May 5, 1942. W. A. PEARL 2,281,594

SEALING TUBES TO TUBE SHEETS OF HEAT EXCHANGERS AND THE LIKE

Filed Dec. 27, 1940

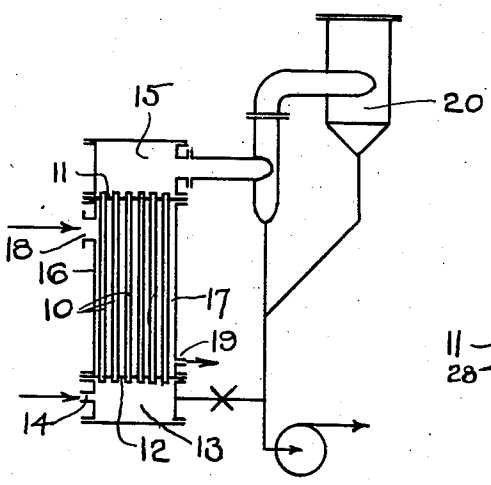


Fig. 1.

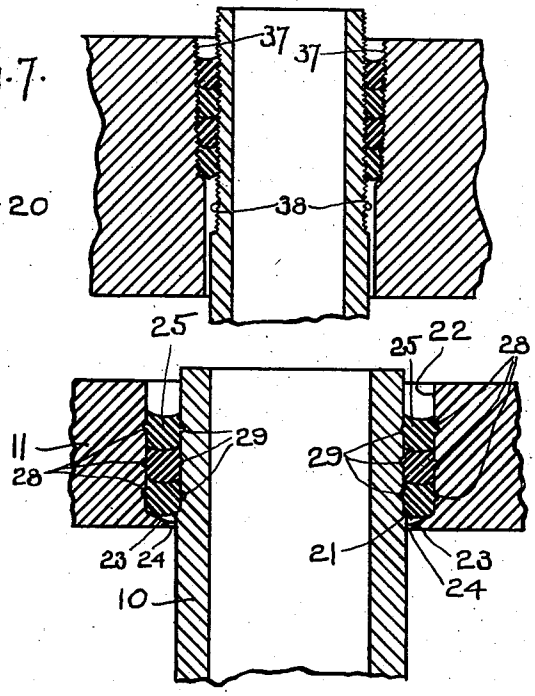


Fig. 2.

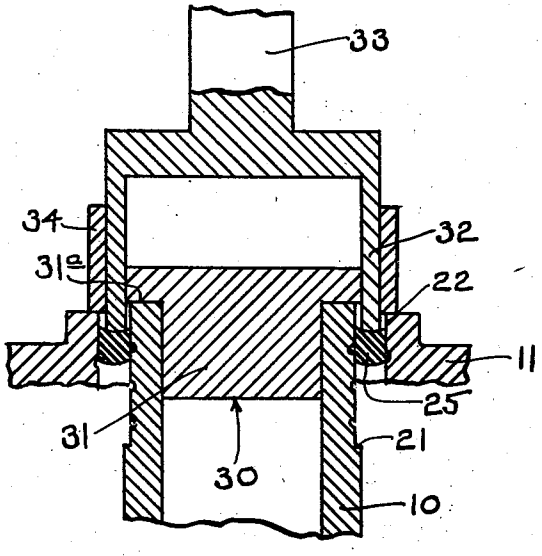


Fig. 6.

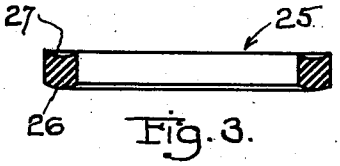


Fig. 3.

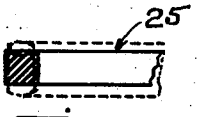


Fig. 5.

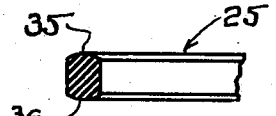


Fig. 4.

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2,281,594

SEALING TUBES TO TUBE SHEETS OF HEAT EXCHANGERS, AND THE LIKE

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3 Claims. (Cl. 285—45)

This invention has to do with improvements in the joining of tubes to tube sheets of heat exchangers, and the like; and also generally to improvements in gas tight and vapor tight connections between parts which are subjected to severe conditions of heat and corrosive action. Generally speaking, the present improvements have been devised with a view to meeting the conditions existing in such units as evaporators of the "long tube vertical" type, but it will be evident that these improvements may also be used to great advantage and benefit in many other locations, and in many other types of units. I have, however, for convenience in illustration, and for other reasons, herein illustrated these features as embodied in a heat exchanger of the long tube vertical type, but in so doing it will be understood that I do not thereby intend to limit myself to such applications of said features, except as I may limit myself in the claims to follow.

