Dec. 6, 1960 O. W. HEIMBERGER ET AL 2,962,805

METHOD OF MAKING HEAT EXCHANGER TUBE-TUBE SHEET JOINTS

Filed July 11, 1957 2 Sheets-Sheet 1

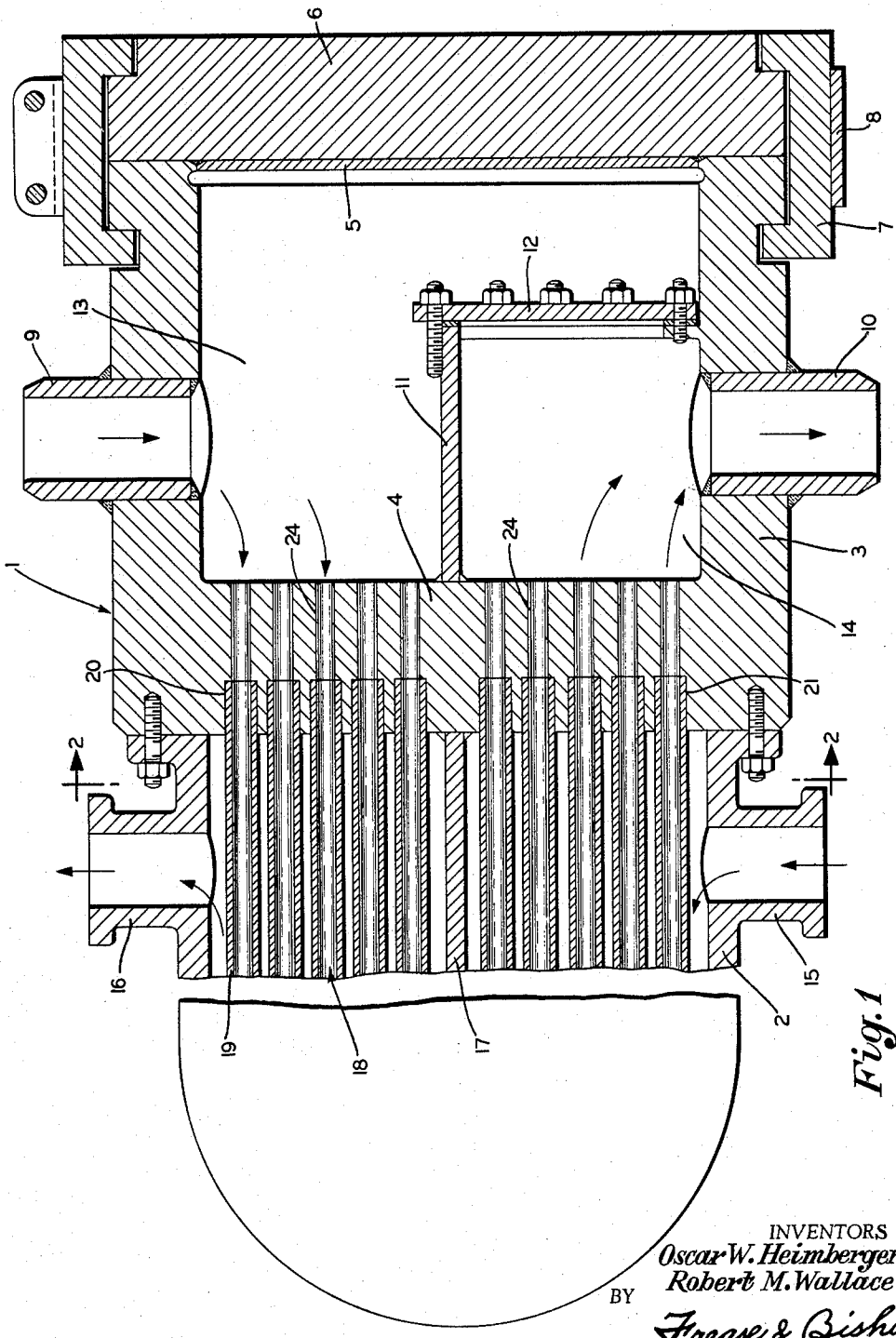


Fig. 1

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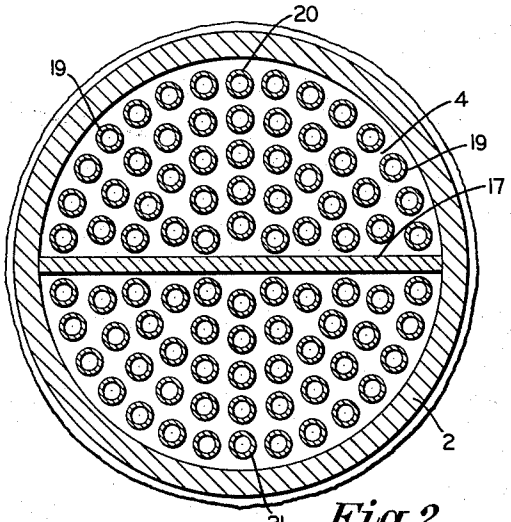


