

[54] **METHOD OF FABRICATING A TUBE SHEET ASSEMBLY**

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[58] Field of Search 29/471.1, 497.5, 157.4, 471.3, 29/421 E, 478, 479, 486, 470.1

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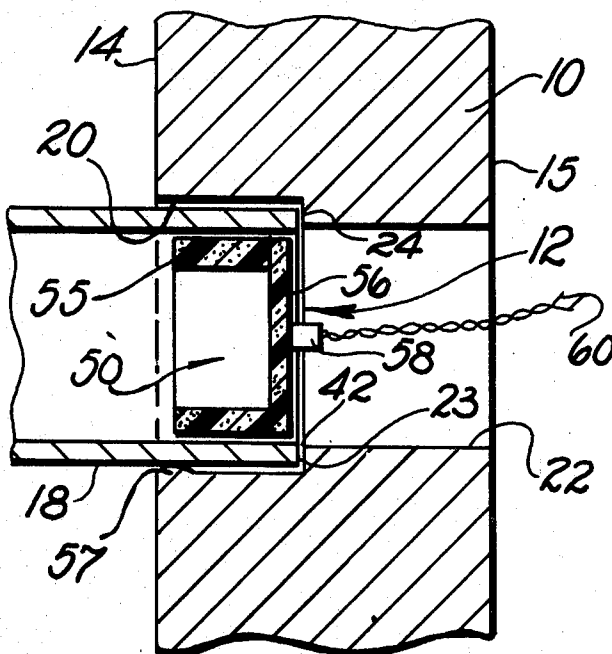
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[57] **ABSTRACT**

A tube sheet assembly has tube sheets with a plurality of orifices formed therein with an enlarged bore inner portion extending partially through the thickness of the sheet for slidably receiving the tube ends intersecting with a coaxial smaller outer bore portion extending through the rest of the sheet thickness corresponding to the inner diameter of the tube. With the ends of each tube positioned in the enlarged inner bore portion of the respective orifices, an explosive welding charge is inserted through the smaller outer bore portion to be positioned within the end of each tube. The charges may then be detonated simultaneously to weld the outer surfaces of the tube ends to the surrounding inner tube sheet surfaces within the enlarged bore portion of the orifices, thus providing an essentially uniform fluid flow path free of discontinuities from the tube sheet into the tubes.

5 Claims, 3 Drawing Figures



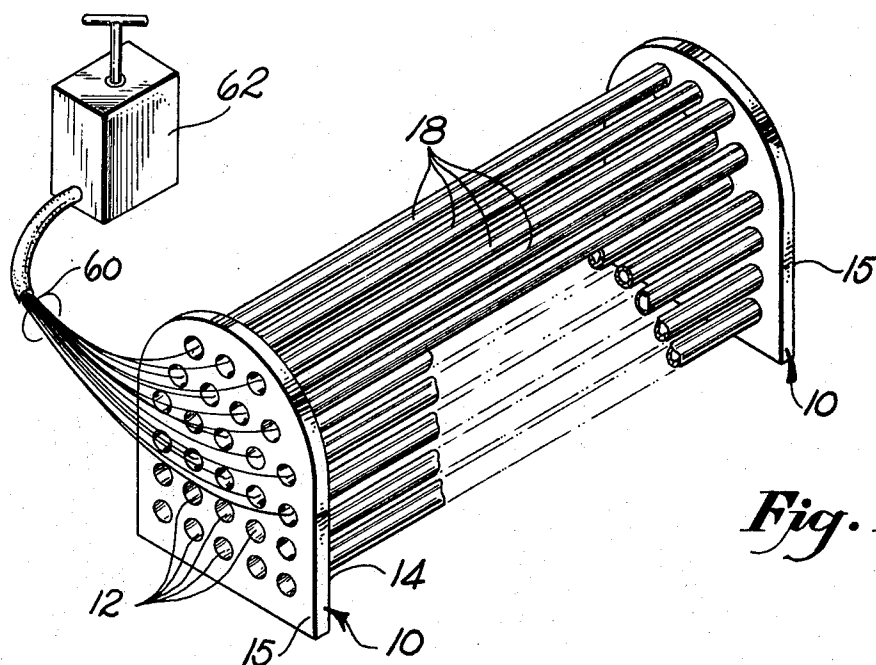


Fig. 1.

