PATENT SPECIFICATION

(11) 1 564 821

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(21) Application Nos. 24153/76 (22) Filed 10 June 1976
4741/77 4 Feb. 1977
(23) Complete Specification filed 23 May 1977
(44) Complete Specification published 16 April 1980
(51) INT. CL.³ F22B 1/06 // 37/20
(52) Index at acceptance
F4A 36 37 8C

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(54) TUBE IN SHELL HEAT EXCHANGERS

(71) We, UNITED KINGDOM ATOMIC ENERGY AUTHORITY, London, a British Authority, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to tube-in-shell heat exchangers and is primarily directed to exchangers for effecting heat exchange between liquid metal and water.

Liquid metal, such as sodium, is used in the nuclear reactor art as a coolant for fast breeder reactors mainly because of its high thermal capacity. Because of the high operating temperatures and the aggressive nature of the liquid metal heat exchangers for use as superheaters and re-heaters have been made from austenitic steel but considerable difficulty has been experienced with these units. In spite of the most stringent quality control tests during manufacture, tube-to-tube sheet joints have failed.

It is an object of the invention to provide an improved tube-in-shell heat exchanger for use in heat exchange between liquid metal and water and less prone to failures which could result in sodium water reactions.

According to the invention, in a tube-in-shell heat exchanger for use with liquid metal each heat exchange tube extends through an individual aperture in a tube sheet with clearance between the tube and the tube sheet, the tube being sealed to the tube sheet by a sleeve upstanding from a face of the tube sheet and sealed at its free end to the outer wall surface of the tube, the tube and sleeve being sealed together by an interposed bonding metal to effect the seal, the bonding metal being of a kind not requiring, for the making of the bond, any recourse to temperature as high as would be required for the making of the joint by fusion welding. In a preferred construction the sleeves are sealed to the tube with brazing metal and fusion welded to the tube sheet, and the heat exchange tubes are made so that within the shell they are of continuous unjointed lengths of tubing.

By adapting the tube to the tube sheet with a sleeve which is brazed to the tube, and by making the tubes within the shell of continuous unjoined lengths of tubing, fusion welds in the sodium to water barrier of the heat exchanger are avoided. Thus, according to another aspect, the invention resides in a tube-in-shell heat exchanger for use with liquid metal on the shell side, all of the tubes entering the shell by passing with clearance through individual tube sheet apertures and all being in continuous unjointed lengths over the entire run within the shell, each of the tubes being sealed at each aperture by a sleeve upstanding from a face of the tube sheet and having at its free end a joint with the outer wall surface of the tube which joint is formed by an interposed bonding metal of a kind not requiring, for the making of the bond, any recourse to temperature as high as would be required for the making of the joint by fusion welding so as to alleviate impairment of the integrity of the tube wall and hence of the barrier between the liquid metal and heat transfer medium within the tube. The construction is readily stress relieved at the brazed joint and at the fusion welded joint between the sleeve and the tube plate so that neither the tube nor tube plate are left in a highly tensile stressed condition such as would promote stress corrosion cracking. The upstanding sleeves are preferably fusion butt welded to a spigot projecting from the surface of the tube sheet.

The invention will reside in a tube-in-shell heat exchanger wherein each heat exchange tube extends through an individual aperture in a tube sheet with clearance between the tube and the tube sheet, the tube being sealed to the tube sheet by a sleeve upstanding from a face of the tube sheet and sealed at its free end to the outer wall surface of the tube, the tube and sleeve being sealed together by a tubular transition piece and an interposed bonding metal, the bonding metal being of a kind not requiring, for the making of the bond any recourse to temperature as high as would be required for the making of the joint by fusion welding said tubular transition piece being bonded at opposite extremities to the tube and sleeve respectively. The sleeve can be arranged to pass over the tube with a substantial clearance thereby facilitating assembly. The transition piece is made to make close fit with the outside surfaces of the tube and sleeve suitable for effecting brazed joints.

The invention will reside in a tube-in-shell heat exchanger comprising an elongate vessel having inlet and outlet ports for liquid metal and housing a demountable heat exchange tube assembly, wherein the heat exchange tube assembly comprises, a flanged extension forming a closure for the vessel, a bundle of U-shape heat exchange tubes having legs of unequal lengths suspended from the extension, an annular shroud arranged co-axially with the vessel and enveloping the bundle of 'U'-tubes, a cylindrical baffle suspended from the extension and defining inner and outer annular chambers in the shroud, and means for laterally supporting the 'U'-tubes extending parallel with the longitudinal axis of the vessel, a longer limb of each tube extending along the inner chamber of the shroud to penetrate an end wall of the extension which thereby forms a first tube sheet of the heat exchanger, and a shorter limb of each tube extending along the outerchamber of the shroud to penetrate the flange of the extension which thereby forms a second tube sheet of the heat exchanger, each leg of each tube penetrating a complementary tube sheet through an individual aperture with a clearance between the tube and the tube sheet, the tube being sealed to the tube sheet by a sleeve upstanding from a face of the tube sheet and sealed at its free end to the outer wall surface of the tube, the tube and sleeve being brazed together to effect a seal.

The invention also resides in a method of constructing a tube-in-shell heat exchanger according to the preceding paragraph and wherein the tube and sleeve combinations are brazed individually using radio frequency electric induction heating means with an inert gas atmosphere enveloping the joint.

Constructions of tube-in-shell heat exchanger in accordance with the invention are described, by way of example, with reference to the drawings accompanying the Provisional Specification filed with application no. 4741/77 wherein:

Figure 1 is fragmentary sectional view,
Figure 2 is a plan view,
Figure 3 is a fragmentary sectional view of a detail designated III of Figure 1 drawn to a larger scale,
Figure 4 is a fragmentary sectional view of a detail designated IV in Figure 3, drawn to an even larger scale,
Figure 5 is a fragmentary sectional view of a detail designated V in Figure 1 and drawn to a larger scale,
Figure 6 is a fragmentary plan view on line VI-VI of Figure 1,
Figures 7 and 8 are fragmentary sectional views of alternative features, and
Figures 9, 10, 11 and 12 are fragmentary views of two alternative support arrangements for the lower ends of the heat exchange tubes, and with reference to the drawings accompanying the Provisional Specification filed with application no. 24153/76 wherein:

Figure 1 is a fragmentary sectional view,
Figure 2 is a cross-section on line II-II of Figure 1,
Figure 3 is a fragmentary cross-section on line III-III of Figure 1 and drawn to a larger scale,
Figure 4 is a cross-section on line IV-IV of Figure 1,
Figure 5 is an enlarged fragmentary view of the detail enclosed by broken line and designated V on Figure 1,
Figure 6 is a cross-section on line VI-VI of Figure 1,
Figure 7 is an enlarged fragmentary view of the detail enclosed by broken line and designated VII in Figure 1,
Figure 8 is a fragmentary detail view of Figure 3, as seen in the direction designated VIII, and
Figure 9 is a fragmentary sectional view on line XI-XI of Figure 8.