Fig. 2

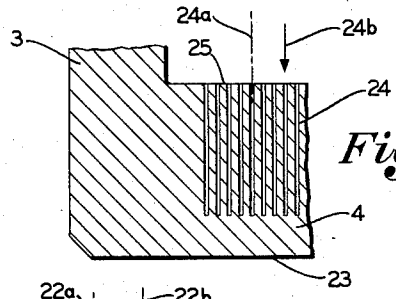


Fig. 3

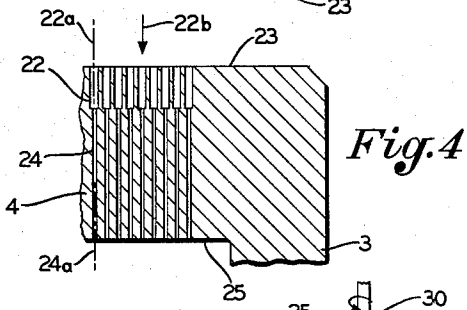


Fig. 4

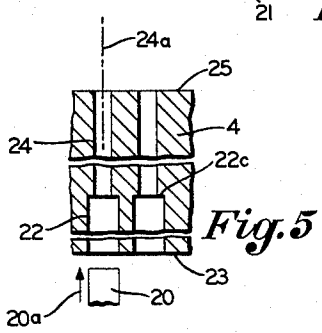


Fig. 5

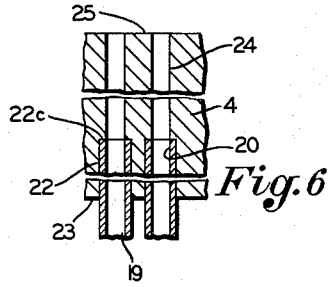


Fig. 6

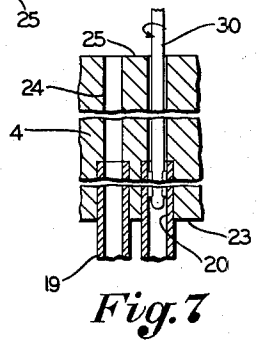


Fig. 7

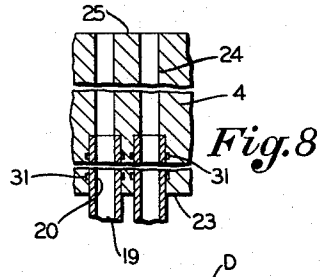


Fig. 8

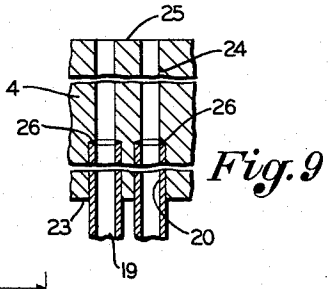


Fig. 9

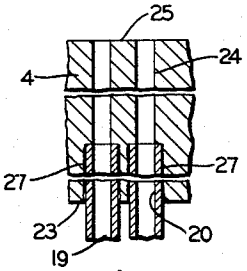


Fig. 10

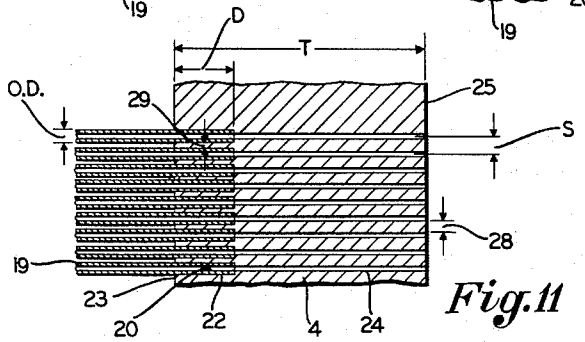


Fig. 11

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2,962,805

METHOD OF MAKING HEAT EXCHANGER TUBE-TUBE SHEET JOINTS

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Filed July 11, 1957, Ser. No. 671,247

4 Claims. (Cl. 29—157.4)

The invention relates to heat exchangers and more particularly to a method of making a joint construction between the ends of small-diameter thin-walled tubes and the tube openings therefor in the heat exchanger tube sheet; and this application is a continuation-in-part of our copending application Serial No. 380,168, filed September 15, 1953, now abandoned.

