FIAT FINAL REPORT NO. 577

UNCLASSIFIED

# SURVEY OF THE LEADING MANUFACTURERS OF PRESSURE VESSELS



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# SURVEY OF THE LEADING MANUFACTURERS

# OF

# PRESSURE VESSELS

BY


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[illegible] Intelligence Objective[illegible]


FIELD INFORMATION AGENCY, TECHNICAL

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## OBJECTIVE

The purpose of this survey was to investigate and evaluate the leading and most important manufacturers of pressure vessels, in order to determine what innovations had been made in methods or manufacturing technique, in relation to the production of pressure vessels.

To see what new types of vessels, if any, had been evolved, due to scarcity of materials or other causes, through the duration of the war.

To note what progress had been made in the manufacture of clad steels.

## INTRODUCTION

The number of pressure vessel manufacturers in Germany, is comparatively large; but the great majority of them limit themselves to one of several classes. In the first class are a relatively small number, which can manufacture vessels of the heavier type, and who have the necessary equipment to properly handle this work.

The second class, contains a number of firms which can manufacture vessels of a medium thickness and length, but who lack certain equipment and are dependent upon one or two of the larger shops to a great extent.

Then, there are quite a large number of shops, which specialize on certain items for the various process industries [illegible] have only the necessary equipment to carry on their own particular work, and, accordingly are a negligible quantity in the industry and not capable of handling the ordinary run of plate work.

Most of the better shops are located in the Ruhr District of the British area, and very few are in either the United States or French areas. There are several large shops located in the Russian occupied area, but these were not considered in this investigation.

The data for this report was obtained in all cases, from discussions with the manufacturers themselves, and from a personal survey of their plants and equipment in conjunction with their technical and operating executives. In all cases a personal inspection of their product was made, whenever such products were available.

DISCUSSION

The P.V. industry as a whole is not a diversified industry. There are a great number of small shops which limit themselves to general repair work or a small specialty which they have developed, perhaps in cooperation with one or another of the manufacturing process companies. These can be discarded as immaterial to this discussion.

The larger and better companies have shown considerable progress and ingenuity, not in new fields of investigation, but rather in perfecting technique in relation to their own particular manufacturing methods.

In their welding practice I saw nothing outstanding in a general way, but a small number of them are doing a very high grade of work. Quite considerable of the work is Oxy-Acetylene welded, but the great majority limit themselves to arc-welding of the hand variety and I saw no automatic machines at all.

One or two of the firms have been doing considerable work with the Union Melt Process and are getting very good results. Two of these firms, Mannesmann, Duisburg and Deutsches Rohrenwerke A.G., Thyssen Werke, Mülheim (Ruhr), have been particularly active in this process and will be discussed briefly in the later reports on individual companies.

Quite a number of pressure vessels in Germany are either forged or of the pressed seamless variety and here they are making an excellent product. In addition, they of course make quite a few under the Roechner Process. Boiler drums are a particular product of either one of these methods and they produce some very fine work.

The cost of these types of vessels is very hard to figure on account of a number of factors, of which forced labor, excessive use of labor, and subsidation of the work in many cases are contributing items. For the sake of a rough comparison of the various types, one firm stated that where the cost of arc welded vessels would run about 700 R.MKs per ton, the vessels manufactured under the Roechner process would run about 800 R.M. per ton and forged vessels approximately 1300 R.M. per ton. This relative comparison was checked with several of the other firms and the proportion of costs seems to be fairly general. No relative costs were obtainable ~~on the banded vessels.~~

The average good shops manufacture vessels with a plate thickness of 20 mm to 50 mm, but the better shops are producing them up to 100 mm thickness. Of course, in the forged and banded vessels, the thickness of the shells are considerably greater with a limit on the banded vessels of approximately 200 mm.

Their normalizing and stress relieving facilities are not comparable to ours as a great number of them do not have the equipment and if called on to do this, they send the completed vessels to other shops which have the necessary installation.

The largest furnaces are limited to three meter diameter vessels, and a maximum length of eighteen meters. This is roughly nine feet diameter by fifty five foot length and there are only two of this capacity.

In the case of longer vessels they stress relieve each end separately. In many cases only the section in the girth seam is stress relieved and this is accomplished by means of a brick lined sectional portable furnace built around the weld of the vessel to be stress relieved.

In regard to X-raying the welds, only the larger firms go into this very thoroughly, and they report very satisfactory results after the instructional period has been completed.

The outstanding new type of pressure vessel developed is the wrapped band vessel as designed by I.G. Farbenindustrie, A.G. and manufactured by the Deutsches Rohrenwerke A.G.-Thyssen Werke, Mülheim a/Ruhr. A discussion of the manufacture and also a translation of the method of calculating stresses will be submitted in later pages of this report.

The translation of the stress calculations is not the result of a discussion of the vessels by the writer, but is purely a translation of a specification by one of the leading engineers of the I.G. Farbenindustrie, A.G., which was given to the writer by one of the manufacturers.

# MANUFACTURE OF PRESSURE VESSELS IN CARBON AND ALLOY STEELS FOR CHEMICAL INDUSTRY IN THE RUHR DISTRICT

Group I

| Name and Location | Type of Industrial Plant | Production Capacity | Note |
|---|---|---|---|
| A. Makers of seamless rolled or seamless forged vessels | | | |
| 1. Deutsche Röhrenwerke A.G. Thyssen Werke Mülheim - Ruhr | Steel works, Drum and Plate Shops | High | Seamless rolled Röchner Process Banded vessels |
| 2. Friedrich Krupp Essen-Ruhr | " " | High | Seamless forged |
| 3. Press-und Walzwerk A.G. Dusseldorf | Press shops Forge shop Steel mill | High | Seamless forged Pressed drums |
| 4. Rheinmetall Borsig A.G. Dusseldorf-Berlin (Tegel) | Steel works machine, and vessel shop | High | Seamless forged |

PRESSURE VESSEL MANUFACTURERS, CONT.

Group I

| Name and Location | Type of Industrial Plant | PRODUCTION CAPACITY | NOTE |
|---|---|---|---|
| B. Makers of High Pressure Vessels, Hydrogen Welding | | | |
| 1. Deutsche Röhrenwerk A.G. Thyssen Werk Mülheim-Ruhr | Steel works, Drum and Plate shop | High | |
| 2. Mannesmann Röhrenwerk A.G. Duisburg-Huckingen | Pipe and Vessel shop | High | |
| 3. Rheinmetall-Borsig A.G. Dusseldorf-Berlin (Tegel) | Steel Works Machine & Drum shops | High | |
| 4. Ruhrstahl A.G. Werke Henrichshütte Witten-Ruhr | Steel Werk Vessel & Drum shops | Medium | |

## PRESSURE VESSEL MANUFACTURERS, CONT.

| Name & Location | Type of Industrial Plant | Production Capacity |
|---|---|---|
| C. Makers of High Pressure Vessels Electric Welding | | |
| 1. Deutsche Röhrenwerke, A.G. Thyssen Werk Mülheim-Ruhr | Steel Mill Drum and Vessel shops | High |
| 2. Friedrich Krupp Essen-Ruhr | " " | High |
| 3. Mannesmannröhrenwerk A.G. Duisburg-Huckingen | " " | High |
| 4. Rheinmetall - Borsig A.G. Dusseldorf-Berlin | " " | High |

All Firms in Group I are expert in vessels, for Chemical Industry.

## PRESSURE VESSEL MANUFACTURERS, CONT.

| Name and Location | Type of Industrial Plant | Production Capacity | Note |
|---|---|---|---|
| Makers of Medium Sized Plate work and Vessels for Medium Pressure | | | |
| 1. Deutsche Rohrleitungsbau A. G., Dusseldorf | Machine and Vessel shops | High | Chemical Industry |
| 2. Gutehoffnungshutte Oberhausen-Sterkrade | " " | High | " |
| 3. Dortmunder Union Brückenbau A. G. Werk Orange-Gelsenkirchen Dortmund-Ruhr | " " | High | " |
| 4. Klöckner-Humboldt Deutz A.G. Köln-Deutz | " " | Medium | " |
| 5. Wilke-Werke, A.G. Braunschweig | " " | Medium | " |
| 6. Ewald Berninghaus Duisburg | [illegible] Boiler shop | Medium | |
| 7. Vereinigte Kesselwerke A.G. Dusseldorf | Boiler shop | Medium | |
| 8. Walther & Cie. A.G. Köln Dellbrück | Boiler shop | Medium | |
| 9. Wilhelm Küsters Aachen | Boiler & Vessel shops | Medium | |

## MANUFACTURERS CONTACTED

| | |
|---|---|
| Vereinigte Deutsche Metallwerke, A.G. | Hesse Strasse, Frankfurt/ Heddenheim |
| Lurgi G. fur Chemie and Hüttenwesen | Gervinus Strasse, Frankfurt Target - 31/86 |
| Kühnle, Kopp & Kausch | Frankenthal |
| Maschinen Fabrik Esslingen | Esslingen/Stuttgart |
| W. Schiltze Lechtmetallbau | Feuerback/Stuttgart |
| M. A. N. | Nürnberg<br>Augsburg<br>Gustaveburg |
| Stahlwerke-Rachling-Buderous | Wetzlar |
| Samesreuther and Co. G.m.b.H. | Butzbach |
| Warmefang u. Ventilaforbau | Hackethal Strasse 71 Langenhagen-Hannover |
| Prometheus Werke G. fur Apparatebau | Entenfangweg 12 Herrenhausen/Hannover |
| Babcock Werke | Oberhausen |
| Gutehofinungshütte | Sterkrade/Oberhausen |
| Deutsche Röhrenwerke [illegible] | Mülheim/Rhld |
| Ewald Berninghaus | 71 Vulkan Str[illegible] Duisburg Rhld. |
| Gronemeyer u. Banck [illegible] | Brackwede - Westf |
| Schmidtsche Heisdam A.G. | Wilhelmshöher Allee [illegible] Kassel |
| Rheinmetall-Borsig A.G. | Ulmen Strasse 125 Grafenburg - Dusseldorf |
| Walther & Cie. | Köln-Delbruck |

| | |
|---|---|
| Paul Schutze A.G. | Oggersheim - Palatinate |
| Mannesmann Röhrenwerke A.G. | Huckingen/Duisberg |
| Press und Walzwerke A.G. | Reisholz and Düsseldorf |

## REPORT ON INDIVIDUAL FIRMS

Vereinigte Deutsche Metallwerke, A. G. - Heddenheim/Frankfurt

Director: Herr K. Plesser

Metallurgist: Dr. E. Lay

They make no pressure vessels of any kind. During the war they did make copper wire wound spheroid containers for V1 bombs, but these were very small and they never got into heavy production of them.