The tube-in-shell heat exchanger shown in the drawings accompanying the Provisional Specification filed with application no. 4741/77 is for use in a steam generating circuit of a liquid metal cooled fast breeder reactor installation. The disclosed heat exchanger is intended for use as a superheater but heat exchangers in accordance with the invention for use as evaporators and re-heaters are of generally similar construction. The shown heat exchanger comprises a generally cylindrical shell 1 closed at the lower end and open at a flanged upper end. The shell has a sodium inlet port 2 in the base, side outlet ports 3, a drain port 4 and a pressure release connection 5 for relief, of pressure in the shell in the event of the occurrence of a sodium water reaction. The open end of the shell has a flanged cylindrical extension 6 which is closed at its upper end the flanges of the shell and extension being bolted together and peripherally sealed with a light weld at 7. The heat exchange tubes designated 8 are of 'U'-shape having legs of unequal length and are suspended within the shell from the extension 6. The longer legs 8*a* extend along the extension to penetrate the end cover which thereby forms an inner tube sheet 9 and the shorter legs penetrate the flange of the extension which forms an annular outer tube sheet 10. The tubes are enclosed by an annular shroud 11 bounded by two co-axially arranged cylindrical members 11*a*, 11*b*, and there is a cylindrical baffle 12 carried from the inner tube sheet (as shown in Figure 3) which extends co-axially within the shroud 11 between the long and short legs of the tubes. The sodium flow path from the inlet port at the base of the shell is upwardly through the inner cylindrical member 11*b* of the shroud to a distributor 13 in the extension 6 thence downwardly over the longer legs of the tubes, upwardly over the shorter legs thence to leave the shell by way of the outlet ports 3. The long and short legs of the 'U'-tubes are connected to external outlet and inlet steam headers 14 and 15 respectively shown in Figures 1 and 2. The 'U'-tubes 8 are of 9% chrome alloy steel but because of the difficulty in welding and heat treating this material on site, transition pieces designated 16 of 1% chrome alloy steel are interposed between the tube sheets and the headers. 1% chrome alloy tails can be attached to the 9% chrome alloy tube ends and header tail pipes and heat treated during manufacture. Inter-connection can be made readily on site, no further heat treatment being required. Argon cover gas is disposed above the sodium levels on each side of the cylindrical baffle 12 and branches, such as those designated 17, are provided to enable the cover gas to be checked for hydrogen content and to enable the sodium levels to be detected.

As shown in Figures 3 and 4, each of the tubes 8 passes through its relevant tube sheet 9, 10 by way of a clearance aperture and is sealed to the tube sheet by a sleeve 18. To effect the seal the lower end of each sleeve is butt welded to an externally projecting spigot 19 bounding the aperture on the upper face of the tube sheet and the free end of the upstanding sleeve and the outside wall surface of the tube are sealed together by an interposed bonding metal which is of a kind not requiring for the making of a bond, any recourse to temperature as high as would be required for the making of the joint by fusion weld. The bond is effected by a brazing technique. Access for welding the sleeves to their respective spigots on each tube sheet is gained from inside the sleeves prior to passing the tubes through and the welds are all stress relieved simultaneously by heating the entire tube sheet. The brazed joints are made individually and prior to making a brazed joint the outer surface of the tube and the inner surface of the free end of the sleeve are first carefully cleaned in the joint areas. For successively making each joint a strip of braze metal designated 20 (Figure 4) is attached to the bore of the sleeve. The tube is threaded through the sleeve to a position just beyond that at which the joint between sleeve and tube is to be made and by means of an internally operating roll the tube is swaged outwardly for effecting a close fit with the free end of the sleeve. The tube is then withdrawn into the sleeve to engage the expanded region of the tube with the free end of the sleeve. An R/F induction heating coil (also shown in Figure 4 and designated 21) is placed about the sleeve and heat is applied for approximately one minute to melt the braze metal the joint area being enclosed by a sealed cover designated 22 which is charged with argon to prevent oxidation of the materials.

The braze metal is Nicrobraz 135, a nickel based alloy (Nicrobraz is a registered trade mark), and the brazing operation is carried out at a temperature within the range 1050°C-1200°C. The joints are subsequently stress relieved.

Each braze is ultrasonically checked for bond area, helium leak tested and visually examined to ensure a satisfactorily sealed joint. The appearance of filler material at the extreme end of the sleeve bears witness to the effectiveness of the bond. The tubes 8 are made from continuous lengths of tubing so that no joints occur within the shell whereby, in the event of a defect occuring, sodium could come into contact with water.

The complex of tubes is laterally supported by the cylindrical baffle 12 which is suspended from the underside of the inner tube sheet 9. The baffle is double walled to reduce heat transfer therethrough and there are pads 23 (shown in Figure 5) disposed at intervals between the inner and outer walls to space them apart during handling operations. The pads 23 are welded to the inner wall but have sliding contact with the outer wall to accommodate differential thermal linear expansion of the walls in the axial direction. Inner and outer annular cellular grid plates 24, 25 for laterally supporting the heat exchange tubes 8 are secured within the annular shroud at axially spaced intervals. Each plate comprises inner and outer rims 33, 34 interconneced by cellular spokes 35 as shown in Figure 6 which illustrates a fragment of an inner cellular plate 24. The spokes 35 have apertures each for accommodating a single tube with clearance. Between the spokes movable anti-vibration plates 26 are disposed the plates having clearance apertures for the tubes. The anti-vibration plates 26 are slidably supported from the outer rim 34 on two (vertically spaced) radially projecting dowels 37 and are secured to the inner rim 33 by set bolts 27 which can be adjusted to move the plates radially inwardly or outwardly. The grids are arranged in series in the shroud in such a manner that each tube leg passes alternately through a spoke 35 and an anti-vibration plate 26. By displacing the anti-vibration plates radially the tubes can be loaded laterally to restrain vibrations. In an alternative construction inner and outer annular, cellular grid plates 24, 25 are secured to the inner and outer walls of the cylindrical baffle 12 at axially spaced intervals, the grid plates having large clearance apertures or slots for passage of the tubes. The grid plates each support a group of angularly spaced anti-vibration plates through which the tubes also pass with clearance. The anti-vibration plates are arranged to be movable radially relative to the grid plates by means of set bolts extending through the cylindrical members 8*a*, 8*b* of the shroud so that they can be pulled or pushed radially against the tubes 8 to prevent vibration. The direction of the applied movement to load the tubes can be alternated inwardly and outwardly. The cylindrical members 8*a*-8*b* of the shroud have removable sections (not shown) to give access to the anti-vibration plates which are also arranged to be axially displaceable to enable the contact area of the tubes to be examined for fretting during post operation inspection of the heat exchanger and, if the need arises, to be repositioned to provide new areas of contact with the tubes.

The straight portions of the legs of the 'U'-tubes 8 below the lower grid plates 24, 25 can be supported by stiffening sleeves 31 as shown in Figures 9 and 10. The sleeves closely embrace the tubes at the upper and lower ends of the sleeves and the upper end of each sleeve is rigidly secured within a tube conducting cell of the lower grid plate 24, 25. Intermediate the ends the sleeves are spaced from the tubes and have windows 32 to enable liquid sodium to contact the tubes. The stiffening sleeves reduce to an acceptable level deflections of the 'U'-tubes caused by cross-flow induced vibration and buffetting from grid turbulence.

An alternative support sleeve arrangement shown in Figures 11 and 12 has bushes 33 of aluminised nickel base alloy intermediate the 'U'-tubes and the sleeves. The aluminised bearing surfaces of the bushes have a low coefficient of friction so that fretting damage due to thermal expansion induced longitudinal movement of the tubes and vibration is considerably reduced.