There are more and more frequent requirements for the design and construction of heat exchangers to handle higher and higher operating pressures. In the past, heat exchanger operating head pressures of 1000 pounds per square inch were considered high. However, the modern trend in the design of pressure equipment is such as to require heat exchangers which will handle head pressures of from 3500 to 6500 pounds per square inch. For example, where boilers are being operated with pressures of the order of 3500 to 6500 pounds per square inch, the boiler feed water must be pumped into the boiler at higher than boiler pressure and feed water heaters for such boilers must be capable of containing and heating water at higher than boiler pressure in order to feed the heated feed water to the boiler.

Normally the tube sheet thickness in the head of a heat exchanger is determined by the maximum allowable bending stress, but with pressures higher than certain values, the shearing stress through the tube sheet ligaments, that is the tube sheet wall portions extending between adjacent tube sheet openings, becomes the controlling factor.

From the standpoint of design, calculations and construction, this controlling factor means, in effect, that the tube sheet thickness begins to vary directly with the pressure instead of with the square root of the pressure; and the required tube sheet thicknesses become enormous, when judged by ordinary standards, for containing operating pressures of the high values indicated.

This problem, which from another standpoint involves the increased weight of such enormously thick tube sheets, has another complicating factor beyond the thickness and weight factors. Particularly where the tube diameters are small, such as ⅜" tubes and commonly such as ⅝", ¾" and 1" outside diameter tubes for high pressure heat exchangers, the drills for drilling the openings for receiving the tube ends in the extremely thick tube sheet, say in tube sheets in excess of 8" to 10" in thickness, or in excess of about 12 tube diameters in thickness, tend to run off and there is always a likelihood of interference between the tube holes toward the face of the tube sheet away from that face on which the tube centers are laid out for drilling. This drill run-off tendency can in some cases be such as to seriously damage the tube sheet during fabrication, or it may seriously decrease the thickness of metal in the ligaments between adjacent tube openings.

As indicated, the possibility of drill run-off may be present whenever the depth of a drilled hole is in excess of 12 times the diameter of the hole being drilled. Thus in tube sheets thicker than 12 times the diameter of tubes

to be secured thereto there is the possibility of drill run-off in drilling the tube receiving holes.

There have been attempts to overcome this difficulty by drilling the tube openings of uniform diameter from both faces of the tube sheet toward the center plane, but again the problem of drill run-off decreases the chance that the center lines of the drilled openings will coincide exactly at the center plane of the tube sheet.

In order to overcome these difficulties in high-pressure heat exchangers, the tube spacing has had to be increased to such a point that the ligaments on the head face of the tube sheet between tube openings, large enough to receive the tubes, drilled from the shell face of the tube sheet, even with drill run-off, are not less than a specified minimum value. This latter requirement increases the diameter of the tube sheet and of the entire heat exchanger head as well as the shell thereby increasing the weight and cost of the equipment; even though such requirement in general does not affect the tube sheet thickness appreciably because of the gain in ligament width due to the wider tube spacing.

Concurrent with the foregoing difficulties and problems are the further considerations that the smaller is the diameter of the tubes used the thinner may be the tube walls, giving decreased weight. And the smaller is the diameter of the tubes, the greater is the tube surface per unit of volume of the heat exchanger or per unit of face area of the tube sheet. Normal tube wall thicknesses of tubes used in such high pressure heat exchangers of the diameters indicated are from 0.049" to 0.134", depending on the pressures and the kinds of metal required to be used in making the tubes.

Thus, the tube sheet thickness ultimately becomes a function of the pressure, the head diameter, the tube diameter, and the tube spacing. It is desired that the ratio of the number of tubes times their outside diameter (or circumference), to the face area of the tube sheet, should be as high as possible. At the same time, the ratio of the number of tubes times the inside flow area thereof, to the face area of the tube sheet, should be as low as possible to provide maximum ligament section.

We have discovered a solution to these complicated interrelated factors, problems and difficulties by which the tube sheet thickness may be a minimum, the tube sheet, head and shell diameters a minimum, and the tube and tube sheet weights substantially decreased while providing a heat exchanger tube sheet and tube joinder construction adapted for operation at high pressures of the order of 3500 to 6500 pounds per square inch.