Their principal products at this plant were sheets, copper and nickel electroplated, and copper wire. They plate steel sheets with copper, nickel or aluminum for the manufacture of coins.

I was expecting to find that they manufactured clad steels, but their process is strictly an electro-chemical plating process.

At the Altena/Hamm plant they plate with nickel and copper for small chemical containers.

At Duisburg they make condenser tubes of plated material, 70% Copper, 20% Zinc and 10% Tin. Due to the shortage of Tin, they changed the analysis to 76% Copper, 2% Aluminum, 22% Zinc.

Duisburg also makes heat exchanger tubes of 96% Copper and 4% Aluminum.

Dr. Philippi - Dir. Manager - Duisburg Plant

Dr. Baum - Chem. Metallurgist

Lurgi G. für Chemie & Hüttenwesen - Gervinus Strasse 17 - 19 - Frankfurt

Director Behlert

This is an engineering and design firm entirely. They assume the contract and buy all vessels and apparatus from various shops. They do, however, build electric precipitators (Cottrell) for gas cleaning at their Friedberg Plant. They do the erection at complete chemical plants and furnish operating organizations.

The Lurgi Warme subsidiary has offices at Heddenheim with Dr. Danulat as the Chief Engineer in charge. Again they limit their activities to design and operation.

Dr. Danulat stated that all their vessels were built by Mannesmann or M.A.N. at Gustavesburg.

He says that annealing or stress relieving capacity in Germany is limited to 3 meters diameter by 15 meters long, and that there are only 3 firms in all Germany who can handle this class of work.

The limit on their pressure vessels is 50 mm. thickness.

- - - - -

Kühnle Kopp und Kausch - Frankenthal

Director Dr. Winkler

They have made a few pressure vessels for I. G. Farbenindustrie and during the war, but pressure vessels are not a standard product with them. Their products are compressors, small steam turbines and axial flow fans.

They have made 8 or 10 agitators of stainless clad steel for I. G. Farbenindustrie. Several of these were still in the plate shop and were 2.800 meters diameter and 2.300 meters seam to seam. The shell was 20 mm. thick with stainless cladding 2 mm.. The clad steel furnished by Deutsches Edelstahlwerke, Krefeld, who are associated with Deutsche Röhrenwerke A.G., Mülheim a/Ruhr.

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Kühnle Kopp & Kausch are not a factor in pressure vessel manufacture.

Maschinen Fabrik Esslingen - Esslingen/Stuttgart

| | |
|---|---|
| Dr. Ludwig Kessler | First Director |
| Dr. Otto Klüsener | Second Director (Engineering) |
| Herr Koch | Chief Engineer |
| Dr. Klingenstein | Blast Furnace Engineer |
| Herr Huth | Locomotive Department |

These people are primarily locomotive boiler and railroad car builders, but they also make steam or gas driven compressors for gas and gasoline plants. They are definitely not a pressure vessel shop, but during the war they did make 3 rivetted towers for I. G. Farbenindustrie on the synthetic rubber program.

- - -

W. Schiltze Lechtmetallbau - Feuerbach/Stuttgart

Before and during the war they manufactured air receivers and light containers. The containers were of aluminum and magnesium. They do no pressure vessel work other than this.

The plant is entirely destroyed.

- - -

M. A. N. - Nürnberg

This plant has not made any pressure vessels but state that they have been making them at either one or both of their other plants. The works has been about 80% destroyed.

At Nürnberg before and through the war they manufactured coal and ore bridges, cranes, diesel engines, auto trucks and prime movers.

- - -

M. A. N. - Augsburg

Chief Director - Herr Otto Myer
~~Metallurgist - Prof. Dr. E. Sovensen~~
Acting Director - Herr Meyr

They have made no pressure vessels at Augsburg and informed me that their pressure vessel business was carried on at the Gustaveburg plant.

This plant manufactures diesel engines, heavy machinery for dye plants and breweries, printing machinery and during the war they added guns and heavy ammunition.

- - -

M. A. N. - Gustaveburg

| | |
|---|---|
| Director | Reinhart |
| Director | Hübner |
| Supt. Boiler Shop | Herr Silberhorn |

This shop produces pressure vessels to a small extent for the chemical industry. They also make waterless gas holders, bridges, pontoons, submarine sections and are the largest producers of roller dams in Europe.

They use electric arc and Union Melt and have been getting very good results with Union Melt up to 50 mm. thickness. They arc weld up to a limit of 105 mm., doing all their scarfing with acetylene torch on the heavy plate.

They have several bending rolls, but the large one - 10 meters long - is a four roll outfit with the top roll adjustable horizontally and vertically. The two outside bottom rolls adjustable vertically. They do all cold rolling and the machine can handle 100 mm. plate not over 800 mm. wide or 50 mm. at a width of 4 meters.

Their X Ray equipment has a limit of 75 mm. above that the results are problematical. They also have one of the largest stress relieving furnaces in Germany and can handle vessels 3 meters diameter with a maximum length of 15 meters.

They have never worked on clad metals and have not been particularly active in pressure vessel production. Their particular specialty is on roller dams and closed gate (double) dams. They have built the great majority of the dams in the Upper Rhine and various other rivers in Germany, others in Norway and Sweden, and one on the Grand River in Colorado for the United States Reclamation Service.

- - -

Stahlwerke - Rochling - Buderous A.G. -- Wetzlar

Metallurgist - Dipl. Ingeneur Otto Lucas

This plant was supposedly a factor in the chemical industry for towers and vessels, but they have never made any equipment of this kind.

It is an alloy steel plant specializing on stainless steels and produces about 67,000 tons annually.

They have one analysis of stainless - 18% Chrome, 8% Nickel, 0.08 to 0.15% Carbon - but their normal production is 20% Chrome, 10% Nickel and 1.2 to 2.5% Molybdenum which is very similar to Krupp's Stainless V2A.

- - -

Samesreuther and Co. - Butzbach

A small shop doing considerable locomotive boiler repairs, but they do manufacture small heat exchangers with welded tubes and also medium size autoclaves of various pressures. The outer shell has a series of indentations press into it before rolling, and each of the bulbs are welded to the inner shells. Attached illustrations show the construction.

They also make quite a few of these vessels with an alloy lining or the innershell of clad steel. They are, however, a rather negligible quantity in pressure vessel production.

- - -

Warmefang u Ventilaforbeau - Langenhagen/Hannover

This firm is entirely out of the vessel business as it is a total ruin from bombs. Their principal product was small heat exchangers of cast iron with rolled tubes and cast iron economizers in banks for stationary boilers.

[illegible]/Hannover

This is a small plate shop doi[illegible] medium size. Their largest capacity is plate of 30 mm. thickness.

They have about 8 welding outfits and one Kjellberg semi automatic welder. They have never worked with clad steels and most of their production is rivetted tankage for petroleum plants.

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They have no stress relieving equipment; and if this is called for, they ship the vessels to the Ruhr shops to have it done. There is nothing outstanding in their practice, and they are comparable to our ordinary small shop.

Babcock Werke - Oberhausen

Director - Herr Jantscha

Babcock Werke have limited their production to boilers alone, doing no other pressure vessel work. They can roll plate to 30 mm. thickness, but most of their welding is done on water conditioning and pulverizing equipment. They built economizers of both cast iron and steel pipe in addition to their boiler work.

They buy all their boiler drums from Thyssen Werke and these are seamless 4" thick and 8 meters long for a pressure of 125 Atmospheres. Their headers are bought from Press u. Walzwerke, Dusseldorf, and they weld the ends and forge them to suit in their own shop.

They have one annealing furnace 2 meters by 2 meters, 10 meters long but use it only for tubes and steel castings. They also have one small portable X-Ray machine of 125 volts which is used only on boiler repairs and air-conditioning and pulverizing equipment.

At the present time they are working on boiler repairs for the coal mining industry.

\- - -

Gutehoffnungshutte - Oberhausen A.G. - Oberhausen/Sterkrade, RHLD

| | |
|---|---|
| Herr Kollerman | Chief Director |
| Herr Muhle | Acting Director |
| Dr. Otto Zechet [illegible] | Chief Metallurgist |
| Herr Schulz | Chief Engineer and Manager |
| Herr Fleischer | Supt. - Boiler Shops |

This [illegible] ...d plate shop and can handle [illegible] the heaviest class. The plate and boiler shop is one of the many different manufacturing divisions. As a general manufacturer, they produce heavy machinery of all kinds, boilers, blast furnace plants, coal mining machinery, transmission equipment, bridges of all kinds and complete installations for petroleum, chemical and rubber industries.

In the shop they have a very good line of heavy equipment, such as a four-roll set of bending rolls with a capacity of bending ~~cold plate 50 mm. thick - 6 meters width~~, a shear with circular knives capacity at 25 mm. plate making the cut either vertical or scarfing it for welding, and a 1000 ton press made by Ehrhart u. Sehmer, Saarbrucken, Cantilever Herringbone Rack and Gear, operated with electric drive and hydraulic kickout, which is a particularly fast operating close precision press.

Their average welded work runs about 60 mm. in thickness, but they also make quite a large number of vessels up to 105 mm. and any length or diameter required.

Their stress relieving furnace is capable of taking work 3 meters in width, 4 meters in height, and 25 meters in length, with a very close range on the three heat controls. This is the largest and best stress relieving equipment in the entire pressure vessel industry, but it is out of operation and under repair at the present time.

They have 50 Kjellberg 500 KW welders and also 2 Union Melt machines, both of the later temporarily out of operation from bombing. They also have a large number of motor driven trunnions and at least 10 or 12 positioners of various sizes.

I have shown in accompanying pages the class of work that they do and included a cut of a catalyst oven for the Fischer-Tropsch Process of which they have built quite a number. Their heat exchangers are all of the welded tube variety, not being interested in the changeable tube nest type.

The workmanship and product of this firm is of the highest calibre and they rank with the top grade manufacturers in all Europe.

- - -

Deutsche Röhrenwerke, A.G., Thyssen Werke - Mülheim a/Ruhr

| | |
|---|---|
| Herr Giliax | Director |
| Dr. Simoneit | Works Director |
| Herr Paul H. Inden | Ingenieur and Interpreter |
| Herr Fiene | Supt. Roechner Mill |
| Herr Gruber | Supt. Plate Mills and Boiler Shop |

The Thyssen Werke is one of the outstanding pressure vessel shops in all Germany and makes vessels of all categories, particularly of the seamless and banded varieties.

I have submitted separate reports in the following pages which cover their activities in these lines. They are the only shop manufacturing the banded vessels; they also manufacture vessels under the Roechner Process; and they make clad steel for corrosion resistence, all three of these items being covered under separate reports later in the text.

Their welded pressure vessel shop is well equipped, but this is the minor one of their activities. All of their products are of a high grade and they are considered a potential unit in the steel as well as the pressure vessel industry.