By adapting the heat exchange tubes 8 to the tube sheets 9, 10 by means of the sleeves 18 a tube sheet boundary between water and sodium is avoided. The complex stresses normally set up by a fusion welded tube to tube sheet joint are eliminated so that the tube sheet itself is not prone to stress corrosion cracking. A brazed joint between the sleeve and the tube avoids the use of fusion welds within the sodium water boundary and it can be readily made and stress relieved. The cover gas space in the top of the outer annulus of the shroud is carried up to the inner tube sheet and thereby maintains the temperature of the inner edge of the outer tube sheet at an acceptable level.

In alternative constructions of heat exchanger embodying the invention, a seal between each tube and the relevant sleeve is effected through a transition piece. Referring now to Figures 7 and 8 a tube 8 penetrates a tube sheet 9, 10 by means of a clearance aperture and is sealed to the tube sheet by a sleeve 18. The tube passes through the sleeve with substantial clearances at each end and is sealed to the free end of the sleeve by a tubular transition piece 28 with interposed bonding material 29. The transition piece is in the form of a collar which is machined to make a close fit with the upper end of the sleeve and to the outer surface of the tube and is brazed to the tube and sleeve. The sleeve 18 is welded at the lower end to the tube sheet. The interposed bonding metal 29 may be positioned between the transition piece and the tube before applying heat to melt the braze metal as shown in Figure 7 or, alternatively, may be positioned in appropriately positioned grooves 30 in the transition piece as shown in Figure 8. The brazing operation would, as in the previous embodiment, be carried out in an inert atmosphere and would also be stress relieved after the operation. Such constructions have the economic advantage that the multiplicity of tubes are more easily threaded through the sleeves during assembly of the construction prior to brazing.

In another alternative construction the tubes are sealed to the tube sheet by means of sleeves directed inwardly of the heat exchanger. Although the manufacture of heat exchangers with inwardly directed sleeves is more complex such heat exchangers have the advantage that multiple pockets which are difficult to decontaminate of sodium deposits are largely avoided.

The cellular grid plates of the described constructions are machined from plate but in conditions where a lower pressure drop through the shell is required cellular grids of a more complex form would be necessary and such plates could more economically be formed by a spark erosion technique.

The heat exchanger shown in the drawings accompanying the Provisional Specification of application no 24153/76 is an evaporator and as shown in Figure 1 comprises an elongate vessel 1 having inlet and outlet fluid flow ports 2, 3 and housing a readily demountable heat exchange tube assembly 4. The heat exchange tube assembly 4 comprises an end closure 5 for the vessel 1 and a plurality of interchangeable 'U'-tube units 6. An annular shroud 7 arranged coaxially with the vessel envelopes the 'U'-tube units 6 and there is a cylindrical baffle 8 which defines inner and outer coaxial chambers 9, 10 in the shroud. The tube units 6 are demountably attached to the shroud 7 and baffle 8. The tube units 6 each comprise a series of interjacent 'U'-tubes 11 having limbs which extend parallel with the longitudinal axis of the vessel to penetrate the end closure 5 the axes of the limbs and the interconnecting loops being arranged on an involute curved plane relative to the longitudinal axis of the vessel as shown in Figure 3. In an alternative construction so that the interconnecting loops can be arranged in flat planes, the axes of the limbs of the 'U'-tubes are arranged in planes which approximate involute curves relative to the longitudinal axis of the vessel. Anti-vibration rods of hairpin form (not shown in drawings) are thrust upwardly into the nests of interconnecting loops to prevent rattling. One limb of each tube extends along the inner chamber 9 of the shroud and the other limb of each tube extends along the outer chamber 10. The end closure 5 comprises an elongate tubular extension 13 of the vessel and has a flange 14 by which it is sealably secured to a flange 15 of the vessel 1. The limbs of the 'U'-tubes which extend through the inner chamber 9 of the shroud also extend through the end closure to penetrate an end wall 16 and the limbs of the 'U'-tubes which extend through the outer chamber 10 of the shroud penetrate the flange 14 of the end closure. The end wall 16 and the flange 14 of the end closure 5 thereby form tube sheets for the 'U'-tubes which are sealed to the tube sheets through intermediate thermal sleeves designated 17 in Figure 7 of the drawings accompanying the Provisional Specification filed with application no. 24153/76. The thermal sleeves are sealed to the tube sheets by fusion welds and to the tubes by brazed joints the interposed bonding metal being braze metal designated 17a in Figure 7. The free ends of the 'U'-tubes are connected to opposed sub-headers 18, 19 of approximate involute form (Figure 4 and 5) and each of the sub-headers 18, 19 is connected to one of two opposed main headers which form inlet and outlet headers for water/steam. The header serving the outer, shorter limbs of the 'U'-tubes is arranged to be an inlet header 20 for water whilst the header serving the inner longer limbs of the 'U'-tubes is arranged to be an outlet header 21 for water/steam mixture; the outer shorter limbs serve as an economiser section of the heat exchanger whilst the inner longer limbs serve as a boiling section. The sub-headers 18, 19 are provided with demountable caps 22 (Figure 5) disposed on the axes of the limbs of the 'U'-tubes. The 'U'-tubes 11 are of 9% chrome alloy steel which is difficult to weld and heat treat in situ so transition pieces 18a, 19a, 20a and 21a of 1% chrome alloy steel are welded to the sub-headers and headers and heat treated during manufacture in the workshop. In situ, the sub-headers and headers are connected by further tubing of 1% chrome alloy steel, the welds being readily made and requiring no heat treatment.

In greater detail, the vessel 1 has a single inlet port 2 for liquid metal sodium which is connected to a central tube 23a by means of an expansible joint 24. Although in Figure 1 of the drawings accompanying the Provisional Specification filed with application no 24153/76 there is shown an expansible joint 24 in the form of a bellows unit, a sliding joint could be used as an alternative. The central tube 23a extends into a central duct 23 which then extends into the end closure 5 and terminates at a distributor head 25 whereby the liquid sodium is distributed around the upper end of the chamber 9. Sodium flow is downwardly in heat exchange with the longer limbs of the 'U'-tubes then upwardly through the outer chamber 10 in heat exchange with the shorter limbs of the 'U'-tubes thence to four outlet ports 3 of the vessel (see Figure 2 of the drg filed with app no 24153/76). Baffles (not shown) attached to the tube supports are arranged to induce swirl to the flow of sodium thereby to improve heat exchange and to counteract hot slug flow when some of the tubes are plugged after some operating service. A sliding seal 26 is interposed between the shroud 7 and the vessel wall to close the annular clearance defined by the shroud and vessel wall to liquid sodium flow. Slidable guides 27 (shown in Figures 2 and 6 of the drawings filed with application no 24153/76) are provided to locate the shroud 7 coaxially in the vessel 1. The vessel has two pressure relief ports 28 in the plane of the outlet ports and two pressure relief ports 29 in the base of the vessel. The base is also provided with a drainage port 30 for sodium and the vessel has two mounting brackets 31. The end closure 5 carries a gastight cover 32 for the sub-headers 18 on the flange 14 and a gastight cover 33 for the sub-headers 19 on the end wall 16, the connections to the headers 20, 21 being sealed to the covers by flexible joints 34. Although not shown in the drawings the covers 32 and 33 are clad externally with thermal insulation and house instruments for detecting the presence of gases denoting, leakage from the heat exchanger. Gases which may be detected are sodium vapour or argon (or, perhaps, a tracer gas, such as helium, added to argon cover gas in the sodium side of the heat exchanger) thereby indicating a leak from the sodium side of the heat exchanger, and moisture thereby indicating leakage from the water side of the heat exchanger. The flange 14 and end wall 16 also carry branch pipes 35, 36 whereby the formation of hydrogen and the level of the sodium in the vessel and the extension can be detected. An inspection hand hole 37 is provided to give access to the inner surface of the end wall 16.