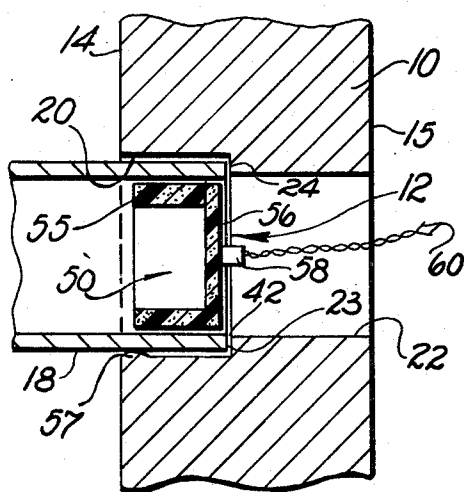


Fig. 2.

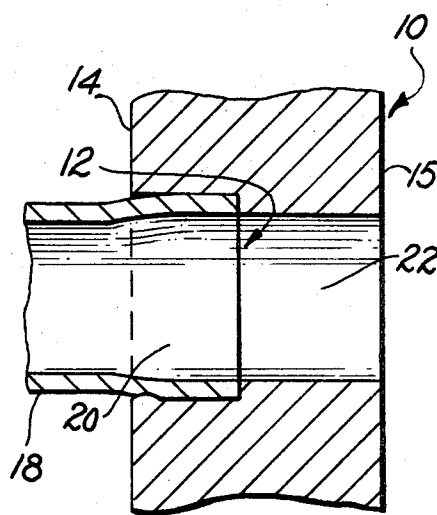


Fig. 3.

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METHOD OF FABRICATING A TUBE SHEET ASSEMBLY

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to an improved method of forming tube sheet assemblies, and more particularly, to such a method employing explosive welding techniques for joining the tube ends to the tube sheets.

2. Description of the Prior Art

Many types of conventional heat exchangers, such as boilers, condensers, coolers and the like, employ tube sheet assemblies to transfer heat between two fluids flowing on opposite sides of the tube walls. While one fluid flows through the interior of the tubes, the other fluid at a different temperature flows through the heat exchange space past the exterior of the tubes bounded by the inner tube sheet surfaces. Heat is transferred due to the temperature difference through the tube walls formed of a suitable metal having good heat conductivity. For any given set of heat transfer parameters, including temperature difference between the fluids, conductivity of the tube material, tube dimensions, and fluid flow rates, the overall heat exchange efficiency improves with the number of tubes employed to carry one of the fluids. Obviously, the larger the number of such tubes, the greater is the flow capacity and the greater the area of the heat exchanging surfaces between the fluids, thus providing a higher rate of heat transfer.

In many heat exchangers, the tubes are affixed to extend inwardly across a heat exchange space defined between two opposing tube sheets, to which they are attached at their opposite ends. In such assemblies, orifices formed in both tube sheets at the tube ends provide direct flow communication between the tube interiors and the headers or fluid filled enclosures covering the outer tube sheet surfaces, and the tube ends must be welded or otherwise sealed to the tube sheets at each orifices to provide a fluid tight flow path between tube sheets. In other types of heat exchangers, U-shaped tubes have their ends inserted in orifices formed in separate inlet and outlet manifold areas defined adjacent the outer tube sheet surface.

