Dr. Donath stated that he had heard that the Japanese made aviation petrol from rubber, but he did not know any details of the process, location or the extent of this activity. Dr. Donath had also heard that the Japanese had some production of iso-octane or alkylate.

XI. DEVELOPMENT OF WICKEL PRESSURE VESSELS

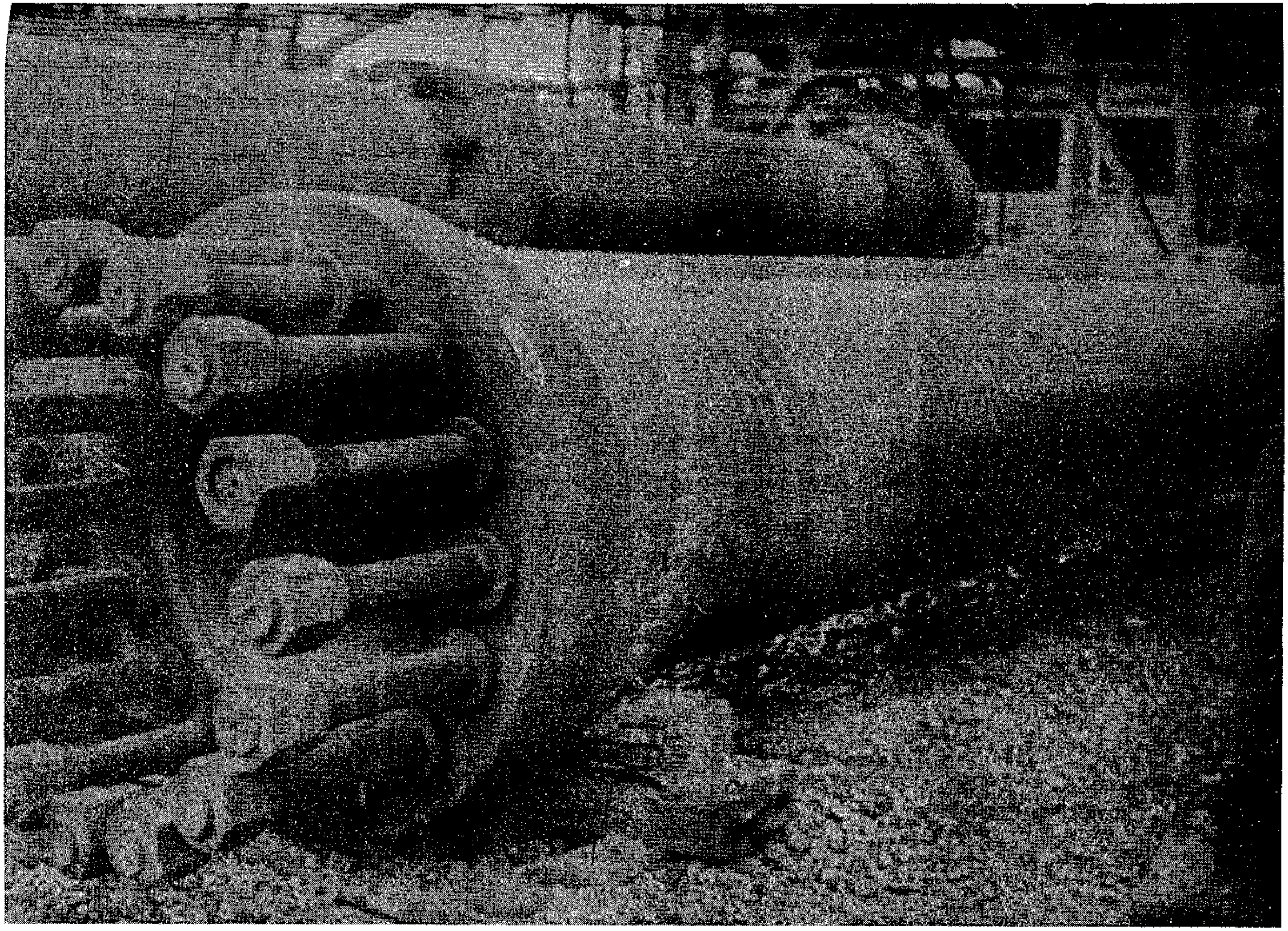
A. INTRODUCTION & GENERAL DESCRIPTION OF PROCESS

The following account of this development was obtained from Dr. Schierenbeck, the inventor of the process for producing high pressure vessels by winding tape on to a thin walled tube. The need for a large number of vessels for the Four Year Plan was first felt in 1937 and the I.G. were not satisfied that the Forgemasters could deal with the demand in the time set by the State. They therefore set out to see whether they could produce vessels suitable for use at high temperatures and pressures using the old process for wire-winding of guns or some modification of this method. The initial intention was to speed up the delivery of vessels rather than make any great technical advance in vessel design such as saving weight.

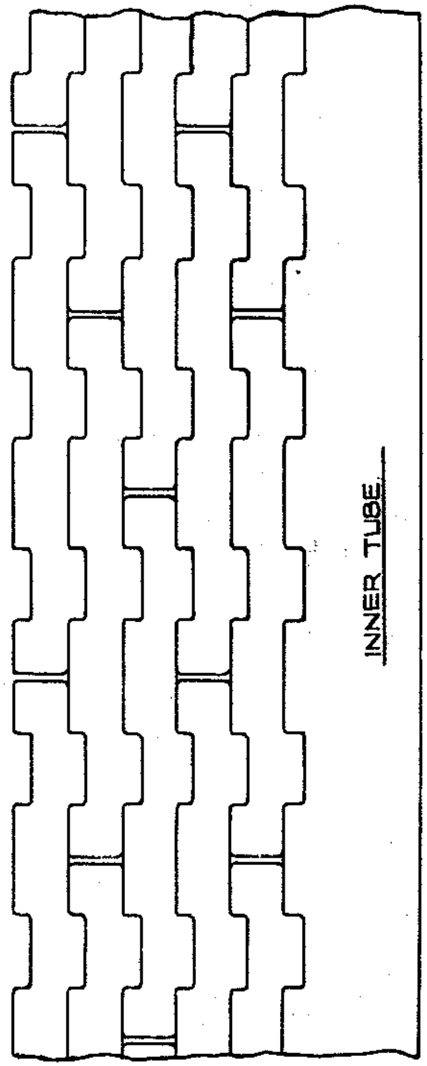
At first the experiments were made with small vessels of 100 to 300mm bore and 1-2 M long, the winding being done on a small hand-controlled machine. These vessels were tested to destruction, measurements being taken of the extension of vessels in several directions. On the basis of the tests, the I.G. set up at Oppau a plant for the production of wound vessels up to 1200 mm bore and 18 M long and, from the beginning of 1938, were able to make vessels on a production basis.

The process requires a lathe capable of taking the finished vessel and a large travelling bed to carry the tape spool and the other equipment for handling the tape. A length of tape sufficiently long to wind one length of the vessel is first wound on the tape spool which is roughly 7 ft. in diameter. (These long lengths of tape are made by welding together a number of lengths as delivered to the plant by the tape makers). The free end is then welded on to the end of the vessel and winding begins. The tape, on its passage from the drum, passes between two rollers which act as one connection to a source of low voltage electric current. When the tape reaches the vessel it is pressed on to it by another roller which acts as the other electric connection. The current passing through the tape is about 4-6,000 amps. at 30-40 volts. Immediately before winding the tape is thus heated to about 850°C. Immediately after the tape has been wound it is cooled fairly rapidly by means of high velocity air jets and some distance later, about 5-6 turns of the tape, a series of water jets play on the tape to ensure that the vessel does not heat up. The intensity of this cooling depends on the rate of winding and the thickness of the tube. On completion of the winding of each layer of tape, the tape end is welded to the inner vessel or to the previous tape layer. The speed of winding can be as high as 15 ft/min,

In 1939, under I.G. licence and under I.G. patents, Krupps and Deutsche-Röhren Werke at Mühlheim Ruhr started to make these vessels.