In accordance with our invention, the openings in tube sheets in excess of 12 tube diameters in thickness for receiving the ends of ⅜" to 1" diameter tubes are drilled large enough to accommodate the tube ends only a minor part of the way through the tube sheet from the shell side face to a depth of 2½ to 7 times and preferably about 6 times the outside diameter of the tubes. Smaller holes with a diameter less than the outside diameter of the tubes are then drilled through the remaining major portion of the tube sheet thickness preferably from the other face. The tube ends are expanded or brazed or welded in the large opening portions; and the interior of the tubes communicate with the smaller diameter portions although not necessary concentric therewith.

These discoveries of the present invention have provided a number of advantages. The ligament efficiency is increased by the smaller diameter tube opening portions which extend through a major portion of the tube sheet, thereby permitting a reduction in tube sheet thickness. The problem of drill run-off becomes unimportant because it is not necessary that the center lines of the large and small hole portions coincide exactly where these

portions meet. Therefore the tube sheets may be drilled at a higher speed and from opposite faces if desired.

Furthermore, a considerable length of tubing material is saved. Tube sheets have been calculated as requiring a thickness as great as 16" for heat exchangers having upwards of 1000 tube ends. In accordance with the invention the larger tube opening portions for say 5/8" tubes need be drilled to a depth of only about six times the tube diameter, or approximately 4" into the shell side of the tube sheet, and 1000 feet of tubing may be saved, which represents not only a substantial saving of tubing metal but also a very substantial cost saving where for instance Monel metal tubing, which is relatively expensive, is used. This saving of tubing becomes even greater where smaller diameter tubes such as 3/8" tubes are used. As a result of the improved ligament efficiency, it is possible to use a closer tube spacing which decreases the head and shell diameters and saves considerably in the equipment weight.

Accordingly, it is an object of the present invention to provide a new method of making a heat exchanger tube sheet and tube joint construction for high-pressure operation.

Also, it is an object of the present invention to provide a new method of making a heat exchanger tube-tube sheet joint construction for high-pressure operation which enables the tube sheet to be designed with minimum thickness and the tube sheet, head and shell built with minimum diameters.

Furthermore, it is an object of the present invention to provide a new method of making a tube-tube sheet heat exchanger joint construction for high-pressure heat exchanger operation with relatively small-diameter tubes in which the tube sheet openings are drilled on two diameters extending partway through the tube sheet from each of the two faces thereof without requiring the center lines of the drilled portions to coincide exactly where they meet, thereby avoiding drill run-off difficulties heretofore involved in drilling thick tube sheets with uniform small-diameter tube sheet openings large enough to accommodate the outside tube diameter, and thereby obtaining increased ligament efficiency.

Also, it is an object of the present invention to provide a new method of making tube and tube sheet connections in a heat exchanger designed for high-pressure operation which enables substantial savings to be effected in the length of tubing required for fabricating the completed heat exchanger.

Finally, it is an object of the present invention to provide a new method of making a high-pressure heat exchanger tube-tube sheet joint construction which solves existing problems in the art, eliminates prior art difficulties in the manufacture of tube sheets and tube joints for high-pressure heat exchangers, generally improves heat exchanger manufacturing procedures, and obtains the foregoing advantages and desiderata in a simple and effective manner.

These and other objects and advantages apparent to those skilled in the art from the following description and claims may be obtained, the stated results achieved, and the described difficulties overcome by the methods, steps, and procedures which comprise the present invention, the nature of which is set forth in the following general statement, preferred steps of which—illustrative of the best modes in which applicants have contemplated applying the principles—are set forth in the following description and shown in the drawings, and which are particularly and distinctly pointed out and set forth in the appended claims forming part hereof.

The nature of the improvements in method of making heat exchanger tube-tube sheet joints of the present invention may be stated in general terms as preferably including the steps of providing a tube sheet of from 8" to 16" or more in thickness or in excess of 12 tube diameters in thickness having a shell side face and a head side face, drilling a plurality of tube holes on centers formed in the shell side face through a minor portion of the tube sheet thickness to a depth of 2½ to 7 and preferably about 6 times the outside diameter of 3/8" to 1" diameter tubes to be joined to the tube sheet, forming said tube hole diameters large enough to accommodate the outside diameter of the ends of tubes to be joined to the tube sheet, drilling a plurality of smaller diameter holes through the remaining major portion of the tube sheet thickness, forming said smaller diameter holes to have a diameter less than the outside diameter of the tubes to be joined to the tube sheet, aligning the centers on which the tube holes and smaller diameter holes are drilled so that said tube and smaller diameter holes communicate, the difference in diameters between the tube and smaller diameter holes forming annular shoulders where said holes drilled on aligned centers communicate, telescopically inserting the ends of tubes to be joined to said tube sheet into said tube holes to substantially abut said shoulders, and securing the telescopically inserted tube ends in said tube holes by expanding, welding or brazing, whereby the smaller uniform diameter holes extending from said shoulders to the head side face of the tube sheet provide maximum ligament area between adjacent smaller diameter holes throughout a major portion of the tube sheet thickness despite drill run-off which may occur in drilling said holes.

