that a particular section of plant is free from gas under pressure, it is advisable to use every means of testing available, and also prevent the subsequent development of pressure through an undetectable leak by having all blow-offs open. Particularly when dealing with high pressure it is a good working rule to assume that any valve is leaking until it has been proved to be tight. In many cases double isolation valves are provided for such cases and they should always be used if possible. If the job cannot be made free from danger while the plant is running, the plant must be closed down to do the job, if important, or the job held over until an enforced shutdown. The same considerations apply to jobs which are to be done on systems containing dangerous liquids, e.g. caustic soda, and anhydrous ammonia. In the same way, if it should be necessary to leave open for any time ends of pipes which are connected to sources of gas under pressure or liquid, and only isolated by valves, it is advisable to add the additional safeguard of a blank of appropriate strength.

3. Purging: The plant to be placed under maintenance may contain combustible or toxic gas. Under these circumstances, the section must be purged with inert gas both before and after the job. This purge gas is normally nitrogen containing about 18% CO₂ from the nitrogen plant, but in certain cases steam or "blow" gas from the generators may be used.

Two methods of purging may be used:

- (A) Sweeping through with nitrogen either under holder pressure or boosted by the compressor, taking care that the plant is swept from end to end, and that the gas sample after purging is taken at the exit.
- (B) By putting up to pressure several times with the nitrogen compressor and blowing down. In using this method it is well to realise that if a given volume of gas is used for purging, it is more efficient to use it in several portions than in one portion, e.g. it is better to put the plant up to three atmospheres three times than nine atmospheres once.

Normally a plant is considered purged when the hydrogen is down to 1%. Should it be necessary to enter a vessel after purging, it is then necessary to sweep out with air until a test has been obtained which shows 20 - 21% oxygen.

When handing such plant back to the operatives it must be purged free from oxygen, since the explosive limits for the gases in the process increase rapidly with pressure. Purging is carried out as described above but the limit to be attained is a maximum of 1% oxygen.

Slip-plating

There are many major maintenance jobs which require absolute protection from the risk of gas, e.g. working in an oxide box and extensive work on the lower stages of the 910 h.p. compressor. In such cases all gas lines to the section must be slip-plated. It is usually possible to arrange to slip-plate a gas line when it is not under pressure, but if it is not possible to arrange to do this the slip-plate can be put in under gas pressure (max. 20-30 milliatms). In such cases a compressed air mask must be used by the fitter and his mate. It is not advisable to try to slip-plate a 9" to 12" main under pressure. The same effect as slip-plating can be obtained at the gas-holders by water sealing the inlet and outlet pipes at the inlet and exit lutes which are provided for this purpose.

Leaking Joints

One of the problems which often arise involves a leak at a high pressure joint. The following set of recommendations is based on an assessment of the stresses developed in the joint bolts.

1. 350 atms. joints not greater than $\frac{3}{4}$ " i.d. Small leaks may be tightened by hand. On no account must joints be hammered or "slogged" up whilst under pressure.
2. 350 atms joints greater than $\frac{3}{4}$ " and not greater than 1 $\frac{1}{2}$ " i.d. These must not be tightened unless pressure is reduced to 50 atms. Under exceptional circumstances (such as small leaks and obviously loose joints) the engineer may assume responsibility for giving permission to tighten these joints under full pressure.
3. 200 atms joints: While under pressure these joints may only be tightened if obviously slack or if the leak is very small, at the discretion of the engineer. On no account may spanners be hammered or extended.
4. Steam joints: May be tightened by hand, but spanners must not be slogged.
5. Compressed Asbestos Fibre Joints: Leaks developing in such joints almost invariably break down the jointing material. They cannot be corrected by tightening of the joint bolts.

SECTIONAL SAFETY RULES

Gas Generator

When a generator is due for maintenance, the Lynn washer will be purged with blow gas before steaming down. It is often possible to purge the Lynn washer with steam, but in either case it should subsequently be swept through with air after a slip-plate has been put immediately before the gas isolation valve, so that the seal box can be drained. It is well to remember that the blow gas used for purging is high in toxic CO.

No entry is to be made to the generator until the coke has been removed, the bowl drained and steam put on the stack. After a satisfactory air test the generator may be entered.

Lynn Washer and Seal Box

Special conditions must be observed for jobs on this section when the generator is alright (e.g. changing a cooling water control valve on the Lynn washer or replacing a sight glass on the seal box). If the job is a long one, the top gas valve can be disconnected and closed after purging the Lynn washer with blow gas. For a short job, a low air rate with the stack valve closed will keep a positive pressure on the system and prevent ingress of air. In such a case a compressed air mask must be worn.

Top Gas Valve

To clear this valve wait until the top of the generator is reasonably hot (400°C.), purge the Lynn washer and put the generator on standby. Remove the bottom plate carefully, being careful in case of a blow-back through delayed ignition of the air admitted. The generator top is made hot to ensure ignition of this air. Clean the valve quickly and replace the plate.

Gas Washing Fans

The chance of a gas leak at an isolation valve here is rather high and the consequences serious both from the risk of a gassing accident in the building and from the risk of fire. The fan should therefore be slip-plated before going to maintenance. This will involve temporarily shutting down the section of plant and blowing the pressure off the main between the raw gas-holder and the oxide boxes.

Oxide Box

To be purged with nitrogen, double isolation valves closed and intermediate blow-off opened, and slip-plated if the box is to be emptied.

Hydrogen Plant

If the plant is to be opened up, it must first be cooled down. This is done either by steaming down to a temperature of 250°C. (not below the saturation temperature of the steam) and/or cooling off by passing gas through the catalyst until the temperature is down to 50°C. Finally it is purged with nitrogen and slip-plated.

Compressor.

Major maintenance to the first three stages involves purging with nitrogen and slip-plating both the suction line (on the downstream side of the isolation valve), and the gland leak

line. If it is not possible to slip-plate on the downstream side of the suction valve, the hydrogen plant may be isolated to do the job, but the inlet valve should be cracked occasionally to keep a positive pressure on the set. In purging the compressor with nitrogen it should be barred round with the bypasses closed, until a test on the third stage at least shows no combustible gas.

On completion of the job, the machine should be purged once again and the precaution taken of running to atmosphere with all the bypasses closed for a couple of minutes.

CO and CO₂ Removal Towers

Before blowing the pressure off the towers, the liquor must be blown out of the tower completely. This is best done at a reduced pressure (50 ats and 40 lbs./sq. inch respectively). If the tower is to be opened up it must be purged. When removing packing from the CO removal tower, it is essential that all workers wear goggles on account of the risk of copper liquor splashing from the ground.

Regeneration Tower

This is most easily purged with steam. It should be slip-plated from the Hydrogen Plant.

Convertor

If the convertor is to be opened up the catalyst, due to its pyrophoric nature, must be cooled down to less than 50°C. This also serves to reduce the ammonia content of the gas if the cooling off is done in the proper manner by means of the circulator. Before opening it, the convertor must be purged out with CO₂ free nitrogen, and while it is open, it must always be under nitrogen holder pressure to prevent access of air to the catalyst. It is important that the gas in such circumstances passes over the catalyst. Therefore, if the top cover is to be removed, the nitrogen connection must be made at the exit of the convertor. If the bottom cover is to come off, put nitrogen on to the direct bypass line.

Changing Ammonia Catalyst

(a) Removal: This necessitates lifting the top cover of the convertor. It is important that a slow stream of nitrogen be kept passing up through the convertor until all the catalyst has been removed.

(b) Recharging: An atmosphere of nitrogen is not necessary during recharging of catalyst. For Australian convertors the total weight of catalyst should be approx. 1,500 lbs; the exact weight must be carefully determined.

The whole operation of removal and recharging takes approximately seven hours.

20 ats Let Down Vessel

This can be emptied of liquid ammonia by raising the pressure with gas from the synthesis system and blowing down all liquid to stock tanks. During this operation care must be taken not to lift the relief valves on these tanks

Ammonia Stock Tank Level Gauges

It is essential to empty a tank as far as possible and then allow the pressure to fall to atmospheric by blowing off, before endeavouring to remove a gauge for cleaning. When emptying these tanks it is important to disconnect the steam lines and to dry out the heating coil by blowing air through it. If water is left in this coil there is a risk of it freezing and shattering the line, due to evaporation of liquid ammonia from the surface of the exposed coils.

MAINTENANCE PROCEDURE

General

In order to keep the plant on line for as long as possible and to reduce the number of unmediated shutdowns to a minimum, the planning of maintenance is based upon the following principles:

1. All machinery which is in duplicate should be kept permanently in good order.
2. Machinery which is not in duplicate will, of course, be maintained as found necessary but in addition certain operations should be performed at regular intervals.
3. There should be an annual shutdown during which all the machinery in category 2 is thoroughly overhauled.

Plant which is in duplicate should not need to be touched during the annual shutdown. This is important, as the amount of unduplicated plant is large and provides all the work which it is possible to do in the time allocated to this shutdown, normally ten days.

In order to comply with this system a log is kept of changeover of plant and also the running hours of the larger machines.

Gas Plant

As the whole of this plant is in duplicate it is thus not affected by the annual shutdown. In line with other parts of the plant for which spares are installed, this section has the running plant shut down and the spare plant started at regular intervals.

As soon as possible after the changeover, the idle plant is examined and all defects which are liable to cause trouble are rectified. The plant is thus left in a condition to start at the shortest notice should unexpected trouble develop in the running unit.

The changeover intervals for this section are as follows:

Generators	every six months
Air Fans	weekly
Gas Washing Fans.....	weekly
Circulating Pumps.....	two weeks on and one week off.

Generators: When a generator is changed over the following points are examined:

1. State of generator generally,
2. State of generator plating in water jacket,
3. State of grate and drive.

The operator and valve gear require special attention; the wear on pins and stops in this machine is heavy. The clutch and reduction gear box are units requiring close examination at every shutdown.

The top and bottom gas valves and also the stack valve are also dismantled and inspected; it is sometimes found necessary to refit these within six months.

Air Fans: After the weekly changeover, the fan bearings are opened, examined and regreased and the motor is examined. The clearance between the rollers and the race on the bearings of these machines, due to their relatively high speed, is critical. The normal figure is 0.003" and the bearing should be renewed if this clearance is appreciably exceeded. Wear up to 0.009" (or a total clearance of 0.012") is the maximum allowable before replacement.

Gas Washing Fans: The successful operation of these fans depends upon careful balancing of the revolving parts and attention to the sealing gland. Only sufficient steam to balance the blower pressure need be applied to the gland. Due to the heat from the sealing steam the bearings on this unit are liable to become overheated and care must be taken not to overgrease them to aggravate this tendency.

The bearings are changed when the weekly check reveals a total clearance of 0.012".

Circulating Pumps: The strainers are cleaned daily, and if any reduction in output is observed the pumps are opened up on changing over and the impellers cleaned. Due to coke breeze in the circulating water there is fairly heavy wear in these pumps at the neck rings and glands.

Routine Operations at Gas Plant: (1) The bottom gas valve is cleaned regularly each week. The top gas valve is only cleaned when absolutely necessary.

(2) Greasing is carried out at regular intervals on the valves and valve control gear. The valve stems, the stack valve points and the operator parts are oiled daily. Other parts are oiled or greased each week.

(3) The oil levels in the hoist and operator reduction gears are checked weekly.

Gasholders

An internal inspection for estimation of corrosion is carried out once every three years. This is likely to occur on the tank bottom, internal water line, and in the cups, externally. The nitrogen holder is likely to be attacked in the crown also.

Routine Operations: A monthly check of the tank water is made and this is purged if necessary. Ammonium carbonate concentrations and acidity are controlled. On some overseas plants the cups are oil filmed with a light engine oil; however, due to the stains and discolouration of the bell resulting from the presence of this oil, this practice has not been adopted in Australia.

Gas Mains: Periodic cleaning of the gas mains to and from the raw gas holder is carried out at four monthly intervals.

Oxide Boxes

These do not require any attention other than inspection when the boxes are opened for renewal of the oxide.

Hydrogen Plant

This plant requires little maintenance and unless some trouble has been observed it does not require any work during the annual shut-down period.

The following failures may occur. They are readily identified and normally only develop slowly.

- (1) Interchanger leaks
- (2) Choked packing
- (3) Catalyst breakdown.

Routine Operations: The water pumps are changed over weekly.

Compression Plant

Annual Shutdown: The compressor is partially stripped as follows:

1. 4th, 5th and 6th stage cylinders are removed.
2. Main bearings have caps removed and brasses examined; clearances and wear down of bearings are recorded.
3. All valves are withdrawn.
4. Big ends and little ends are examined and clearances are taken and recorded.
5. Piston rod glands are inspected and cleaned if necessary. Unless there are signs of excessive wear these are not stripped as they tend to match with their respective rods and take on an excellent surface.
6. Motor bearing caps are removed and wear down recorded.
7. Motor slip rings are opened up and examined.

The first three stages are not opened up unless there is evidence of wear or damage of the cylinder walls. All cylinders are "miked"; liners are replaced when wear exceeds 0.030" for 4th and 5th stage and 0.020" for the 6th stage.

Old liners can be reground but this necessitates the provision of oversize pistons and normally they are scrapped.

New rings are fitted to the 4th, 5th and 6th stages.

When reassembling the engine it is necessary to line up the upper cylinders carefully. This is done by placing the piston of the cylinder concerned on top dead centre and pressing the crosshead firmly to the guide; (when operating these double acting pistons result in the crosshead bearing on the guide on both strokes; so that to achieve operating conditions during lining up, the crosshead is held against the guide) and harden down the upper cylinder in such a way that the rod is central in this cylinder. Feelers are used to check this.

The oil sump is cleaned and the motor starter examined and tested by the electricians.

The interstage coolers are normally dismantled and the water passages were brushed and painted with "Apexior".

Routine Operations: The sump is emptied and cleaned every 4,000 hours. The H.P. lubricators are cleaned thoroughly every six months.

The composition of the electrolyte in the speed controller is checked weekly.

Ordinary Maintenance: The most common trouble is valve failure, and this results in high delivery temperatures and abnormally high pressures in the stages before the cylinder in which the actual failure has occurred.

Thus high 5th stage pressures are due to failure of the 6th stage valves.

A failure of the 6th stage piston rings will have a similar effect on the 5th stage pressures, but will also cause the 2nd stage pressure to be abnormally high as the gas will leak into the 3rd stage and dam up the flow gas from the 2nd stage.

CO₂ Removal Plant

Annual Shut-down: The top cover of the CO₂ tank is removed and packing examined, and if this is dirty it is removed and cleaned by rumbling.

The pump is opened up and the neck ring and glands examined, also the impellers may become worn and require renewal. The motor and starter are checked. All bearings are examined and clearances are taken and recorded.

The Larner-Johnson valves are opened up, also the non-return valves, and overhauled where necessary.

Routine Operations: There are no special routine operations other than oiling and greasing on this section.

CO Removal Plant

Annual Shut-down: The CO tower is opened during the annual shut-down, the packing is removed for cleaning and the distributor is cleaned.

The crank case of the injector is opened up and the bearings examined. The glands and valves of this machine require regular attention throughout the year and so receive no special treatment at the annual shut-down. The non-return valve on the injector delivery should be examined and rescated if necessary.

The motor driving the injector is examined and attention given to the brush gear, bearings and speed control equipment.

Routine Operations: The CO tower is normally boiled out every 4,000 hours.

The bed plate oil on the injector is liable to contamination with copper liquor and is normally changed every 2,000 hours of operation.

Ordinary Maintenance: Items on this plant requiring regular attention are the injector valves, rams and relief valve.

Leaking injector valves should be changed at once to avoid damage to the seats due to wiredrawing. The signs are unsteady delivery pressure and loss of output, but the first indication is a wheezing noise in the valve chest which is quite distinctive.

The glands on the injector require regular attention; they are never tightened hard and a small leak of copper liquor when running is desirable to lubricate the packing. When adjusting they must be set square by means of caliper measurement, and then locked in position by means of the locknuts. The normal packing is two turns of dry cotton and one of greasy hemp alternatively; about fourteen turns are required in all.

The rams are of nitralloy steel and have a hard skin depth of up to 0.013". After use resulting in 0.010" wear they can be reground and built up by means of hard chrome plating. If this is done they must be reground again before use. The rams are double ended and reversible.

Final Purification

Annual Shut-down: The charcoal in the charcoal tower should be replaced; the used charcoal is regenerated in a lagged vessel through which is blown highly superheated steam.

The caustic tower is washed out. The caustic injection is maintained throughout the year and requires no special attention at the annual shut-down.

Routine Operations: There are no special requirements on the maintenance side. The life of the charcoal is normally at least six months. The smell of the make-up gas is the best guide as to the condition of the charcoal tower, and it is of interest to sample the used charcoal for sulphur content.

Ammonia and Methanol Synthesis Plants

Annual Shut-down: The circulators are completely examined, particular attention is paid to the piston ring glands. Gland liners which are of pearlitic cast iron are renewed when the maximum wear exceeds 0.020", all piston rings showing signs of wear are replaced.

