April 9, 1963 D. K. DAVIES ET AL 3,084,742

HEAT EXCHANGE APPARATUS

Original Filed May 6, 1954 4 Sheets-Sheet 1

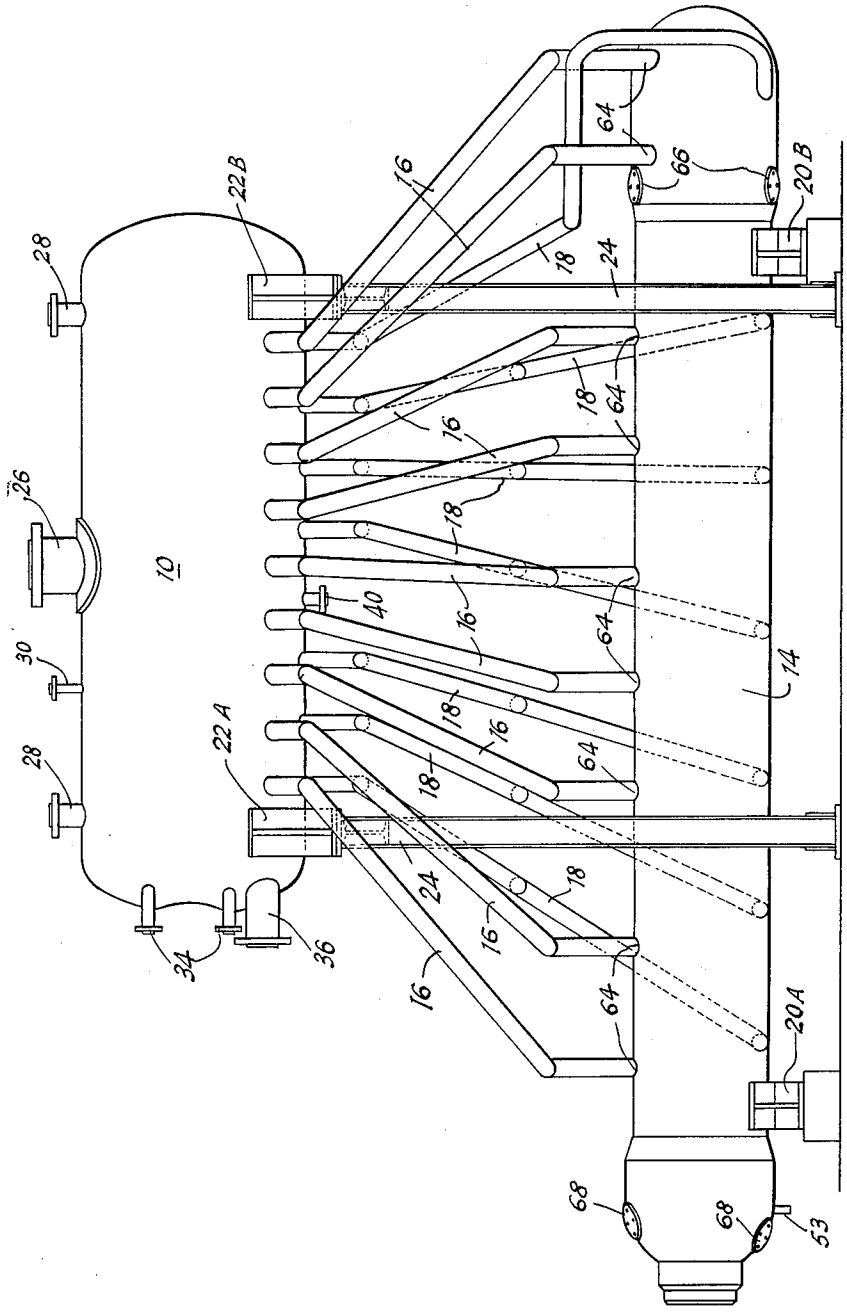


FIG. 1

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HEAT EXCHANGE APPARATUS

Original Filed May 6, 1954 4 Sheets-Sheet 2

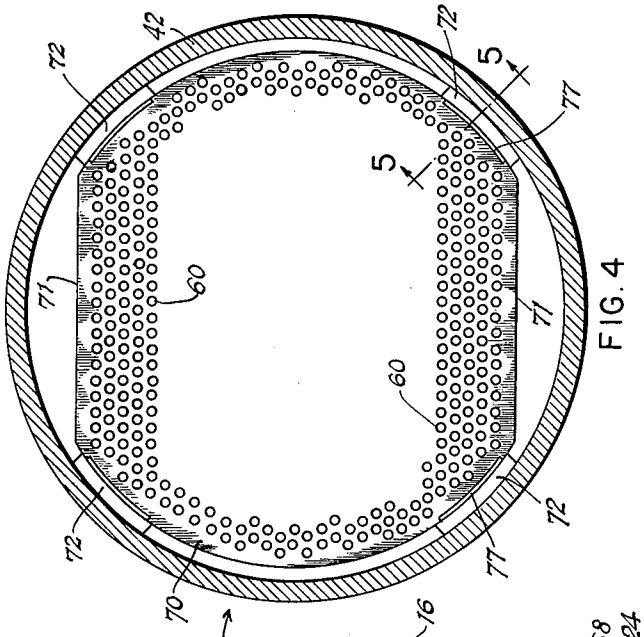


FIG. 4

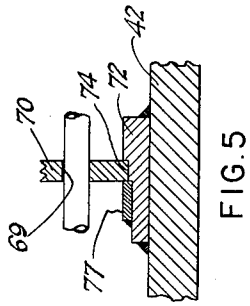


FIG. 5

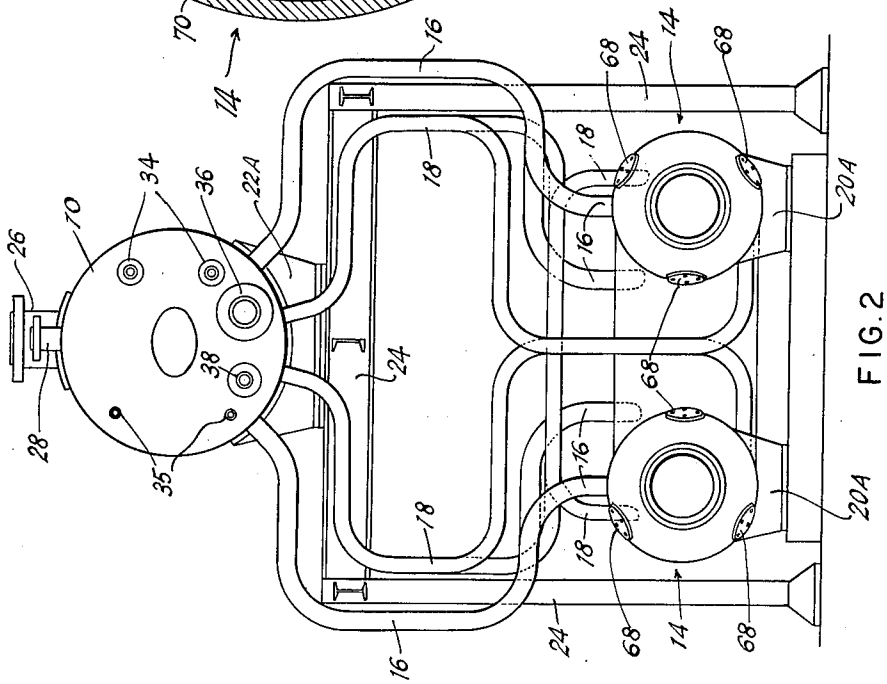


FIG. 2

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HEAT EXCHANGE APPARATUS

Original Filed May 6, 1954 4 Sheets-Sheet 3

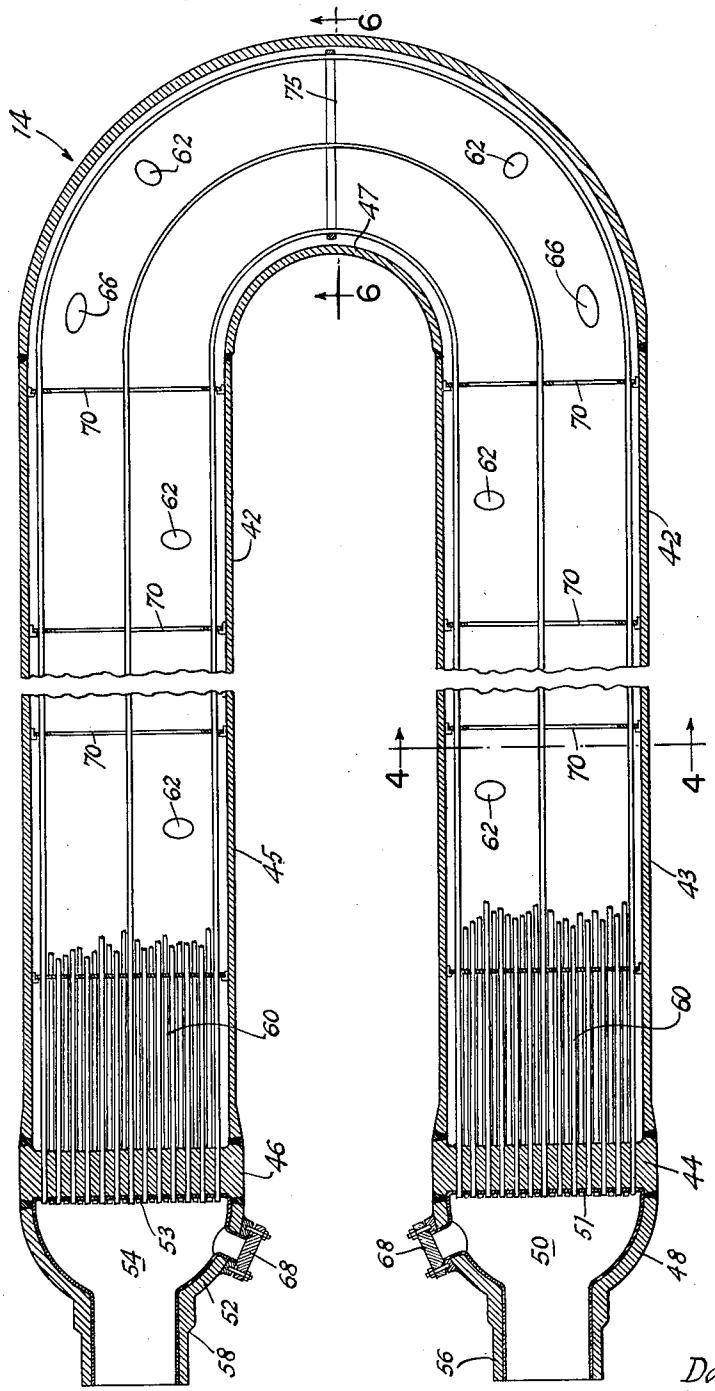


FIG. 3

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HEAT EXCHANGE APPARATUS

Original Filed May 6, 1954 4 Sheets-Sheet 4

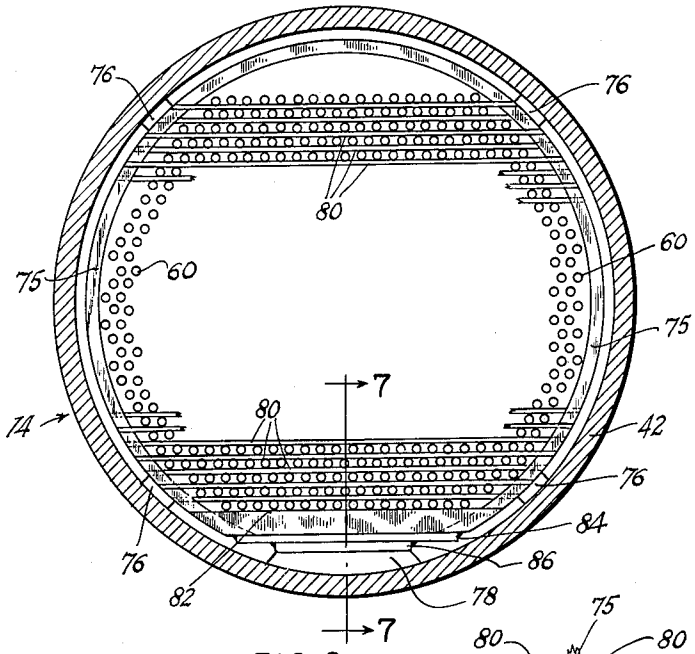


FIG. 6

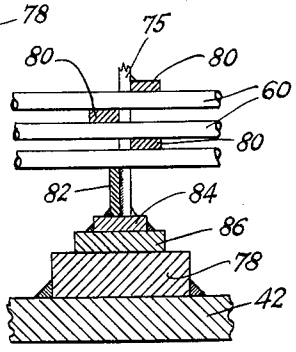


FIG. 7

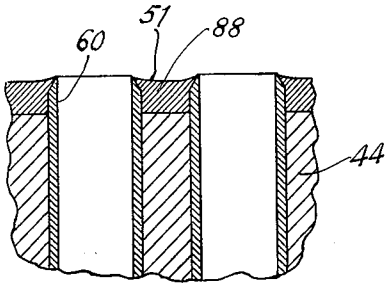


FIG. 8