In such applications as the foregoing there are provided tube sheets between which extend numerous tubes of considerable length. A suitable form of shell is provided around the group of tubes, and is connected to the tube sheets in vapor and air and liquid tight manner, and the tubes themselves are sealed to the tube sheets in tight manner; so that thereby there is provided a chest or space around the tubes and between the tube sheets, and the interiors or bores of the tubes are sealed from said space or chest.

During the heat exchanging operations of such an application as the "long tube vertical" evaporator type, it is customary to introduce steam or vapor into the space of the chest and around the tubes, and to flow the liquor being treated up through the tubes, so that a heat exchanging operation takes place, and so that vapor is boiled or driven off from such liquor in the tubes or elsewhere, and is delivered into a suitable vapor chest above the upper tube sheet, or in communication therewith.

Due to the difference in co-efficient of expansion of the materials from which the tubes and the shell are made it follows that proper provision must be made for either resisting the stresses caused by such expansion conditions, or else suitable provision must be made for relative movements between the tubes and one or both of the tube sheets; but in any case the arrangement must be such as to ensure steam or vapor and liquor tight connections between the tubes and the tube sheets at all times. Heretofore various expedients have been devised for taking care of the conditions above referred to; including the rigid or unyielding connection of the tubes to the tube sheets, and also including so-called slip connections between these parts, whereby the end portions of the tubes are allowed to slip back and forth through the tube sheets by the use of packed joints or the like. In any case serious objections exist to both these types of connections.

The difficulties of this problem are aggravated by reason of the temperatures to which the parts are subjected; the nature of many of the materials or liquors to be handled, including corrosive liquors and the like; and the kinds and characteristics of the materials used for the tubes and tube sheets. The temperature co-efficients of expansion for the tubes used in these operations are often very different from the co-efficient for the shell, so that a further serious aggravation is caused by this circumstance. In this connection I also contemplate the use of non-metallic tubes, that is, tubes made of non-metallic material such as "graphitized carbon," and also the sealing of these tubes to the metallic tube sheets presents a further requirement of the solution of the problem. Frequently the tube sheets are made of lead or other corrosion resisting material, or at any rate are lined or surfaced with such material.

When slip joints are provided between the tubes and the tube sheets, it is generally necessary to provide some form of sealing gasket at the joint. Heretofore it has been customary to use some form of gasket and a metallic gland or ferrule for this purpose and application; and when this is done such gasket or gland or ferrule is generally of metal different from either or both the tube and the tube sheet. As a result there may be produced serious electro-chemical reactions at these joints, with consequent corrosion and other troubles, either chemical or mechanical or both. Furthermore, the use of such gaskets and metallic ferrules or glands entails the use of expensive materials, and usually considerable space is needed for accommodation of such slip joints so that the tubes must be placed at correspondingly greater separation from each other, and the tube capacity of a unit of given overall dimensions is accordingly reduced.

The main object of my present invention is to provide between the tube end and the tube sheet an integral or permanent non-metallic connection which is of a yielding nature so that an absolute seal is established between the parts at all times, while still allowing for the necessary movements to take place between the parts due to

temperature changes, and due to the different co-efficients of temperature expansion. This sealing but yielding connection is effected by the use of material which is non-metallic, so that the troubles due to electro-chemical reactions are avoided; yet a material is used which establishes a perfect seal with the materials of the tube and the tube sheet; and said material is of a nature which permits the necessary amount of flexure and distortion to occur in the body of the seal itself without damage to the material of the seal itself, and without damage to the sealing connection thereof to both the tube and the tube sheet. Furthermore, said material is of such a nature that it is not adversely affected by the heat to which the parts are subjected during normal ranges of operation, for example up to two hundred or two hundred fifty degrees F., is not affected by highly corrosive liquors such as are encountered in the concentration of chemical liquors and the like, and said material seals itself to both the tubes and the tube sheets by action of heat (and pressure), so that the very operation conditions themselves actually serve to effect the sealing attachment of said seals to the parts after a very short interval of preliminary operation.