Bearings of these machines are examined and clearances and wear-down are noted and recorded; the reduction gear boxes are opened up and examined.

The valves will receive periodical attention throughout the year and are dealt with under general maintenance.

The motors are inspected and brush gear checked.

The convertor should not require special attention at this time as it is dealt with under ordinary maintenance.

The convertor coolers normally require cleaning. This is carried out in a similar manner to the compressor coolers.

Routine Operations: The oil in the circulator bedplates and gear boxes require changing every 4,000 hours.

Steaming out of the condensation system is carried out as dictated by the pressure drop in the circulation system.

Ordinary Maintenance: The special features of this section are the convertors. Internal failures here are difficult to locate and repair.

It is important that this section of the plant should never be blown down rapidly, except in great emergency as this practice is liable to rupture the internal sheaths.

A gland or sheath failure will cause sudden loss of temperature in the catalyst, and it can be located by putting a pressure test on the wall cooling sheath using nitrogen at 30 lbs. per square inch. The loss of pressure should not be greater than 1 lb. per minute.

An interchanger failure is difficult to distinguish from loss of catalyst activity, as it results in reduced conversion and lower temperature of the exit gas from the convertor. Failure of the internal cooling tubes of the catalyst basket produces a similar effect but this will also produce an unusual temperature gradient.

It is only by careful consideration of the conditions prevailing, such as temperature gradient of catalyst, rates of direct and indirect bypass and other temperature considerations, that a correct diagnosis of the trouble is achieved.

The cause of failure in a Methanol convertor is easier to trace than in an Ammonia convertor because of the simpler construction of the former.

The special precautions and work in the circulators are mostly in connection with the glands and these should be put up to pressure and blown down slowly and only when the machine is running, otherwise scouring of the gland liners and failure of the cast iron rings will result. In other respects the circulators require similar attention to the H.P. compressor.

Testing of Safety Devices

A large number of safety devices and alarms are provided on these plants and it is essential that they be tested regularly to ensure efficient operation in the event of an emergency. It is not always possible to carry out these tests under actual plant running conditions, but in many cases simulated conditions can be obtained. In some cases visual examination only is possible.

The following schedule indicates the class of test required for each of the various devices and the frequency with which these tests are carried out.

Classes of Tests:

- A. Tests under actual conditions
- B. Tests under simulated conditions
- C. Visual examination.

Device to be tested	Class of Test Required	Frequency
Water to Lynn Washer Alarm	A	Weekly
Water level in Gas Plant Cooling Water Sump	B	"
R.G.H. Low Level Alarm	B	"
Differential Pressure across Oxide Boxes Trip	B	"
Hopkinson Steam Valve Trip	B	"
Hot Water Circulating Pump Trip	B	"
Cat. G. H. Low Level Alarm	B	"
Compressor cooling water Low Pressure Alarm	B	"
Compressor Crank Case Oil Low Pressure Alarm	A	"
Differential Pressure across CO ₂ Tower Indicator	B	"
20 Ats Let-down Vessel Low Level Alarm	B	"
H.P. Condenser No. 1 Relief Valve	C	"
H.P. Condenser No. 2 Relief Valve	C	"
20 Ats Let-down Vessel Relief Valve	A	"
Methanol Let-down Vessel High Level Indicator	B	"

DESIGN OF HIGH PRESSURE PLANT AND EQUIPMENT.

INTRODUCTION.

In the following pages an attempt has been made to evaluate the general principles of design of industrial equipment operating at pressures up to 500 atmospheres. The number of units operating at elevated pressures is small and the requirements are far from uniform. A certain amount of standardisation has been found to be possible but this only applies to items such as pipe lines, valves, branch fittings, etc., which are used in relatively large quantities on any one plant. Vessels and machines are invariably designed for specific installations.

There has been a tendency since high pressures were introduced for Britain, America and the Continent to develop their design technique in three distinct ways. British practice has been more conservative than American as regards pipe lines and joints. British manufacturers of H.P. compressors have favoured vertical multi-crank units whereas the Continental practice favours single crank horizontal machines. The former type saves floor space but the latter are more accessible for maintenance work.

The notes that follow concern British practice and are applicable to the design of plant for industrial use. A large number of devices have been developed mainly for laboratory use specially at super-pressures but these have not been included as in general they are not applicable to full scale plant work.

HIGH PRESSURE VESSELS

(For use up to 360 ats.)

Pressure vessels operating at pressures above approx. 1000 lbs/sq.in. are invariably manufactured from hollow steel forgings.

The two main factors involved are the choice of the type of steel to use for forging and the design of the vessel.

The main factors influencing the choice of material are:-

- (1) Working pressure.
- (2) Size of vessel.
- (3) Maximum temperature to which vessel will be subjected.
- (4) Effects of process on the vessel.

The three main steels used for industrial high pressure vessels are low carbon steel, 3% chrome steel and Ni-Cr-Mo steel. The first is satisfactory for small and medium sized forgings where the operating temperature will not be greatly above atmospheric. The use of 3% chrome and Ni-Cr-Mo steels have replaced the medium carbon and high carbon steels for large forgings on account of the consistency with which good mechanical properties can be reproduced, and also because their better elastic properties render them particularly suitable for use in cases where elevated temperatures and thermal shock effects increase the working stress of the vessel.

In ammonia synthesis and hydrogenation processes when the partial pressure of hydrogen in the restrained fluid is high the effect of hydrogen attack on the steel must be considered. Both 3% chrome and Ni-Cr-Mo steels possess good hydrogen attack resistant properties, particularly the latter at more elevated temperatures.

The preparation of the forging is primarily the responsibility of the steelmaker, and he is called upon to supply a full report covering the melting of the steel together with a complete thermal history of the subsequent treatment. The composition of the three steels as normally used for forging purposes are as follows:-

Low Carbon Steel

Carbon	0.2 - 0.3%
Manganese	0.4 - 0.8%
Silicon	Not more than 0.3%
Sulphur	" " " 0.04%
Phosphorus	" " " 0.04%
Nickel	" " " 0.5%

3% Chrome Steel.

Carbon	0.2 - 0.3%
Chrome	2.5 - 3.5%
Molybdenum	0.35 - 0.50%
Manganese	0.30 - 0.60%
Silicon	Not more than 0.3%
Sulphur	" " " 0.035%
Phosphorus	" " " 0.035%
Nickel	" " " 0.5%
Vanadium	May be present up to 0.25%

Ni-Cr-Mo Steel.

Carbons	0.22 - 0.32%
Nickel	2.2 - 2.6%
Chrome	0.6 - 0.9%
Molybdenum	0.25 - 0.45%
Silicon	Not more than 0.3%
Sulphur	" " " 0.035%
Phosphorus	" " " 0.035%
Vanadium	May be present up to 0.15%.

In the preparation of the forging the ingot is stripped as soon as possible after complete solidification and is adequately cropped at top and bottom to remove any defects. It is customary to charge the billet without delay into a heating furnace while its temperature is above 600°C. The furnace having been previously prepared so that it is not more than 100°C. from the billet temperature. In this furnace the temperature of the billet is raised for blooming. In the case of 3% Cr. Steel the ingot is worked at temperatures not less than 850°C. and in the case of Ni-Cr-Mo steel at temperature not less than 800°C. After blooming the ingot is annealed slowly for trepanning. It is important that the size of the trepanned hole be sufficient to remove all central weaknesses. At this stage all laps and surface cracks are removed and sulphur prints are taken as required.

The trepanned forging is then heated slowly to the forging temperature, which for 3% Cr. steel is not less than 850°C. and for Ni-Cr-Mo steel not less than 800°C., and hollow forged. After forging the mild steel or 3% Cr. steel is heated to 900°C. and after obtaining a uniform temperature throughout is allowed to cool in the furnace. The Ni-Cr-Mo steel is heated above its upper critical range for sufficient time to achieve a uniform temperature and then cooled freely in air to 300-400°C., it is then soaked at 650°C. before being allowed to cool slowly.

The forging is then rough machined and in the case of the 3% Cr. and the Ni-Cr-Mo steels is hardened by quenching in oil at a temperature above the upper limit of the critical range of the steel. It is removed from the oil bath at a temperature just below the flash point of the oil and tempered by heating to 575-650°C. and then cooled in air. A final reheat to a temperature sufficiently high for an adequate period to relieve any stresses that might have been set up during the heat treatment is then carried out. The temperature and time of this final treatment is dictated by the thermal history and by experience of similar forgings.

Test pieces are then cut from the forging for tensile, bend and izod tests. The physical properties to be attained are as follows:-

	<u>M.S.</u>	<u>3% Cr.</u>	<u>Ni-Cr-Mo</u>
Ultimate tensile stress, tons/sq.in.	30-35	42-45	42-52
Elongation on 2", %	< 20	< 18	< 16
Reduction in area, %	< 35	< 35	< 35
Izod Impact, ft/lbs	-	< 30	< 30
Proof load, tons/sq.ins.	14-15	30	30

A bend test on a stand test piece is carried out and a microscopical examination of appropriate sections is also done to ensure that a fine grained sorbitic structure has been achieved.

The forging is then finish machined and hydraulically pressure tested.

Considerable importance is attached to the hydraulic pressure test which is carried out at a pressure 50% higher than the working pressure. The object of the test is to compare the permanent volumetric stretch and the volumetric stretch at full test pressure, and also to obtain a curve giving the volumetric strain over the pressure range.

The test is carried out by filling the forging with water and then by means of a small hydraulic ram pump raising the pressure in 50 ats steps to the full test pressure. At each step the volume of water added is recorded. The pressure is then let down in 50 ats steps and the water discharged at each step is measured. The results are recorded on the test sheet. The test is considered satisfactory if the ratio of permanent stretch to total stretch at full test pressure is less than 10% and when the graph of strain plotted against test pressure is a straight line.

In this test the volume compressive strain of the liquid is considerable and has to be accounted for. For thin walled vessels where the compressive strain of the forging is neglected the correction factor is:-

$$\frac{\text{Volume of water pumped in}}{\text{volume strain of cylinder}} = \frac{\frac{0.95 \text{ } pd}{Et} + \frac{p}{K}}{0.95 \frac{pd}{Et}}$$

$$= 1 + 1.05 \frac{Et}{Kd}$$

For water $K = 0.32 \times 10^6 \text{ lbs/in}^2$
and $E = 30 \times 10^6 \text{ lbs/in}^2$

$$\therefore \text{ correction factor } = 1 + 100 \frac{t}{d}$$

For thick walled vessels this expression becomes:-

$$= \frac{\frac{Et}{Kd}}{2\left(1 + \frac{1}{m}\right) \frac{t}{d} + \left(5 - \frac{4}{m}\right) \frac{d}{4(d+t)}}$$

where

t = wall thickness of forging
 d = internal diameter
 p = internal pressure
 E = mod. of elasticity of material of forging.
 K = bulk modulus
 $\frac{1}{m}$ = Poisson's ratio.

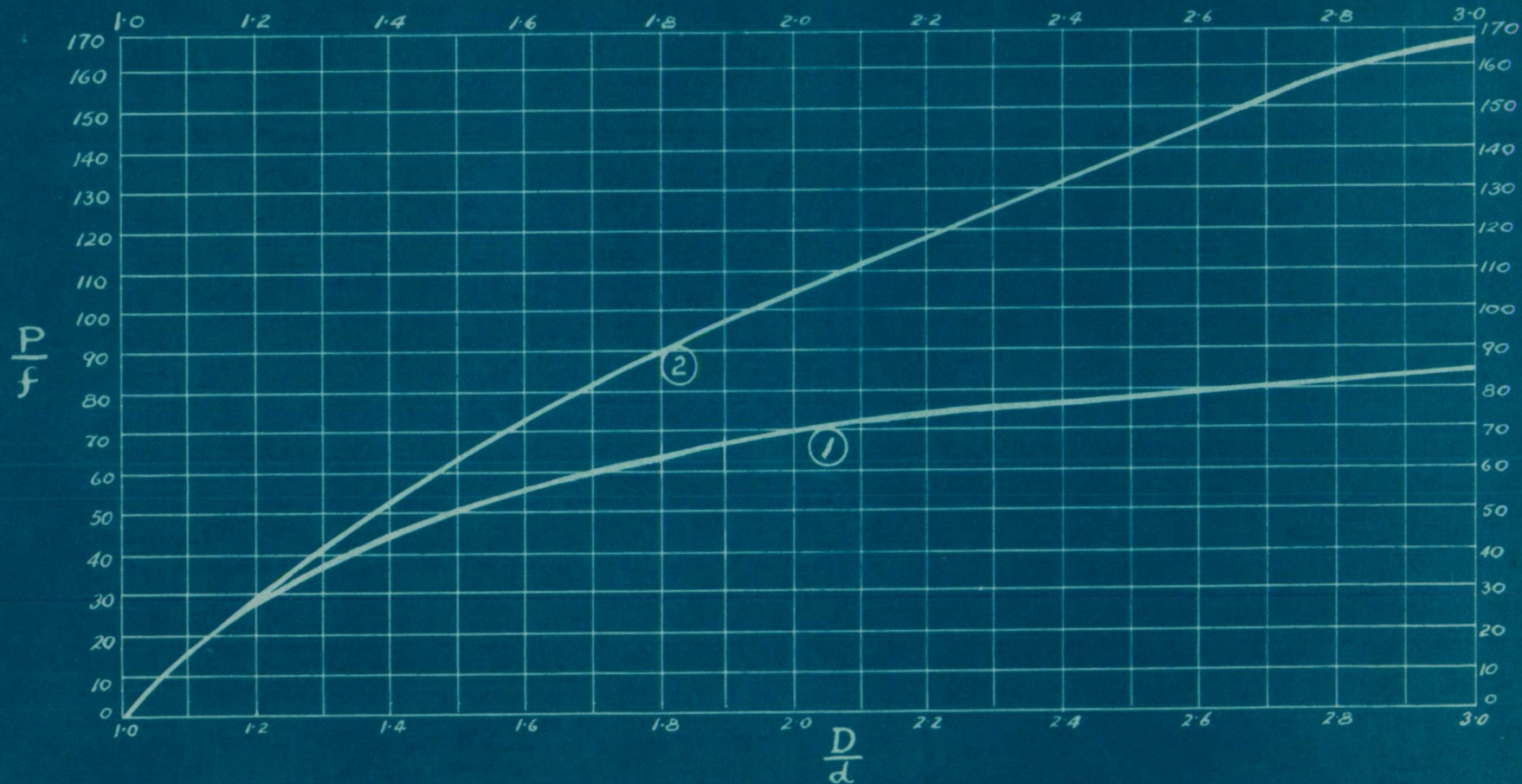
This expression leads to the following correction factors for various values of $\frac{t}{d}$

$\frac{t}{d}$	Corection factor.
0	$1 + 100 \left(\frac{t}{d}\right)$
0.1	$1 + 84 \left(\frac{t}{d}\right)$
0.2	$1 + 72 \left(\frac{t}{d}\right)$
0.3	$1 + 62 \left(\frac{t}{d}\right)$
0.4	$1 + 55 \left(\frac{t}{d}\right)$
0.5	$1 + 49 \left(\frac{t}{d}\right)$

STRENGTH OF THICK CYLINDERS

ACCORDING TO:-

- ① STRAIN ENERGY THEORY. (ELASTIC CONDITIONS)
- ② CREEP THEORY. (PLASTIC CONDITIONS.)



P = INTERNAL PRESSURE IN ATMOSPHERES

f = EFFECTIVE STRESS IN TONS/INCH²

D = EXTERNAL DIAMETER

d = INTERNAL DIAMETER

In the design of thick cylinders for pressures up to 350 ats working pressure where no appreciable creep takes place the strain energy theory is normally used. The attached graph relates the ratio of diameters with the effective stress and the internal pressure. In practice the process considerations normally dictate the inside diameter, the material of construction, the factor of safety to yield point, and hence the effective stress and the internal pressure, leaving only the outside diameter to be fixed.

For more accurate work the following formulae is applicable.

$$\left(\frac{D}{d}\right)^2 = \frac{1 + \sqrt{3.8\alpha^2 - 3.12\alpha^4}}{1 - 2.6\alpha^2}$$

$$\text{where } \alpha = \frac{np}{152.42f}$$

$$\text{or } \frac{np}{f} = 94.526 \frac{\left(\frac{D}{d}\right)^2 - 1}{\sqrt{\left(\frac{D}{d}\right)^4 + 0.46154}}$$

where n = factor of safety to yield point
 p = working pressure diff. in ats.
 f = yield point in tons/in² at working temperature.
 D = outside diameter any units.
 d = inside diameter in same units.

These formulae assume Poisson's ratio = 0.3 and are derived on a strain energy basis.