By way of example, a heat exchanger made in accordance with the invention, and the new procedures for making the same are shown in the accompanying drawings in which:

Figure 1 is a somewhat diagrammatic, broken, sectional view of a heat exchanger made in accordance with the improved method;

Fig. 2 is a section looking in the direction of the arrows 2—2, Fig. 1;

Fig. 3 is a fragmentary diagrammatic view illustrating the first step in one procedure of forming the tube-tube sheet joints in accordance with the improved method of the present invention;

Fig. 4 is a view similar to Fig. 3 diagrammatically illustrating the next step of the improved method;

Fig. 5 is a larger scale view similar to Figs. 3 and 4 diagrammatically illustrating the next step of the improved method;

Fig. 6 is a view similar to Fig. 5 showing the tube ends inserted in the shell side holes drilled in accordance with the present invention;

Fig. 7 is a similar diagrammatic view illustrating one manner in which the tube ends may be secured to the tube sheet by expanding;

Fig. 8 is a view similar to Fig. 7 illustrating a variation in a manner of securing the tube ends to the tube sheet;

Fig. 9 is a view similar to Figs. 7 and 8 showing the tube ends secured to the tube sheet by welding;

Fig. 10 is a view similar to Figs. 7, 8 and 9 showing the tube ends secured to the tube sheet by brazing; and

Fig. 11 is an enlarged diagrammatic view showing several dimensional characteristics and relationships established and maintained in carrying out the improved method of the present invention.

Similar numerals refer to similar parts throughout the various figures of the drawings.

A high-pressure feed water heater generally indicated at 1 is shown somewhat diagrammatically in the drawings and includes a shell 2, a head barrel 3 provided with a tube sheet generally indicated at 4 which is relatively thick and has a substantially uniform thickness, as shown. The head barrel 3 is provided with a head closure diaphragm 5, and a head member 6 secured to the barrel portion 3 by any usual means, such as by a split ring annular channel shaped clamping member 7 held assembled by a tie strap 8. Thus, the head closure construction illustrated may be similar to that shown in Patent No. 2,766,903, dated October 16, 1956.

The head barrel 3 may be provided with an inlet connection 9, an outlet connection 10, and partitions 11 and 12 forming a head inlet compartment 13 and a head outlet compartment 14. The shell 2 likewise may be provided with an inlet connection 15, an outlet connection 16, and a central baffle 17 extending longitudinally within the shell.

The tube bundle, indicated generally at 18, contained within the shell 2, may be composed of U-tubes 19 with one end of each U-tube, such as 20, joined to the tube sheet 4 in communication with the head inlet compartment 13, and with the other end of each U-tube 19, such as 21, joined to the tube sheet 4 in communication with the head outlet compartment 14.

Referring particularly to Figs. 3, 4, 5, 6 and 7, in accordance with one procedure of the present invention, the tube sheet tube openings are formed in a particular way to avoid the difficulties heretofore encountered where thick tube sheets of 8" or more and up to say 16" in thickness, or in excess of 12 tube diameters in thickness, are involved. Initially, a plurality of holes 24 are drilled on centers, indicated by the dot-dash line 24*a* and in the direction of the arrow 24*b* in Fig. 3, formed in the head side face 25 of the tube sheet 4 through a major portion of the tube sheet thickness. The holes 24 are drilled to have a diameter less than the outside diameter of the tubes 19 to be joined to the tube sheet 4.

Then another series of holes 22 are drilled on centers formed in the shell side face 23 of the tube sheet 4. The centers for the holes 22 are indicated by a dot-dash line 22*a*, and the drilling is in the direction of the arrow 22*b* in Fig. 4. The centers 22*a* for the holes 22 on the shell side face 23 of the tube sheet 4 are aligned with the centers 24*a* for the holes 24 on the head side face 25 of the tube sheet 4.