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United States Patent Office 3,084,742 Patented Apr. 9, 1963

3,084,742

HEAT EXCHANGE APPARATUS

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Original application May 6, 1954, Ser. No. 428,038, now Patent No. 2,904,013, dated Sept. 15, 1959. Divided and this application Jan. 9, 1959, Ser. No. 785,891

2 Claims. (Cl. 165—133)

The present invention relates in general to the construction and operation of heat exchange apparatus, and more particularly to vapor generating units which are especially designed for service with a high temperature and pressure corrosive heating fluid which is subject to very rapid changes in temperature during operation and which must be maintained relatively uncontaminated by fluid leakage or products of corrosion.

The present application is a division of Serial No. 428,038 filed May 6, 1954 and now Patent No. 2,904,013.

It has heretofore been known to construct the fluid contacting parts of heat exchangers utilizing one or more corrosive fluids entirely of austenitic stainless steels. Since austenitic steels have a considerably higher coefficient of thermal expansion than carbon steel, it has been considered impractical to construct coextensive connected parts of such heat exchangers of such different metals to reduce the total cost, inasmuch as the austenitic steels are approximately five times the cost of carbon steels. Austenitic steels are also objectionable for heat exchanger parts because of their low resistance to thermal shock. It is also difficult to fabricate large diameter thick plate required for high pressure tube sheets of austenitic stainless steels.

Where non-contamination of a fluid at high temperatures and pressures is required in a heat exchanger, the normal practices of using floating heads, packed tube joints, and expansion joints are not sufficient to satisfy the stringent leakage requirements and a welded or integral connection of the tubes to the tube sheets and of the tube sheets to the shell is required. Where a welded construction of thick pressure parts is required, austenitic stainless steels are objectionable because of their poor welding characteristics.

Heat exchangers having a single tube sheet divided by an associated partition into inlet and outlet sections, a bank of U-shaped tubes extending between and connected to the inlet and outlet sections, and a single shell encompassing the tube sheet and tube bank, are well known. While this construction permits differential thermal expansion between the tubes and the shell, it is undesirable when large, e.g. 150 F. temperature differences exist between the heating fluid and the cooling or heated fluid. Such temperature differences tend to cause distortion in the shell and tube sheet and frequently result in failure of the heat exchanger.