Forged pressure vessels are designed in such a way that all stresses are as nearly determinant as possible; this is achieved by observing the following conditions:-

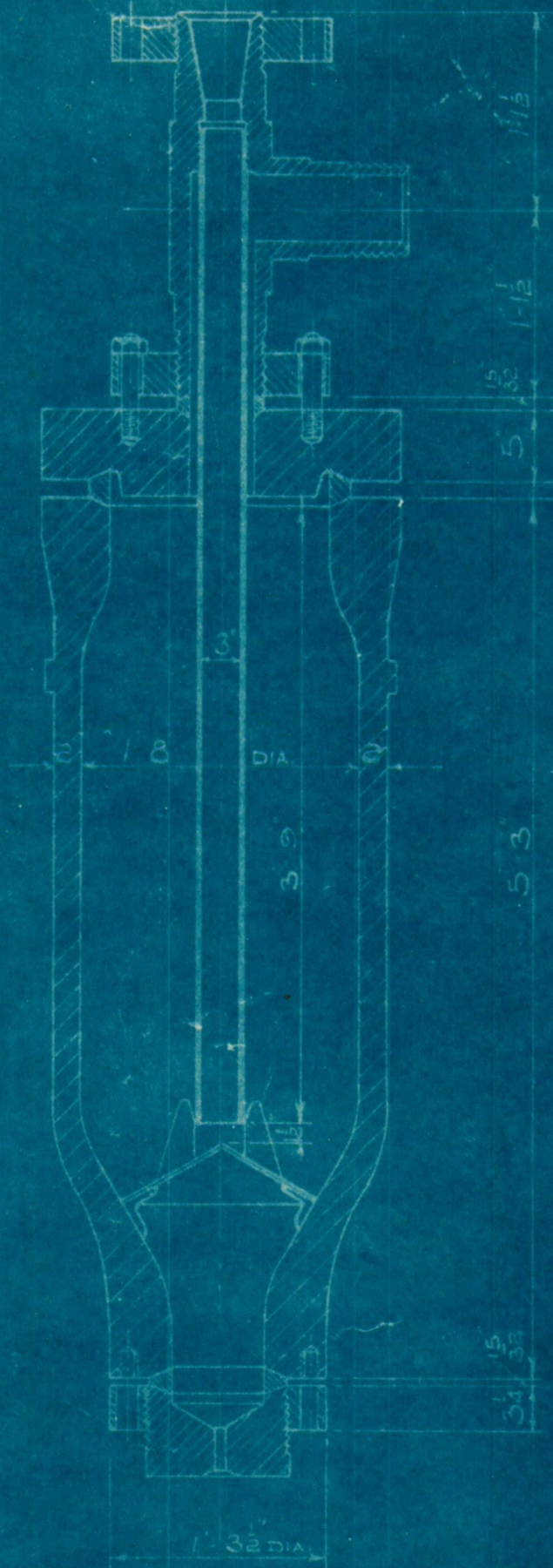
- (1) There are no sudden changes in section
- (2) There are no holes in the walls of the vessel. Normally the end covers carry the openings, where holes in the walls of the vessel are essential they are carried by a thickened ring machined into the vessel.
- (3) The bore is concentric with the external surface and there are no offset faces at the ends.

End closures usually require a thickening of the forging wall, and ample metal is allowable at these points for stud anchorage and joint stiffness.

For mild steel forgings it is usual to design vessels to an effective stress of 6.5 - 7 ton/sq.in.

For 3% Cr. and Ni-Cr-Mo steel vessels the conditions of service particularly the emergency conditions that are liable to occur usually increase the factor of safety to yield point that it is necessary to use thus reducing the effective stress used in design. For vessels such as ammonia converters where stresses induced by thermal shock may be present it is customary to use an effective stress figure of approximately 5 tons/sq.in.

It is not necessary to increase the elastic strength of H.P. vessels operating up to 350 ats pressure by any of the processes such as wire winding, compounding or auto-frettage, although these techniques can with advantage be employed on vessels operating at considerably higher pressures. It is



TYPICAL ARRANGEMENT OF CATCHPOTS

noteworthy that these strengthening processes affect the ultimate bursting pressure by only a few per cent as with a ductile material the dilatations which occur before bursting may be very considerable and are of the order of 20-25%.

IRON STUDS ARE USED IN CONNECTION WITH H.I. BOLTS their design requires careful attention. They are normally machined from Cr.No. steel fitted to the VOBOL in a hardened and tempered condition. The Whitworth form of thread is used in British practice, 6-8 W.T.I. being dictated according to the diameter of the stud. Sudden changes of section are avoided, the diameter of the stud is reduced to the thread root diameter at the end of the threaded portion, and gradually increased to the full stud diameter over a distance of half the stud diameter.

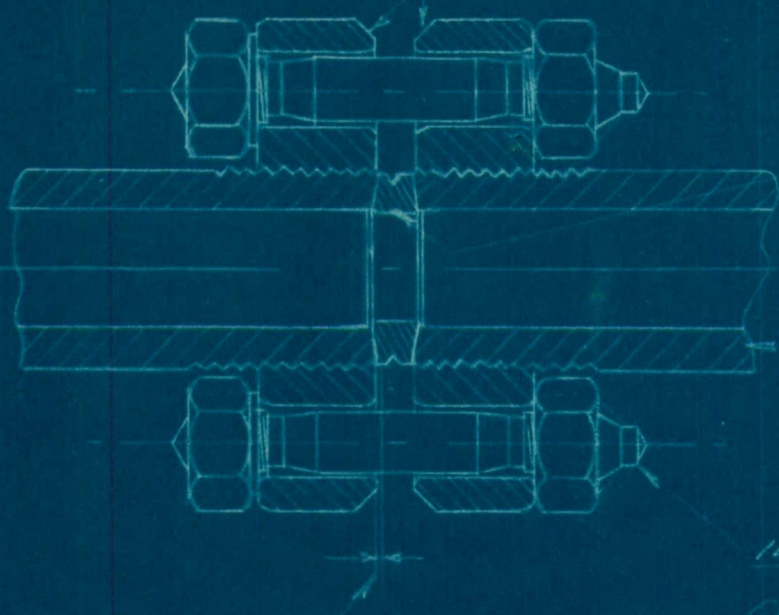
Cr.No. studs are usually designed on the basis of a maximum safe working stress of 30 tons/sq. inch at normal working pressure. This stress is made up of two components, the first being the initial stress imposed upon the stud to operate the joint and the second being the induced stress due to the internal pressure. The initial load that can be imposed upon a stud by tightening is assessed by the following formula:-

$$\begin{aligned} \text{Total bolt load (lbs)} &= 10,000 \pi (\text{stud diameter in ins.}) \\ &\quad \text{for } 4" \text{ and above studs.} \\ &= 24,000 \pi (\text{stud diameter in ins.}) \\ &\quad \text{for } 5\frac{1}{2}" \text{ and below studs.} \end{aligned}$$

This formula assumes that the studs are tightened by hand using a spanner 15 to 20 times the bolt diameter, and followed by a final hammering on a "logging" spanner. If greater stresses are required special methods must be resorted to i.e. heating studs, etc.

IDENTIFICATION CHAMFER FOR

0.4% MO. STEEL FLANGES.



LENS RING.

H.P. PIPE.

IDENTIFICATION HEAD FOR

CHROME-MO. STUDS.

PIPE END TO BE $\frac{1}{16}$ \"/>

TYPICAL ARRANGEMENT OF
H.P. PIPE JOINTS.

HIGH PRESSURE JOINTS AND COUPLINGS

LENS RING JOINTS

The lens ring joint is the simplest and most commonly used of all H.P. joints for small and medium joint sizes. In its crudest form the two parts to be joined are finished flat and pulled up against a ring which has convex curved surfaces on each side.

An improvement on this type is made where the ring mates with conical seatings; this is the form used in commercial practice. The mating faces are mitred at 30° in the case of vessels and 20° in the case of pipework. The 20° mitre gives less self tightening effect but the thickness of the ring is materially reduced, an important point in long pipe runs.

The lenticular surface of the ring is designed so that a line of contact is formed at or near the centre of the mitre face. On tightening the joint deformation of the curved surface takes place to a sufficient degree to ensure that the small surface irregularities are overcome.

In a properly designed lens ring the stiffness of the ring is made less than the stiffness of the restraining wall so that a self tightening effect is achieved when pressure is applied.

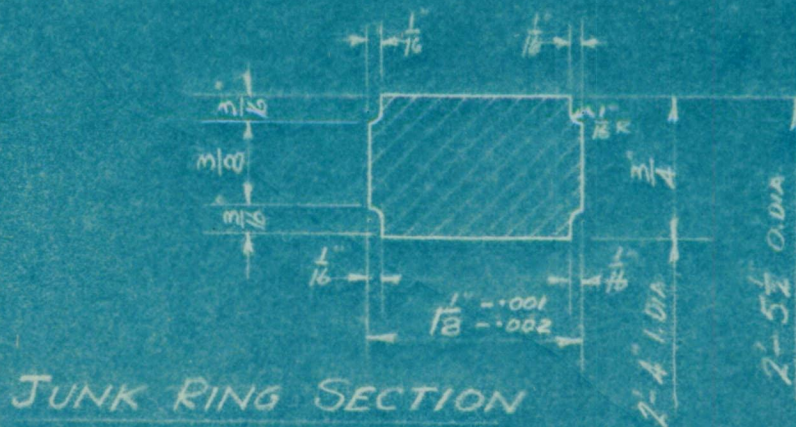
In the design of a lens ring to fit a 30° mitred joint on a vessel or end closure the bore of the ring is usually made the same as the bore of the vessel. The outside diameter of the ring is made equal to the outside diameter of the mitred face and the diameter of line contact is then fixed, equidistant between these two dimensions. It is convenient to make the radius of curvature of the lenticular surfaces equal to the contact circle diameter for 30° joints and this is usually done. Having fixed these dimensions a thickness of ring is chosen to give the required degree of stiffness. A pressure induced stress of 8 - 10 tons/sq. inch is sufficient for normal joints using a U.S. lens ring.

For pipe joints using lens rings the coupling is tightened by means of flanges screwed to the pipe. These flanges are an easy running fit and impose no radial restraint on the pipe. Lens rings for these joints must be less stiff than the corresponding pipe wall. In designing lens rings for these joints the bore of the ring is made equal to the bore of the pipe. The diameter of contact is chosen to give an appropriate sealing line on the mitred face. The radius of curvature of the lenticular faces is then determined such that

$$\frac{\text{diameter of contact circle}}{2 \times \text{radius of curvature}} = \sin 20$$

The ring thickness and outside diameter are chosen to achieve a suitable stiffness. Usually a pressure induced stress of 9 - 11 tons/sq. inch is used on U.S. lens rings and 10 - 12 tons/sq. inch for 3% chrome steel rings.

Lens ring joints can be made and remade a number of times without machining the mitred face and are easily assembled by unskilled labour. The rings are cheap and robust. These advantages make it a particularly suitable joint for general industrial use and it finds wide application in all sizes of joints up to 2 feet diameter.



VICKERS-ANDERSON JOINT AND COUPLING

This type of joint and coupling has been developed for use on large closures where the restraining forces are such that the number and size of the bolts and the flange dimensions required for normal joints would be inconveniently large.

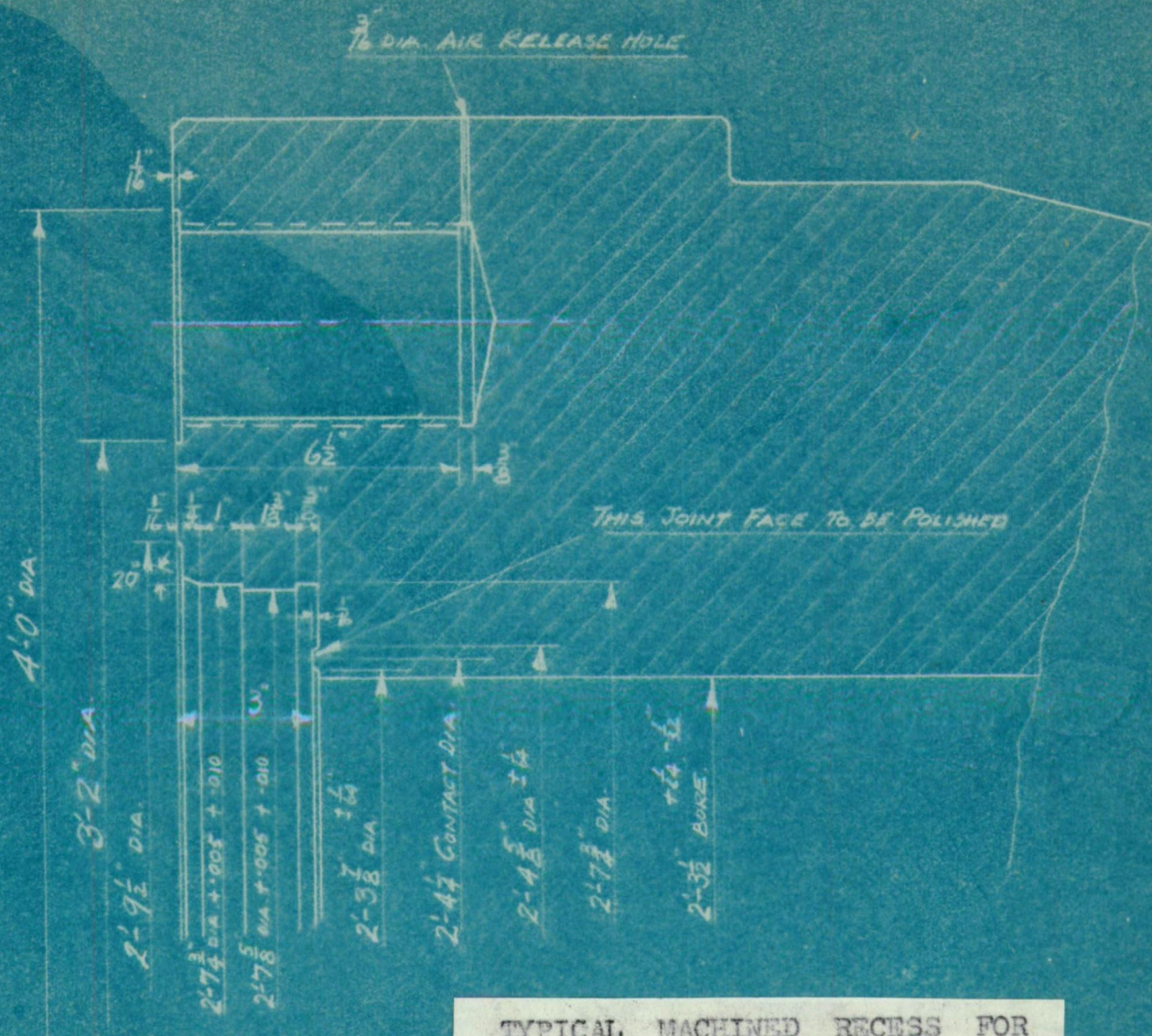
In the Vickers-Anderson joint the coupling is achieved by the use of a U-shaped three-segmented clamp ring which fits over a shoulder on the end of the vessel and over the end cover or mating section. Close contact and the required contact pressure is obtained by machining a conical surface on the adjacent faces of the clamp ring and the shoulders. The angle of this shoulder, which must be less than the friction angle of the materials used, is usually ca. $12\frac{1}{2}^{\circ}$. In order to make the conditions of operation determinate the sealing ring is designed so that the joint will be sealed when the adjacent faces of the mating sections are in contact. In making the coupling the two sections are brought together - they usually register by means of a spigot - and segments of the clamp ring are loosely placed in position. The gap between the mating faces of the main sections is then ascertained by means of feeler gauges and the reduction of the radial gaps in the clamp rings necessary to close the coupling calculated. A jacking ring is then placed over the clamp ring and the segments of the latter jacked up till the radial clearance is reduced sufficiently and then bolted in position by means of six clamp bolts. As the angle of the shoulder is less than the angle of friction of the material the clamp bolts are not required to hold the clamp ring in position; their chief uses are to assist in locating the clamp ring during assembly and to safeguard the segments from dislodgement by some external agency.

The jacking ring consists of a circular ring of hollow box section fabricated by welding from M.S. plate. It carries a number of small hydraulic jacks located radially which are connected to a common header. A small hydraulic ram pump supplies oil under pressure to the header for the operation of the ring. Usually 3 to 4 jacks are provided for each segment.