The holes 22 are drilled into the tube sheet wall to a depth of about 2½ to 7 times and preferably about 6 times the outside diameter of the tubes 19 to be joined to the tube sheet. The depth of the holes 24 is sufficient that the holes 24 communicate with the holes 22. The openings 22 are drilled with a diameter just sufficient to permit the insertion of the tube ends 20 or 21 therein as indicated in Fig. 5 where a tube end 20 is indicated prior to insertion in a hole 22. The tube ends 20 are telescopically inserted in the holes 22 as indicated by the arrow 20*a*, in Fig. 5, and the tube ends 20 after insertion in the holes 22 are shown in Fig. 6.

Since the diameters of the holes 22 and 24 differ, an annular shoulder 22*c* is formed where the holes 22 and 24 drilled on aligned centers communicate. When the tube ends are inserted in the shell side holes 22 the free ends of the tubes substantially abut the shoulders 22*c*, as indicated in Fig. 6.

Although the holes 24 have been described as being drilled first and the holes 22 drilled thereafter to communicate with the holes 24, the order of drilling may be reversed, if desired. In drilling the holes 22 and 24 it is attempted to maintain the axial alignment initially established by the aligned centers 24*a* and 22*a* formed in the head side tube sheet surface 25 and the shell side tube sheet surface 23. However, depending upon the tube sheet thickness and particularly the length of the smaller diameter head side holes 24, some axial misalignment may occur where the holes 22 and 24 communicate, due to drill run-off. However, such misalignment does not cause flow difficulty since it will not appreciably affect tube fluid flow. Furthermore, the misalignment if it occurs due to drill run-off only occurs at the place where the holes 22 and 24 communicate. Since, in accordance with the invention, the holes 24 which extend through a major portion of the tube sheet thickness have a smaller diameter than the holes 22, the ligament efficiency of the wide ligaments 28 (Fig. 11) is not seriously impaired by any such misalignment due to drill run-off.

Although the procedure has been described as being carried out by drilling the holes 22 and 24 from opposite faces of the tube sheet 4, the improved method may be carried out by drilling both hole portions 22 and 24 from the shell side face 23 of the tube sheet 4 in either of two manners.

First the holes 22 may be drilled from the shell side face 23 to the required depth D of 2½ to 7 times the outside tube diameter. Such depth D is sufficient to obtain a satisfactory tube joint in any of the manners hereinafter described. Then the smaller diameter holes 24 may be drilled, also from the shell side face 23 of the tube sheet 4, on the same centers, and preferably using the drilled holes 22 as pilot means, throughout the remainder of the thickness T of the tube sheet 4 to the head side face 25 thereof.

Alternately, the holes 24 may be drilled through the thickness T of the tube sheet 4 from the shell side face 23 to the head side face 25 on centers formed in the shell side face 23. Then the larger diameter hole portions 22 may be drilled, also on the same centers from the shell side face 23 to a depth of 2½ to 7 times the outside diameter of the tubes 19 into the tube sheet 4.

Drilling equipment has recently become available with which drill run-off difficulties may be minimized. Such drilling equipment uses hollow drills and a coolant is pumped directly to the drill cutting edges which washes the chips away as formed.

The improved procedure for forming the joint, regardless of whether the different diameter hole portions are drilled from the same or opposite sides of the tube sheet, increases ligament efficiency and permits close tube spacing for two reasons. First, the drilled portions 22 and 24 are each shorter than one uniform diameter hole drilled completely through the tube sheet 4 having the diameter of drilled portions 22 and receiving a tube end throughout the entire length of the hole. Second, the smaller diameter portions 24 have a wider ligament width 28 throughout the major portion of the thickness T of the tube sheet than the ligament width 29 between the hole portions 22. Thus, the greater ligament width 28 and the shorter depths (T minus D) and D of the holes 24 and 22, respectively, minimize the effect of any drill run-off for a tube sheet of given thickness T.

After the tube ends 20 and 21 have been telescopically inserted in the holes 22, the tube ends may be expanded in such holes in the usual manner by an expanding tool indicated at 30 in Fig. 7.

It is to be understood that usual small-dimension grooves 31 (Fig. 8) may be formed in the tube-receiving holes 22 in the usual manner in connection with forming an expanded tube joint where desired.

Alternatively, either in addition to or instead of expanding, the tube ends may be welded to the tube sheet 4 as indicated at 26 in Fig. 9 or the tube ends may be brazed in the tube holes 22 as indicated at 27 in Fig. 10.