In heat exchangers arranged for the generation of vapor and which have been constructed of austenitic stainless steel, a cracking of the steel has commonly occurred. Experience has shown that the cracking occurs when the stainless steel is in the presence of a water having dissolved solids therein which makes the water electrically conductive. Generally, the presence of chlorides or caustics in water are sufficient to cause the stainless steel to crack. Further, the cracking seems to occur during the simultaneous application to the metal of stress and corrosive liquids. Also, neither of these two conditions alone seem to be sufficient to cause cracking. Due to the widespread difficulties with stress cracking, there has been considerable developmental work directed to the solution of this problem.

Accordingly, this invention has a principal object to prevent stress cracking in stainless steel that is in the presence of a corrosive vaporizable liquid. Accordingly, the invention provides stainless steel attached to carbon steel where both are in the presence of a boiling water which acts as an electrolyte.

The further object of this invention is the provision of heat exchange apparatus having a construction capable of safely withstanding the thermal stresses due to differential expansion of the fluid contacting parts, such as a tube bank and enclosing shell, resulting from one of the fluids being at a high temperature and pressure. A further object is the provision of heat exchange apparatus of the character described designed for service with corrosive heat transfer fluids at a high temperature and pressure and wherein contamination of the heating fluid is avoided. A further object is the provision of heat exchange apparatus designed for service conditions in which substantially all of the heat is supplied by a corrosive fluid at a high temperature and pressure and which is characterized by its low space requirements, relatively low cost, substantially uniform heat transfer conditions throughout the heat transfer area, and restriction of the thermal stresses between its component fluid contacting parts to safe operating limits.

The various features of novelty which characterize the invention are pointed out with particularity in the claims annexed to and forming a part of this specification. For a better understanding of the invention, its operating advantages and specific objects attained by its use, reference should be had to the accompanying drawings and descriptive matter in which there is illustrated and described a preferred embodiment of the invention.

Of the drawings:

FIG. 1 is an elevation of a vapor generating unit constructed in accordance with the present invention;

FIG. 2 is an end view of the vapor generating unit shown in FIG. 1;

FIG. 3 is a plan section of the U-shaped heat exchanger section of the vapor generating unit shown in FIGS. 1 and 2;

FIG. 4 is a vertical transverse section taken on the line 4—4 of FIG. 3;

FIG. 5 is a fragmentary section taken on the line 5—5 of FIG. 4;

FIG. 6 is a vertical transverse section taken on the line 6—6 of FIG. 3;

FIG. 7 is a fragmentary section taken on the line 7—7 of FIG. 6; and

FIG. 8 is a fragmentary section showing the tube attachment to the tube sheet.

In the drawings we have illustrated a steam generating unit designed for high pressure-high temperature service constructed in accordance with the invention and comprising a horizontally arranged elongated vapor-liquid separating drum 10, a horizontally arranged U-shaped heat exchanger 14 symmetrically arranged below the drum, and riser tubes 16 and downcomer tubes 18 extending between the drum and the heat exchanger and connected thereto. The heat exchanger 14 is supported by a longitudinally spaced group of pedestal supports 20A and 20B, the heat exchanger being secured in the forward group 20A and arranged to slide in the after group 20B while being restrained in a vertical direction. The drum 10 is supported in longitudinally spaced saddle supports 22A and 22B, the drum being secured to the saddle 22A and being arranged to longitudinally expand in the saddle 22B while being restrained in the vertical direction. The saddles 22A and 22B are in turn mounted on structural steel work supports 24.

The drum 10 serves as the water storaging and steam-

water separating space of the unit. A steam-water mixture is delivered into the drum 10 by the plurality of uniformly spaced risers 16, where the steam is separated by conventional means, such as centrifugal type separators, and passed to the steam outlet 26. Safety valve connections 28 and a vent nozzle 30 are also provided on the top of the drum. Gage glass connections 34, remote level indicator connections 35, a feed water inlet 36, and a chemical feed connection 38, are provided at one end of the drum. In the center bottom portion of the drum there is a blowdown nozzle 40.