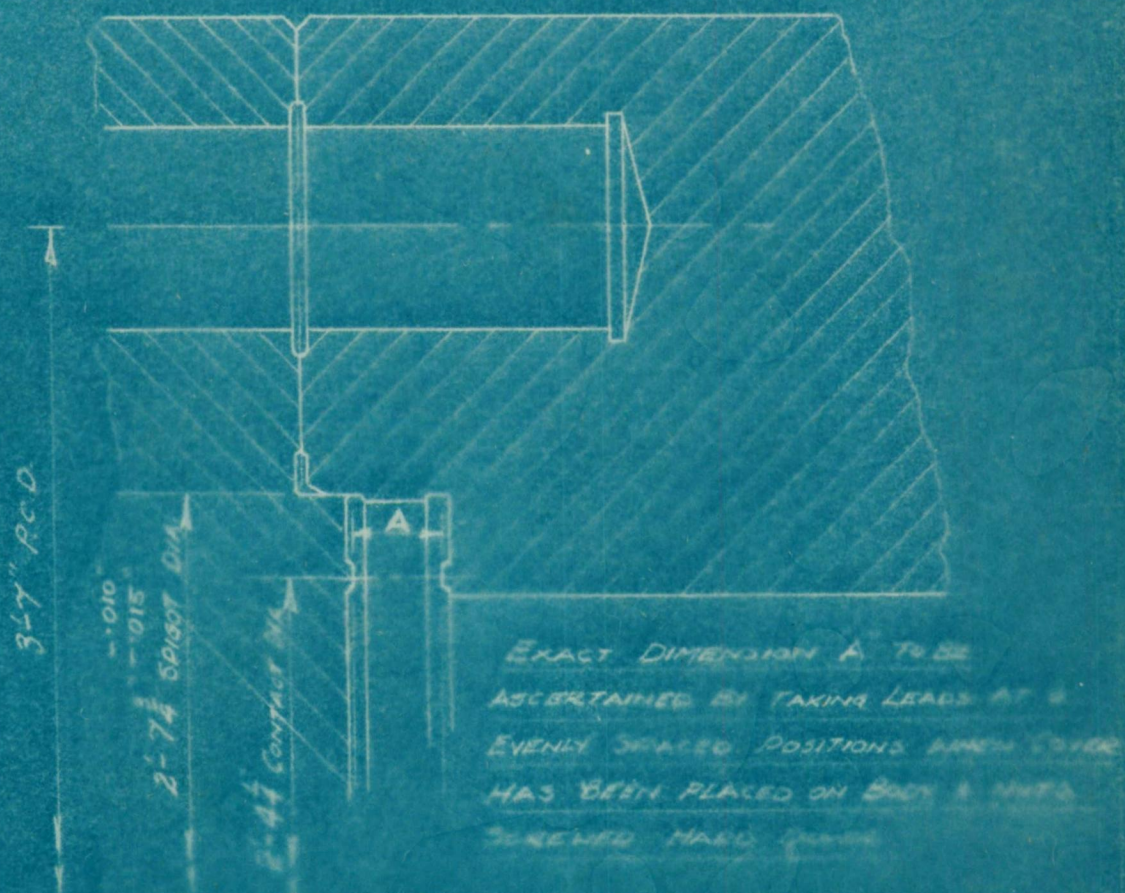
An alternative method of closing the coupling is to assemble the main sections without the obturating ring and then clamp the segments in position. A measurement of the radial gaps between the segments of the clamp ring will indicate the amount of jacking required when the coupling is subsequently assembled with the sealing ring in position.

Both the clamp ring and the shoulders on the main forgings are subject to a considerable bending moment; care is necessary in their design to prevent concentrations of stress at the inside corners of the conical faces. The clamp bolt holes are drilled through the corners of the segments at points of low stress.

The obturating ring for these couplings is normally a hollow U-ring which fits into a recess machined into the bore of the main forging. The joint faces are annular ridges on either side of the ring usually $\frac{1}{8}$ inch to $\frac{5}{32}$ inch wide by $\frac{1}{16}$ inch to $\frac{3}{32}$ inch high; a corresponding but wider face is machined on the mating faces of the main forgings. A junk ring fits into the hollow portion of the U-ring, this is segmented to facilitate its removal, the purpose of this ring is to provide a restraint against which the U-ring can be pressed. The size of the components is arranged so that there is an interference between the faces on the main forging and the faces of the U-ring; in the case illustrated this is 0.012 inches to 0.013 inches. On tightening the joint this interference is taken up in two ways, first by the deformation of the U-ring to conform to the junk ring



TYPICAL MACHINED RECESS FOR VICKERS-ANDERSON JOINT RING.



TYPICAL ARRANGEMENT OF FORGING ASSEMBLY FOR VICKERS-ANDERSON JOINT.

DIRECT BYEPASS
THIS BYEPASS IS
IN FORGING 9+7
ONLY

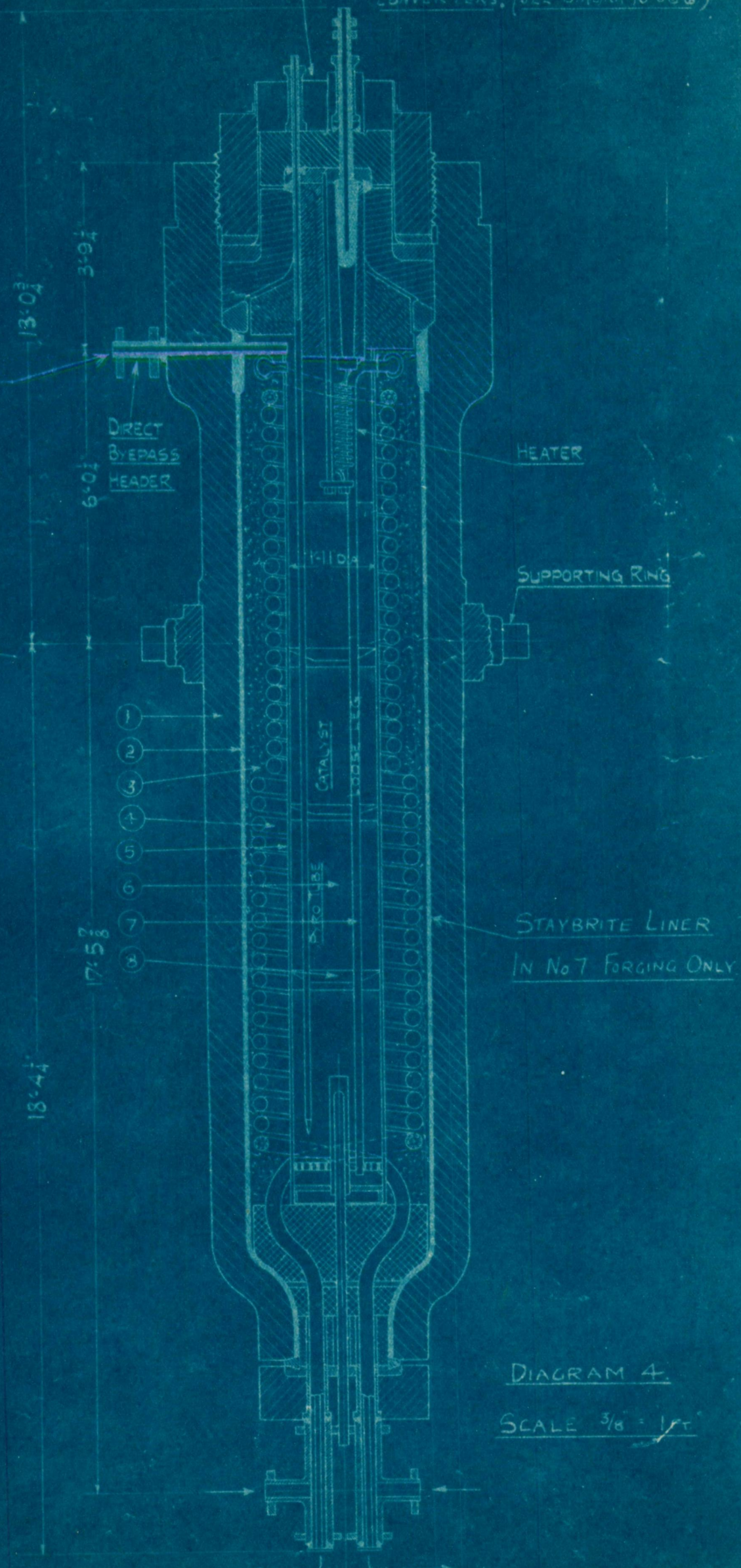


DIAGRAM 4.
SCALE 3/8" = 1'-0"

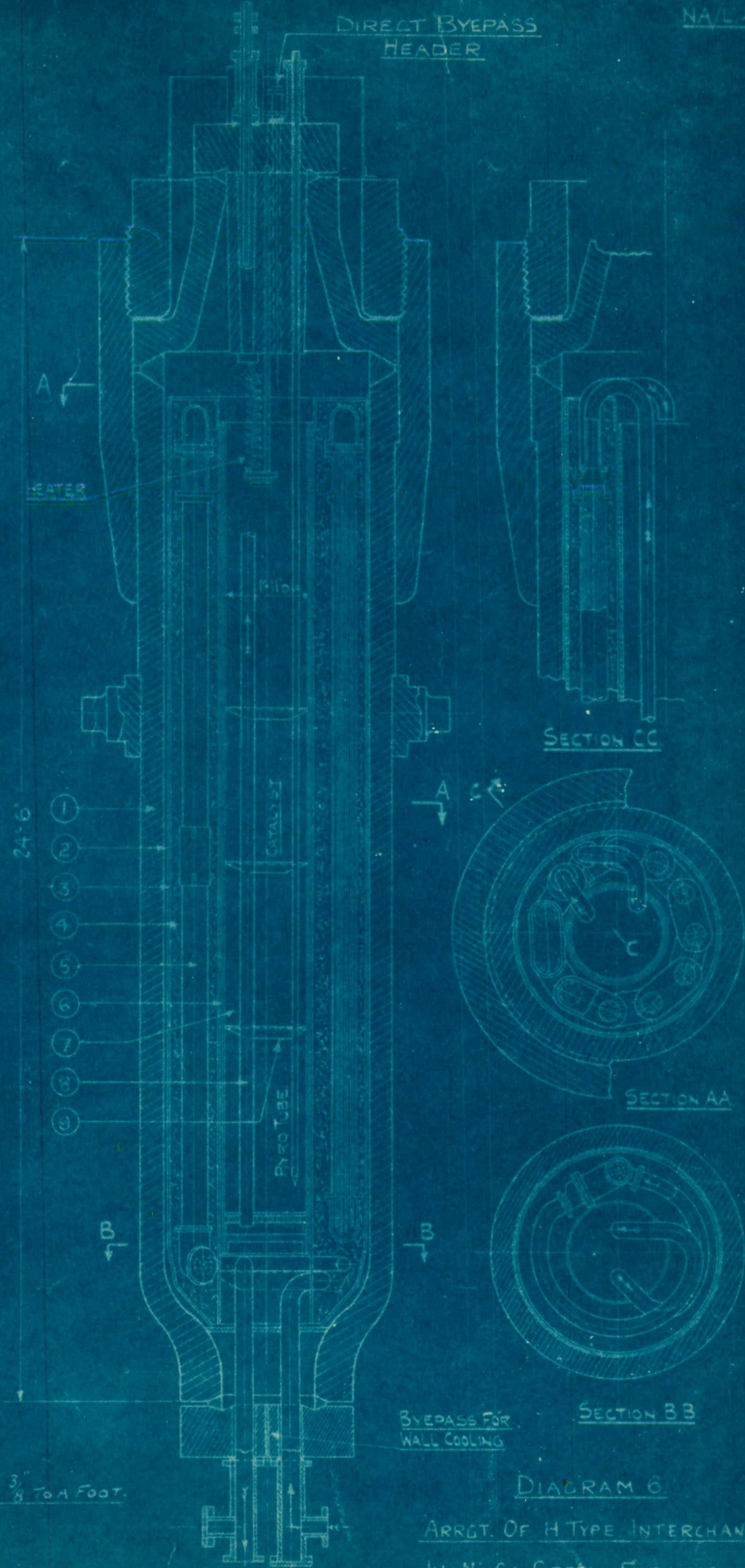


DIAGRAM 6

ARRGT. OF H TYPE INTERCHANGER
IN NI-CR STEEL FORGING

and second by the deformation of the four bearing surfaces. There are thus three forces tending to close the joint faces when under pressure. First that due to the elastic deflection of the ring, second that due to the deformation of the faces, third that due to internal pressure. The deformation of the faces is necessary to overcome small irregularities of the surface and this together with the elastic deflection ensures adequate obturation at low pressures. Under normal operating conditions the internal pressure which imparts a self sealing action to the ring is responsible for the generation of the major stresses; in the case illustrated the crushing stress generated under 350 ats is ca. 75,000 lbs./sq. inch and the tensile stress in the central portion of the ring due to internal pressure alone is ca 14,000 lbs./sq. inch.

A steel with good physical properties, usually a Nickel-Chrome Molybdenum steel is used for the U-ring; M.S. is suitable for the junk ring.

The clamp ring coupling arrangement is particularly suitable for large connections; it is normally used for closures of over 3 feet diameter and for smaller sizes where flanged joints are not suitable or where it is not possible to thicken the forging to carry studs.

The U section sealing ring is used with the Vickers-Anderson coupling and also in a variety of other cases where the space available on the bore of the vessel prevent the use of a lens ring. This type of joint can be broken and remade frequently without replacement of the ring. It seldom fails under pressure.

The Vickers-Anderson joint and coupling have replaced the earlier type of closure for large forgings which consisted of a plug screwed into an internal thread at the closure, the sealing in this case being achieved by the use of a lens ring.

Arrangements of these types of closures are shown.

WILLS PRESSURE FILLED JOINT RINGS

These jointing rings consist of a sealed ring made from a tube of suitable material such as aluminium or copper which is gas filled under pressure.

For sealing joints these rings are placed in a recess at the joint face and as the joint is made the ring is deformed by the two faces. The pressure of the gas within the tubular ring is sufficient to make the relatively soft ring seal any irregularities in the jointing faces.

One advantage of this type of joint is that the rings can be supplied in any desired shape to suit particular conditions. They find application in gas compressors and H.P. hydraulic machinery where the space for making joints and seals is restricted.

For general use they have several major disadvantages. The joint is not self sealing and once a leak starts it seldom takes up. A new ring must be used each time the joint is broken. It is imperative that the articles to be jointed should at some part bear metal to metal in order to prevent the compression of the ring to less than the designed figure; this criterion is additionally important to ensure that the ring is not fatigued under pulsating loads. Should the ring joints become damaged it is necessary not only to reform them but also to turn down the whole of one bearing face to bring the depth of the ring groove back to the correct figure; this may in some cases be disadvantageous.

For sealing closures up to 2½ inches o.d., 1/16-inch, 3/32-inch and 1/8-inch tubing is used; from 2½ inches o.d. to 12 inches o.d. 3/32-inch and 3/16-inch tubing is used and above 12 inches o.d. 1/2-inch tubing is customary.

The following table is recommended as good practice:

<u>Operating Pressure</u> <u>Lbs/Sq. In.</u>	<u>O.d. of Ring</u>	<u>O.d. of Recess</u>	<u>Depth of Recess</u>
Up to 500	Y + 3d.	D + 0.03d.	0.73d.
1000	Y + 3d.	D + 0.09d.	0.70d.
3000	Y + 3d.	D + 0.10d.	0.63d.
3000	Y + 3d.	D + 0.11d.	0.66d.
4000	Y + 3d.	D + 0.12d.	0.64d.
5000	Y + 3d.	D + 0.13d.	0.63d.
6000	Y + 3d.	D + 0.14d.	0.66d.

Where Y is the bore of the closure,
D is the tube diameter from which the ring is made.

The recommended sizes of depth and width of recess are as follows:

<u>D.</u> <u>in.</u>	<u>Width of Recess</u> <u>in.</u>	<u>Depth of Recess for various pressures</u> <u>in inches (lbs/sq. inch)</u>						
		<u>500</u>	<u>1000</u>	<u>3000</u>	<u>3000</u>	<u>4000</u>	<u>5000</u>	<u>6000</u>
3/32	5/32	.015	.070	.036	.032	.059	.037	.055
1/8	3/16	.093	.088	.094	.090	.077	.075	.073
5/32	1/4	.117	.112	.103	.104	.101	.099	.097
3/16	5/16	.139	.133	.129	.125	.122	.120	.118
1/4	3/8	.179	.174	.170	.166	.163	.161	.159

WAVE RING JOINT*

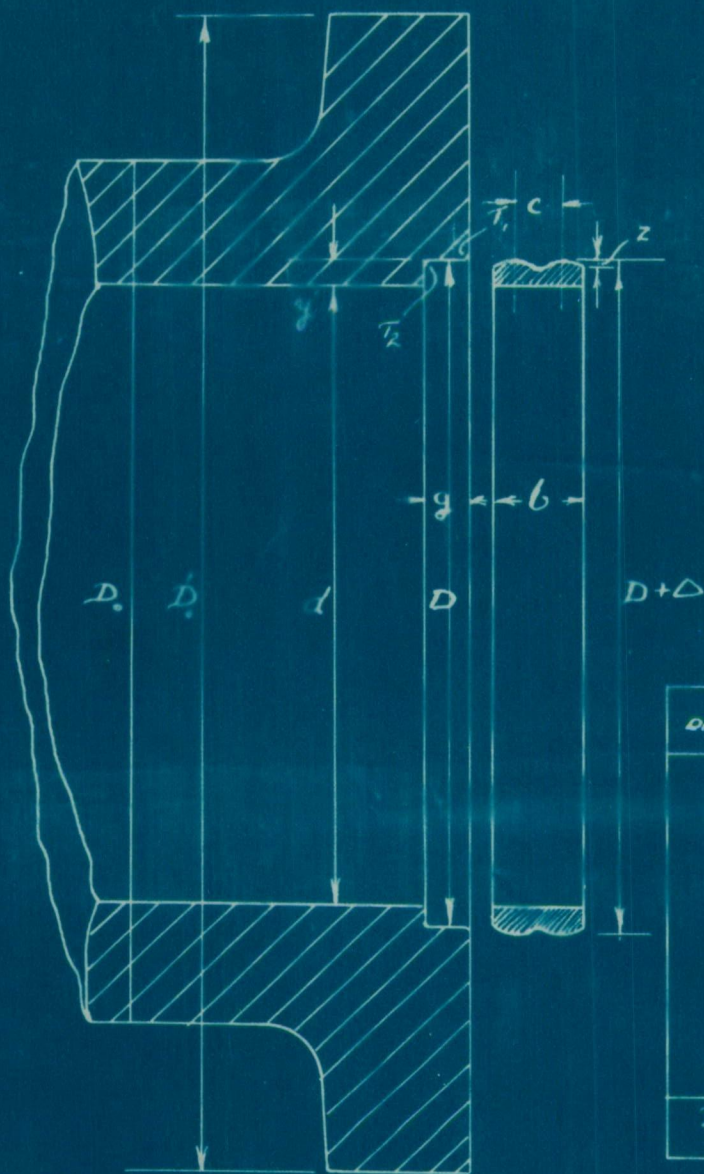
A wave ring joint assembly consists of a cylindrical ring with a double wave on the outer face fitting into recesses machined in the two items to be joined. The general dimensions are shown in the accompanying figure.