Irrespective of the mode of securing a fluid-tight joint between the tube ends 20 or 21 and the tube sheet 4, the tube ends only extend into the tube sheet to a depth of from 2½ to 7 times the outside diameter of the tubes 19 as shown, in Fig. 11 where the depth of the holes 22 indicated by dimension line D, is six times the tube diameter O.D., and is a minor portion of the tube sheet thickness T. In this manner, substantial ligament area indicated generally by the arrow 28 in Fig. 11, is provided between adjacent holes 24 extending through a major portion of the thickness T of the tube sheet so as to provide maximum ligament efficiency.

This arrangement enables the ligament thickness indicated at 29 between the larger diameter holes 22 to be very small, permitting close tube spacing and obtaining a low ratio of number of tubes times inside flow area to tube sheet face area, along with a high ratio of number of tubes times outside diameter to tube sheet

face area, which results in maximum tube surface per unit of volume of a heat exchanger.

The feed water heater **1** illustrated may heat feed water for a boiler by the passage of feed water through head inlet **9**, through the tubes **19** in the direction of the arrows, and through the head outlet **10**, while steam may comprise the heating medium and may be passed into the shell through inlet **15**, around the tubes **19** and baffle **17** and through shell outlet **16**, as indicated by the arrows.

An important aspect of the invention in addition to the large tube sheet opening portions **22** and the smaller communicating portions **24** having an annular shoulder portion **22***c* formed therebetween, is the fact that the openings **22—24** are formed only on two diameters entirely through the tube sheet without any further enlargements or restrictions which affect or reduce the ligament strength or thickness.

Normally in the design of a heat exchanger tube sheet, the tube spacing by rule-of-thumb may be figured in the ratio of about 5 to 4 with respect to the outside tube diameter in order that sufficient metal is present in the ligaments to withstand the pressure of expanding the tube ends in the tube openings. In accordance with the present invention, this general rule-of-thumb may be followed in designing tube sheet constructions for high pressure heat exchangers. That is to say, the tube spacing indicated by the letter S may be a minimum and may be laid out with respect to the outside diameter O.D. (Fig. 11) of the tubes **19** in the ratio of about 5 to 4 in high-pressure heat exchangers without requiring a greater tube spacing due to drill run-off in drilling long-length small-diameter holes.

As an example of a design of heat exchanger for handling head pressure as high as 6500 pounds per square inch, the tube sheet thickness T may, because of the head diameter and number of tubes invloved, be 16", the outside tube diameter O.D. may be 5/8" with a tube wall thickness of .109" and with the tubes formed of Monel metal, the tube opening spacing S in the tube sheet may be about 27/32", and the tube ends may be telescoped in the larger diameter tube opening portions to a depth D of six times the tube diameter which is slightly less than 4".

Accordingly, the present invention proivdes an improved method of making a heat exchanger tube sheet construction which solves problems and difficulties previously encountered in the manufacture of high-pressure heat exchangers; by which ligament efficiency is increased permitting reduced tube sheet thickness; by which drill run-off becomes unimportant because the large and small tube sheet opening portions need not coincide exactly axially, thereby permitting higher speed drilling; by which considerable tubing length may be saved, providing both cost and weight savings; and by which it is possible to use closer tube spacing, resulting in a smaller head and shell diameter and a lower head and shell weight.

In the foregoing description, certain terms have been used for brevity, clearness and understanding, but no unnecessary limitations are to be implied therefrom beyond the requirements of the prior art, because such words are used for descriptive purposes herein and are intended to be broadly construed.

Moreover, the steps and sizes illustrated and described are by way of example, and the scope of the present invention is not limited to the exact details so illustrated and described.

Having now described the invention, the improved steps in the manufacture of a tube-tube sheet joint construction for high-pressure heat exchangers, and the advantageous, new and useful results obtained thereby, the new and useful methods, steps and procedures, and reasonable mechanical equivalents thereof obvious to those skilled in the art, are set forth in the appended claims.