Ewald Berninghaus, 71 - 73 Vulkan Strasse, Duisburg, Rhld.

| | |
|---|---|
| Ewald Berninghaus | Director |
| Dr. Greve | 2nd Director |

This firm is primarily a marine boiler and shipbuilding organization; but, as a fill-in, they manufactured pressure vessels of medium size.

About the only equipment they had at this plant were 10 or 12 welding machines as they sent the plates to another shop for scarfing and rolling.

This plant is a negligible quantity in pressure vessel production, but they informed me they had another plant in Herne a little better equipped.

The Duisburg shops were 90% destroyed and the Herne plant about 65%.

- - -

Gronemeyer u. Banck Kesselsmeide - Brackwede-Westf.

This firm is a very small outfit doing nothing but stationary boiler repair work.

They have made in the past a few pressure vessels of light plate and some heat exchangers with tubes welded in. They have very little equipment, and what they have is very old.

- - -

[illegible] Wilhelmshöher Allee [illegible] Kassel

These people are builders of small marine boilers for river boats of 50 and 150 ATM pressure. They had light equipment and have never been considered in the pressure vessel category.

The plant is 90% destroyed.

- - -

[illegible]metall - Borsig, A.G. - Ulmen Strasse 125, Grafenburg/Düsseldorf

Borsig at this works was formerly fairly active in pressure vessel manufacture of the forging class. They are primarily an artillery and high speed tool steel production firm, but all the equipment for pressure vessels and artillery had been evacuated to Berlin and Eastern Germany in the summer of 1943.

They have a larger plant in Berlin which I expect to visit later on.

Walther and Cie. - Köln/Delbruck

Herr Wolfram Ahn - Commercial Director

Walther is strictly a boiler shop and has never manufactured pressure vessels of any other class. They do, however, have a very complete plant for the manufacture of boilers, but they buy their drums from Thyssen and Mannesmann.

- - -

Paul Schutze, A.G. - Oggersheim - Palatinate

Director - Herr Schulte

This company is a small repair shop but has made a number of small pressure vessels during the war. They also have worked on clad steels to a small extent.

The principal products are small lead lined tanks and kettles and also enameled kettles.

They definitely are not a factor to be considered in the pressure vessel industry.

Mannesmann Röhrenwerke - Huckingen/Duisberg

Works Manager - Herr Ing. Otto Weinrich
Director of Research - Dr. Buckholtz
Asst. Manager of Works - Dr. Knapp

Mannesmann are one of the most important units in the manufacture of pressure vessels in all Germany. Their pressure vessel work is carried on at Huckingen and Berlin.

The principal products at Huckingen are pipe, boiler drums and pressure vessels welded by either water gas, electric arc, or Union Melt process. They have the shop laid out on a production basis - and they have the necessary equipment for any type of pressure vessel up to a plate thickness of 104 m.m. The great majority of their work averages about 60 to 75 m.m. thickness.

Their equipment is excellent and they have plenty of everything. They cold roll plates to 60 m.m. thickness and have several other rolls which will handle 40 to 50 m.m. plate. They have a considerable number of driven trunnions and positioners of all kinds.

They have progressed farther in the use of Union Melt than any other firm in Germany. In fact, they are the pioneers in this process in Germany. Their set up at the Union Melt process is particularly flexible as they have a very well designed outfit to handle work of at least 4 meters diameter and 18 meters long.

There are three separate installations for Union Melt, two of which are used for pressure vessel manufacture and the other one for pipe welding. They also use a small portable outfit on rails to weld the inside seems.

Their heat treating and normalizing equipment is one of the best in Germany being able to handle 3 meters diameter by 18 meters length. They handle considerable of the work of this type for many of the other pressure vessel manufacturers.

Mannesmann are considered in Germany, as the top rank of pressure vessel manufacturers and their executive and research personnel is of high calibre; their product is very high class and I would rate them as the leading manufacturer with Thyssen Werke as a close second.

Press Und Walzwerke A.G. - Dusseldorf

Managing Director - Rudolph Krautheim
Director - Wilhelm Martin

This firm is not particularly active in pressure vessel manufacture with the exception of boiler drums. They have two methods of manufacture; first, the extrusion of boiler drums and second, the forging of some few vessels.

They make a very fine product under each method but are known particularly for the pressed boiler drums.

## PRELIMINARY RULES FOR CALCULATING BANDED HIGH PRESSURE VESSELS

Banded high pressure vessels are manufactured, according to Dr. Schierenbeck of I. G. Farbenindustrie A.G., by rolling profiled steel bands in several or more layers, in a spiral with a width of the various steps in the cross section of the band, similar to the spiral grooves turned on the corepipe, which has a relatively low wall thickness. The bands are rolled on a red heat, varying as to the use of the vessel (hot or cold use), and shrink tight to the corepipe when cooled. The thrust edges of the winding bands of the consecutive layers are staggered and the bands have a profile that grip into one another of two positions. The corepipe also has grooves turned on the outside, spirally, with width and pitch conforming to that of the band, thus allowing the first layer to get a firm grip on the corepipe.

Through this rolling of the profile bands together and also with the clamping action obtained by shrinkage of the outer layer on the corepipe and the succeeding layers on each other, a very homogenous structure results, which allows the transmission of axial forces with safety.

This band construction has been proven by various tests. Compared with plain wall vessels, a higher strength is obtained, which is a result of better elaboration of material and a more even distribution of tension. The superiority of the banded vessel even allows us to exceed the elastic limit in some places, either in the manufacturing process or in the operation; whereas with plain wall vessels, this condition must strictly be avoided. Naturally, a loosening of the band from any manner of working influence must also be avoided. This may be taken care of either by including the calculation of additional stresses (perhaps heat) beforehand or by close supervision of temperature while the vessel is in operation (safety against overheating and any other causes).

### I. Calculating The Wall Thickness

According to tests, the distribution of the circular and radial stresses raised by internal pressure, corresponds to those of Liners or Cores with plain walls. Whereas with plain wall liners, the longitudinal stress is $\frac{\sigma_t + \sigma_r}{2}$ at any place, this value is exceeded with the banded

at the liner. The rolled up band, however, on account of a greater flexibility has a much lower value. The rolling up process brings the inner forces of the liner or core in the circular direction under compression preload, the outer forces under tensile load.

As the value of this preload and that of the longitudinal stress is not exactly laid down, the stress calculation may only be done with the mean strength by internal pressure figured out with the help of the shearing stress hypothesis. This is

$$\phi_{v_m} = 0.5 \frac{P}{100} \times \frac{d_i + s}{s}$$

in which - $P$ = Internal Pressure - $K_g/cm^2$ (1)
$d_i$ = Inside Diameter of Vessel - mm
$s$ = The Whole Wall Thickness - mm

As with banded vessels, a 1.6 times safety against deformation of larger scale is sufficient on account of better elaboration of the band material, the wall thickness of the vessel should be made to suit the following condition

$$\phi_{v_m} \begin{matrix}\text{(is less than)} \\ \text{(or equal to)}\end{matrix} \frac{\phi_{0.2}}{1.6} \qquad (2)$$

in which $\phi_{0.2}$ = yield point of original material respectively of band at working temperature. (Calculation should be based on a yield point 0.7 times the value of stress.)

The necessary wall thickness is:

$$S = \frac{d_i}{2 \times \phi_{v_{mzul}} \times \frac{100}{P} - 1} = \frac{d_i}{2 \times \frac{\phi_{0.2}}{1.6} \times \frac{100}{P} - 1} \qquad (3)$$

A careful production process with regard to the wrapping of the bands will secure the complete compactness of the individual layers. Any allowances do not seem, therefore, to be required.

The yield point should only be inserted into calculation as a maximum value of 0.7 of the stress.

As already mentioned, the stressing in axial direction of the container wall, as well as in the core liner, cannot be determined accurately by calculation. However, actual tests have indicated that this axial stressing is considerably less than the tangential stressing. An after calculation of the safety in axial direction is, therefore, not necessary with regard to the wrapped body, as well as the full walled body and the core liner.

In order to avoid too high longitudinal stresses in the pipe core, its wall thickness should not be less than 10% (an in case of interlocking, 15%) of the total wall thickness. The 15% takes into account the grooves turned in the core outer shell. The yield point of the core liner should not be lower than that of the wrapping material. Assuming "a"% of the wall thickness, consisting of material with yield point of $\phi_{0.2_I}$, the remaining "b"% of a material with yield point $\phi_{0.2_{II}}$ then equation (2) will have the following form:

$$\phi_{v_m} = \frac{1}{1.6} \left( \frac{a}{100} \times \phi_{0.2_I} + \frac{b}{100} \times \phi_{0.2_{II}} + ---- \right) \quad (4)$$

If the core liner has a longitudinal seam, the yield point must be multiplied by a weakening factor, $V = 0.9$. Calculation of the wall thickness according to equation (3) has to be performed with this new value.

As the preloads resulting from wrapping up and also the thermal stresses of vessels working at higher temperatures rise with an increasing of the wall thickness, it is recommended to limit the wall thickness of wrapped vessels to not more than approximately 200 mm. as long as we do not have enough experience available as to the effect of the aforementioned stresses. At the same time only wrapped vessels for wall temperatures not exceeding 350° should be used. The material used for the wrapping bands must be less sensitive to ageing from fatigue and a minimum elongation, $\phi_5 = 15\%$, following the heat treatment required in the wrapping process.

## II. Testing The Stress of Heat Tensions

Under the influence of stresses evoked by internal pressure and heat on vessels working at higher temperatures and on account of a decrease in the yield point, a diminuation or lessening of the shrinkage will take place. In order to leave a sufficient pre-tension after diminuation of shrinkage and still have a good compactness of the wrapping after taking away the internal pressure, it is necessary that on the outside the sum of the circular tension evoked by the working pressure -

$$\phi_{t} = \frac{p}{100} \cdot \frac{2}{U^2 - 1}$$

[illegible] $U = \frac{d_a}{d_1}$ = the ratio of diameter (5)

and the heat tension which corresponds to the prevailing temperature drop $D_t$, then $\phi_w$ is approximately $0.2 \times D_t$ (6)

and is not higher than 75% of the yield point of the material at working temperature.

At wall temperatures up to 350° it has to be figured with a temperature drop

$$D_t = 0.2 \times S \quad \text{(with S in mm.)} \quad (7)$$

provided it cannot be proven that a lower temperature drop is prevailing.