A further object of the invention is to provide a form of seal for this and similar purposes which is extremely simple in construction or structure, very cheap to build, of small size so that the tubes may be brought to close nesting within the heat exchanger, and readily installed into sealing position by use of simple installation operations.

For the foregoing and similar purposes I have discovered that various forms of so-called "artificial rubber" or synthetic rubber or rubber-like material are admirably adapted to establish the seals between the parts. Such "artificial rubber" may comprise "neoprene" products; derivatives of "butadiene"; "butyl rubber"; and other materials, the same being vulcanizable or otherwise altered by application of heat (and pressure) to establish the sealing connection thereof to the tubes and to the tube sheets.

Generally speaking, I use a thermo-plastic material subject to permanent deformation to conform to the irregularities of the surfaces of the tube and tube sheet to effect a more vapor-tight, non-slip joint which may be distorted to accommodate the relative movements of the tube and the tube sheet with respect to each other, but without slip with respect to either of said parts.

Generally speaking, also, I prefer to provide, between the end portion of the tube and the tube sheet itself, an annular recess or channel of relatively narrow size, measured radially of the tube, and to provide the seal proper in the form of a ring or an annulus, or in some cases, a number of such rings or annulae, said rings or annulae being slightly thicker than the recess or channel, so that thereupon I force the ring or rings down into such channel under pressure, thereby ensuring tight engagement thereof with the faces of the channel established by the tube sheet and by the outer surface of the tube itself. Generally, also, I prefer to so form these rings or annulae that they are convex towards the location of higher pressure, so that when the steam or vapor pressure is exerted against such ring it tends to distort the same against both the tube and the channel face, and thus exert a considerable lateral pressure of the ring against said parts, thereby further improving the sealing action. Sometimes, I form each such ring with a convex surface facing against the higher pressure, and with a concave surface facing towards the lower pressure, so as to increase such tendency towards distortion laterally by exertion of the differential of operating pressure. Or again, sometimes I prefer to form each ring with convex surfaces on both its ends for a similar purpose.

When such a sealing arrangement is first subjected to the action of the heat (and pressure) of the heat exchanging operations, said ring or rings will be slightly attached or stuck to the surfaces of the tube sheet wall of the channel, and to the tube; but after a short interval of operation it will be found that a true sealing attachment takes place, the ring "vulcanizing" or sticking or adhering or otherwise attaching itself to the surfaces of the channel wherein it has been forced, being the surface of the tube sheet and of the tube itself. When this occurs it is found that a permanent and perfect sealing attachment is established between the ring and the parts, and that any movement of the tube with respect to the tube sheet does not entail any slip between either the tube sheet or the tube and the ring but rather that such movement between the tube and tube sheet is accompanied by a distortion of the ring without disconnection thereof from either the tube or the tube sheet, and without any breakage of the perfection of the seal existing between the tube and the tube sheet. In other words, I have provided an integral seal between these parts, that is, one which becomes actually a portion of both parts, a seal which is flexible to the extent that the necessary movement between the tube and the tube sheet is provided for, a seal in which such movement is effected not by slippage between the parts, but rather by distortion of the sealing ring itself, and a seal which is non-metallic and therefore such that substantially no electro-chemical actions can occur between any part of such seal and either the tube sheet or the tube, no matter what metals may be used for those parts. Furthermore, my seal is one which is not adversely affected by the heat of the operations normally carried on, nor by the presence of highly corrosive liquors.

Sometimes I provide a single ring between the tube sheet and the tube, and located within the channel; but sometimes I provide two or three or more rings, placed on top of each other, or at any rate axially along the length of the tube. In any case, however, I prefer to force the rings home into the channel under pressure so that there is assurance that firm and continuous contact is established between the ring or rings and the surfaces of the channel. When several rings are used the pressure of the steam or vapor when in service will act most effectively, in any case, on that ring nearest to the interior of the steam or vapor chest; with consequent greatest force on said ring to compress it laterally against the walls of the channel; but nevertheless some force will be communicated to the ring or rings further removed from the interior. Nevertheless, due to the heat of the tube and tube sheet themselves there will be effective vulcanizing or sticking or adhering and sealing action between all the rings of such series and the tube and tube sheet after a period of operation. The use of a number of distinct rings makes possible the provision of a seal along a considerable length of the tube without the use of a ring whose thickness lengthwise of the tube is excessive.