This type of joint, which is fully self-tightening, has been developed from the lens ring joint. A high degree of accuracy is required in preparing the components; the sockets must be identical, circular and parallel within fine tolerances, the interference between the sockets and the crests of the waves on the joint ring is of the order of 0.002" of the i.d. of the ring.

The joint ring can be made in a variety of metals, the following have proved satisfactory in service:

Mild Steel
3½ Chrome Steel
6½ Chrome Steel
13½ Chrome Steel
Austenitic 18/8/1/2 Steel
"Vibroc" Steel
Copper
70-30 Brass
Silver
Nickel
Monel Metal

* Acknowledgment - W.A.D. Manning - Chem. Eng.
Group 19/11/37.



DIMENSION	RECOMMENDED SIZE
l	$3 \text{ to } 5 \times y'$
g	$1.01 \times b/2$
c	$0.6 \times b$
z	$1/10 \text{ to } 1/5 \times b$
Δ	$0.0002 \text{ to } 0.0005 \times d$
T_1	$1/10 \text{ to } 1/5 \times y'$
T_2	$1/8 \text{ to } 1/4 \times y'$
$D_o'/D = D_o/d$	

DETAILS FOR WAVE-RING JOINT

EMG

Provided the walls of the sockets are sufficiently rigid to withstand the internal pressure without deformation and the ring sufficiently weak to deform under the working pressure a tight joint can be made. In normal practice the design of the ring is based upon elastic stressing, this occurs for rings of normal profile when

$$y^1 > \frac{Pd}{6Y}$$

P = internal pressure
d = bore of ring
Y = tensile yield stress
y¹ = greatest ring thickness

It is customary, therefore, to make the i.d. of the ring equal to the bore of the pipe and

$$\frac{Pd}{2Y} > y^1 > \frac{Pd}{5Y}$$

An important detail in shaping the sockets is the lead or radius that is given to the mouth to enable the ring to be pushed home squarely without damage. The rings are usually "flashed" with copper and the sockets well lubricated before assembly.

One advantage of these joints is that the axial thrusts on the coupling are lower than most other H.P. joints and are completely determinant. There is an appreciable amount of "give" in the joints which is an advantage where "creep" is liable to occur. On the other hand the first cost of the rings is high, they are easily damaged, and a wide gap is required for making and breaking joints which is not always available on long pipe lines. For these reasons the ring has never replaced the more robust lens ring for smaller diameters or the Vickers-Anderson joint ring for larger sizes of joints. It is particularly suitable for very high pressures and recent developments in the organic synthesis field at pressures over 1,000 ats may lead to its application in the industrial field.

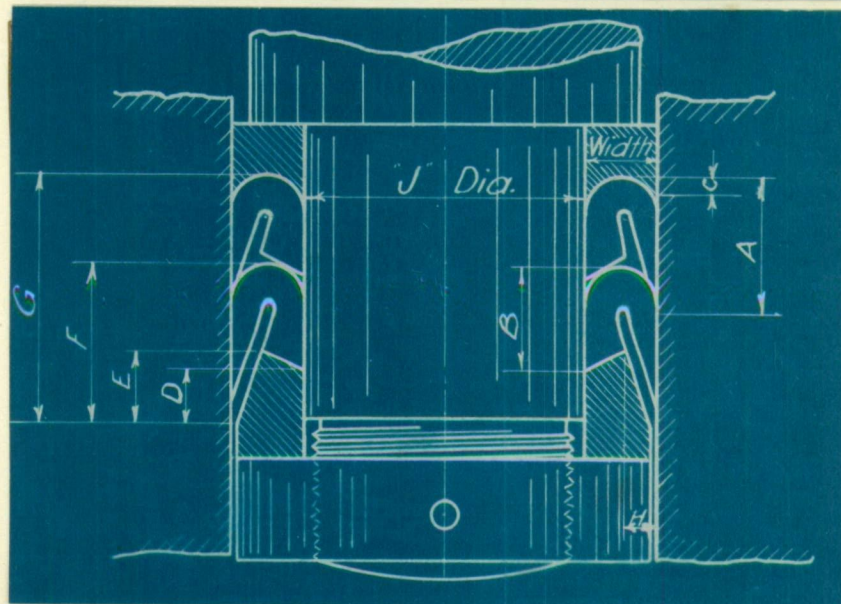
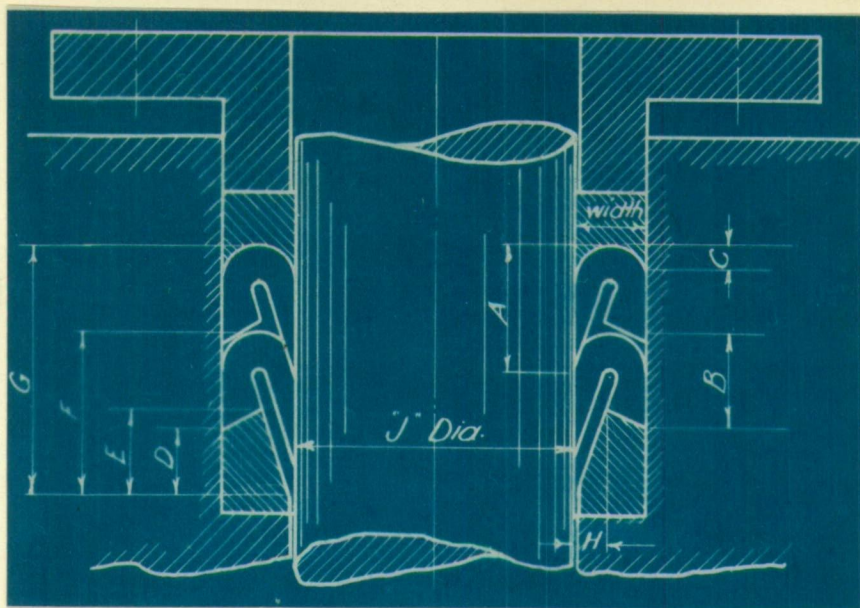
SPIGOT AND SOCKET JOINT

A useful joint for small closures where space is limited is the spigot and socket arrangement. Obturation is achieved by means of a sealing ring of compressed asbestos fibre reinforced with woven wire or by a serrated metal ring. It is necessary to give lateral support to the joint ring and for this reason it is usually located in an annular recess or seated on the centre of a triple stepped face.

The main disadvantage of this type of closure is the fact that it is not self sealing; it thus requires high bearing pressures for satisfactory operation and this limits the maximum practical size of the ring to about 6 inches diameter. When used on machines and items of plant the sealing pressure is normally achieved by a ring of studs although American practice favours the use of union nuts for small sizes.

Where compressed asbestos fibre rings are used the ring is designed to fit snugly into the seating recess. Thin sections are used - normally 1/32 inch thick - and the width varies from 1/8 inch for small diameters up to 3/8 inch. The bearing pressure required for satisfactory sealing at 360 ats. is 4 - 6 tons/sq. inch.

In the case of metal sealing rings the section of the ring is designed to give line contact. The initial bearing pressure is two to three times the crushing stress of the jointing material resulting in considerable deformation of the ring during tightening.

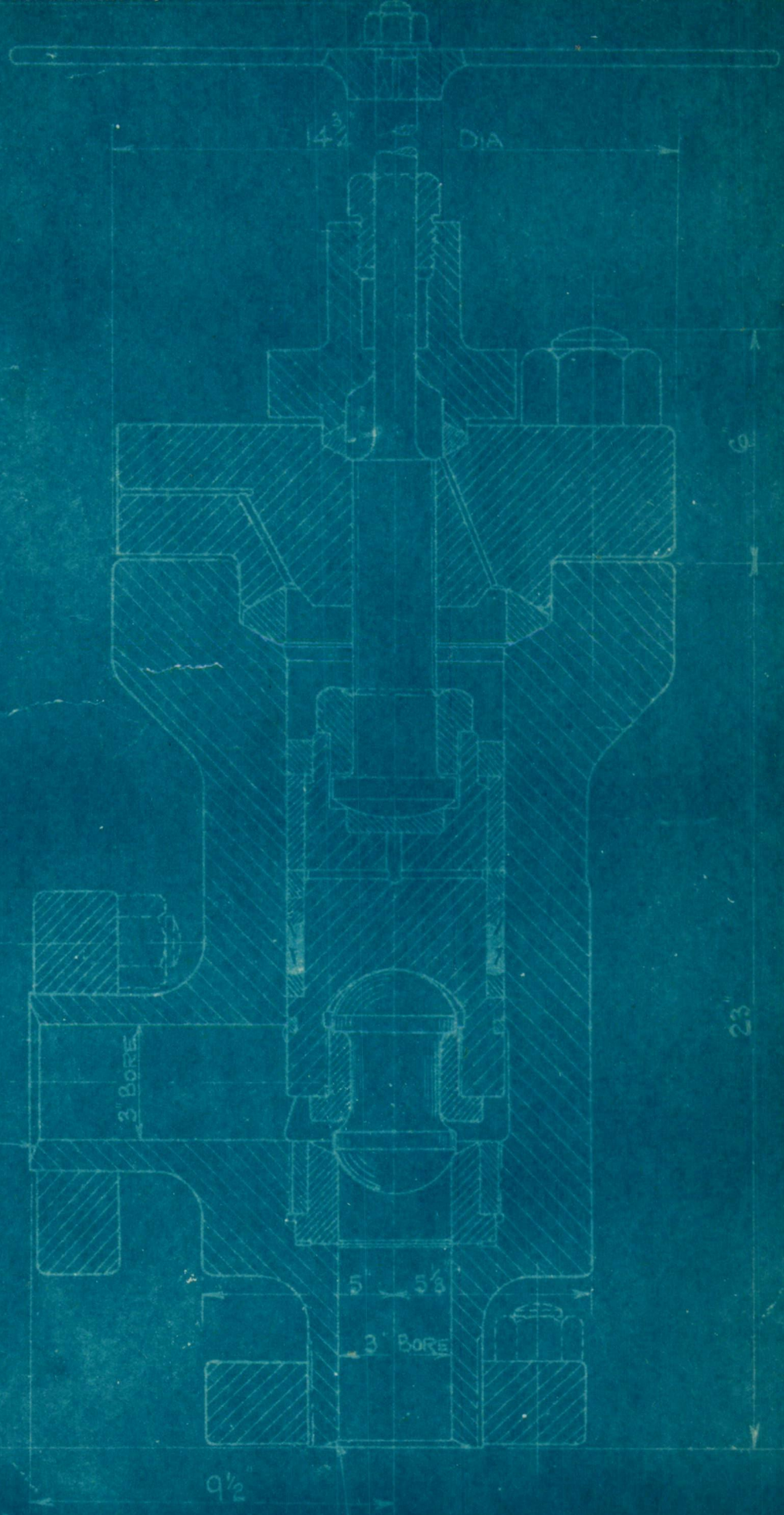


Width	A	B	C	D	E	F	G	H	J
$\frac{1}{4}$ "	$\frac{3}{8}$ "	$\frac{5}{16}$ "	$\frac{1}{32}$ "	$\frac{5}{32}$ "	$\frac{7}{32}$ "	$\frac{15}{32}$ "	$\frac{47}{64}$ "		
$\frac{5}{16}$ "	$\frac{9}{16}$ "	$\frac{7}{16}$ "	$\frac{1}{32}$ "	$\frac{9}{32}$ "	$\frac{3}{8}$ "	$\frac{23}{32}$ "	$\frac{13}{32}$ "		
$\frac{3}{8}$ "	$\frac{21}{32}$ "	$\frac{1}{2}$ "	$\frac{1}{16}$ "	$\frac{11}{32}$ "	$\frac{7}{16}$ "	$\frac{27}{32}$ "	$\frac{19}{32}$ "	$\frac{5}{32}$ "	
$\frac{7}{16}$ "	$\frac{49}{64}$ "	$\frac{31}{64}$ "	$\frac{1}{16}$ "	$\frac{13}{32}$ "	$\frac{1}{2}$ "	$\frac{63}{64}$ "	$\frac{1}{2}$ "	$\frac{13}{64}$ "	
$\frac{1}{2}$ "	$\frac{7}{8}$ "	$\frac{21}{32}$ "	$\frac{1}{16}$ "	$\frac{7}{16}$ "	$\frac{9}{16}$ "	$\frac{13}{32}$ "	$\frac{21}{32}$ "	$\frac{7}{32}$ "	
$\frac{5}{8}$ "	$\frac{13}{32}$ "	$\frac{53}{64}$ "	$\frac{3}{32}$ "	$\frac{35}{64}$ "	$\frac{11}{16}$ "	$\frac{13}{8}$ "	$\frac{23}{32}$ "	$\frac{17}{64}$ "	
$\frac{3}{4}$ "	$\frac{15}{16}$ "	1 "	$\frac{1}{8}$ "	$\frac{21}{32}$ "	$\frac{13}{16}$ "	$\frac{121}{32}$ "	$\frac{29}{16}$ "	$\frac{21}{64}$ "	
$\frac{7}{8}$ "	$\frac{17}{32}$ "	$\frac{15}{32}$ "	$\frac{1}{8}$ "	$\frac{13}{16}$ "	1 "	$\frac{131}{32}$ "	3 "	$\frac{3}{8}$ "	
1 "	$\frac{13}{4}$ "	$\frac{15}{16}$ "	$\frac{1}{8}$ "	$\frac{59}{64}$ "	$\frac{1}{8}$ "	$\frac{215}{64}$ "	$\frac{25}{64}$ "	$\frac{7}{16}$ "	
$\frac{1}{8}$ "	$\frac{163}{64}$ "	$\frac{133}{64}$ "	$\frac{1}{8}$ "	$\frac{7}{8}$ "	$\frac{1}{8}$ "	$\frac{225}{64}$ "	$\frac{33}{64}$ "	$\frac{15}{32}$ "	
$\frac{1}{4}$ "	$\frac{25}{32}$ "	$\frac{121}{32}$ "	$\frac{3}{16}$ "	1 "	$\frac{1}{4}$ "	$\frac{221}{32}$ "	$\frac{41}{8}$ "	$\frac{17}{32}$ "	
$\frac{3}{8}$ "	$\frac{211}{32}$ "	$\frac{125}{32}$ "	$\frac{3}{16}$ "	$\frac{123}{64}$ "	$\frac{19}{32}$ "	$\frac{39}{64}$ "	$\frac{425}{64}$ "	$\frac{39}{64}$ "	
$\frac{1}{2}$ "	$\frac{25}{8}$ "	2 "	$\frac{1}{4}$ "	$\frac{113}{32}$ "	$\frac{11}{16}$ "	$\frac{313}{32}$ "	$\frac{513}{64}$ "	$\frac{41}{64}$ "	
$\frac{3}{4}$ "	$\frac{31}{32}$ "	$\frac{25}{16}$ "	$\frac{1}{4}$ "	$\frac{123}{32}$ "	$\frac{1}{2}$ "	$\frac{41}{32}$ "	$\frac{61}{8}$ "	$\frac{49}{64}$ "	
2 "	$\frac{37}{16}$ "	$\frac{25}{8}$ "	$\frac{1}{4}$ "	$\frac{155}{64}$ "	$\frac{1}{4}$ "	$\frac{431}{64}$ "	$\frac{653}{64}$ "	$\frac{7}{8}$ "	

DIAMETERS TO SUIT JOB AS REQUIRED

GLAND SEALING RINGS SHOWING STANDARD SIZES.

2'-4" WHEN FULLY OPEN



Because they are not self-sealing, both these joints are liable to develop leaks under pulsating pressures. New rings must be used each time the joint is broken.