The shroud 7 comprises a transverse top plate 42 having depending inner and outer cylindrical flanged shells 7a, 7b bolted thereto; the top plate is suspended from the flange 14 of the end closure. The annular baffle 8 is a double walled cylinder which extends through the top plate 42 and is secured to the flange 14. The inner shell 43 extends through the end closure 5 and is attached to the end wall 16. The inner and outer shells 7a, 7b and baffle 8 are assembled in cylindrical sections, each section being provided with a circumferential lip for receiving the end of an adjacent section and to which the adjacent section is secured. The lower end of the shroud is closed by an annular cover 45.

Referring now to Figure 3 of the drawings filed with application no 24153/76, there are thirty-eight 'U'-tube units 6 in the heat exchanger each unit comprising ten interjacent 'U'-tubes 11. The 'U'-tubes are carried within the vessel 1 by two series of spaced support members 38 of involute form, one series extending along each of the inner and outer chambers 9, 10 of the shroud. Complementary support members 38 in each chamber are arranged on an involute curve. Each tube 11 is secured to each support member 38 by a clip 39 (Figure 8 of the drawings filed with application no 24153/76) having fastenings 40 which are slidably captive in elongate apertures 41 (Figure 9 of the drawings filed with application no 24153/76) in the support member thereby to accommodate linear thermal expansion of the tube. The ends of the support members are located by spacer bars 42 which are releasably attached to the corresponding wall of the shroud 7 or baffle 8.

For inspection of the upper tube sheet access can be gained to the internal side simply by removal of the cover 37 whilst access to the internal side of the lower tube sheet can be gained through the outlet ports 3. Inspection of individual 'U'-tubes of the heat exchanger merely requires removal of the covers 32, 33 and the caps 22 on the sub-headers 18, 19 and an inspection probe, for example, an eddy current test probe such as those disclosed in Patent No. 1,488,833, can be inserted.

In order to effect a temporary repair to a defective 'U'-tube unit the unit can be blanked off merely by cutting out sections of the pipework between the main headers 20, 21 and the appropriate sub-headers 18, 19, plugging the sections and replacing them.

WHAT WE CLAIM IS:—

1. A tube-in-shell heat exchanger for use with liquid metal each heat exchange tube extending through an individual aperture in a tube sheet with clearance between the tube and the tube sheet, the tube being sealed to the tube sheet by a sleeve upstanding from a face of the tube sheet and sealed at its free end to the outer wall surface of the tube, the tube and sleeve being sealed together by an interposed bonding metal to effect the seal, the bonding metal being of a kind not requiring, for the making of the bond any recourse to temperature as high as would be required for the making of the joint by fusion welding.

2. A tube-in-shell heat exchanger according to claim 1 wherein the tubes and sleeves are sealed together by brazing.

3. A tube-in-shell heat exchanger for use with liquid metal on the shell side, all of the tubes entering the shell by passing with clearance through individual tube sheet apertures and all being in continuous unjointed lengths over the entire run within the shell, each of the tubes being sealed at each aperture by a sleeve upstanding from a face of the tube sheet and having at its free end a joint with the outer wall surface of the tube which joint is formed by an interposed bonding metal of a kind not requiring, for the making of the bond, any recourse to temperature as high as would be required for the making of the joint by fusion welding so as to alleviate impair-

ment of the integrity of the tube wall and hence of the barrier between the liquid metal and heat transfer medium within the tube.

4. A tube-in-shell heat exchanger according to any one of the preceding claims wherein each sleeve has a taper portion for forming, as the free end of the sleeve, a neck portion lapping the outer wall surface of the respective tube.

5. A tube-in-shell heat exchanger for use with liquid metal each heat exchange tube extending through an individual aperture in a tube sheet with clearance between the tube and the tube sheet, the tube being sealed to the tube sheet by a sleeve upstanding from a face of the tube sheet and sealed at its free end to the outer wall surface of the tube, the tube and sleeve being sealed together by a tubular transition piece and an interposed bonding metal, the bonding metal being of a kind not requiring, for the making of the bond any recourse to temperature as high as would be required for the making of a joint by fusion welding said tubular transition piece being bonded at opposite extremities to the tube and sleeve respectively.

6. A tube-in-shell heat exchanger according to claim 5 wherein the bonding metal is braze metal.

7. A tube-in-shell heat exchanger according to any one of the preceding claims wherein the sleeves are directed inwardly of the heat exchanger shell.

8. A tube-in-shell heat exchanger the exchanger comprising an elongate vessel having inlet and outlet ports for liquid metal and housing a demountable heat exchange tube assembly, wherein the heat exchange tube assembly comprises:

a flanged extension forming a closure for the vessel,

a bundle of U-shape heat exchange tubes having legs of unequal lengths suspended from the extension,

an annular shroud arranged co-axially with the lengthwise axis of the bundle and enveloping the bundle of 'U'-tubes,

a cylindrical baffle suspended from the extension and defining inner and outer annular chamber in the shroud, and

means for laterally supporting the 'U'-tubes from the baffle, the limbs of the 'U'-tubes extending parallel with the longitudinal axis of the vessel, a longer limb of each tube extending along the inner chamber of the shroud to penetrate an end wall of the extension which thereby forms a first tube sheet of the heat exchanger, and a shorter limb of each tube extending along the outer chamber of the shroud to penetrate the flange of the extension which thereby forms a second tube sheet of the heat exchanger each leg of each tube penetrating a complementary tube sheet through an individual aperture with clearance between the tube and the tube sheet, the tube being sealed to the tube sheet by a sleeve upstanding from a face of the tube sheet and sealed at its free end to the outer wall surface of the tube, the tube and sleeve being brazed together to effect a seal.

9. A tube-in-shell heat exchanger according to claim 8 wherein the means for laterally supporting the 'U'-tubes from the baffle comprises a series of axially spaced cellular grids supported by the cylindrical baffle and penetrated by the heat exchange tubes, a series of angularly spaced anti-vibration plates associated with each grid, the anti-vibration plates having apertures penetrated by the tubes, and draw means for displacing the anti-vibration plates radially relative to the grids to bear laterally against tubes.

10. A tube-in-shell heat exchanger according to claim 9 wherein at least some of the 'U'-tubes have stiffening sleeves for supporting the 'U'-bends of the tubes against vibration, the stiffening sleeves depending from the grid plate adjacent the 'U'-bends and extending towards the 'U'-bends.

11. A tube-in-shell heat exchanger according to claim 10 wherein aluminised inconel bushes are interposed between each stiffening sleeve and is complementary tube.

12. A method of constructing a tube-in-shell heat exchanger according to claim 7 wherein the tube and sleeve combinations are brazed individually using radio frequency electric induction heating means with an inert gas atmosphere enveloping the joint.