Wickel pressure vessels



ARRANGEMENT OF LAYERS OF WICKEL WOUND VESSEL

FIGURE. XXIX.

Since this date they have made 50 vessels for testing purposes and about 200 for service in plants. It is estimated that at least 75% of these vessels have been in service. They have been built for production plants for pressures up to 700 ats. and small ones for research laboratories or up to 4,000 ats.

The first vessel to go into service (1938) was a 500 mm 200 ats. CO scrubber on the Oppau plant. The first converter to be used in a production plant was a 800 mm ammonia converter at Oppau in 1939. The largest vessel so far built is a Tanol converter of 1,200 mm bore and 18 M long, and this was put into operation at Oppau in 1940.

The I.G. feel that they made a mistake when they gave a licence to Krupps instead of to a competitor. They have been charged the same price for the Wickel bodies as for solid wall forgings while their own experience has shown them that a Wickel body is cheaper than a solid wall forging by about 20%.

B. DETAILED DESCRIPTION OF PRESSURE VESSEL MANUFACTURE

Production of the Wound Body

The inner tube on which the tape is wound is made from the material most suited to the service for which the vessel is intended, i.e. material which is corrosion resistant, hydrogen resistant etc. So far, the thickness of this inner tube has been 20 mm. Up to 800 mm bore the tube is built up of seamless tubes welded together to get the necessary length. For greater diameters the tube is built up of rolled plate welded both circumferentially and longitudinally. Recently, in order to save costs where the tube has to be made of high alloy material or where the alloys required are in short supply, tests have been made with thin walled tubes of 5-6 mm thickness. In order to obtain the necessary stiffness of the tube for winding purposes, the thin walled tube is filled with concrete. This means that internal water cooling cannot be used as in the case of the 20 mm thick tubes and resort has been made to more intensive external water cooling. The inner tubes themselves need not be truly round as far as the winding process is concerned as the tape is continuously pressed on to the tube by the roller. The degree of roundness depends on the service for which the vessel is intended, i.e. whether or not any internal parts have to be inserted.

The Wickel tape used for large high pressure vessels is 80 mm wide and 8 mm thick. Its cross-sectional shape is shown in figure XXIX. The surface of the inner tube is machined with a spiral groove so that the tape sits closely and longitudinal movement is prevented. Tape of smaller dimensions (5 x 50 mms) is used for smaller vessels, it being essential that, in any vessel, the number of layers of tape should exceed a certain minimum.

The material of the tape was as follows:-

For cold vessels F.T.2 52. A normal carbon steel of 0.20% Carbon having an elastic limit of 23 Tons/sq.in.

For hot vessels F.K.15, an alloy steel of 1% Cr., 0.5% Mo., 0.15%C. and having a creep limit at 350°C of 22 Tons/sq.in. The temperature of 350°C instead of 300° (normal for solid wall vessels) is specified because windings have a lower conductivity than solid metal and therefore the wound vessel wall is hotter than that of a solid vessel under the same conditions.

By special heat treatment of the tape either before winding or during winding, the elastic limit of the metal is raised to 44 Tons/sq. in. For cold vessels, it should therefore be possible to reduce the first weight below that of a corresponding forging. Also when designing a normal solid wall vessel one has to take into account the fact that the metal, because of its thickness, is not homogeneous. With a wound vessel, one can be certain that the material is homogeneous and it should therefore be possible to reduce the design factor of safety. So far, however, the I.G. have made Wickel vessels of the same dimensions as forgings.