Furthermore, by the use of a series of such rings, each one can be individually set into place, or afterwards, if desired, removed, without the need of using excessive force, and without serious distortion of each ring during such insertion or removal.

In practical operation the amount of shift of the tube with respect to the tube sheet for which provision must be made will depend on the lengths of the tubes, the materials of which the tubes and the shell are made, and the temperature changes which must be provided for. In the specific case of a graphitized carbon tube eight feet long with a steel shell and heavy lead tube sheets, the movement may be as much as one thirty-second of an inch, or more, but this movement is perfectly accommodated by seals embodying the present invention.

It is a further feature of my present invention that I have provided a heat exchanger in which the tubes may be made of non-metallic material such as "graphitized carbon," the tube sheets of metal, such as lead. I have found that seals such as herein disclosed will effectively seal themselves both to the metal of the tube sheet and to the material of the non-metal tubes, such sealing action being possible by reason of the use of artificial rubber compositions which it has been found are possessed of the ability to thus seal themselves to both these classes of materials. This is a very great advantage in the use of seals incorporating my present invention, since it makes possible the satisfactory use of such non-metallic tubes for many operations wherein they would not otherwise be satisfactory. Among such operations are those involving vacuum evaporation of corrosive liquors.

Furthermore, when such non-metallic tubes are used they are relatively thick, so that the desirability of using such seals which do not occupy more than a small space is greatly augmented, in order to be able to place these tubes as close together as possible, and thereby increase the heat-transfer ability of the unit as much as possible.

Furthermore, these non-metallic tubes have a relatively low co-efficient of expansion, so that provision must be made for a relatively greater amount of movement at the joints, than would be the case when the tubes had a co-efficient more nearly equal to that of the shell surrounding the tubes. Such provision is effected by the seals herein disclosed.

These seals may be used at either one or both tube sheets; but generally I prefer to provide these seals at the locations where the tubes pass through both tube sheets, thereby dividing the relative movement at each end into a smaller amount than would be the case where provision for such movement was made at only one end.

In the drawing:

Figure 1 shows diagrammatically a simple form of a so-called "long tube vertical" evaporator, showing the tube sheets, and the tubes connected thereinto by seals embodying the present invention;

Figure 2 shows on enlarged scale a fragmentary detailed section through one end of a tube and portion of the adjacent tube sheet, with a seal of the present invention between these parts;

Figure 3 shows a detailed section through one of the sealing rings of the arrangement of Figure 2, removed from the tube and tube sheet; this sealing ring having one end convex and the other concave, so that the ends of a series of such rings will nest together;

Figure 4 shows a fragmentary section through a modified form of sealing ring, same having both ends convexed;

Figure 5 shows a fragmentary section through still another modified form of sealing ring, which has flat ends, but which ends will be distorted when the ring is forced home into the channel between the tube sheet and the end of the tube;

Figure 6 shows in section a simple form of tool for forcing the rings into place within the channel between the tube sheet and the tube; and

Figure 7 shows a fragmentary section through a modified form of seal in which the outer surface of the tube and the surface of the channel are serrated or provided with small ringlike corrugations instead of relatively larger grooves as in the forms of Figures 2 and 6.

Referring first to Figure 1, I have therein shown diagrammatically a simple form of "long tube vertical" evaporators, having the outer shell, the vapor head, etc. In this case, the tubes are shown at 10, the upper and lower tube sheets at 11 and 12, the lower or liquor inlet chamber at 13, delivering liquor to the lower ends of the tubes, the liquor inlet connection at 14, the vapor head above and in communication with the upper ends of the tubes, at 15, the shell surrounding the tubes at 16, establishing the steam or vapor space 17, the steam or vapor inlet connection at 18, the condensate connection at 19, and finally the separator to which the distilled vapors are delivered is shown at 20. All the foregoing are well understood in this art, and need no greatly detailed description in this case.