13. A tube-in-shell heat exchanger substantially as hereinbefore described with reference to Figures 1 to 12 of the drawings accompanying the Provisional Specification filed with application no. 4741/77.

14. A tube-in-shell heat exchanger substantially as hereinbefore described with reference to Figures 1 to 6 and Figures 8 and 9 of the drawings accompanying the Provisional Specification filed with application no. 24153/76.

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Agent for the Applicants.

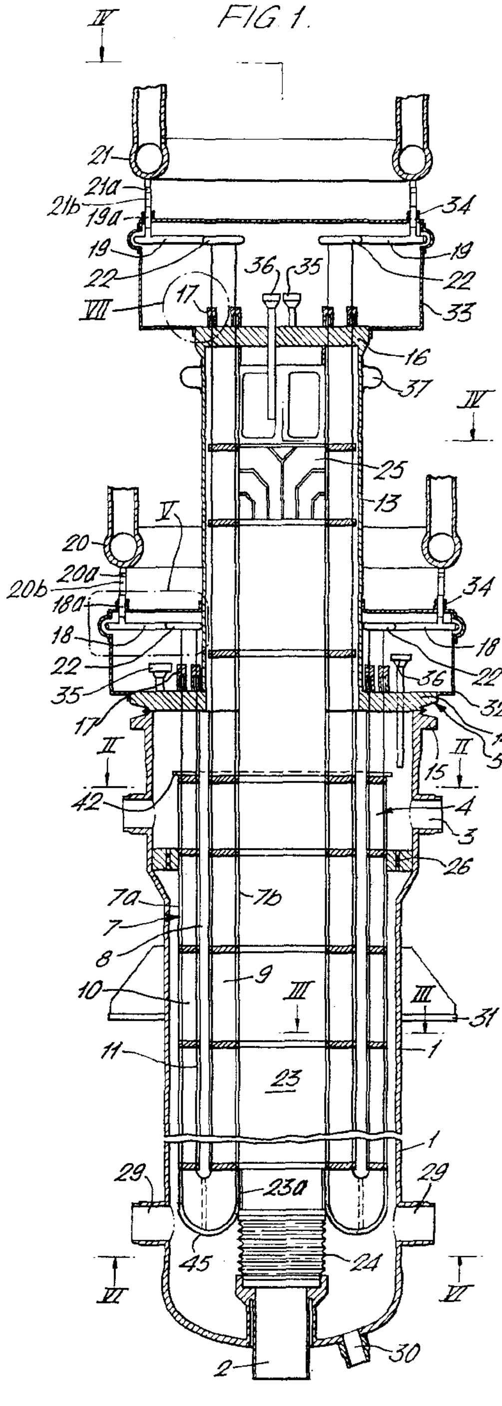
Printed for Her Majesty's Stationery Office by The Tweeddale Press Ltd., Berwick-upon-Tweed, 1980
Published at the Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained

1564821 PROVISIONAL SPECIFICATION No. 24

6 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

FIG.1.



1564821 PROVISIONAL SPECIFICATION No. 2[illegible]

6 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 2

FIG. 2

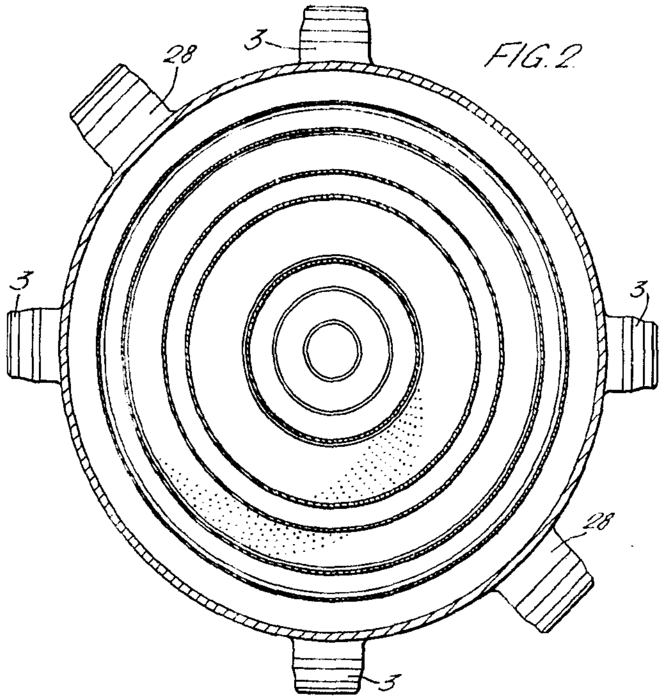
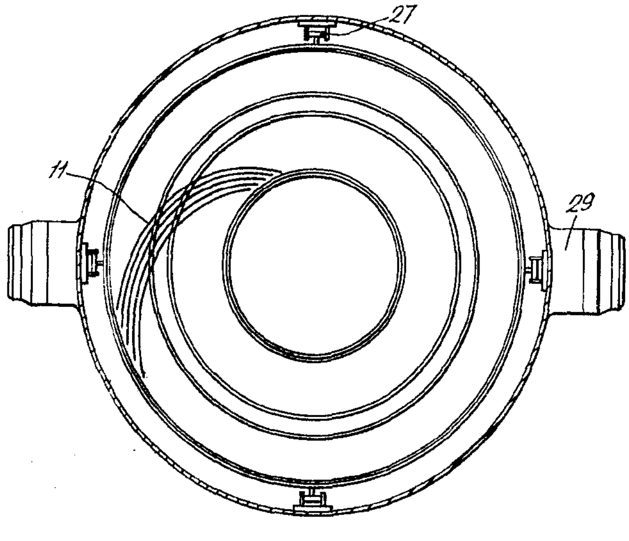


FIG. 6.