As previously mentioned, the tape is electrically heated on its way to the tube to 800-900°C. As it passes under the roller, which is grooved to the same profile as the tape and has a diameter of 150 mm, it is pressed on to the tube with a load of one Tonne. This small load ensures that the tapes sit against one another closely and that the lands on one tape are thoroughly pressed into the grooves of the underlying tape. Each successive tape is laid on so that the gaps between successive turns are staggered by a distance of one third the length of the tape, the tape having three grooves and three lands. This ensures that the successive turns are interlocked and that there is not a straight passage from inside to outside of the tube. Variations in the proportions of the grooves and lands were being experimented with, to try to produce a vessel which has a smaller longitudinal extension than the normal wound vessel.

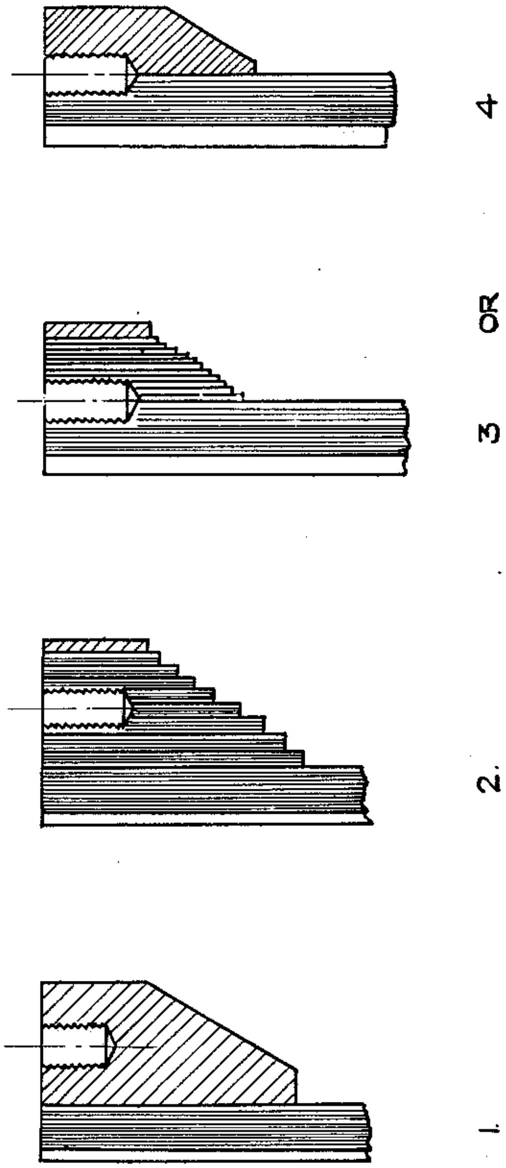
In order to ensure that the tube does not distort during winding, owing to the pressure of the contact roller, a supporting roller is fitted diametrically opposite.

When the main parallel wall body has been completed, the ends have to be stiffened to take the cover. This is achieved either by screwing heavy solid stiffening rings on the ends of the vessel or by building up the end with more windings of tape and finally screwing on a thin ring to secure the windings. In both cases, the ends of the original wound tube where the windings are welded together and to the inner vessel are finally cut off, leaving only the interlocking grip of the tape to hold the turns together. The studs for the cover are screwed into the tape or into heavy solid stiffening rings. (Fig. XXX).

Dr. Schierenbeck felt that the Wickel method should enable much lighter vessels to be used for processes requiring very high pressures, for example 700 ats. and above. He pointed out that with solid wall vessels the stress distribution in the wall of the vessel was such that the maximum stress was at the inner face and that, as the working pressure was increased, the wall thickness went up much faster than the pressure. With the wound vessels the stress throughout the wall thickness was even, so that an increase in pressure of 50% meant an increase in wall thickness of 50%.

FIG. XXX.