Gland Rings

Self sealing gland rings are used in glands where rotary motion is required. There are two normal types: the standard pattern sealing against the rotating shaft or spindle, and the inverted type which is fixed to the central element and seals against the cylindrical walls of the housing. Both these types are illustrated, together with the leading dimensions of stock sizes.

The rings are of molded rubber reinforced with fabric. Various types are obtainable for specific duties, i.e. neoprene for applications where oil will be present, etc. For the majority of duties natural rubber is used.

They give satisfactory service in cases where rotary motion only is encountered, but for reciprocating translatory motion they have only a limited life due to the disintegration of the rubber at thin sections. Their main application is in the sealing of valve spindles.

HIGH PRESSURE PIPES AND FITTINGS.

High Pressure Pipes.

For pressures above a few hundred lbs./sq. in., seamless, solid drawn steel tubing is used exclusively.

The material of construction is low carbon steel for normal purposes having the following physical properties:-

Ultimate tensile stress	Not less than 25 tons/sq. in.
Yield stress	" " " 50% U.T.S.
Elongation on 2"	" " " 25%
Reduction of area	" " " 45%

For high temperature conditions pipework manufactured from 3% Cr. steel is normally used and the following physical properties are specified.

Ultimate tensile stress	Not less than 35 tons/sq. in.
Elongation on 2"	" " " 23%
Reduction of area	" " " 45%

The 3% Cr. piping is suitable for temperatures up to 450°C., and the low carbon steel piping for temperatures up to 200°C.

For industrial use the application of H.P. piping is standardised both as regards working pressure and pipe sizes. British practice on ammonia synthesis and high pressure hydrogenation processes is to confine the design of H.P. pipes and fittings to three pressure ranges - up to 55 ats., up to 260 ats., and up to 360 ats. The following tables list the standard sizes of pipe in these three ranges.

1. Low Carbon 55 ats. piping.

<u>Nominal Bore</u>	<u>Outside Diameter</u>	<u>Wall Thickness</u>
2½"	3¼ + .065" - .0	⅜ + .04" - .04
3"	3⅜ + .075" - .0	⅜ + .04" - .04
6"	7 + .14" - .0	½ + .05" - .05
8"	9⅛ + .185" - .0	9/16 + .06" - .06
12"	13-11/16 + .275" - .0	27/32 + .085" - .085
16"	18 + .36" - .0	1 + .10" - .10

2. 260 ats. - 200°C. piping.

<u>Nominal Bore</u>	<u>Outside Diameter</u>	<u>Wall Thickness</u>
2"	3-9/32 + .07" - 0	41/64 + .065" - .065
3"	4-11/16 + .095" - 0	27/32 + .085" - .085

2. 260 ats. - 200 c. piping (cont.)

Nominal Bore	Outside Diameter	Wall Thickness
4"	6-3/16 + .125" - 0	1-3/32 + .110" - .110
5"	7-25/32 + .16" - 0	1-25/64 + .140" - .140
6"	9 1/4 + .185" - 0	1 1/8 + .165" - .165

3. 360 ats. - 200c. piping.

Nominal Bore	Outside Diameter	Wall Thickness
3/16 + 0" - .031	1 1/16 + .031" - 0	-
3/8 + 0" - .031	27/32 + .031" - 0	-
1/2 + 0" - .031	1-1/32 + .031" - 0	-
3/4 + .015" - .046	2-5/32 + .062" - 0	-
2"	3 1/8 + .075" - 0	1 7/8 + .087" - .087
3"	5 1/2 + .11" - 0	1 3/4 + .125" - .125
4"	7.1 + .142" - 0	1.55 + .155" - .155
5"	8.85 + .177" - 0	1.925 + .192" - .192

4. 360 ats. - 450°c. - 3% Chrome Steel Piping.

Nominal Bore	Outside Diameter	Wall Thickness
1 1/4 + 0" - .031	1-1/16 + .031" - 0	-
1 1/2 + 0" - .031	1-11/16 + .031" - 0	-
1 3/4 + .02" - .05	2-1/32 + .07" - 0	-
2"	3-3/32 + .1" - 0	35/64 + .054" - .054
3"	4-9/16 + .091" - 0	25/32 + .077" - .077
4"	6 + .120" - 0	1 + .10" - .10
4 1/2"	6 3/4 + .135" - 0	1-1/16 + .106" - .106
5"	7 3/8 + .147" - 0	1-3/16 + .119" - .119

The maximum safe stress allowed in low carbon tubing is 10,500 lbs./sq. in., and the formula used for computing wall thickness is:-

$$T = \frac{Pd}{2S} + C$$

when T = wall thickness

P = test pressure (1½ working pressure)

S = max. safe tensile stress

C = factor varying from 0.18 for 3/16" bore to 0.05 for 5" bore tubing.

The maximum safe stress for 3% chrome tubing is 21,000 lbs./sq. in. at the test pressure of 700 ats. The factor in this instance varies from 0.155 for small piping to zero at 4" bore tubing and above.

The cost of H.P. tubing is high and in the design of H.P. plants the quantity of pipework required is considerable. In addition, the compression costs involved represent an appreciable proportion of the total operating costs. In order to assess the optimum pipe diameter required for a specific duty the capital cost of the pipework and the cost of the pressure drop involved is expressed as a function of the pipe diameter. By differentiating with respect to the diameter and equating to zero, an expression is obtained giving the most economic pipe diameter. Two cases arise - one when the Reynolds number is very large and where the friction factor can be considered constant, the other for turbulent flow where the friction factor is considered to be proportional to the - 0.24th power of the Reynolds number.

In the first of these cases the optimum pipe diameter can be expressed by the following equation:-

$$d_{opt.} = \sqrt[7]{\frac{64 a f p^1 V^3 b}{15 \pi^3 (K^2 - 1) c p e g}}$$

and in the second case -

$$d_{opt.} = 0.3649 \cdot 6.76 \sqrt[6]{\frac{p^1 0.76 v^{2.76} \mu^{0.24} a b}{(K^2 - 1) c p e}}$$

where f = friction factor in the Fanning Equation

g = acceleration due to gravity, M/sec²

e = Fixed charge rate of pipe/year

a = working hours per year

b = cost of power (K.W.H.) charged at the switch board for every horse power absorbed in compression. £.

d = inside diameter of pipe. M.

k = ratio of outside diameter to inside diameter

c = cost of pipe material per unit weight. £/kg.

p = fluid density under pressure. kg/M³

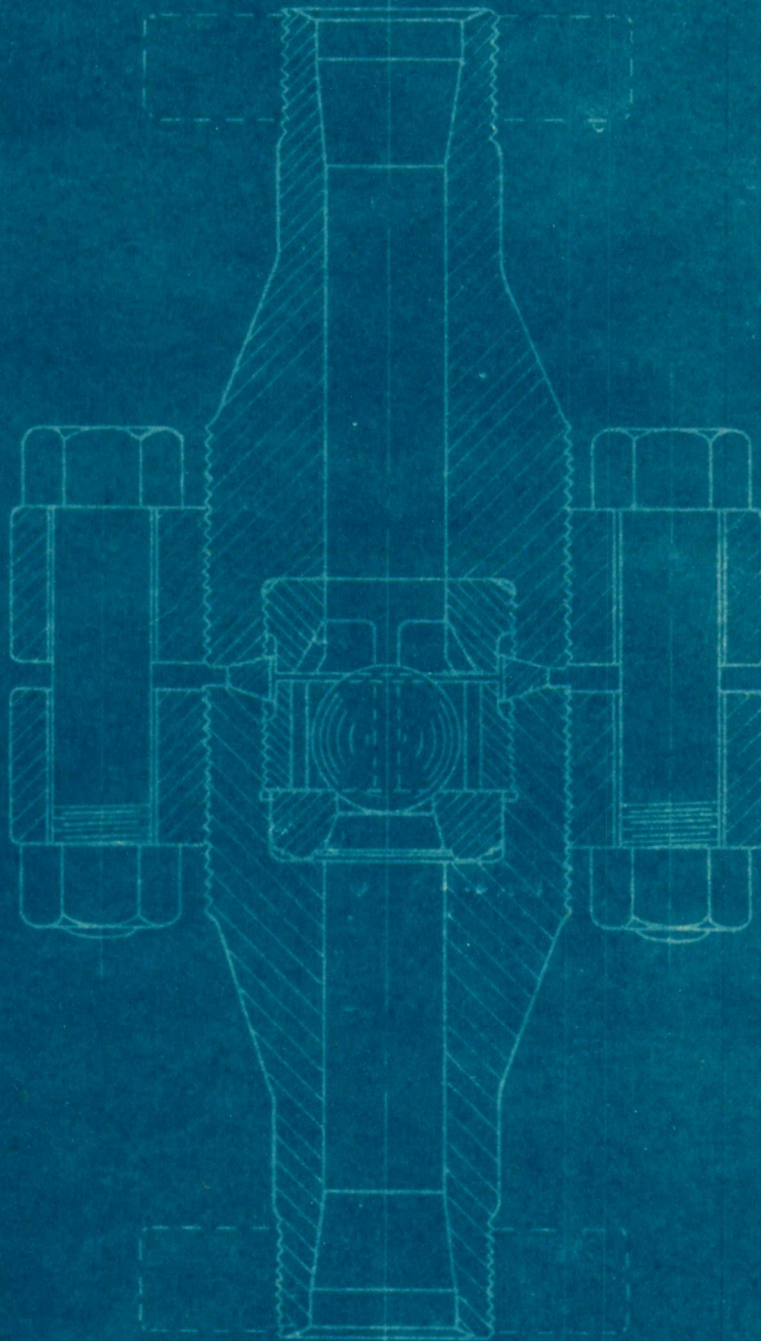
p¹ = density of pipe material. kg/M³

V = volume of fluid passing through pipe under pressure in unit time. M³/sec.

μ = viscosity of flow of fluid under pressure. kg/M/sec.

In the second case, the modified Blasius equation $f = 0.087 (dv p^1 / \mu) - 0.24$ is assumed to be applicable.

The former equation is normally appropriate for gases and the latter for liquids. Under the current prices of power and steel operating on the Mainland of Australia, the optimum velocity for gases and liquids works out at



3" SINGLE BALL TYPE NONRETURN VALVE

20 - 22 ft./sec. and 5 - 7 ft./sec. respectively.

Manufacture of H.P. Pipes.

H.P. tubes may be either hot drawn or cold drawn and it is left to the discretion of the manufacturer as to which process shall be employed for particular sizes of pipe.

Care is required in forging the billet before drawing to ensure that sufficient work has been expended upon it to completely break down the cast structure. Test pieces and, if necessary, sulphur prints are taken at this stage to check that the condition of the steel is satisfactory for the subsequent processes.

If the tubes are hot drawn they are delivered in the hot finished condition. If cold drawn they are normalised after drawing by heating above the critical range of the steel and then cooling freely in air.

A set of test pieces is taken for every 500 ft. run. In addition to the normal tests, a flattening test is carried out which consists of cold flattening a short length of tube to half its original diameter. This test is particularly useful in showing up longitudinal cracks and fissures which have been perpetrated and magnified during the sinking process. Cases have been found where these fine cracks extended half way through the tube wall.

The tubes are required to be straight to within $\frac{1}{8}$ " in 10 ft. and to be parallel to within $\frac{1}{16}$ " in 25 ft.

Pipe Fittings.

Pipe fittings are made up in standard sizes to match the various standard pipe sizes and standard working pressures. The units are forged from low carbon steel similar in composition to that used for H.P. tubing. Special care is exercised in the various forging steps to ensure that there is sufficient work expended on the billet to break down the "as cast" structure and to achieve suitable flow patterns at bends and at changes of section.

The following fittings are those usually employed for industrial practice:-

Reducers. Obtainable in most pipe sizes but not in applications calling for a reduction from large to very small pipe diameters; in these instances single branch connections are normally used. The reducers are screwed at either end to carry flanges; the ends are machined to form a lens ring seat. The tapered section of the reducer is kept short; sudden changes of section are avoided but 20 - 400 tapers are used.

Elbows. These may be equal or unequal elbows. The branches are screwed and the end faces are machined to form a standard lens ring seat. The body of the elbow is normally left in the "as forged" condition.

Tees and Crosses. The former may be equal or unequal but the latter are usually equal. They are finished in a similar manner to the elbow fittings.

Single and Double Branch Connections. These fittings constitute a very useful means of tapping a small branch into a relatively large pipe. The single branch connection consists

essentially of a thickened lens ring with a long protuberance extending from one side. This extension is drilled down the centre thus forming a branch connection from the main pipe on which the lens ring is located in the usual way. The branch is screwed and mitred at its extremity to form the usual H.P. joint.

Pressure points, sample points, analysis points, etc. all employ branch connections to tap into the piping system.

Double branch connections are similar to single branch connections but a second branch is added usually diametrically opposite the first branch.

Plugs. These fittings are used for blanking off H.P. pipe lines. They consist of a solid bar of metal whose length is usually three times the appropriate flange thickness; one end of the bar is drilled a short distance to correspond with the internal bore of the H.P. pipe. The outside of this end of the bar is screwed to take an H.P. flange and the usual 20° mitre is machined on the face. With the aid of a lens ring a standard H.P. joint is made between the H.P. pipe and the plug thus effectively sealing off the end of the pipe.

HIGH PRESSURE VALVES.

Stop Valves for use up to 360 ats.

In British practice stop valves are standardised to sizes corresponding to the various standard pipe bores and pressures. There are two basic designs, the hand operated and the hydraulically operated. The hand operated type is used for all sizes up to 3 in. for 55 ats, 250 ats and 360 ats pressures. Above these sizes hydraulically operated valves are essential due to the large operating forces involved.

All hand operated valves are right angled. They consist essentially of a rectangular forged steel body to which is screwed or bolted the valve spindle operating mechanism. The body is forged from low carbon steel and in the smaller sizes screwed projections on the inlet and outlet mate with the pipework. On the larger sizes a lens ring face is machined in the body at the inlet and outlet apertures and the body is drilled and tapped to carry studs by which the pipe flange is fastened to the valve body.

All valve noses and valve seats are removable and are turned from 18/8/1 stainless steel rod. Lock nuts hold them to the valve spindle and the valve body respectively. The valve seat is machined to give a right angled line ring contact and the noses which are self centring seal with 60° cone sections.

The spindle traversing gear is so arranged that the spindles are non-turning and the operating handles have no transverse movement. Sealing of the spindle is achieved by means of a set of three gland sealing rings and the thrust is normally taken by a built-in ball thrust race. The spindle and nut is cut with a square thread; the whole of the traversing gear, with the exception of the valve handle, is covered with a cylindrical sheet metal sheath.

The high operating pressures involved dictate the need for a robust design of valve which tends to make these valves relatively heavy. For example, a 2" 360 ats valve weighs 375 lbs. and measures 33" overall; the valve handle being 32" diameter. In order to prevent strain of the pipework and straining of the pipejoints, it is essential to mount the valves securely and this is done by drilling and tapping one of the faces of the rectangular body and by this means bolting the valve to the supporting structure.

Some designs for larger sized hand operated valves incorporate a gas balancing arrangement and a typical cross-section through a 250 ats 3" valve is shown. The valve nose and seat on this valve is the type used for hydraulically operated valves, the nose being self centring and fully floating and the seat is given a slight lead to guide the nose home as the valve is closing. The body of the valve is extended to allow the formation of a cylinder in which the valve plunger carrying the nose and spindle can move. This plunger is sealed with gland rings. A line from the H.P. side of the valve to the upper end of the balancing cylinder allows the valve to be easily closed by hand. It is noteworthy that this three inch valve which is 37½" overall weighs 850 lbs.

Hydraulically operated valves are used for all applications over 3" bore. They require the use of an auxiliary high pressure oil system for their operation. The smaller sizes are right angle valves and are similar in construction to the 3" gas balanced valve, the main difference being in the separation of the valve spindle from the valve

plunger. In the right angled type the spindle is useful for locking the valve after it has been closed. A safety measure of this type is essential in maintenance work to guard against the failure of the hydraulic system.

For larger hydraulically operated valves a straight through design is normally used. These are double sealing valves fitted with opposed plungers, the operating fluid being injected into the centre of the plunger cylinder. The gas passes through passages around the outside of the plunger cylinder. The same type of hemispherical seat as on the right angled valves is used. No locking spindle is possible in these straight through valves but a similar function is achieved by the use of isolating valves on the hydraulic lines.

Sample Valves.

These valves which are 1/8" in bore are used in cases where small gas samples are required or where pressure gauge connections lead off larger lines. They can be either straight through or right angled valves.

The bodies are forged from low carbon steel and are shaped so that two protuberances form the inlet and outlet connections. These are screwed (7/8 B.S.F.) to carry H.P. flanges and are machined to seat a standard lens ring. The upper portion of the valve body, which is 2" diameter, is drilled to carry the spindle and gland. The seal is provided by three gland rings surmounted by a locking nut. A bridge piece is screwed on to this portion of the body. The spindle, which is 1/4" diameter, screws through the bridge piece and passes down through the gland to the seat. 1/8" lines are drilled obliquely from above and below the seat to the inlet and outlet connections. The small size of these valves prevent the use of replaceable noses and seats. The former consists of a taper machined in the stainless steel spindle and the latter is machined into the valve body.