As the pre-tension and the working stress at the inside of the vessel work in opposed directions, it is not necessary to test the stresses

## III. Transmission of Forces at the Ends

In order to get a good transmission of the longitudinal forces from the flanges to the bands, the shrunk ring or rolled up flanges have to have at least such a height that the shearing area (product of number of actual grooves, times groove width, times circumference) equals the area of the wall of the vessel

If

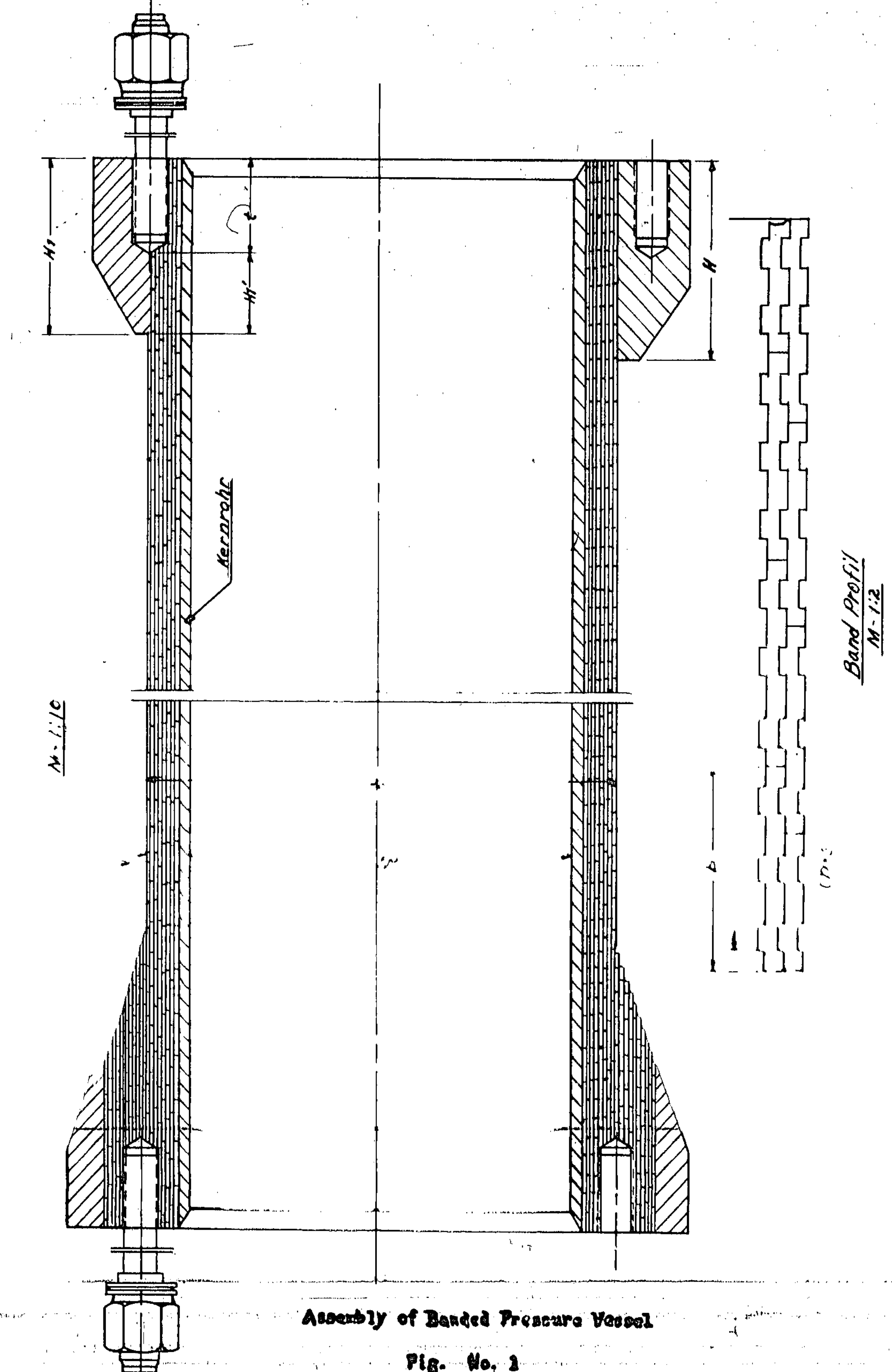
$B$ = band width in mm.
$b$ = groove width in mm.
$n$ = number of grooves in band width
$d_a$ = outside diameter vessel in mm.
$F$ = area of wall of vessel in $mm^2$

the necessary number of grooves in

$$Z = \frac{F}{3.1416 \times d_a \times b} \qquad (8)$$

and the height of the flange is:

$$H = \frac{Z \times B}{n} = \frac{F}{3.1416 \times d_a} \times \frac{B}{n \times b} \qquad (9)$$



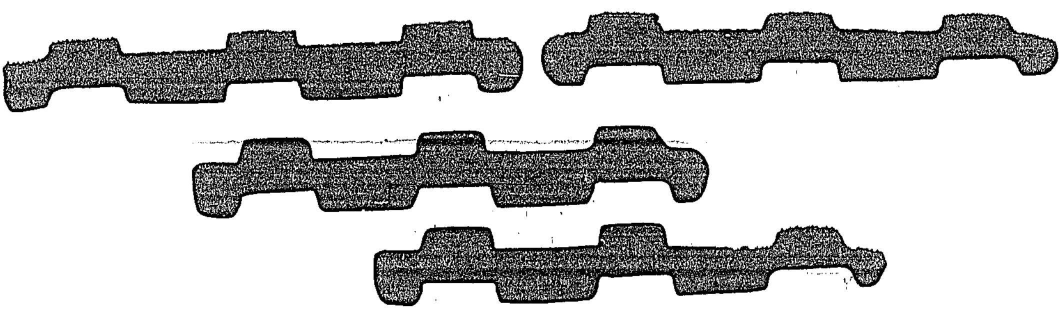

**Assembly of Banded Pressure Vessel**

**Fig. No. 1**



Flanschausführungsformen für Wickelmantel W3370-10

Section of Band
for
Wrapped Band Vessel



Assembly of Bands (Spread) for
Wrapped Band Vessel

## MANUFACTURE OF BANDED VESSELS

The wrapped band vessel was first brought out in 1940 by I. G. Farbenindustrie, A. G., in order to relieve heavy forging and pressing equipment to some extent for work in the production of other war materials. Actually, it was designed, not so much to relieve heavy equipment, but rather to increase facilities for the production of high pressure vessels. The shops capable of making vessels for high pressures were scheduled to capacity and very few, if any, quit production of vessels for the manufacture of other war items. It was an additional facility to increase the production of pressure vessels which were sorely needed for the chemical, rubber, and petroleum industries. This is the general consensus of opinion of most of the pressure vessel manufacturers.

The banded vessel did relieve to a certain extent the pressure on the production capacity of the heavy plate mills, but this was counter-balanced by the load thrown on the smaller bar mills.

The entire production of banded vessels was concentrated in one plant, the Deutsches Röhrenwerke, A. G., Thyssen Werke, Mülheim a/Ruhr.

The vessel, as designed by I. G. Farbenindustrie and shown in the accompanying drawing, Figure No. 1, Page [illegible] of this report, shows a central core pipe 20 mm. thick with a series of bands about 8 mm. thick by 79 mm. wide, wrapped spirally around the core pipe.

The successive bands are interlocked in the [illegible] wrapping is stepped forward one or two steps in order to straddle the gap of approximately 1 mm. which occurs in each wrapping on each layer.

In order to give the first band wrapped the required grip on the core pipe, it is necessary to machine turn an exactly similar spiral groove the complete length of the core pipe. The core pipe, as originally designed by I. G. Farbenindustrie, had a minimum thickness of 20 mm., but in subsequent practice they found a core pipe of 25 mm. a better pipe to use, mainly from the fact that 25 mm. pipe was available more often than the 20 mm. pipe and also allowed the groove turning without reducing the thickness of shell too much. Core pipes of various thickness to a maximum of 40 mm. have been used.

The vessels were all built in standard sizes and lengths, and the specifications of steel analysis had a wide range, dependent upon whether or not it was for hot or cold use and other varied local conditions in the plant in which it was to be used.

The standard diameters were 600 mm., 800 mm., 1000 mm. and 1200 mm., and the standard lengths - 6 meters, 8 meters, 10 meters, 12 meters, 14 meters and maximum 18 meters. The ends were always covered, without exception, with a bolted blind plate cover through which all connections and openings were made. They had been unable up to the present time to take any connection of any size through the side wall, as any hole drilled through the side wall would cut through the open space between bands at some level of the wrapping bands. They had in mind making connections through the side walls by drilling and inserting nozzles and welding these inside and outside but had not produced any in this manner at the Thyssen plant. They had no knowledge of I. G. Farbenindustrie attempting this at the operating plants.

The vessels were constructed for two operating pressures. One, to operate at 325 atmospheres, was tested at a pressure of 425 ATM. and the other class at operating pressure of 700 ATM. to be shop tested at 925 ATM.. The "hot use", or as they express it "hot going", vessel operated at a temperature of 350°C and the "cold use" vessels at 20°C. All vessels were reactors and regenerators for "hot going" and washers for "cold going".

Their standard specifications required core pipe tests of "cold going" vessels with a tensile strength of 50-60 KG $^{mm2}$ and a yield point which must be above 30 KG.; while the "hot going" vessels required T.S. of 40 KG $^{mm2}$ and a Y.P. above 20 KG.. The wrapping bands required a T.S. of at least 50 KG. with a minimum Y.P. of 32 KG. for "hot going" vessels. The specifications for the "cold going" vessel bands were about the same as the "cold going" core pipe specifications.

In explaining the manufacture of the vessels, I ask your tolerance, as it may be necessary at various times to break the continuity of the technique, to pick up some point farther back in the manufacturing method.

The principal pieces of equipment are: first, a coiling machine with an electric heating element, and second, a heavy machine lathe which has an unwinding machine with electric heating element to heat the bands before application to the core pipe.

The bands are produced on the bar mills with a section as shown in the upper corner of Figure No. 1, Page 27 and are delivered to the vessel shop in 35 to 40 meter coils. The bands are specified 80 mm. wide with an 8 mm. standard thickness but an overall thickness dimension of 10.8 mm.. This would give a depth of groove of 2.8 mm. with an approximate width of the groove of 15.5 mm.. You will note that one end of the band has a square vertical with very small fillets top and bottom, while the other end has a semicircular section. It was intended that both ends have the square vertical section, but difficulties in the rolling of the bar dictated the round end on one end. The bars, when rolled to a square vertical on both ends, seemed to form a small projection of excess material on the top or laying side of the band which prevented a closely wrapped vessel. It was, therefore, decided to accept the band with the rounded edge as the lesser of the two evils. Unfortunately, this gives a gas leak as each successive ring is wound, which extends the entire spiral length of the vessel in each layer; this, however, has no effect on the vessel itself.