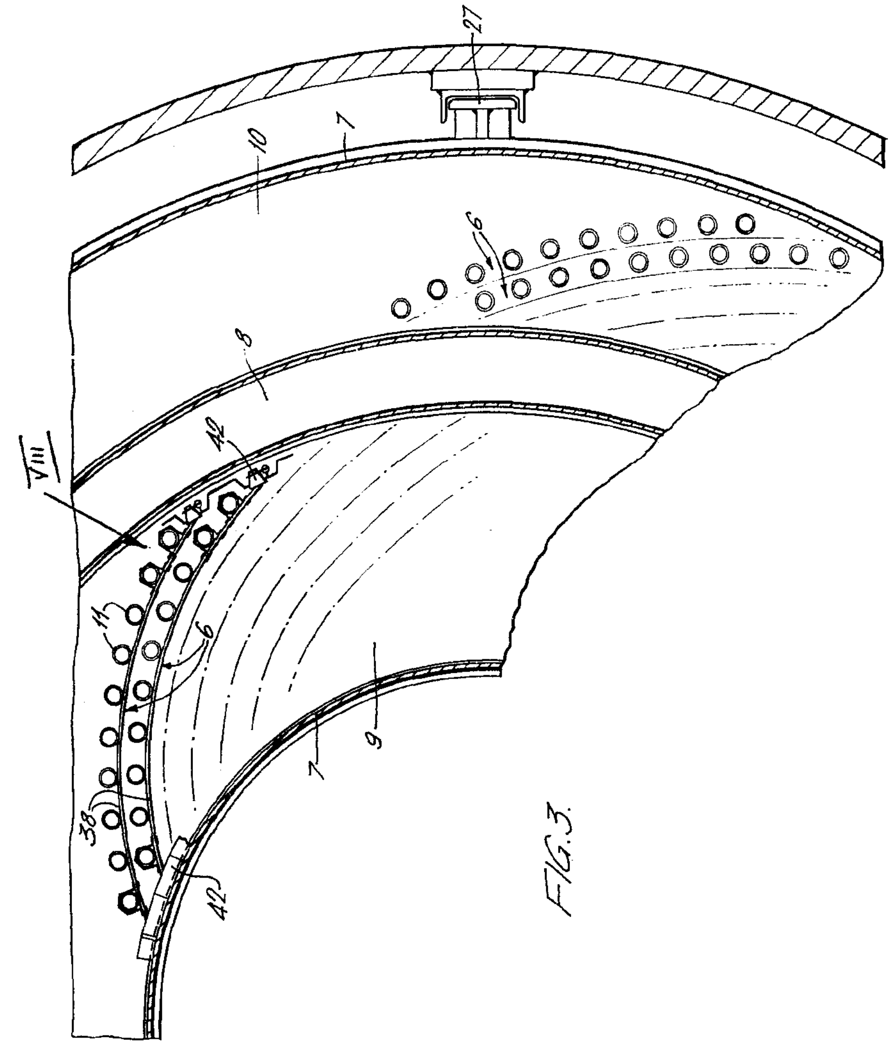
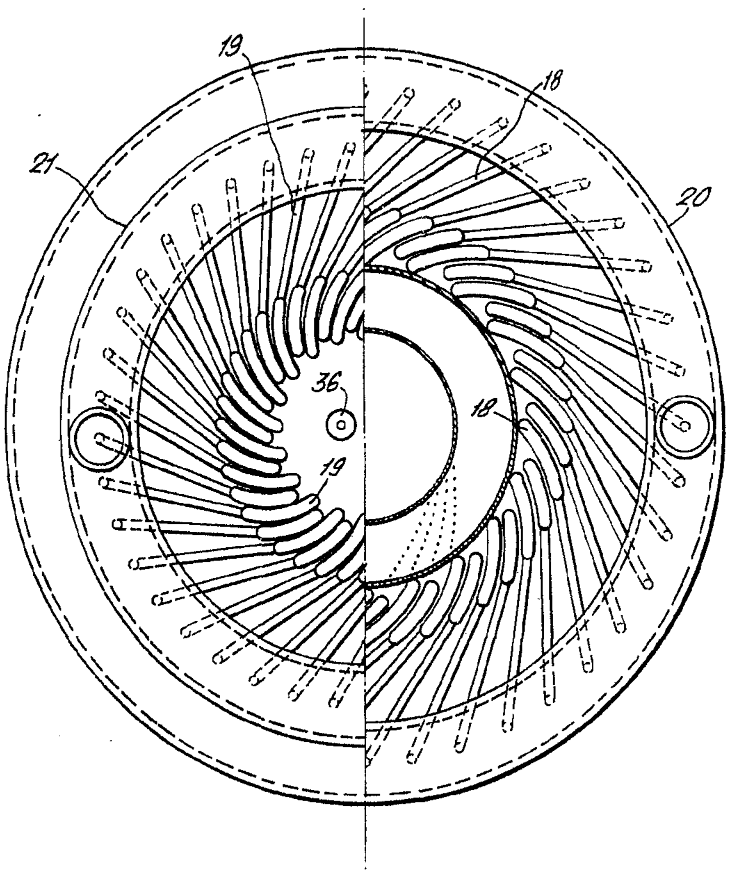


FIG.3.

1564821 PROVISIONAL SPECIFICATION NO. 2
6 SHEETS *This drawing is a reproduction of the Original on a reduced scale*
Sheet 4

FIG. 4.



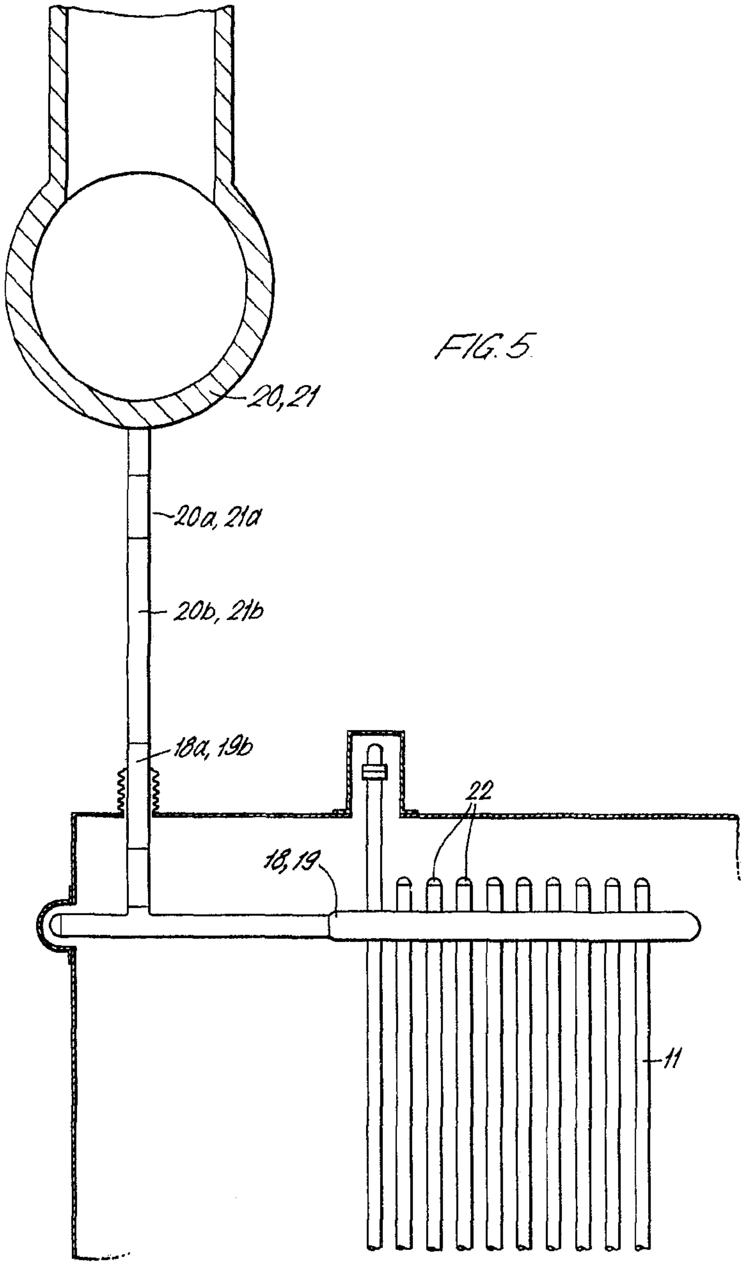


FIG. 5

1564821 PROVISIONAL SPECIFICATION No. 2[illegible]

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FIG. 7.