We claim:

1. The method of making joints between the ends of thin-walled 3/8" to 1" outside diameter tubes and tube openings extending through a heat exchanger tube sheet in which the tube sheet thickness is in excess of 12 tube diameters and in which the ratio of tube spacing to outside tube diameter is 5 to 4; which includes the steps of providing a tube sheet in excess of 12 tube diameters in thickness having a shell side face and a head side face, drilling a plurality of tube holes on centers formed in the shell side face extending into the tube sheet for a minor portion of the tube sheet thickness to a depth of from 2½ to 7 times the outside diameter of 3/8" to 1" diameter tubes to be joined to said tube sheet, forming said tube holes with a diameter large enough to accommodate the outside diameter of the ends of the tubes to be joined to said tube sheet, drilling a plurality of smaller diameter holes on centers aligned with said tube holes extending between said tube holes and the head side face of the tube sheet for a major portion of the tube sheet thickness, forming said smaller diameter holes with a diameter less than the outside diameter of the ends of the tubes to be joined to said tube sheet, the difference in diameters between the tube and smaller diameter holes forming annular shoulders where said holes communicate, spacing the tube hole centers in the shell side face with a ratio of about 5 to 4 with respect to the outside diameter of the tubes to be joined to said tube sheet, telescopically inserting the ends of tubes to be joined to said tube sheet into said tube holes to abut said shoulders, and securing the telescopically inserted tube ends in said tube holes, whereby the smaller diameter holes extending between the shoulders and the head side face of the tube sheet provide maximum ligament area between adjacent smaller diameter holes throughout a major portion of the tube sheet thickness despite drill run-off which may occur in drilling said holes.

2. The method of making joints between the ends of thin-walled 3/8" to 1" outside diameter tubes and tube openings extending through a heat exchanger tube sheet in which the tube sheet thickness is in excess of 12 tube diameters and in which the ratio of tube spacing to outside tube diameter is 5 to 4; which includes the steps of providing a tube sheet in excess of 12 tube diameters in thickness having a shell side face and a head side face, drilling a plurality of tube holes on centers formed in the shell side face extending into the tube sheet for a minor portion of the tube sheet thickness to a depth of at least 2½ times the outside diameter of tubes to be joined to said tube sheet, forming said tube holes with a diameter large enough to accommodate the outside diameter of the ends of the tubes to be joined to said tube sheet, drilling a plurality of smaller diameter holes on centers aligned with said tube holes extending between said tube holes and the head side face of the tube sheet for a major portion of the tube sheet thickness, forming said smaller diameter holes with a diameter less than the outside diameter of the ends of the tubes to be joined to said tube sheet, the difference in diameters between the tube and smaller diameter holes forming annular shoulders where said holes communicate, spacing the tube hole centers in the shell side face with a ratio of about 5 to 4 with respect to the outside diameter of the tubes to be joined to said tube sheet, telescopically inserting the ends of tubes to be joined to said tube sheet into said tube holes to abut said shoulders, and securing the telescopically inserted tube ends in said tube holes, whereby the smaller diameter holes extending between the shoulders and the head side face of the tube sheet provide maximum ligament area between adjacent smaller diameter holes throughout a major portion of the tube sheet thickness despite drill run-off which may occur in drilling said holes.

3. The method of making joints between the ends of thin-walled ⅜" to 1" outside diameter tubes and tube openings extending through a heat exchanger tube sheet in which the tube sheet is in excess of 10" in thickness and in which the ratio of tube spacing to outside tube diameter is 5 to 4; which includes the steps of providing a tube sheet in excess of 10" in thickness having a shell side face and a head side face, forming a plurality of centers in the head side face, drilling a plurality of holes in said head side face centers into the tube sheet wall for a major portion of the tube sheet thickness, forming said drilled holes to have a diameter less than the outside diameter of tubes to be joined to the tube sheet, forming a plurality of centers in the shell side face of said tube sheet aligned with said head side face hole centers, drilling a plurality of holes on said shell side centers in the shell side face into the tube sheet wall to communicate with said head side face holes at a depth of from 2½ to 7 times the diameter of tubes to be joined to the tube sheet, forming said shell side face hole diameters large enough to accommodate the outside diameter of the ends of tubes to be joined in the tube sheet, spacing the tube hole centers in the head and shell side

faces with a ratio of 5 to 4 with respect to the outside diameter of the tubes to be joined to said tube sheet, the difference in diameters between the head and shell side face holes forming annular shoulders where said holes drilled on aligned centers communicate, telescopically inserting the ends of the tubes to be joined to said tube sheet into said shell side face drilled holes to abut said shoulders, and securing the telescopically inserted tube ends in said shell side holes, whereby the small sized holes extending from said shoulders to the head side face of the tube sheet provide maximum ligament area between adjacent head side holes throughout a major portion of the tube sheet thickness despite drill run-off which may occur in drilling said holes.

4. The method defined in claim 3 in which the tube ends are secured to the tube sheet by internally welding the tube ends to said shoulders.

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