As stated, the bands are delivered in coils of 35 to 40 meters, and they are immediately placed in the coiling machine to be unwound and recoiled in larger coils of 3500 meters.

The band is unwound in the coiler and runs through [illegible] heater element which heats it to a temperature of 950°C for annealing and recoiling. The successive coils are flash welded to the ends to produce a continuous band. The heater element is a resistance heater with 25 volt 3500 AMP 300 KVA current and is $3\frac{1}{2}$ meters long. The band travels through the heater at a speed of [illegible] M.P.M.; and if it is to be used for "cold going" vessels, it is immediately recoiled without any tempering of the band.

If the bands are to be used in fabricating "hot going" vessels, immediately after leaving the heating element they are tempered over an air-cooled jet system, $1\frac{1}{2}$ meters long, to a temperature of 600°C and then recoiled.

The recoiling is necessary for two reasons: first, annealing, and second, to get a coil long enough to make at least one or more complete wrapping of the vessel being fabricated. Some of the largest vessels require as high as 21000 to 22000 meters of bands.

The core pipe, which has previously been turned in another shop with a thin skin turning inside and outside full length and the spiral turned to match the grooves in the band, is always about 500 to 800 mm. longer than required dimension. The grooves on the pipe are an 80 mm. spiral pitch which allows for any variation in the 79 mm. width of the band. The core pipe may be either electric or water gas welded or of the seamless variety.

The wrapping machine is a lathe without a tool carriage. On the back of the lathe, a travelling carriage is attached which carries the entire wrapping and heating mechanism.

The core pipe is chucked in the lathe and the band is fed through the electric heater which heats it to approximately 850°C for "cold going" and slightly less for "hot going" vessels. The hot band is attached to the core pipe by tack welding, while the machine is turning, the lugs of the band fitting into the grooves turned into the outer surface of the core pipe. As the band progresses around the spiral grooves, the entire carriage with coil and heater travels ahead on the lead screw of the lathe.

The band moves at a speed of 5 meters per minute and the heater element is about 4 meters long. The uncoiler has an adjustable brake which holds just enough tension on the band and core to insure a tight contact and at the same time allow no deformation or elongation to the band during the winding process. The band, as stated before, is heated to a temperature of about 850°C; and experience has proven that, in order to get the correct and complete shrink fit, it is necessary that each separate ring around the vessel have a definite close range of cooling temperature as the wrapping progresses.

The core pipe is water cooled, having a running stream ranging from one quarter full at the start of the wrapping to a full pipe as the outer layers are applied, preventing collapse of the core pipe, and cooling the band. They claim that the band leaves the heater at 850°C and it is necessary that 4 complete rings have heat enough for shrinking at all times. The first or youngest of the 4 bands with shrinkage carried a temperature of 600°C, the next one runs close to 500°, the third one 450°C and the last of the four rings about 400°C. From that ring on, the temperature drops so rapidly, due to the inside cooling, that they are not concerned about its temperature. It is claimed that no shrinkage of any great amount is secured after the completion of the fourth ring from the coiling machine.

The carriage progresses to the head end of the lathe; and at the end of the core pipe, the band is clamped, cut off and tack welded. The successive bands are applied in the same manner until the desired thickness of the vessel is acquired.

The application at the present time is about 5 meters per minute and they have been working on the possibility of speeding it up to 10 or 12 meters per minute. The entire problem hinged on the design of a heating element and the necessary investigation and experimentation in regard to the cooling of the bands after they have been wrapped on the core pipe.

Referring again to Figure No. 1, Page 26 of the completed banded vessel, please note that they have several methods of end construction. If the vessel had a shell thickness sufficient to allow for tapped steel stud holes, the ends were not built up with wrapped material on the first few vessels. This, however, was discarded and the practice adopted asshown in Figure No. 1. The most popular form was that showing the wrapped buildup with a machined forging shrunk on the outside, all of the stud holes being in the wrapped section of the end. The other two sketches, showing the studs in either the entire reinforcing ring or half in the ring and the other half in the banded vessel, were used to some extent with the preference shown to the half and half construction. Thyssen were of the opinion that the band build-up without any reinforcing ring was entirely adequate, eliminating the expense of the forging and the necessity of machining the vessel for the shrink fit of the collar.

Due to the fact that the band ends stop and start at various points, the vessels are always made long enough so that each end is machine cut far enough to assure a complete ring on each and every layer at each end. In fact, in all cases the ends so cut off are used as test specimens. As the successive layers are simply tack welded at the start and finish, it is evident that as soon as this cut-off has been made, the vessel would immediately release all tension.

~~In order to prevent this, the last three rings on~~ the top layer are welded completely around the circumference on each end, thus allowing them to make the cut to trim up the ends. After trimming the ends, the tongue ends of the bands on the face of the cylinder often show loose, and it is standard practice to weld these tongues in. The vessels were drilled and tapped; and it was my thought that in the drilling and tapping, the tool hitting the joints of the bands would be likely to break or chip. I am informed that they have never broken either a drill or tap from this cause. The only danger to a drill or tap is in the start of the hole, where the loose tongues might break them.

The reinforcing ring on the outside is an unnecessary expense, according to the fabricator, as the vessel is strong enough and as the last three rings are welded together, there is no likelihood of it releasing tension.

The time factor in manufacturing is an important item. I have been told that after the material, such as core pipe and coiled bands are ready, a complete wrapping can be made of a vessel 800 mm. in diameter and 14 meters long with a wall thickness of 150 mm. in 5 to 6 days of 20 hours each -- this at their present speed of 5 meters per minute, and they were hopeful of increasing that speed to a maximum of 12 m. per minute. Even if they only increased it 8 or 10 M.P.M., you can readily see the decrease in manufacturing time.

They have produced only between 60 and 70 of these vessels, all of them, of course, being for the I. G. Farben-industrie A. G..

Several of the vessels have had bomb hits and the damage showed only through the outer layer and in no cases beyond the second layer. The layers affected were immediately welded to each other and to date they have had no failure of any vessel.

I saw a test cut-out section of one of these vessels and each and every layer could be definitely seen. The layers in some cases showed open spaces between each other, which while small, still were definitely not steel-to-steel contact. This specimen also gave a very clear demonstration of the open gap between the successive layers in each wrapping, where the rounded end of the band would not fit up to the square end of the next band, giving a spiral gas leak the entire length of the vessel in each layer. The vessel is figured evidently to take care of this discrepancy which ~~after all is probably immaterial to the strength of the shell.~~

In many of the vessels, they fitted an alloy lining after the wrapping and blew it up to fit the shell, saving the cost of clad steel.

As stated earlier, this is the only new type of pressure vessel brought out by the Germans during the course of the war.

## MANUFACTURE OF PRESSURE VESSELS BY ROECHNER PROCESS

The Deutsche Röhrenwerke, A. G., Thyseen Werke, Mülheim a/Ruhr, in addition to the wrapped band vessel, also produce seamless vessel shells under the Roechner Process.

They have two mills, the large one for vessels 800 mm. to 1800 mm. dia. and the small mill which can roll cylinders from 400 mm. to 1000 mm. diameter.

The large mill rolls shells of any thickness from 40 mm. to 200 mm., but the average runs 150 mm. with a maximum length of 18 meters. The small mill can roll cylinders from 40 mm. to 150 mm. with an average of 100 mm. to 120 mm. and a maximum length of 15 meters.

The Roechner Process, in a few words, consists of a series of inside and outside rolls working on an ingot at the same time rolling and drawing out the steel to required sizes. The large mill has a mandrel holding 7 rolls that are adjustable but which are idlers. The outside rolls are 7 in number also and are, of course, adjustable, but these rolls are the driving rolls, being driven through pinions by two 7000 H.P. electric motors.

The Trunnion wheels carrying the ingot are movable both ways, vertical and horizontal, and are also motor driven.

The ingots are bored before being sent to the mill. They are heated and twelve passes are made on them through the mill on the first heat. Ordinarily two heats are required to finish an ordinary sized vessel, but often more are required depending on the size and shell thickness of the desired vessel.

All vessels are stress relieved as Thyssen Werke has one of the few large annealing furnaces used in pressure vessel fabricating shops. Their furnace will handle 2 meters width, 2 meters height and 18 meters length.

For some reason, I. G. Farbenindustrie has always specified that these vessels have a light cut taken over both inside and outside surfaces.

Thyssen were opposed to machine turning the shell inside and outside as they were able to hold the diameters and thickness to a very close margin under this process.

Here again they often fit alloy linings inside the completed vessel and blow them up to conform to the finished vessel, plug welding them to the outer shell if necessary.

The maximum size ingot the mill can handle is 110 tons. The cost of these shells is approximately 30 per cent higher than welded vessels.

# MANUFACTURE OF CLAD STEEL

The manufacture of clad steel, or Plattierte Bleche as it is known in Germany, is of several varieties, of which the method employed by the Deutsches Röhrenwerke A. G. - Thyssen Werke, Duisburg a/Ruhr is probably the best.

There is no knowledge of any practice of electric welding alloy sheets cold to carbon steel plates. There is, however, the practice of forming alloy linings to suit the individual vessel, fitting the lining to the vessel and blowing it up to set it in place. More often than not, these linings are then plug welded in spots, the plugs being spaced about one-half meter to a meter apart. Some operators claim that they do not even go to the trouble of plug welding as they think it entirely unnecessary. In these cases, various alloys are used but the most important ones are stainless steel, nickel and copper.

The process employed by Thyssen is an hydrogen welded process, the plates being assembled and then rolled in the plate mill. They have a very wide range of combinations, plating either one or both sides and use almost any alloy, but principally copper, stainless steels of several varieties, nickel, chrome, chrome molybdenum; silver and under special circumstances brass.

Their process is as follows. The pack is made up [illegible] steel plates on the outside. These plates have a steel strip welded around the four sides. This strip is to be used as the seal and the size varies in accordance with the sizes of the pack to be made up. The pack is always made to clad two plates at least with each rolling. Frequently when they have requirements for plates to be clad both sides, the pack will be built with the double clad plates on the inside of the sandwich.

After the plates have been prepared with the [illegible] strip, the alloy cladding is laid inside and covered with a magnesium oxide paste. The second alloy cladding is laid on top of the paste and the top carbon steel cover closes the pack.

Pipe inlets and outlets for hydrogen are fitted into two opposite sides with about 10 foot leads. The sealing edges of the plates are then welded all around and the pack is ready for heating and rolling. The thicknesses of the carbon steel plate and alloy cladding set up in the pack depend entirely on the thickness requirements of each after the plate has been finished-rolled. There is no reasonable limit to the thicknesses required although the great majority run about 1 to 2 mm. thickness of alloy. Again the size of plates has no limit, except the limit of furnaces and mills. The rolling of clad steel is done at Thyssen only on the 3½ meter mill as the furnace and rolling crews on this mill are the only ones competent to handle it.