Conventional techniques used heretofore for sealing numerous tubes to their tube sheets have been difficult and time consuming. Any flow path discontinuities at the tube ends, particularly the inlet, can result in undesirable turbulence and non-laminar flow to erode tube walls and surrounding surfaces and reduce the flow rate and overall heat exchange efficiency. Previously the tubes have been attached to the sheets by either of the two basic methods. In one the diameter of the tube sheet orifices are slightly greater than the outer diameter of the tube ends which are inserted into the orifices from the inner tube sheet surface. With the annular surfaces of the tube ends held flush with the outer surface of the tube sheet, each tube must then be individually welded around its entire perimeter to effect the required fluid tight seal with the tube sheets. The usual method of welding the tube ends to outer tube sheet surface causes flow path discontinuities at the tube ends due to the irregular weld surfaces, resulting in erosion of the tube walls and the weld. A fillet weld applied around the inwardly projecting tubes on the inner tube sheet surface avoids the irregular weld contours in the flow path at the tube entrances, and if the tube ends are carefully machined, cut to exact size and carefully positioned in the tube sheet, a smooth flat surface surrounding the tube entrances can be provided. However, in tube sheet assemblies having numerous closely spaced tubes it may be impossible or extremely difficult to weld the interior tubes on the inner tube sheet surface by reaching between surrounding tube already installed, particularly since tubes cannot be inserted one at a time for welding in opposing tube sheets. Accordingly, the weld must usually be applied to the tube ends at the outer tube sheet surfaces where the irregularity of the weld causes turbulence that gradually erodes both it and the tubes.

An alternative technique sometimes used involves providing tube sheets having orifices with the same diameter as the tube interior. The tube ends must then be exactly positioned in registration with the orifice against the inner surface of the tube sheet while the weld is applied around it. Although this allows each tube to be separately positioned and welded to opposing tube sheets at the same time, thus avoiding the difficulty of reaching interior tubes when they are already surrounded by others, a much weaker structure results because the individual tubes are supported solely by the weld at the tube sheet surface and not at all by the surrounding tube sheet. The entire strength of the structure depends on the inherently weak fillet welds joining the tube ends to the sheet.

SUMMARY OF THE INVENTION

Orifices formed through the tube sheets have an enlarged counterbore inner portion with a diameter slightly larger than the outer diameter of the tube end to be placed therein and a smaller outer bore portion with a reduced diameter corresponding to the inner diameter of the tube. The opposite ends of each tube are inserted into the counterbore portion of the respective orifices, and a suitable explosive welding charge is inserted from the outer surface through the tube sheet into the end of each tube. The charges inserted may be detonated substantially simultaneously to form a metallurgical bond between the outer tube end surfaces and the abutting tube sheet surfaces within the counterbore portions of each orifice. This assembly has increased structural strength as a result of the large weld areas with smooth flow paths at the tube entrances to prevent turbulence and non-laminar flow from eroding the interior tube walls and from reducing flow rates and heat exchange efficiency.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of a simple tube sheet assembly for a heat exchanger such as may be constructed in accordance with the invention;

FIG. 2 is a cross-sectional view illustrating a portion of a tube sheet with a tube end inserted and the explosive welding charge positioned prior to detonation in accordance with the invention; and

FIG. 3 is a view of a completed assembly portion of FIG. 2.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to FIG. 1, which illustrates a simple tube sheet assembly such as might be employed in a typical liquid heat exchanger, a pair of flat tube sheets 10 are positioned in opposing spaced apart parallel relationship. Both tube sheets 10 have identical mirror image patterns of orifices 12 extending through the thickness of each tube sheet between an inner surface 14 and an outer surface 15. The space between the inner tube sheet surfaces 14 in the complete heat exchange assembly constitutes a heat exchange enclosure to be filled with one of the fluids. The outer surfaces 15 of the tube sheets 10 each define one wall for the fluid filled enclosures, sometimes referred to as headers in certain heat exchange applications, that conduct the other fluid into and out of a number of heat exchanger tubes 18 that extend through the heat exchange enclosure. As is well known, for certain multiple pass heat exchangers, the header or outer enclosures would be partitioned into separate spaces each surrounding a different group of holes 12 arranged together on the tube sheet.