Referring now to Figure 2, I have therein shown an enlarged fragmentary section through a portion of the upper tube sheet and the connection of the upper end of one of the tubes thereinto. In this case the tube sheet 11 and tube 10 are shown. The tube shown is a non-metallic tube of "graphitized carbon" already referred to herein, and is relatively thick. Such being the case its end portion may readily be slightly turned down or reduced in diameter as shown at 21 where there is provided a slight shoulder; and the tube sheet may be provided with a channel-shaped annular opening 22 into which the end portion of the tube sets, said channel-shaped opening being provided with the relieve 23 at its inner end. Thus there is provided an annular channel between the outer face of the end portion of the tube and the body of the tube sheet, said channel facing outwardly, or away from the interior of the steam or vapor chest and towards either the vapor head 15 or the liquor inlet chamber 13, as the case may be. It will also be noted that there is a slight annular clearance 24 between the tube sheet and the outer face of the tube, so that the pressure existing within the steam or vapor chest may be directly communicated to the annular channel.

Within the annular channel I force one or more sealing rings 25, these being of "artificial rubber" already referred to herein; and each of these rings is of proper diameter to enter into the channel, and is preferably slightly thicker than the thickness of the channel so that the ring must be forced home into place in the channel. By this means there is assurance that when the ring is thus forced home it will be tightly set into place in the channel, and that it will bear tightly against both the walls of the channel, and

thus provide a very effective seal against both of said walls.

Furthermore, I sometimes provide one end of the ring with a convex surface as shown at 26, preferably the end which faces towards the interior of the steam or vapor chest. By so doing it will be seen that the pressure exerted by such steam or vapor will tend to act in such manner as to still further force the ring to expand outwardly and inwardly against both the walls of the channel, that is, against the wall 22 formed by the tube sheet, and against the surface of the tube proper. The outer end of the ring 27 may be formed concave, so that when a pair of these rings are set together they will nest together as shown in Figure 2. Sometimes, other forms of rings may be used as shown in Figures 4 and 5.

The form of ring shown in Figure 3 is provided with convex surfaces 35 and 36, top and bottom; and when a series of such rings are forced into the channel their convex surfaces will be forced together, thereby producing a very strong lateral or radial compression action, and ensuring a substantial amount of pressure against the walls of the channel, being the surface of the tube and the outer wall of the annular groove, of the tube sheet. Various other forms of rings or annulae may suggest themselves to the designer, but many other forms than herein shown will fall within the scope of my present invention.

In the modified form shown in Figure 5, the ring thereof is of rectangular cross-section when free of the channel and in expanded condition; but when forced into the annular channel this form of ring will be distorted into the general form shown by the dotted lines of Figure 5, due to being compressed radially or laterally. That is, it will assume a more or less convex form on both its top and bottom faces, somewhat similar to the form of Figure 4.

Now in order to improve the attachment or adherence of the rings to the surfaces of the tube and of the tube sheet, (that is, to improve the "vulcanizing action" and attachment thereto), I prefer to form said surfaces with irregularities of relatively small size, so that, due to the compression of the rings the material thereof will be forced into such irregularities, and the action of the heat (and pressure) will produce a very perfect adherence and attachment or "vulcanizing" of the ring or rings to both the surfaces. It should be noted that if these surfaces are left plain or smooth there will of course be a very strong attaching action, but the provision of these irregularities will greatly improve such action, especially when such irregularities are of small size, for example like moderate threads.

Thus, in Figures 2 and 6 I have shown the relatively small grooves 28 and 29 on the surfaces of the tube sheet and the tube, respectively; and preferably there is at least one of each of these grooves in position for sealing engagement by each of the rings. Preferably, quite small grooves or irregularities should be use, as shown, for example, in Figure 7, wherein each of the surfaces is provided with small serrations 37 and 38, so that each ring will engage a number thereof, and so that only a slight amount of deformation of the material of the rings is necessary to ensure complete engagement of the ring with each and every one of the adjacent serrations.

It is found that when using such "artificial rubbers" as "neoprene" products, for example, when these are placed under compression and heat, they will suffer a permanent deformation, but without loss of flexibility or elasticity. Therefore, when such arrangements as shown in various of the figures are used, the compression action will serve, after a short preliminary interval of operation under heat, to permanently deform the rings into the grooves or serrations, and to cause them to stick or adhere or "vulcanize" very strongly to the surfaces of the irregularities. Then, due to the fact that the flexibility of the rings is not impaired they may flex back and forth due to relative movements of the tube and tube sheet, thereby maintaining a perfect seal and also accommodating the needed movements between the parts. Such movements are accommodated by a distortion of the material of the ring, and not by any slipping of the ring with respect to either the tube sheet or the tube. Such distortion of twisting of the ring material may be of necessary and permissible amount, depending on the thickness of the ring, as manifestly the thicker the ring material, the greater the amount of distortion which it may suffer without damage to its body and without tearing away from either the tube sheet or the tube.