The packs are charged into the furnace and the hydrogen fed through the lead pipes. The hydrogen is fed at a very low pressure, just a few ounces above atmospheric pressure. The pack is heated to required heat, the hydrogen being fed during the heating until it comes out in flame at the open end of the outlet lead pipe.

The packs are rolled at different temperatures, dependent on the alloy to be clad. Copper pack rolled at 1000°C, nickel pack at 1200°C and remanit or stainless pack at 1280° C.

When the pack is drawn from the furnace at the correct heat, the lead pipes on each side are broken off and the pack is shunted to the mill. The pack is rolled to the desired thickness, sheared and stripped.

The variation of thickness of the cladding is, of course, dependent again on what thickness had been ordered, but I am told it will vary only 2 to 4% on the widest plate. If the pack has been built of two one-sided and one plate of both sides, the thickness variation of each cladding is greatly reduced.

Thyssen are making [illegible] investigation I am informed that no loose spots are [illegible] and no laminations have been found after forming and welding in the pressure vessel shops.

For the sake of clarity, I am inserting a sketch showing the lay up of the pack of two varieties under Figures 1 and 2, Page No. 37A of this report.

~~Their capacity is about 1000 tons monthly on this~~ particular product.

# CLAD STEEL PACKS

as set up by

## DEUTCHES ROHRENWERKE A. G.

Thyssen Werke - Mulheim a/Ruhr

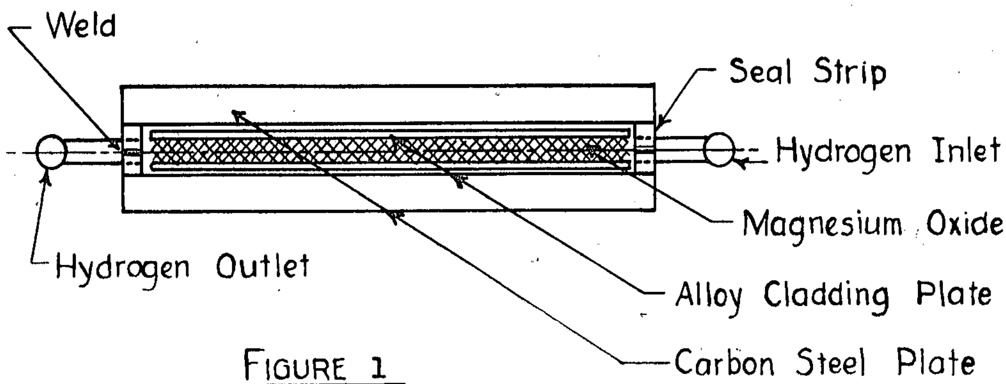



FIGURE 1

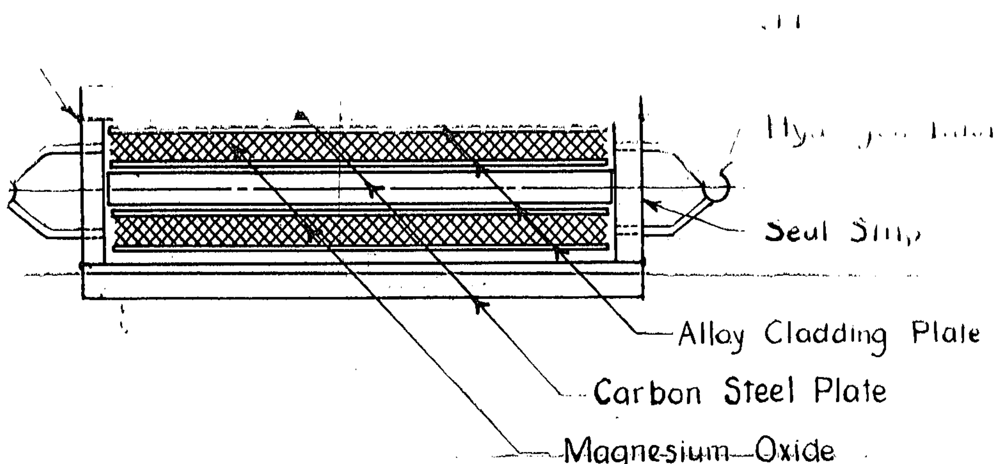
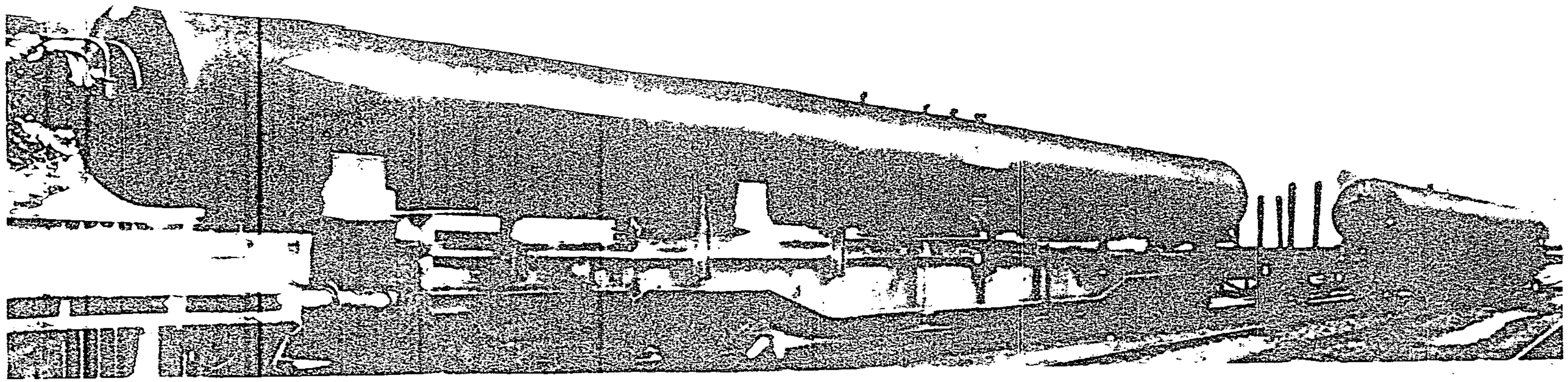
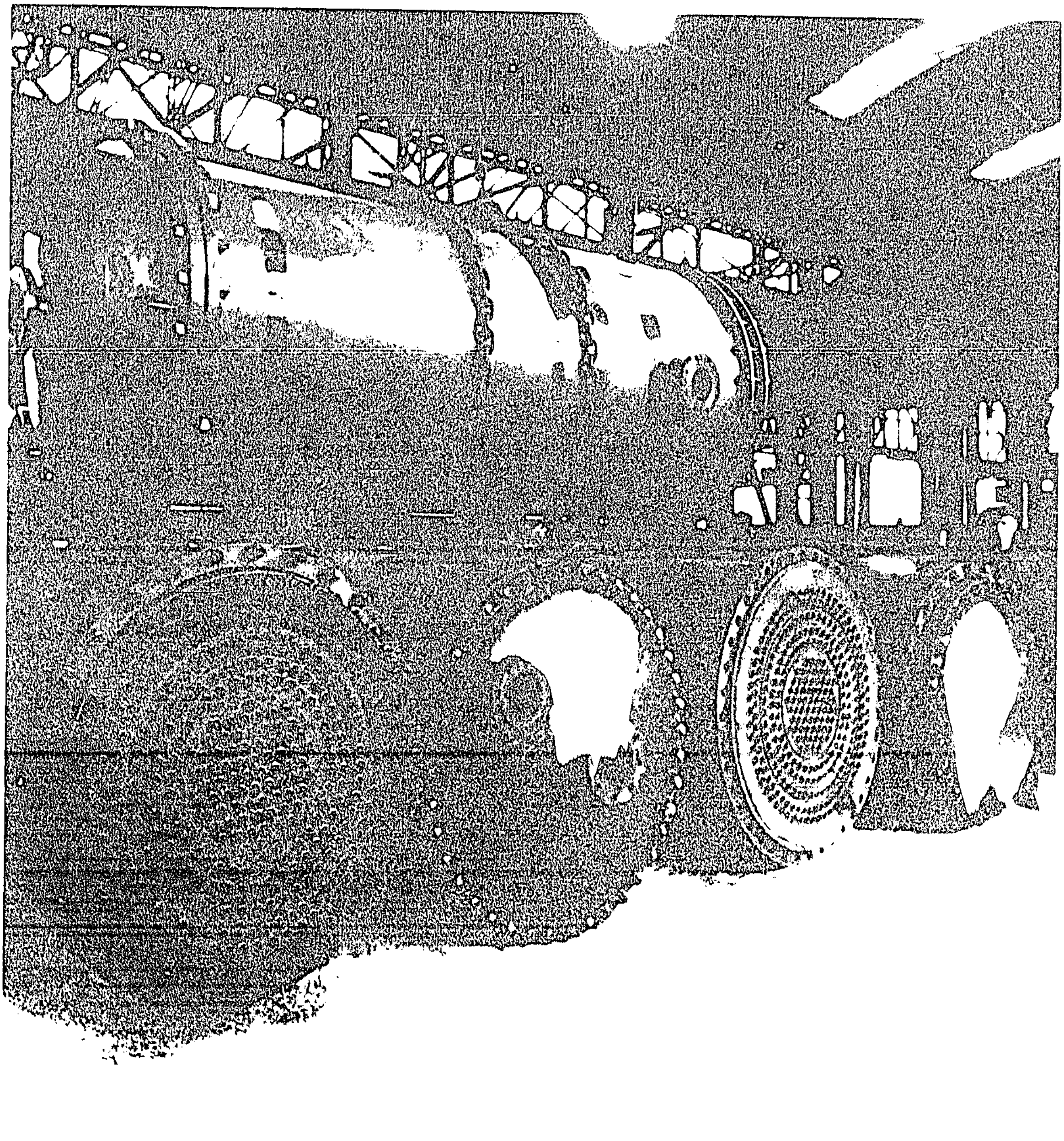