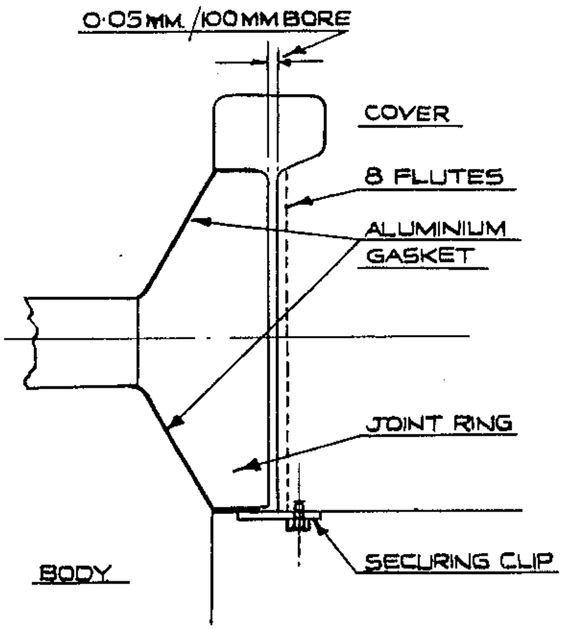
DEVELOPMENT OF WICKEL OFEN END WINDINGS.



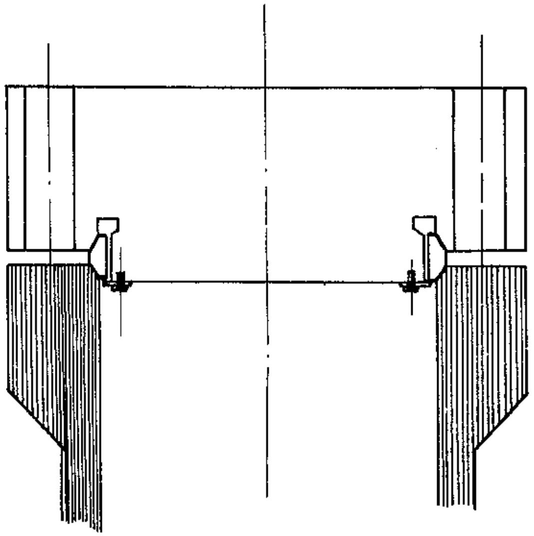
NOT TO SCALE.

FIGURE XXXI

I.G. DOUBLE CONE JOINT



DETAIL OF JOINT RING.



ASSEMBLY

During the winding of Gun-barrels, Dr. Schierenbeck said that great care was taken to ensure that the tape was wound on with the correct tension, so that the final stress distribution was the one desired. No special precautions of this nature had been taken in the case of pressure vessels. No tests had been made to prove that the desired stress distribution in the vessel wall had actually been obtained, apart from a number of tests made to compare the strength of the vessel in the condition it left the winding machine and also after the vessel had been annealed at 700°C for one day to relieve all shrinkage stresses. Photographs of the test curves were seen for these vessels and they showed that a normal wound vessel was 1.4 times as strong as the same-dimensioned solid-wall vessel and that after annealing the vessel was still 1.2 times as strong.

C. OTHER USES OF THE WICKEL METHOD.

The method of producing tubes which are resistant to high pressure by winding on a grooved tape has been tried for the production of GUN-BARRELS, where it was said that the better stress distribution resulted in a lighter barrel.

The I.G. have also experimented with the manufacture of covers for the ends of high pressure vessels, using the same tape as for the manufacture of bodies. They had done tests but had not tried any in service.

Because of troubles with the parts of feed pumps of 700 ats. plants, they had tried the manufacture of pump cylinders and stuffing boxes for their own design of paste injectors and although they had made and tested the parts they had not had any in service. The flanges of the stuffing box were wound direct on to the body and drilled to suit the studs in the body of the cylinder.