Attached to the bottom portion of the drum 10 are a plurality of uniformly spaced downcomers 18 which, as shown in FIG. 2, bend outwardly from the centerline of the drum and then inwardly in an aligned formation into a plane coincidental with the longitudinal centerline of the drum, with the tubes then entering the shell of the heat exchanger 14 along the bottom thereof at uniformly spaced positions. Also attached to the bottom portion of the drum 10 at the outer side of the downcomer tubes is a plurality of riser pipes 16 which also bend outwardly from the centerline of the drum beyond the outer limits of the heat exchanger, thence downwardly and inwardly to enter the heat exchanger at uniformly spaced positions along the top thereof.

In FIGS. 3 to 8 is shown the heat exchanger section 14 of the steam generator which comprises an outer elongated pressure shell 42 of circular cross-section which is formed in a U-shape and having parallel legs 43 and 45 connected by a bight section 47. In the outer end of the shell leg 43 is welded to the shell 42 a thick inlet tube sheet 44 and at a corresponding location in the leg 45 and outlet tube sheet 46. A hemispherical pressure head 48 forming a heating fluid inlet chamber 50 is welded to the tube sheet 44 and a corresponding hemispherical head 52 welded to the outlet tube sheet 46 to form a heating fluid outlet chamber 54. There is a large diameter inlet nozzle 56 formed in the inlet head 48 and a correspondingly single outlet nozzle 58 in the outlet head 52. Disposed within the shell 42 is a bundle of small diameter long bore parallel arranged U-tubes 60 forming the heat exchanger heat transfer surface. The opposite ends of the tubes 60 are secured to the inlet tube sheet 44 and to the outlet tube sheet 46, so that there is formed a continuous fluid flow path from the inlet chamber 50 through the tubes 60 to the outlet chamber 54. The downcomers 18 are uniformly spaced along the bottom of the heat exchanger 14 and connected to discharge the water to be evaporated through the feed inlets 62 indicated in FIG. 3. The water is partly evaporated as it passes upwardly across the tubes and a steam and water mixture discharges from outlets 64 into corresponding uniformly spaced risers 16. Inspection ports 66 are provided in the bight section 47 to allow X-raying of the final weld of the heat exchanger. Inspection and repair access openings 68 are also provided on both the inlet and the outlet hemispherical heads 48 and 52.

The tube bundle 60 is arranged with the tubes on an equilateral pitch spacing, with the tubes substantially and uniformly filling the transverse cross-section of the pressure shell 42, as shown in FIGS. 4 and 6. The distribution of the tubes of the tube bundle 60 is constant so as to present a transverse cross-section which is uniform at all positions along the entire length of the heat exchanger 14 between the tube sheets 44 and 46. As shown in FIG. 5 the tubes are supported in the shell legs 43 and 45 by passing through corresponding slightly oversize holes 69 in support plates 70. Each plate 70, which has a cut out portion 71 at the top and bottom thereof for flow equalization, is mounted concentric with shell 42 on spacer bars 72. Each bar 72 is welded to the shell and has a recessed portion 74 into which the support plate 70 fits. A retaining bar 77 then holds the plate in locked position.

As shown in FIGS. 6 and 7, the tube pattern and general cross-section in the bight section 47 of the exchanger is the same as that in the shell legs 43 and 45. The tubes, however, are supported in a structure which permits linear expansion of the tubes of the tube bundle 60 relative to the shell. This structure has a support ring 75 which encompasses the tube bundle and which is mounted concentrically within the shell 42 on spacer blocks 76 and on a load pedestal 78. The spacer blocks are welded to the ring 75 and slide on the shell 42. Transversely of the tubes and having their outer ends welded to the ring 75 are support bars 80 for each tube row, each located in a plane parallel to the direction of thermal expansion of the tubes of the bundle 60. The bars 80 support and vertically space the tubes with alternate bars being displaced and welded to the ring 75 on opposite sides thereof.