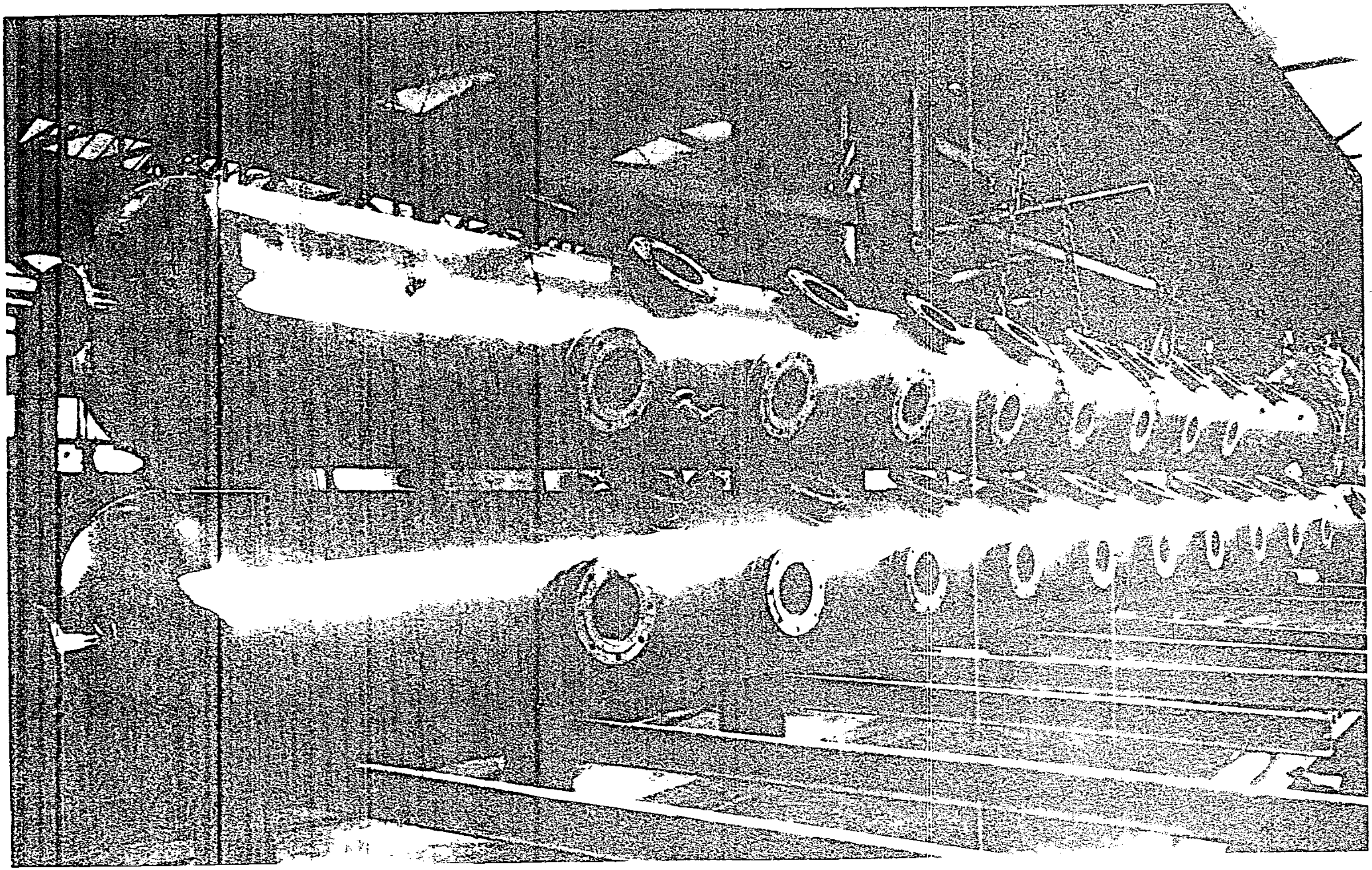

FIGURE 2

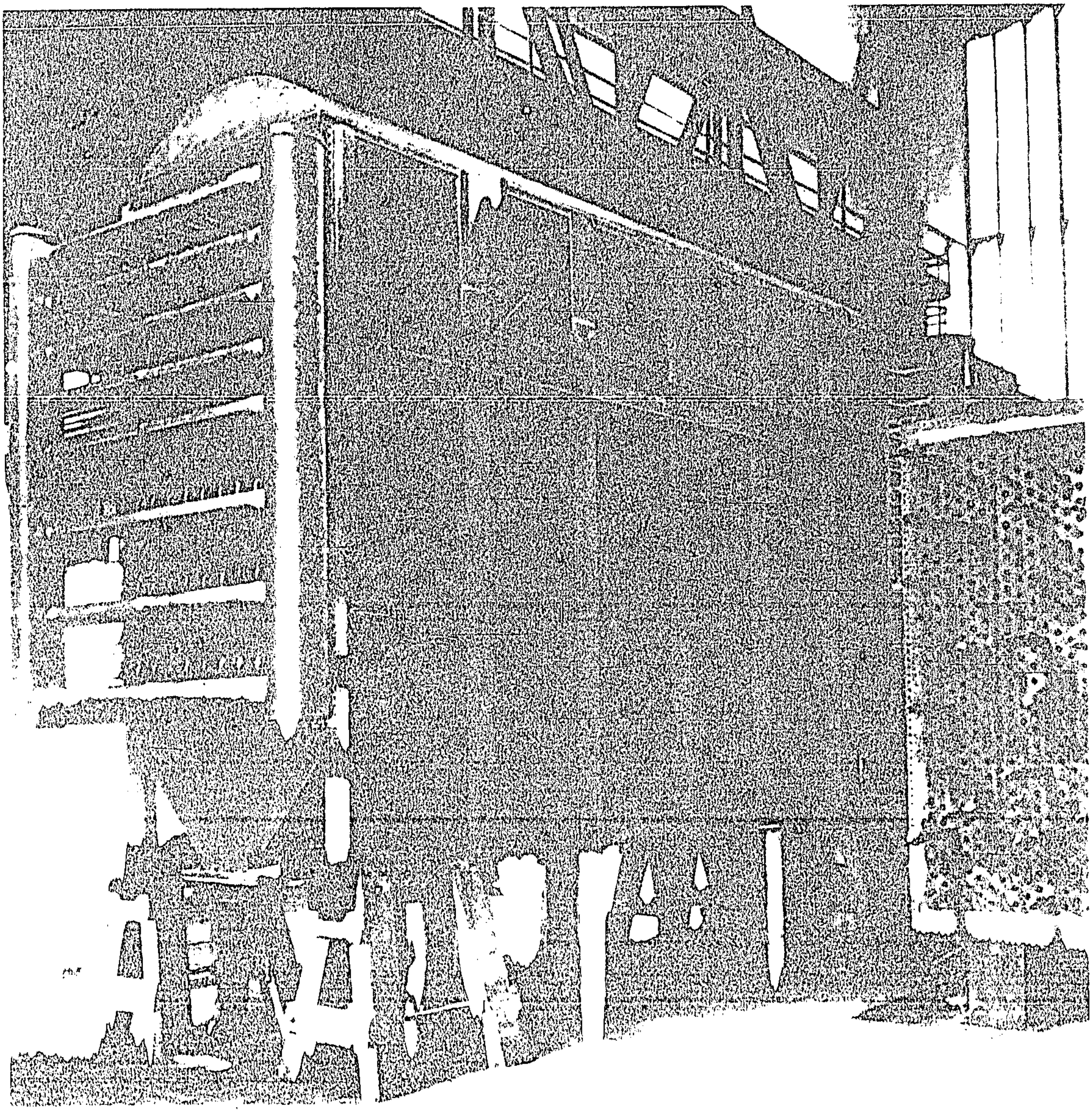
The following pages 39 to 52, inclusive, are reproductions of the work produced by various firms in Germany.

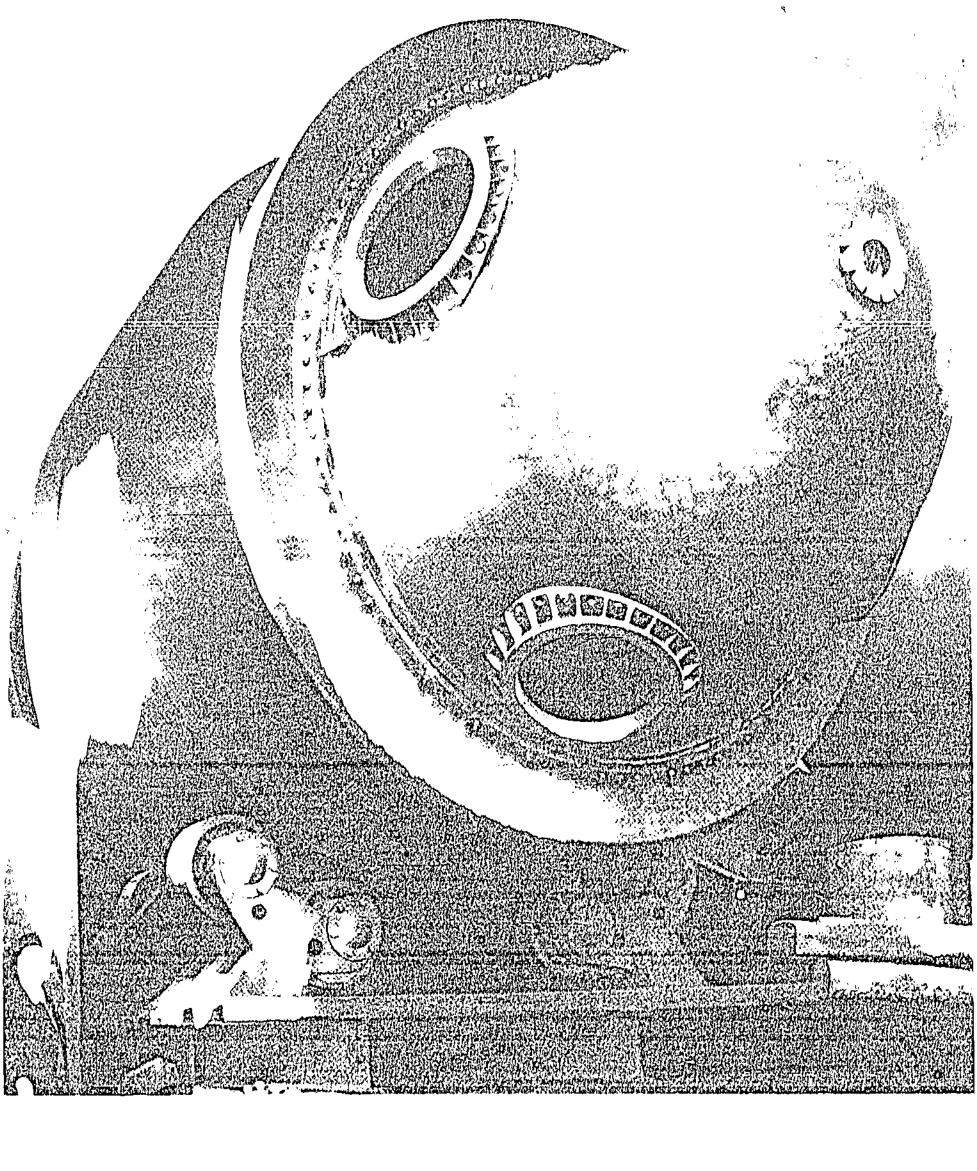
Hochdruckapparat [illegible] - Geliefert 1937 für Italien und Deutschland