XII. DEVELOPMENT OF HIGH PRESSURE VESSELS.

Since 1937, I.G. have made a number of developments in the construction of high pressure vessels with the object of reducing their weight. Altogether, a 26% reduction in the weight of a 1000 mm. bore vessel has been achieved in two steps. The first improvement, which accounted for a 16% saving, was the introduction of double-cone joints in place of single-cone joints and a reduction in the size of the bottom joint and cover; the remaining 10% saving resulted from the redesign of the end covers and stiffening rings.

Originally, I.G. vessels were parallel throughout their length to facilitate lining with a thin tube whose function was to protect the wall of the vessel from corrosion and hydrogen attack. Experience showed, however, that the lining was unnecessary and the design of the 1000 mm. bore vessels for Böhlen and Scholven was modified so that the bottom joint was only 600 mm. in diameter and the end plate correspondingly smaller. In this way, the weight of the vessel was reduced by 14.3%.

The double-cone joint was developed not only to save weight but also to increase ease of handling in the case of the larger vessels, particularly those designed for operation at the higher pressures. The original double-cone joint saved only a further 1.7% but this represented by no means the full saving that could be derived from the change to the double-cone joint. At first some trouble was experienced with the joint when assembled according to a procedure similar to that used for single-cone joints, i.e. merely limiting the initial load in the end-cover studs. Thus, in a number of cases the ring was distorted as a result of excessive compressive stresses. This difficulty was overcome by arranging that when the ring was fitted to the cover there was a specified radial clearance between ring and cover so that tightening up the studs could not lead to an excessive stress in the ring. This clearance, according to a number of drawings, was 0.05 mm. per 100 mm. diameter of vessel. The original rings were found to be stiffer than was required and were reduced in cross section by some 25%; a greater reduction was inadvisable if distortion due to lack of rigidity during machining was to be avoided. A smaller ring would also have suffered from too high a compressive stress on its faces; experimental work had shown that the initial load required in the cover studs was 120% of the working stress. Use of the more flexible ring, together with modifications to the stiffening rings, increased the saving in weight from 1.7% to 8.7%.

Converters with double-cone joints were installed at Gelsenberg, Pölitz and Wesseling. At some plants where the original heavy double-cone joint had been installed, the lighter joint-rings were being used by merely fitting filler rings to the end covers so that the correct radial clearances between joint rings and covers were being maintained. It was claimed that the double-cone joint was self-tightening. Trials had been carried out on another type of joint variously referred to as the Brettschneider or Uhde joint. As at Leuna, the opinion was expressed that for hydrogenation plant vessels the joint was not as suitable as the cone joint.

It was soon realised that use of a double-cone joint avoided the very large outward radial forces at the vessel ends which arose from single-cone joints. As mentioned above, modifications were made to the stiffening rings in order to take advantage of the reduced stresses. These modifications, as always, were principally directed towards reduction of diameter of the stud circle and at first took the form of a reduction in thickness of the vessel wall where the stiffening rings screwed on. In the final design, however, there is no reduction in wall thickness of the vessel, but the stiffening rings are much thinner radially. The studs are screwed into both ring and vessel wall, the pitch circle diameter of the studs being the external diameter of the vessel before threading to receive the stiffening rings. In order that the studs should always be evenly loaded both in the vessel wall and in the stiffening ring it was decided to give the ring an initial load such that movement relative to the vessel wall could not be brought about by any test or working load. Steps were therefore machined on the nose of the vessel and on the ring and the ring screwed up against the shoulder while heated to 200-250°C. On cooling, a tensile stress is developed in the ring between the shoulder and the first thread, which is spaced 70 mm. away from the shoulder. Tests were first carried out on a small 160 mm. bore vessel. At 1.7 x design working pressure the vessel body showed signs of

FIG. XXXII.

DEVELOPMENT OF END COVER OF SOLID WALL FORGING.