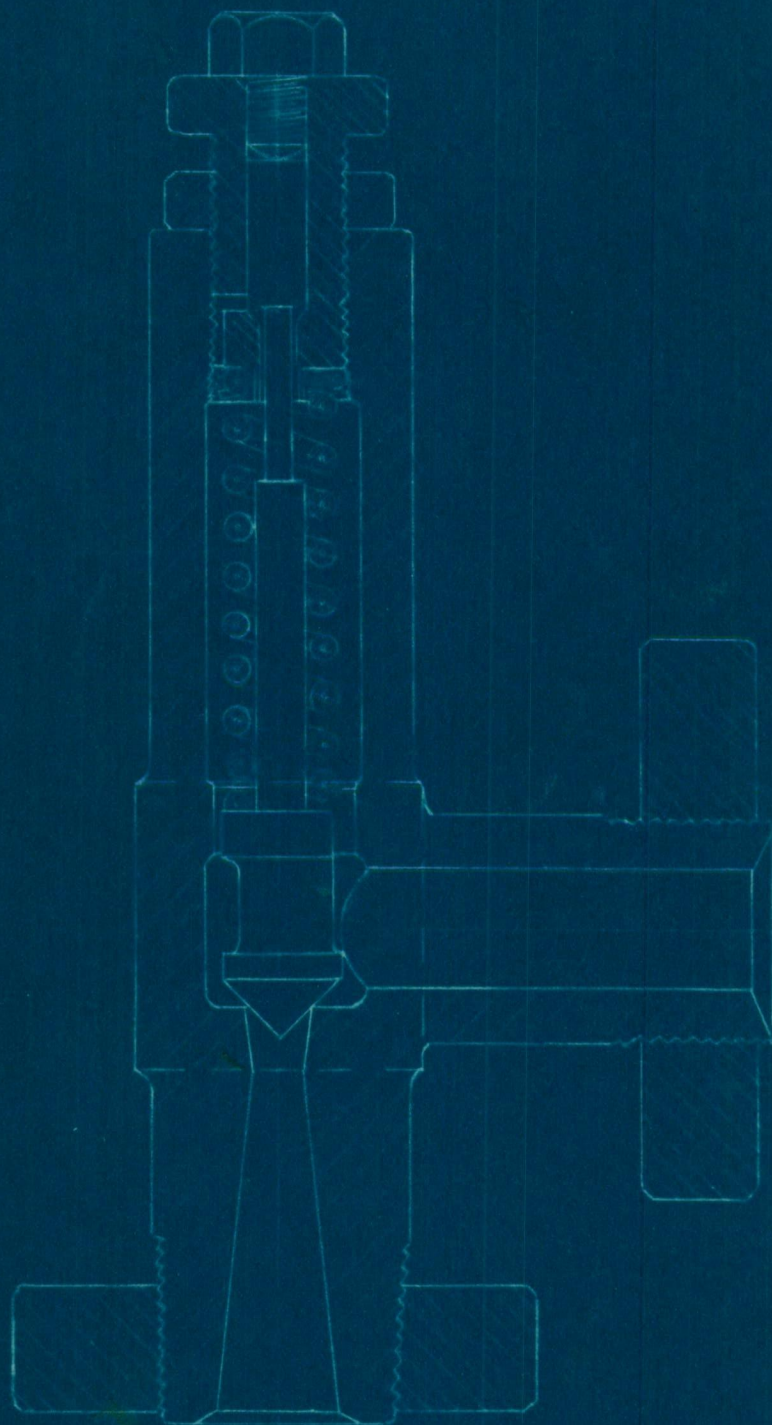
Non Return Valves.

A 3" ball type non return valve is shown and this illustrates the essential features of these units. The bodies are of forged steel and are in two halves with a central joint which may be either a lens ring closure as illustrated or a spigot and socket joint which is the usual practice on smaller valves. The extremities of the body are screwed to take flanges and machined to mate with standard lens rings. The seats of non return valves are machined from 18/8/1/1 stainless steel rod and are fitted into a recess in the body, being held in place by means of a locking ring. A ball lift restrictor is screwed into the other half of the body and its function is to limit the lift of the valve and allow for the passage of gas around the ball. The ball is of hardened steel. To function satisfactorily, it is essential to mount the valve vertically. These valves give good service on either gas or liquids.

Relief Valves.

For pressures up to 360 ats, relief valves are normally a right angled spring loaded type.

The unit illustrated is designed to operate at 260 ats working pressure and to blow at 290 ats. The design of the valve is straight forward, the body is forged from low carbon steel, the spindle is from 18/8/1/1 stainless. The design illustrated suffers from the serious disadvantage that the seat is not replaceable, nor is there sufficient room in the body to machine out the seat after it has become worn and fit a



TYPICAL ARRANGEMENT OF
1 1/4" RELIEF VALVE.

now one. This defect is serious in relief valves as they always continue to leak once they have been lifted. It is therefore necessary to replace relief valves at the first opportunity after lifting and regrind them. This leads to frequent refettling of the valve and in cases such as that illustrated, results in a relatively short valve life.

SUNDRY HIGH PRESSURE EQUIPMENT.

Level Gauge Sight Glasses.

The most common type of H.P. level gauge is the single glass type. This is made in units with either a 9" or a 14" sight length.

They consist of a forged steel body with protuberances at either end to carry the level gauge connections. Holes drilled through these protuberances connect them to a longitudinal slot which carries the gauge glass supported on a longitudinal saddle piece. A slotted cover fits over the front of the level gauge and is bolted to the body. The glasses, which are rectangular and $1\frac{1}{2}$ " wide by $\frac{7}{8}$ " thick, are armoured by the compressed skin process; they are ground dead flat on either side to enable a seal to be made with $\frac{1}{16}$ " C.A.F. jointing material. They are securely held in place by the bridge piece which in turn is restrained by tightening bolts spaced at 2" intervals. These bolts, which are fitted with individual gland seals, enable a uniform pressure to be applied to the bridge piece.

Pressure Gauges.

A reliable and eminently satisfactory gauge for working pressures up to 360 ats can be made in a conventional design using the flattened Bourdon tube principle. In practice the full scale range of the gauge is usually twice the normal working pressure, thus a 750 ats gauge is used for a 360 ats service. In high pressure gauges it is necessary to have a strong case fitted with a gas escape opening on the back cover. This prevents bursting of the case in the event of a tube failure. Similarly, for panel mounted gauges it is customary to cut the panel at a point corresponding to the explosion hole to prevent the gauge being blown from the panel.

An additional precaution against bursting gauges is the fitting of a restriction in the first joint immediately below the gauge. This restriction takes the form of a solid lens ring with a $\frac{1}{16}$ " hole drilled through the centre. In the event of a gauge failure the flow of escaping gas is reduced to a relatively small amount.

Flowmeters.

The measurement of flow in H.P. pipe lines is achieved by the use of the conventional orifice plate in the line itself and the measurement of this pressure drop by means of a balancing manometer of suitable strength to withstand the pressures involved.

The orifice plates which are machined from stainless steel are mounted in a carrier which has lens ring seats machined on either side to enable it to mate with the normal mitred H.P. pipe ends. The restraining bolts pass outside the carrier and hold the flanges, screwed to either pipe end, in position.

Tapping points are arranged in the carrier leading from above and below the orifice plate. Lines from these tapping points lead to catchpots and from there to the high and low pressure bosses on the balancing manometer.

The indicating manometer consists essentially of a thick walled steel tube of uniform bore which is bent into a semi-circular U. The extremities of the U are connected by fine capillary tubes to the high and low pressure bosses. A straight metal arm connects the extremities of the U and in its centre is a knife edge upon which the whole arrangement is

balanced. Sufficient mercury is placed in the U tube to seal the bore.

Whenever flow past the orifice plate induces a pressure difference between the high and low pressure sides of the instrument, the mercury bubble is deflected. This in turn causes the U tube to swing to a new position to counter balance the resulting movement. The degree of deflection is read as a flow rate on a stationary scale by means of a pointer attached to the U tube.

Adjustable weights are fitted to the deflecting mechanism to increase the sensitivity of the balance and to counteract zero errors. The restraining effect of the capillary tubes is nullified by winding each lead into a helix and arranging them so that each acts on the balance in the opposite sense.

These flow-meters can be either used as indicators or recorders and in practice give excellent service. With careful workmanship and accurate machining of the orifice plates, an accuracy of $\pm 2\%$ can be achieved.

H. P. GAS COMPRESSORS

INTRODUCTION

The term "high pressure gas compressor" is usually applied to compressors delivering at over 150 lbs/sq. inch. Over 90% of all compressors made operate at below that pressure and for duties above this figure standard compressors are available only in sizes up to 150 h.p. and 2,500 lbs/sq. inch delivery pressure.

All H.P. gas compressors are reciprocating multi-stage machines. British practice favours the multi-crank vertical cylinder design except for small units. Continental practice follows the single crank horizontal in line cylinders arrangement with the machine operating at a relatively slow speed. American manufacturers, although in the main favouring the horizontal single crank machine, do in some cases produce a vertical multi-crank unit. They claim that the former type is less expensive to manufacture and gives greater accessibility. The latter arrangement on the other hand leads to simpler foundation arrangements, a more compact machine and a large saving in floor space.

DESIGN OF H.P. GAS COMPRESSORS

Factors influencing the design of a compression unit are as follows:

- (1) Quantity and final pressure of gas to be compressed.
- (2) Nature of the gas and its equation of state.
- (3) Permissible or desirable discharge temperature.
- (4) Details of process and the manner in which the gas will be utilised.

Clause (3) usually results in a design in which the work done in each stage is substantially the same.

In the design of H.P. compressors the allocation of compression ratios and interstage delivery pressures is most conveniently arrived at by graphical methods using a T ϕ diagram.

The operating speed at which the compressor will run is controlled by the prime mover to be used and the mean piston speed chosen. The actual figure for the latter is critical and is dictated by previous experience on the type of piston rods, rings and cylinder material to be used in conjunction with the general construction features. The mean piston speed is usually fixed at 450-600 feet/minute. Machines operating above this figure require increased piston and gland clearances which throws heavy loads on rings and sealing glands, resulting in rapid wear in addition to increasing the gland leaks appreciably.

The following table gives details of I.P.H. stroke and H.P.S. of ten compressors

<u>Unit</u>	<u>R.P.M.</u>	<u>Stroke Inches</u>	<u>H.P.S. ft. min</u>	<u>Delivery Pressure ats.</u>	<u>Volume M³/hr.</u>	<u>No. of Stages</u>
1.	120	24	480	55	36650	3
2.	120	24	480	55-260	24000	3
3.	120	27	540	300	-	6
4.	150	20	500	300	-	6
5.	160	18	480	55	23000	3
6.	160	18	480	55-260	24000	3
7.	210	17	595	360	1760	6
8.	245	13 $\frac{1}{2}$	551	260	3900	6
9.	250	15	625	360	5250	5
10.	325	10	542	260	1300	6

It is noteworthy that all these machines gave good service from the outset with the exception of No. 9 unit. In this instance the high piston speed is credited with being one of the major factors responsible for a series of seizures in the initial runs. Increased clearances were required on this unit before satisfactory service was obtained.

Having fixed the operating speed and the mean piston speed the theoretical volumetric efficiency - usually 0.91-0.94 - the stroke and the piston diameters can be determined. This leads to an evaluation of the piston rod loads and the arrangement of cylinders.

The layout of the cylinders is arranged in such a way that the torque variation is reduced to a minimum. In six stage machines it is common practice to use three cranks and arrange pairs of cylinders in line; where this is done it is an advantage to pair off the cylinders in such a way that the pressure drop between them is reduced to a minimum in order to keep the gland leaks as low as possible.

The power requirement can now be calculated. This is made up of the sum of the power required to bring about the change of state at each stage plus the power required to overcome the various frictional losses throughout the system. This latter figure is estimated from the performance of similar machines operating under similar conditions. An iso-thermal efficiency of 60-65% is considered good practice.

CONSTRUCTION DETAILS

The arrangement of the bed plate, main bearings, crank and L.P. cylinders of H.P. gas compressors follows standard air compressor or steam engine practice.

For the higher stages where the pressures exceed 500 lbs. per sq. in. the piston is usually replaced by a plunger rod and the stage made single acting. Considerable care is expended in reducing the clearance volume to the lowest practical minimum at these higher stages.

The cylinders are usually C.I. for the initial stages and cast or forged steel for the higher pressures. In the latter case liners of good quality pearlitic C.I. or nitrided steel are pressed into the cylinders. Water jackets are supplied to all cylinders, cylinder heads, and valve chests in well designed machines.

The sealing of glands, piston rods, and plungers is achieved usually by means of sets of piston rings although older designs of machines have used metallic packing for the sealing of glands. "Clupet" rings consisting of a double ring with mitred ends are particularly satisfactory for these high

pressure conditions and with adequate lubrication and careful fitting these rings will withstand a pressure drop of 10 ats. each. Mitred Ramsbottom rings are used as an alternative to the Clupet ring and being more robust are less easily broken while fitting or in service. Their sealing action is not so effective and this leads to higher gland leak losses. The rings are usually arranged in two sets whose distance apart is dependent upon the stroke of the machine.

To seal effectively the rings must be adequately lubricated and this is achieved by having 2-3 oiling holes let into the wall of the cylinder at a point which is always between the extreme rings in any position of the plunger.

The valves of H.P. compressors are usually the multi-port spring loaded plate type for the lower stages. American practice favours parallel ports in the valve seat with leaf springs; while British practice usually employs concentric ports with spiral springs. The valve seats are of C.I. and the plate of a stainless steel or iron, often 12% Cr. steel. The springs can with advantage be made from 18/8/1/1 steel as this has a longer life than straight spring steel. Springs made from the latter material tend to fail at the extremities. The lift of these valves is small and is maintained at approximately 0.10". The velocity of gas through the ports is important and it is good practice to restrict its value to under 100 ft./sec. to keep the pressure drop over the valve assembly down to a reasonable figure.

For pressures over cca. 800 lbs/sq. in. disc valves are invariably used with concentric ports. 12% Cr. steel gives good service for the seats of these valves and a plate of 18/8/1/1 steel is desirable. Small helical springs - preferably of 18/8/1/1 material - hold the valve against the seat. Four or six of these springs may be used depending upon the size of the valve. Valve lifts are kept at the same figure as for the lower pressure valves but due to the greater density of the gases involved in the later stages gas velocities are kept lower and are of the order of 75 ft./sec.

Valves are normally encased in boxes or recesses which are fitted with bolted covers for easy access and inspection.

Reliability is a major requirement in the performance of H.P. compressors and to achieve this careful design involving robust construction and painstaking workmanship are required. Such features as auxiliary oiling gear are essential equipment.

MATERIALS OF CONSTRUCTION AND SPECIAL FORMS OF CONSTRUCTION.

Introduction.

All the materials that are used on the plants under consideration are in relatively common use and their physical properties and methods of fabrication are well established. In some cases, however, their sphere of application is limited by the operating conditions of the process. In the notes that follow on the various materials used in construction, special attention has been directed to the limiting conditions which circumscribe their use. No attempt has been made to give an exhaustive account of their properties, and the discussion has been confined to their particular applications in the plants under consideration.

Attack of steel by hydrogen and ammonia is discussed. The former of these was the cause of a considerable amount of damage on high pressure plants before adequate design technique and suitable steels were developed to counter its effect.

Low Carbon or Mild Steel.

This is the general purpose material for the construction of the chemical equipment required for the synthesis of ammonia and methanol. It is used for the construction of vessels and pipes on all the low pressure plant and for the high pressure equipment where its limitations do not preclude its application.

For low pressures it is satisfactory up to 350°C. For higher pressures where hydrogen is present in the retained gas its maximum safe working temperature is reduced to 250°C. for 250 atm. pressure and to 200°C. for 350 atm. pressure. If these temperatures are exceeded the steel is quickly embrittled due to hydrogen attack.

Where oxygen is present it is quickly corroded under wet conditions - for this reason it is not used for underground pipes or lute pipes. In these instances cast iron is used in its place.

3% and 6% Chrome Steels.

These two steels are used for similar duties. The latter, which at one time was used extensively, is being replaced in new equipment by the former due to the fact that although the physical properties and the resistance to attack are comparable, the cost of the 3% chrome steel is considerably below the 6% chrome steel.

These steels have a better combination and range of plastic properties than mild steel. The presence of the chromium increases the hardness and strength of the steel without reducing its ductility. The addition of the Molybdenum, although in small quantities, has an appreciable effect in reducing the tendency of the steel to become brittle after prolonged heating.