The bottom bar 82 stands on its thin edge to present a greater resistance to bending. In the lowermost portion of the exchanger, a portion of the ring 75 is removed. The lower bar 82 being welded to the ring 75 carries the entire load of the tube bundle 60. This load is distributed to the shell by the two distributing bars 84 and 86 which are welded to the ring and bar structure. The load pedestal 78 is welded to the shell 42 and on it the bar 86 slides while transmitting the load of the tube bundle 60. This arrangement allows the tubes to freely expand in the horizontal or expansion plane with the tubes being restrained and supported in the transverse or vertical plane. The ring and bar support structure is free to deflect within itself to accommodate unusual differential thermal expansions, and is not secured to the shell but only rests thereon. This structure thus completely and flexibly supports the tube bundle within the shell 42.

The heat exchanger shell 42 is designed to withstand the steam pressure of the steam generator and is preferably constructed of high tensile strength carbon steel. This steel when in the presence of boiling water which is chemically maintained at a pH of 11.5 and with an oxygen content of less than .01 cc. per liter, will not substantially corrode during the design life of the heat exchanger. The tube sheets 44, 46 and hemispherical heads 52, 48 are also fabricated from high tensile strength carbon steel and are designed to withstand the operating pressure of the hot fluid in the chambers 50, 54. The pressure of the hot fluid may be of the order of 1500 to 3500 p.s.i. and the tube sheet 38" diameter and 8" thickness. Tube sheets of this size must be capable of being fabricated with precision and most importantly must have a high resistance to cracking under severe temperature fluctuations. All of these features carbon steel possesses, to a marked degree. Heating fluid temperature fluctuations of the order of 25° F. in five seconds may safely occur in the described construction.

When the heating fluid, e.g. pressurized water at a temperature of 550 to 650 F. circulated from the cooling system of a high rate heat generating device by a high pressure pump (not shown), is corrosive and must be maintained at a high purity, it is imperative that a chemically inert surface be in contact with the hot fluid throughout its flow path. To this end the invention involves the use of austenitic stainless steel cladding to cover the interior surfaces of the hemispherical heads 48, 52, the faces 51, 53 of the tube sheets 44, 46, and the provision of austenitic stainless steel U-shaped tubes. As indicated in FIG. 8, the tubes of the tube bundle 60 are secured in the unit by having their end portions expanded into the tube sheets 44 and 46 and their ends seal welded directly to the austenitic stainless steel cladding 88 of the tube sheet on the hot fluid faces 51, 53, by the method of welding disclosed and claimed in a copending application of O. R. Carpenter, Serial No. 405,959 filed January 25, 1954 and now abandoned. Thus there is a strong mechanical tube attachment plus welds between similar materials, i.e. austenitic stainless steel, assuring little likelihood of leakage between the hot fluid and the heated fluid.

The stainless steel tubes 60 and the internal side of the shell 42 form a shell side fluid flow space which contains boiling water. The water normally contains dissolved solids, such as chlorides and carbonates which make the water electrically conductive. Thus, where the tube 60 contacts the carbon steel, such as tube sheets 44 and 46, there will exist in effect a cathodic cell. The boiling water would then act as an electrolyte for the cathodic cell and there would tend to be produced a preferential corrosion attack on the carbon steel. Thus inherently the heat exchanger described provides an arrangement subject to selective corrosion. Generally, such an arrangement would be detrimental. However, in the present instance this arrangement by preferentially corroding the thick carbon steel sections protects the thin stainless steel tubes from the dangers of stress cracking.

Accordingly, the present invention provides an arrangement whereby stainless steel tubes which are in electrically conductive contact with carbon steel are benefited. Thus there is made possible the construction of a combination carbon-stainless steel heat exchanger for use with a boiling fluid on one side and a chemically pure heating liquid on the opposite side which is specifically adapted for high thermal stresses and use at high temperatures.