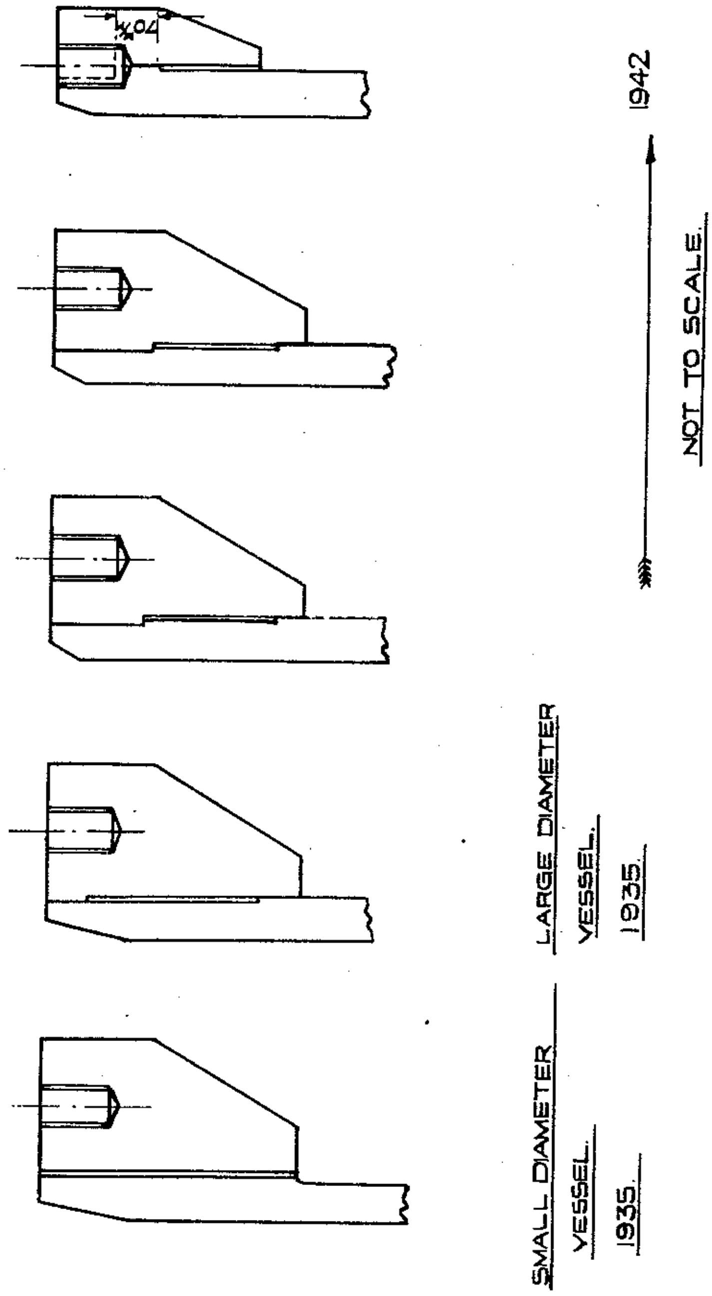


TABLE VII

WEIGHT SAVINGS EFFECTED BY THE VARIOUS DESIGN CHANGES.

Based on the original 1,000 mm. Bore Vessel, and weights for the complete vessel with covers, etc.

Type of Vessel	325 ats Pressure				700 ats Pressure			
	Weight. Tonnes	%	%	Plant using this type	Weight. Tonnes	%	%	Plant using this type
Single Cone Joints Both Ends Equal Diameter	79.14	100		Leuna				
Single Cone Joints One End 600 mm.	67.87	85.7		Böhlen, Scholven				
Large Double Cone Joints One End 600 mm.	66.8	84	100	Gelsenberg, Politz, Wesseling	151.6	100		Gelsenberg, Politz, Wesseling
Small Double Cone Joints One End 600 mm.	60.8	77	91	Brux, Blechhammer	141.5	93.5		Blechhammer
Small Double Cone Joint One End 600 mm. Studs in Body Threads	58.7	74	88	Heydebreck	131.4	87		Blechhammer