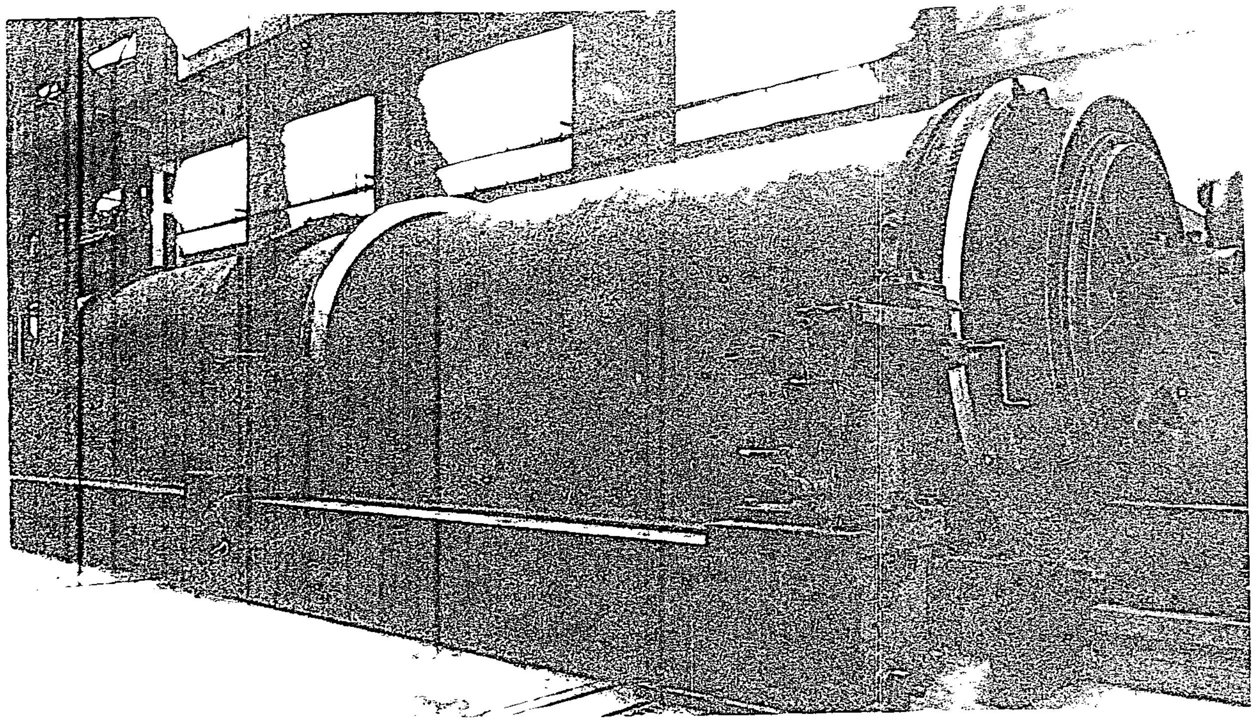


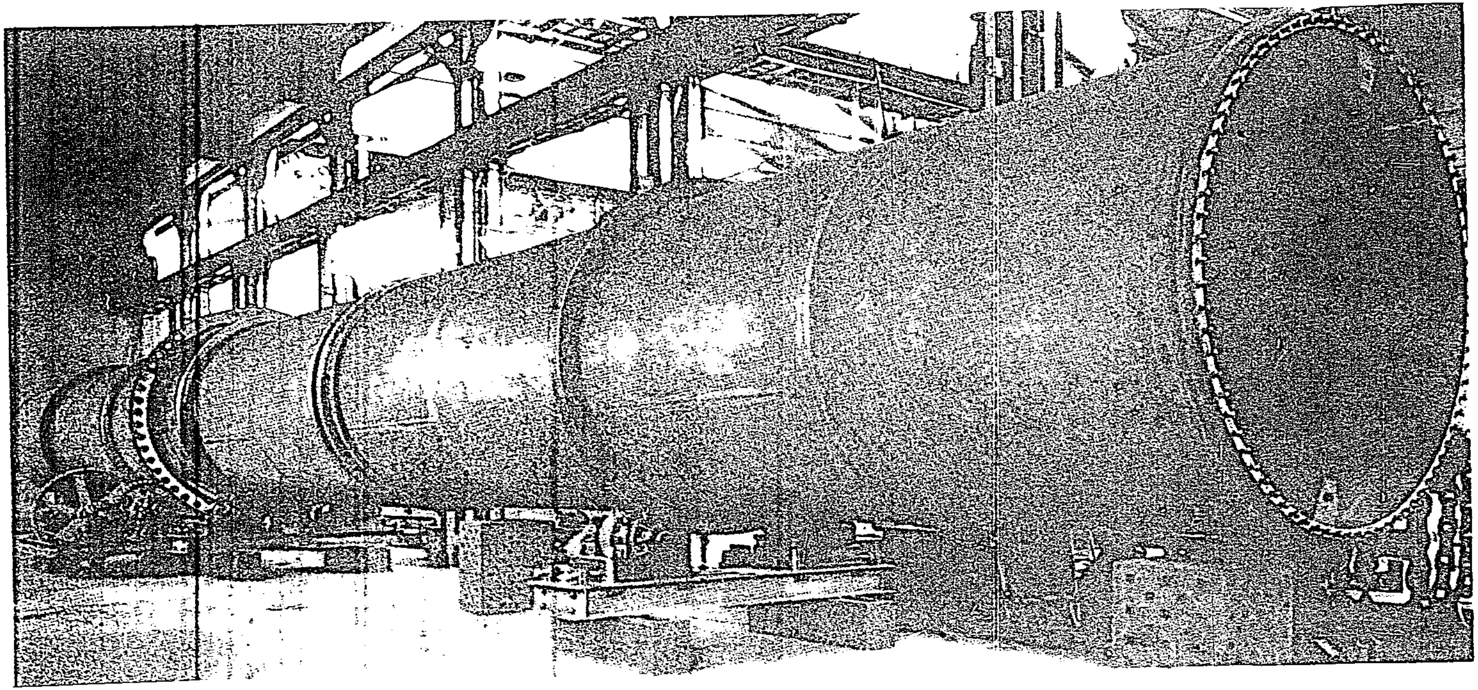


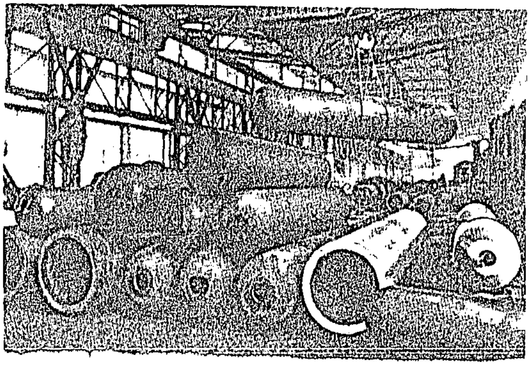


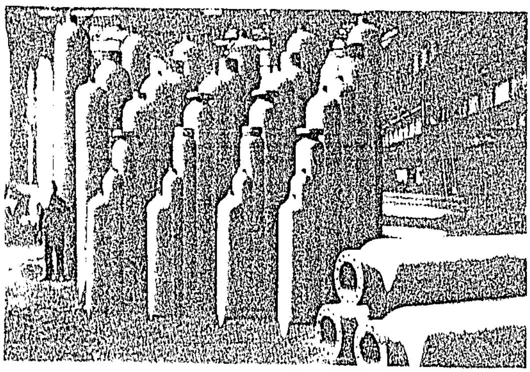




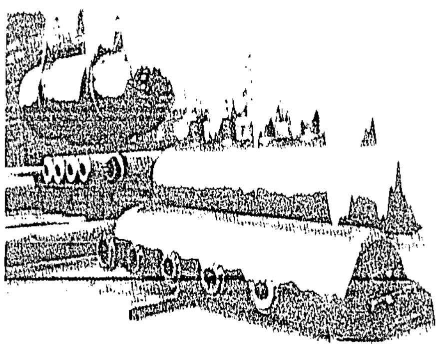


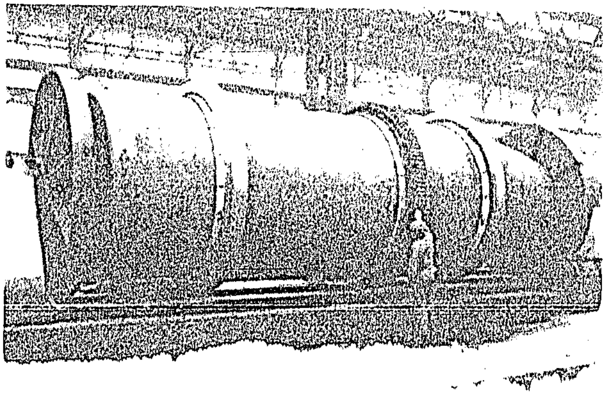


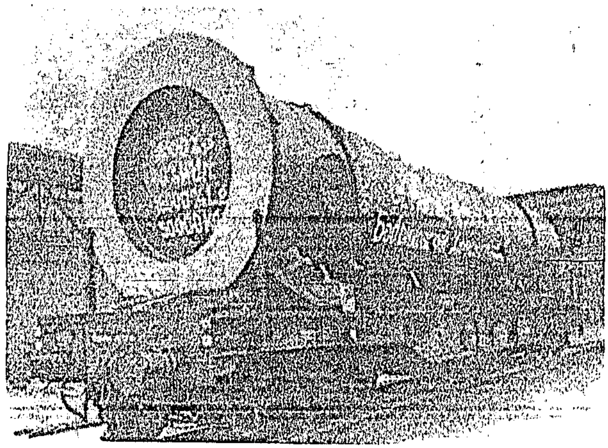


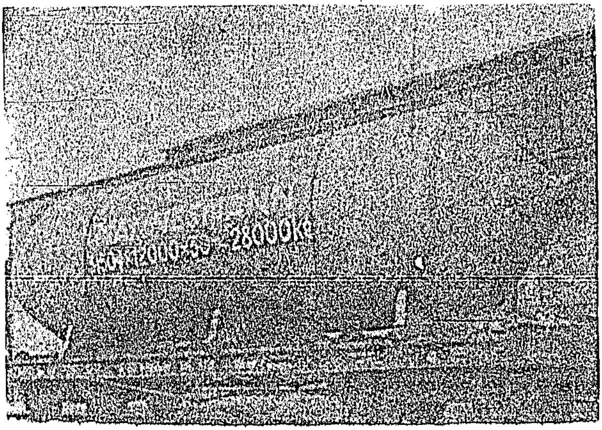


High Pressure
Containers and
Steam Receiver





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