The stainless steel internal cladding of the inlet and outlet chambers, tube sheets of the heat exchanger, and the thin wall stainless steel tubes provides complete assurance that the hot fluid will maintain its purity, thus making it possible to fabricate the thick walled pressure carrying members of the heat exchanger from suitable low cost carbon steel. This large use of carbon steel results in a major reduction in the cost of the heat exchanger.

The provision of a U-tube bank and a U-shaped shell, substantially eliminates any thermal expansion stress concentrations and resultant heat exchanger distortion. The provision of a heat exchanger having a uniform cross-section throughout its length makes possible the realization of maximum heat transfer effectiveness from every square foot of heat surface. This general configuration of heat exchanger when coupled with a series of uniformly spaced longitudinally distributed downcomer and riser connections, provides a single hot fluid pass and cool fluid single pass heat exchanger of maximum effectiveness, mechanical integrity and minimum space requirements.

The longitudinal disposition of an elongated vapor-liquid drum and the longitudinal disposition of the U-shaped heat exchanger with a plurality of downcomer and risers spaced uniformly along the length of said drum and heat exchanger provides a steam generator which requires a low circulation head height while maintaining a high circulation rate and allows the heat exchanger and drum to be independently supported, with the differential expansion therebetween being taken by flexible downcomers and risers connected therebetween.

While in accordance with the provisions of the statutes, we have illustrated and described herein a specific form of the invention now known to us, those skilled in the art will understand that changes may be made in the form of the apparatus disclosed without departing from the spirit of the invention covered by our claims, and that certain features of the invention may sometimes be used to advantage without a corresponding use of other features.

What is claimed is:

1. A high temperature high pressure heat exchanger for heat transfer between a corrosive heating fluid and an electrolytic vaporizable liquid having pressure parts including a carbon steel shell having thick-walled carbon steel tube sheets connected to opposite ends of said shell and defining therebetween a heating chamber having carbon steel internal boundary surfaces, means defining heating fluid inlet and outlet chambers at the outer sides of said tube sheets, means for supplying a high temperature corrosive heating fluid to said inlet chamber, a stainless steel layer lining the walls of said inlet and outlet chambers and the outer side of said tube sheets, a group of stainless steel tubes having their opposite end portions expanded into said tube sheets and directly welded to the stainless steel layer on said tube sheets to form with said inlet and outlet chambers a chemically inert flow path for said corrosive fluid, and means for supplying an electrolytic vaporizable liquid to said heating chamber in direct contact with said stainless steel tubes and the carbon steel section of said tube sheets, said electrolytic vaporizable liquid forming cathodic cells at the junctions of said stainless steel tubes and carbon steel tube sheets causing preferential corrosion of said carbon steel tube sheet sections and thereby inhibiting stress cracking of said stainless steel tubes.

2. A high temperature high pressure heat exchanger for heat transfer between a corrosive heating fluid and an electrolytic vaporizable liquid having pressure parts including a thick walled carbon steel shell having thick walled carbon steel tube sheets welded to opposite ends of said shell and defining therebetween a heating chamber having carbon steel internal boundary surfaces, means defining heating fluid inlet and outlet chambers at the outer sides of and welded to said tube sheets, means for supplying a high temperature corrosive heating fluid to said inlet chamber, a stainless steel layer lining the walls of said inlet and outlet chambers and the outer side of said tube sheets, a group of thin walled stainless steel tubes having their opposite end portions expanded into said tube sheets and directly welded to the stainless steel layer on said tube sheets to form with said inlet and outlet chambers a chemically inert flow path for said corrosive fluid, and means for supplying an electrolytic vaporizable liquid to said heating chamber in direct contact with said stainless steel tubes and the carbon steel section of said tube sheets, said electrolytic vaporizable liquid forming cathodic cells at the junctions of said stainless steel tubes and carbon steel tube sheets causing preferential corrosion of said carbon steel tube sheet sections and thereby inhibiting stress cracking of said stainless steel tubes.

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