The relieve 23 already referred to permits of the necessary movements between the tube and tube sheet without any jamming of the sealing ring against the end of the channel, and therefore without damage to the ring itself. The presence of the slight clearance 24 between the tube and the tube sheet not only serves to permit of free communication of the steam or vapor pressure against the ring surface, but also permits slight rocking movements to occur between the tube and the tube sheet. Thus, any slight misalignment is accommodated, and at the same time perfect sealing action is always secured.

The use of several relatively small or thin rings in place of a single larger or thicker ring presents the further advantage that when, after a considerable period of operation, it is desirable to remove and replace the sealing rings, this may be done much easier since each ring may be torn away from the walls of the channel as an individual unit much more readily than could a single very thick and therefore stiffer and more cumbersome ring. The desirability of such removal and replacement after a period of operation is due to the fact that after a time the material of the rings will become hardened and lose its resiliency or elasticity as an intrinsic property of such materials as are now known.

In connection with the temperature to which the rings will be subjected, it is noted that this may be different from the temperature of either the tube or the tube sheet at the location of the seal, and that frequently the tube and the tube sheet are at temperatures differing from each other by quite a considerable amount. For example, in the case of steam or vapor in the chest at 227 degrees F., the liquor or vapor within the tube at the location of the seal may have a temperature of 160 degrees F., so that the seal itself may be subjected to either or both of these temperatures and conditions on its faces. The above is mentioned only by way of illustration as a possible condition of operation, and not as in any sense a limitation.

While I have herein mentioned certain kinds of rubber-like materials, and certain kinds of "artificial rubbers," still I do not intend to limit myself thereto, except as I may do so in the claims to follow. Generally it may be stated that I use a "thermo-plastic" material, that is, one which will suffer deformation under pressure and

heat, without loss of its placticity or flexibility or elasticity, and which will "vulcanize" or stick or attach or adhere to the surface to which it is pressed. In some cases "natural rubber" may be found satisfactory for the present uses, when the latex is properly treated. In other cases other "artificial rubbers" than herein set out may be used.

While I have herein shown and described the application of my present invention to a construction in which the tubes are placed vertically, still it is evident that the features of my invention are equally applicable to other arrangements, as for example, horizontal tubes, or tubes extending upwardly at an angle.

While I herein shown and described only certain embodiments of the features of my present invention, still I do not intend to limit myself thereto, except as I may do so in the claims to follow.

I claim:

1. In a heat exchanger having a series of tubes and a tube sheet provided with apertures for receiving the ends of the tubes, means to seal and connect the ends of the tubes to said tube sheet comprising an annulus of rubber-like material located between the outer face of the end portion of each tube and the adjacent wall of an aperture in the tube sheet, and means carried by said tube and said tube sheet for anchoring said annulus thereto, whereby relative movement between the tube and the tube sheet is accommodated by shear distortion of the annulus, substantially as described.

2. In a heat exchanger having a series of tubes and a tube sheet provided with apertures for receiving the ends of the tubes, means to seal and connect the ends of the tubes to said tube sheet comprising an annulus of rubber-like material located between the outer face of the end portion of each tube and the adjacent wall of an aperture in the tube sheet, said annulus being under an initial compression in a radial direction whereby said annulus is caused to adhere to both the tube and the tube sheet and whereby relative movement between the tube and the tube sheet is accommodated solely by shear distortion of the material of the annulus, substantially as described.

3. In a heat exchanger having a series of tubes and a tube sheet provided with apertures for receiving the ends of the tubes, means to seal and connect the ends of the tubes to said tube sheet comprising an annulus of rubber-like material located between the outer face of the end portion of each tube and the adjacent wall of an aperture in the tube sheet, said tube and said tube sheet being provided at the location of the annulus with annular serrations and the material of the annulus being distorted into said serrations and adhered thereto, whereby relative movement between the tube and the tube sheet is accommodated by shear distortion of the annulus, substantially as described.

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