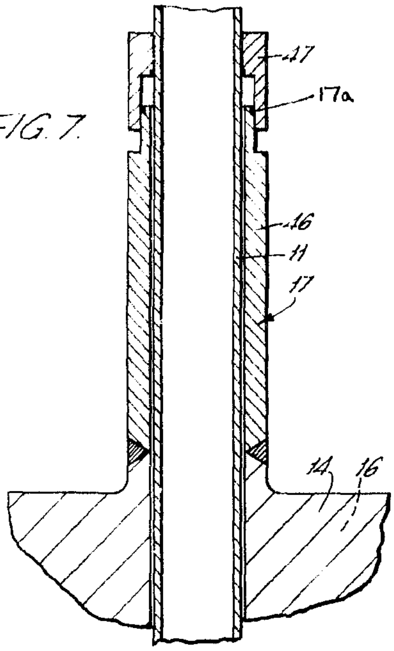


FIG. 8.

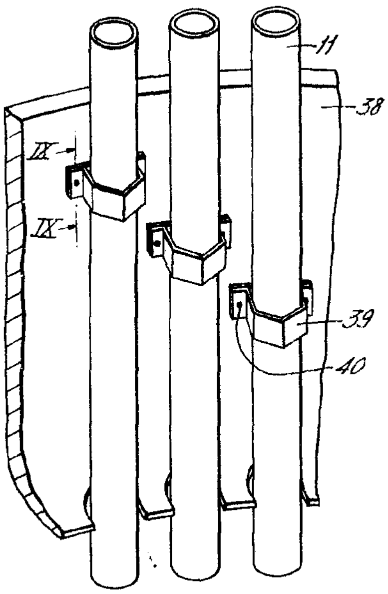
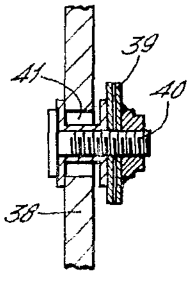


FIG. 9.



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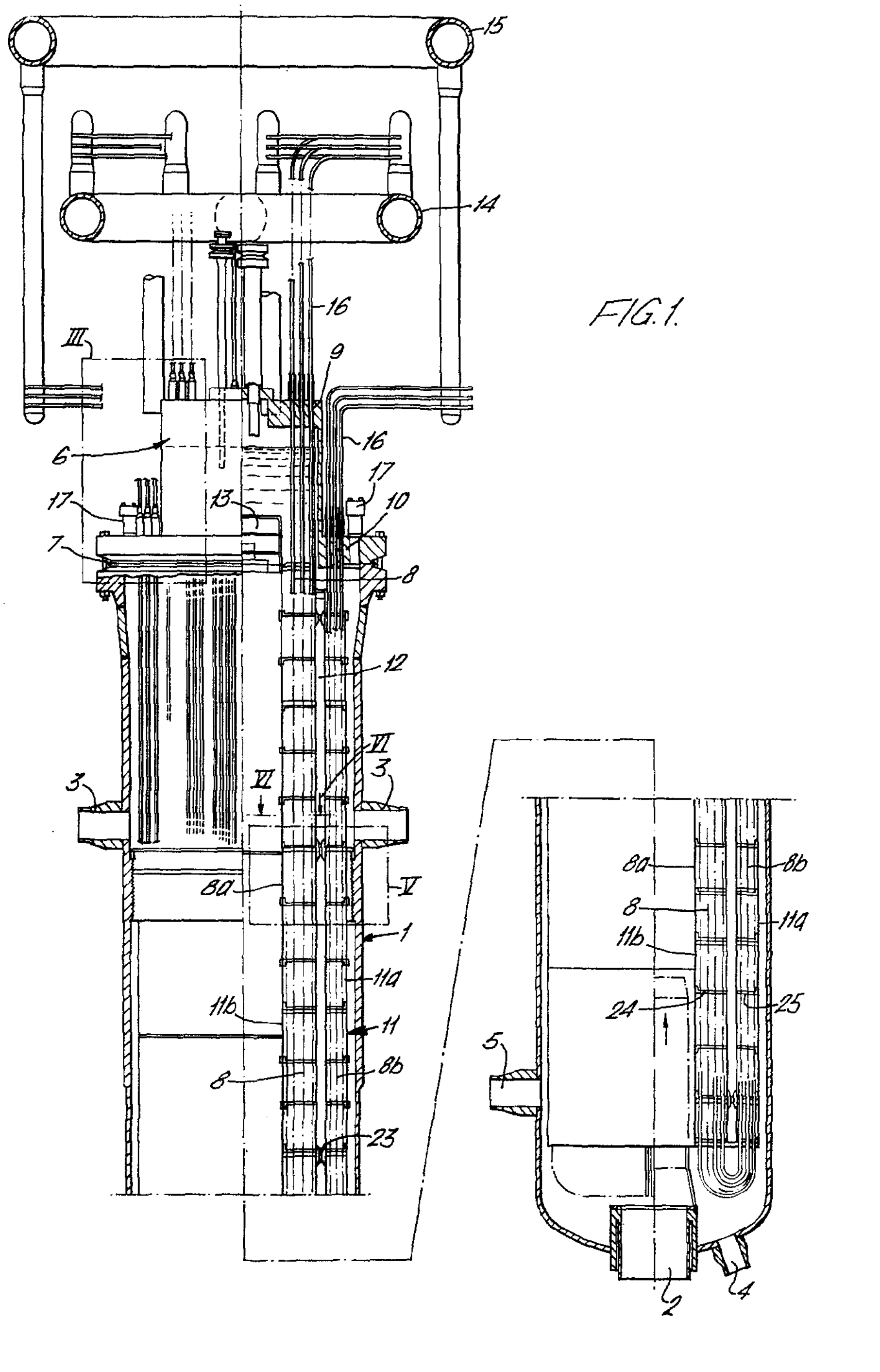

FIG.1.

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Sheet 2

FIG. 2.

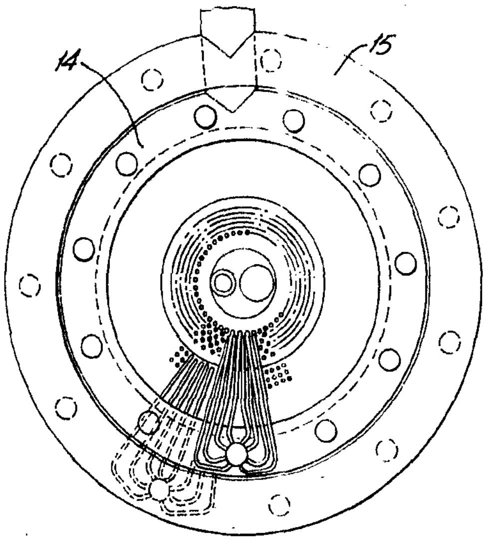


FIG. 5.

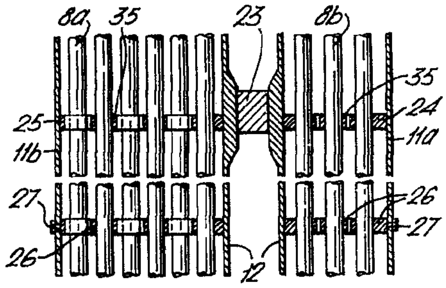


FIG. 6.

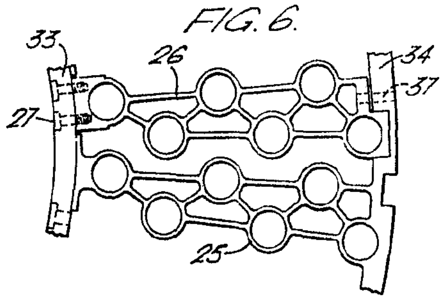


FIG. 3.