The improved grain structure of these steels allow them to be used under pressure at higher temperatures than mild steel. Thus the 3% Cr. steel has a limiting creep stress of 21 tons/sq. in. at 400°C. and 12 tons/sq. in. at 450°C. with a limit of 500°C. for oxidation resistance and 450°C. at 350 atm. when hydrogen is present. The 6% Cr. steel has a limiting creep stress of 21 tons at 400°C., 12 tons at 450°C.,

8.5 tons at 500°C., and 1 ton at 550°C., with a limit of 600°C. for oxidation resistance and 550°C. at 250 ats. and 525°C. at 350 ats. when hydrogen is present.

This type is a good forging steel and is widely used in the construction of heavy walled pressure vessels. It is also used for studs and bolts to replace mild steel where temperature and pressure conditions are conducive to hydrogen attack.

15% and 22% Chrome Steel.

These are temperature resistant steels and are only used where extreme temperatures are likely to be encountered. The 15% chrome steel has an oxidation resistance of 700°C. and has a limiting creep stress at 300°C., 400°C., 450°C., 500°C., and 550°C., of 29 tons, 14 tons, 9 tons, 3 tons and 1.9 tons respectively.

The 22% chrome steel is used for the heater in the ammonia converter. It is particularly suitable for withstanding the extreme temperatures encountered in these coils.

0.4% Molybdenum Steel.

This steel, although similar to mild steel in its elastic properties, is capable of achieving a better grain structure. It possesses a slightly higher resistance to creep at high temperatures and can be used with safety up to 500°C. at which temperature its limiting creep stress is 5 tons.

It is used for flanges on high pressure joints where the temperature is liable to exceed 200°C.

Chrome Molybdenum Steel.

This steel is used extensively for studs and bolts especially in the covers of pressure vessels where the load is high and the number and size of bolts is limited. In the hardened and tempered condition the studs can be designed to carry stresses up to 15 - 20 tons/sq. in. with safety. When in the hardened and tempered condition this steel is very brittle and has a low impact value and is liable to fracture with shock. Cases have been known of large studs failing when accidentally struck with a sledge hammer during the "slogging up" process.

Studs made from this steel are also used for high temperature joints which are subject to temperatures up to 450°C.

Austenitic Stainless Steel.

The 18/8 type of austenitic stainless steel is used extensively where resistance to hydrogen attack or resistance to nitric acid attack is required.

In the former instance it finds extensive application in those parts of the ammonia and methanol converters subject to high temperature. Its properties at elevated temperatures are good; at 400°C. it has a limiting creep stress of 25 tons, at 500°C. this figure is 5 tons and at 600°C. it is 3 tons, the limit for oxidation resistance is 800°C.

Deterioration in a corrosive gas is accelerated above 450°C. The austenitic form of the iron and the fine grain structure of the steel render it immune to hydrogen attack.

The coefficient of thermal expansion is considerably higher than mild steel, being 17.4×10^{-6} at 20°C.

(c.f. U.S. 11.9×10^{-6}) and care in design is necessary when using this type of steel in conjunction with metals having a lower coefficient.

Normally the welding quality types of austenitic irons are used, for example, the 18/8/1/1 type. More recently an American type, 18% Cr. 8% Ni stabilised with 1% Cb. has been successfully employed. The object of the addition of the 1% of Columbium or Titanium is to prevent carbide precipitation in the critical range of 500 - 900°C.

The resistance of these steels to nitric acid is excellent and in consequence they are used exclusively for those sections of the oxidation plant coming in contact with nitric acid or oxides of nitrogen.

Vibrac.

This finds application in the copper liquor injector where it is used for the studs of the injector rod glands. It has been used extensively for hollow forgings in the manufacture of pressure vessels but no applications of this nature occur in the plants under consideration. Its high yield point and relatively high Izod value render it particularly suitable for the gland studs where the alternation in stress is likely to be considerable.

Nitralloy.

This material is used for cylinder liners on the main compressor and also for rods on the copper liquor injector.

The steel used in Australia for these duties had the following composition:-

C	0.35 - 0.45%
Si	0.35% max.
Mn	0.65% max.
P	0.030% max.
S	0.030% max.
Ni	0.25% max.
Cr	1.4 - 1.8%
Al	0.9 - 1.3%
Mo	0.10 - 0.25%

In the case of copper liquor injector rods the material is heat treated to give a core fulfilling the following conditions.

Yield point	Not less than 32 tons/sq. in.
Ult. Stress	" " " 45 " "
Elongation	" " " 16%
Reduction of area	" " " 40%
Impact	" " " 30 ft./lb.

After preparation of the rods by suitable heat treatment they are ground to the finished size and then nitrided for at least 90 hours at 500°C.

This type of steel, which is particularly suitable for nitriding, gives a case hardness of over a 1,000 Vickers. Case depths of 20 thousand can be achieved.

NCT3.

This high chrome-nickel alloy is particularly suitable for facing the joints of H.P. lines which contain liquid methanol. Its extreme toughness enables it to resist the

heavy abrading action of the methanol should an incipient leak occur at any of these joints. It is deposited by electric welding, a layer approximately 1/8" thick being sufficient. The pipe ends are then faced with a cutting tool to give them the correct nitro finish.

Cast Irons.

This material which finds general application throughout the plant for machine castings, underground pipework, etc., is normally good quality grey iron. On the ashboyl of the gas generators, however, where resistance to abrasion is required, a Meehanite type of casting is used. Similarly, for the liners of the circulators cast iron of a pearlitic structure is specified.

Alumbr.

The corrosion resistance and good physical properties of this non-ferrous alloy render it particularly suitable as a general purpose material for condenser and heat interchanger tubes.

Nuntz Metal.

This material finds application only in the ammonia converter when it is used in the construction of the electrodes passing through the top cover to the heater elements. Its mechanical properties at elevated temperatures are poor; but the conditions under which it is used are not arduous as it is protected against excessive thermal effects by water cooling.

SPECIAL TYPES OF CORROSION - HYDROGEN ATTACK.

Gases rich in hydrogen can produce the effect of embrittling, decarburising and fissuring in steel.

The following factors affect the rate of attack:-

1. Pressure
2. Temperature
3. Composition of the steel
4. Structure of the steel
5. Stresses in the steel sections.

The mechanism of the attack is the formation of hydrocarbons by the combination of the hydrogen with carbides in the steel.

Pressure. The partial pressure of the hydrogen has a material effect on the rate of attack. Similarly, at high partial pressures the hydrogen attacks steel at much lower temperatures than those causing attack at normal pressure. Cases have been known of hydrogen attacking steel at atmospheric temperature at 4,000 ats. pressure. Appreciable attack can occur at 200°C. when the pressure is 350 ats., and the corresponding temperature at 250 ats. is 250°C.

Temperature. As with pressure, the higher the temperature the greater the rate of attack.

Appreciable attack occurs with mild steel at atmospheric pressure when the temperature exceeds 550°C.

Cast iron will withstand hydrogen at low pressures up to 400°C.

Composition of the steel. The chromium bearing carbide is more resistant to hydrogen attack than the iron carbide; the resistance increasing with the increase of the chromium content. For this reason, chrome and chrome-moly. steels are used in circumstances when hydrogen would attack straight carbon steels.

3% Cr - Mo steel is the normal material for industrial use in these circumstances and gives satisfactory service up to 550°C. at 350 ats. A reduction in the carbon content increases the resistance of the steel. Two types of 3% Cr - Mo steel are used, one having 0.15 - 0.20% carbon which is suitable for service up to 550°C. and the other 0.20 - 0.25% carbon which is suitable for service up to 450°C.

Ni - Cr - Mo steel and similar alloys have better resistance than U.S. Additions to the steel composition which form a stable resistant carbide result in improvement in resistance to hydrogen attack. Columbium, Titanium and Vanadium are examples of these elements.

Structure of the steel. The coarser the structure the more readily hydrogen will attack steel; thus in U.S. the limiting temperature may be increased by 100°C. in a fine grained steel compared with a coarse grained steel of the same composition.

If the grain structure has been coarsened, as frequently happens in the vicinity of welds, the effect will be an accelerated attack.

The hardened and tempered condition is most resistant to the effect of hydrogen.

Stress in the steel. The chief effect of high stress in steel subjected to hydrogen attack is to propagate fissuring and accelerate failure. The formation of fissures also provides additional avenues for attack. These cracks are developed within the steel by local high pressures of hydrogen or gaseous reaction products.

Steel subjected to no appreciable stress still suffers hydrogen attack; however, in this instance the fissuring and disintegration takes much longer.

Form of Attack.

The first step in the attack by hydrogen is the absorption of hydrogen. In U.S. this causes embrittlement. The next stages are decarburisation and fissuring with consequent very severe loss of strength and ductility. With high temperatures and low stresses decarburisation precedes fissuring. When the stresses are appreciable fissuring generally precedes decarburisation.

3% Cr. Mo steel is not embrittled by hydrogen absorption within the allowable limits of operation but the absorption of hydrogen does affect its welding qualities. These can be restored by releasing the hydrogen by heating to 650°C. for half to one hour.

ATTACK BY AMMONIA GAS.

Gases containing ammonia are capable of attacking steels by nitriding at elevated temperatures. At 250 ats. and above 550°C. 3% Cr. Mo steels have been nitrided by gas containing 2% ammonia. 18/8/1/1 stainless steel is similarly attacked but to a lesser extent. Spraying the surface of the steel with aluminium has been found to be beneficial in some applications.

COMPOSITION AND PROPERTIES OF MATERIALS.

FERROUS ALLOYS.

<u>MATERIAL.</u>	<u>CONDITION</u>	<u>CHEMICAL COMPOSITION - %</u>									<u>Yield</u>	<u>Ult.</u>	<u>Elos.</u>	<u>REMARKS</u>
		<u>C</u>	<u>Si</u>	<u>Mn</u>	<u>S</u>	<u>P</u>	<u>Cr</u>	<u>Ni</u>	<u>Mo</u>	<u>Others</u>	<u>Point</u>	<u>Strength</u>	<u>Mod.</u>	
											<u>Tons/</u>	<u>Tons/</u>	<u>Tons/</u>	
											<u>Sq.In.</u>	<u>Sq.In.</u>	<u>Sq.In.</u>	
Low Carbon Steel	Annealed	0.15	0.15	0.45	0.04	0.04	-	-	-		17	28.5	18500	
3% Chrome Steel	Hardened and													
	Tempered	0.15	0.2	0.5	0.03	0.03	3	-	0.4		23	40	-	
5% Chrome Steel	"	0.15	0.25	0.5	0.03	0.03	6	-	0.4		30	42	-	
15% Chrome Steel	"	0.15	0.25	0.4	0.03	0.03	15	-	-		28	40	13500	
22% Chrome Steel	"	0.15	0.25	0.4	0.03	0.03	22	-	-					
0.4% Nc. Steel	Annealed	0.12	0.20	0.6	0.02	0.02	-	-	0.4		17	28		
Cr. Hdy. Steel	Hardened and													
	Tempered	0.4	0.2	0.5	0.04	0.04	1.4	<0.2	0.7		45	60	-	
18/8/1/1 S.S.	Fully Softened	0.13	0.54	0.27	0.02	0.02	18	8	-	1%W. 1%Ti.	15	45	-	
Vibroc.	Hardened and													
	Tempered	0.28	0.25	0.6	0.04	0.04	0.6	2.5	0.55		55	65	13500	
Nitralloy	"	0.30	0.35	0.65	0.02	0.02	1.6	0.25	0.20	1.1%Al.	40	55	13500	
HCT 3	Fully Softened	0.16	1.0-	-	-	-	25	22	-		12	38	-	
			2.0											
Grey C.I.	As Cast	3.5	1.2	0.5	0.1	0.6	-	-	-		-	10	6500	

NON-FERROUS ALLOYS.

		<u>Cu</u>	<u>Cr</u>	<u>Ni</u>	<u>Mn</u>	<u>Sn</u>	<u>Zn</u>	<u>Pb</u>	<u>Al</u>	<u>Pc</u>	<u>Others</u>				
Alumbro	Worked and														
	Annealed	76	-	-	-	-	22	-	2	-		-	31	-	
Gunz Metal	"	62	-	-	-	0.2	37	-	-	0.2	-	10	25	-	
Monel Metal	Hot Worked	29	-	67	2	-	-	-	-	2		24	39	10,000	

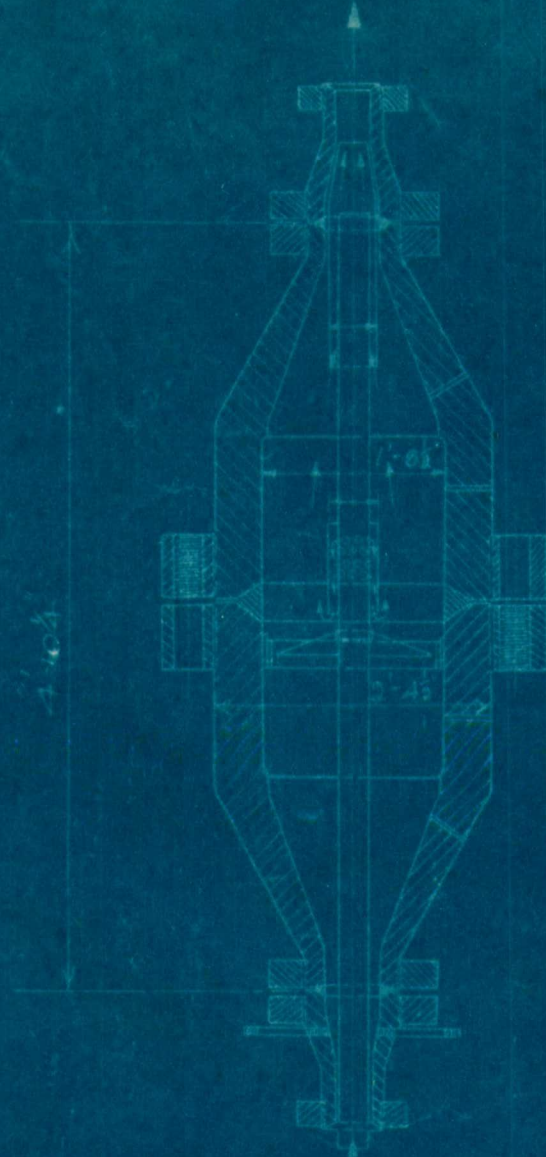


DIAGRAM 10

1-6 HP CATCHPOT (NEW DESIGN)
INLET & EXIT GAS MAINS.

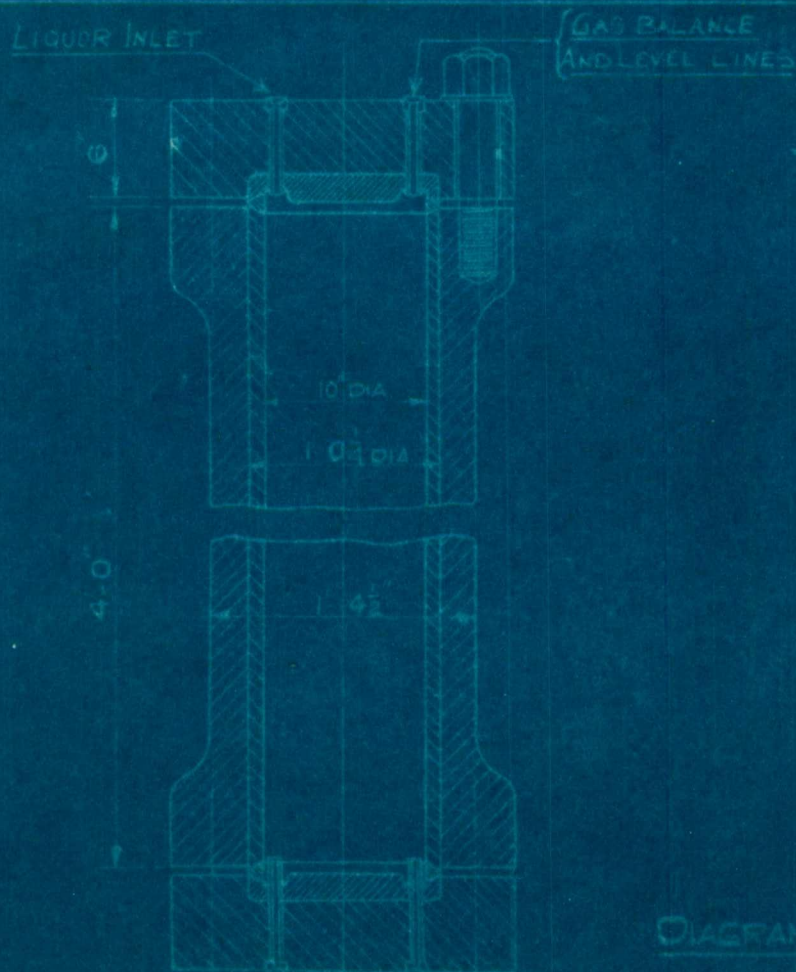


DIAGRAM 11

LIQUOR INLET
LIQUOR OUTLET
METHANOL CAPACITY VESSEL

GAS BALANCE
AND LEVEL LINES
SAMPLE POINT
AND LEVEL LINES