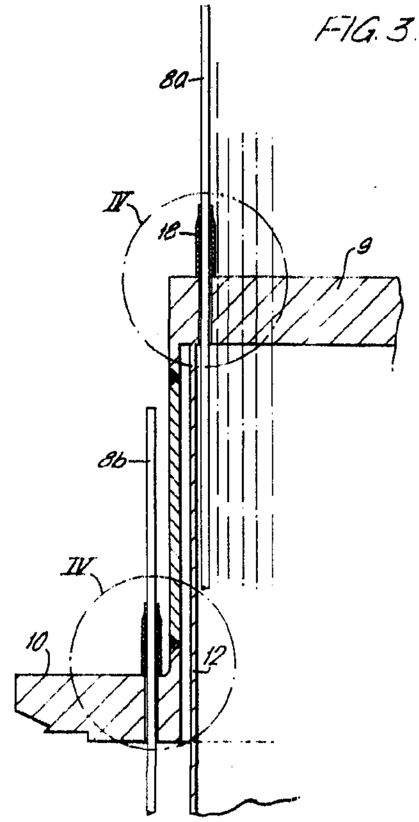
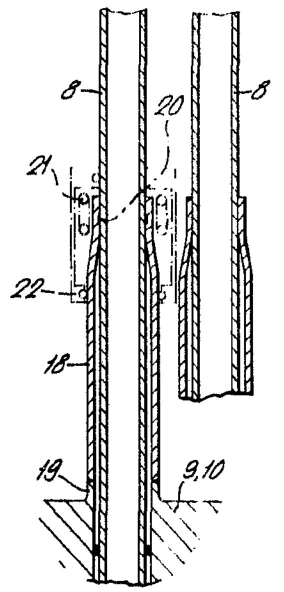


FIG 4



1564821 PROVISIONAL SPECIFICATION No. 4

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Sheet 4

FIG. 7.

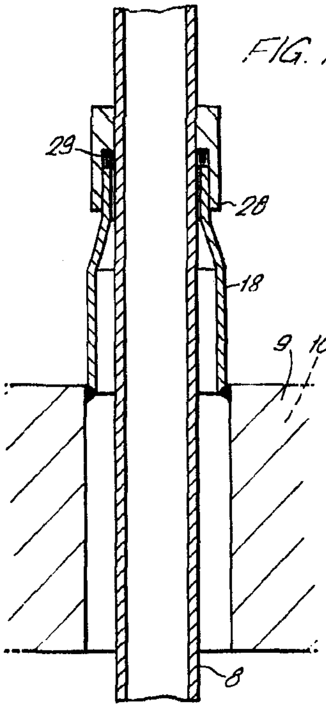
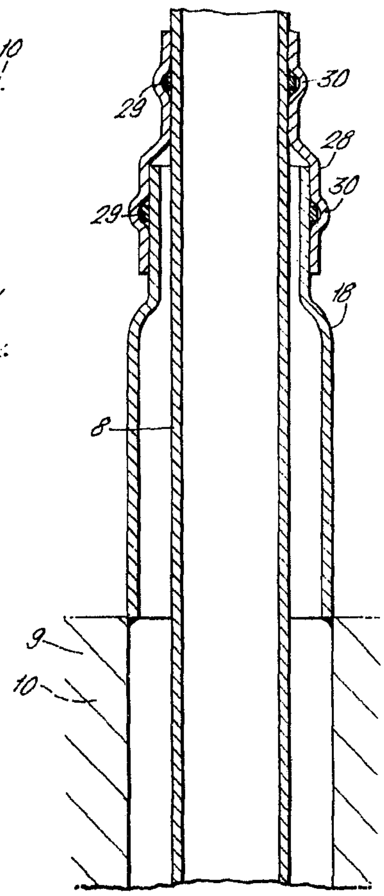


FIG. 8.



1564821 PROVISIONAL SPECIFICATION No. 47
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Sheet 5

FIG. 9.

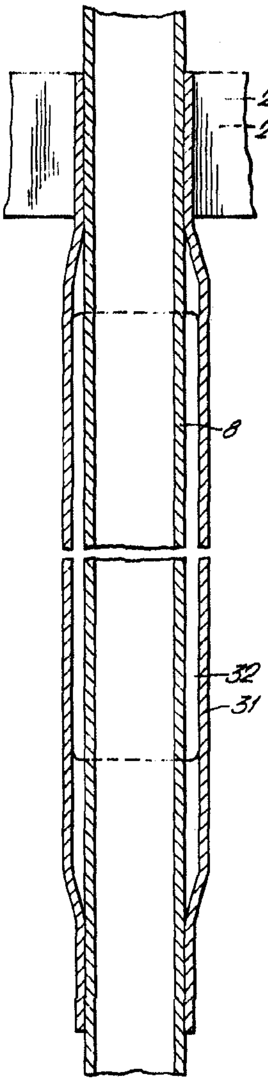

FIG. 10.

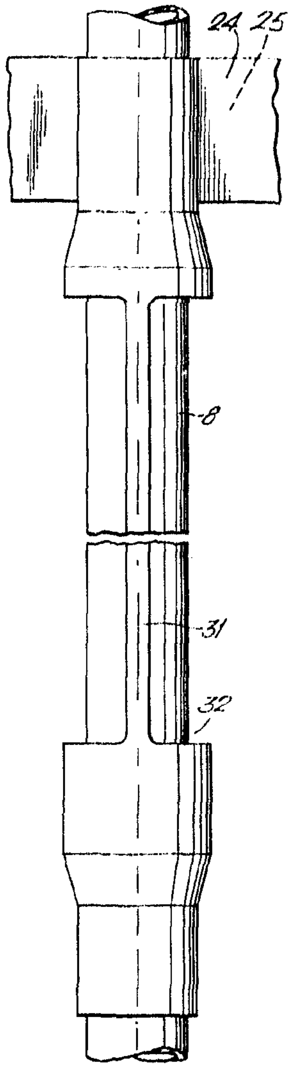

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FIG. 11.

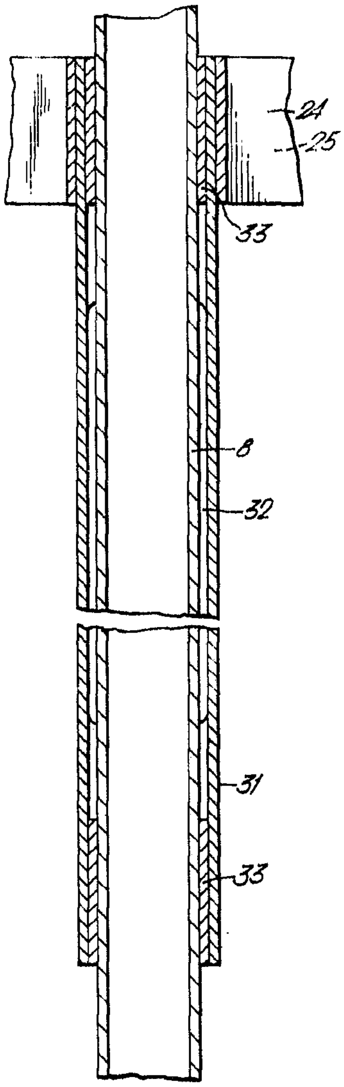

FIG. 12.