As shown in FIG. 2, each of the holes or orifices 12 are drilled or otherwise formed with an enlarged counterbore portion extending partially through the thickness of the tube sheet 10 from its inner surface 14 so that the enlarged bore diameter is capable of slidably receiving the end of one of the tubes 18. Heat is exchanged between the one fluid filling the heat exchange enclosure and the other fluid flowing in the pipes 18 by conduction through the metal tube walls. A smaller bore portion 22 of the orifice 12 extends through the remaining thickness of the tube sheet 10 to the outer tube sheet surface 15.

The enlarged counterbore section 20 of the holes 12 preferably has a diameter slightly larger than the outer diameter of the end of the tube 18 which is slidably received therein, and it extends approximately halfway through the thickness of the tube sheet 10 to form an annular shoulder 24 intermediate the inner and outer tube sheet surfaces 14 and 15. The smaller bore section 22 should have a diameter approximately equal to or slightly smaller than the inner diameter of the tube 18. As shown in FIG. 2, the end of each tube 18 is inserted into the counterbore section 20 of its respective hole 12 at the inner tube sheet surface 15 until its annular end surface abuts against the annular shoulder 24.

In fabricating this type of tube sheet assembly, as shown in FIG. 1, the metal tubes 18 may be cut to standard length from an available longer pipe stock. Since the tube ends in the finished assembly will be shielded from the flow stream by the shoulder 24, as shown in FIG. 3, the cut end surfaces need not be machined to a smooth surface. The orifices 12 may be drilled or otherwise formed in the tube sheet 10. One end of each tube 18 is inserted into a corresponding orifice 12 in a first one of the tube sheets 10 from its inner surface 15. With all of the tubes 18 inserted to extend outward from the first tube sheet 10, the other tube sheet 10 may then be positioned with its orifices 12 in registration with the opposite free end of each tube. With the free ends of all tubes 18 axially aligned with their respective orifices 12 at the inner surface 15, the other tube sheet 10 can be pushed inwardly to slidably engage the free ends of the tubes 18 for insertion into the respective counterbore sections 20. Alternatively the tube ends may already be welded in place in the first tube sheet before inserting the free ends into the other. However, with the tube ends inserted into both tube sheets 10, the tube sheets may be clamped or otherwise held in position against the opposite ends of the tube 18. With a single tube sheet assembly employing U-shaped tubes, the opposite tube ends are merely inserted into the appropriate orifices on the inlet and outlet portions.

As shown in FIG. 2, with the tube ends in place, an explosive welding charge 50 is inserted from the outer tube sheet surface 14 through the smaller bore portion 22 of the respective orifice 12 into the end of each tube 18. In this case, the welding charge 50 has an annular shaped main charge 55 that fits into the tube end with a disc shaped detonating charge 56 bonded at one end to cover the cylindrical opening through the main charge 55. An electrically actuated detonator cap 58 is affixed to the center of the disc shaped detonator charge 56 with lead wires 60 connected to carry on electrical current pulse from an appropriate power source 62. High speed burning explosive, such as "Primacord," can be used to interconnect adjacent charges to avoid the expense of numerous detonator caps 58.

The type of explosive employed to perform the welding operation and the dimensions of the main charge 55 depend primarily on the type of metals employed in the tube 18 and tube sheets 10, the thickness and diameter of the two walls, and the depth of the enlarged counter bore portion 20 as well as the ratio which exists between the inner diameter and the tube wall thickness. For any particular tube assembly operation, suitable explosive welding charge configurations may be selected in accordance with the conventional explosive welding techniques used in joining a cylinder within a cylinder, and the most effective configuration can be ascertained from individual experimental trials. The annular shaped main charge 55 might be a hollow cylinder of pressed or cast explosive, or a thin walled plastic cylinder containing a powdered explosive. Preferably, as shown in FIG. 2, the longitudinal dimension of explosive welding charge 50 generally should be less than the depth of the enlarged counterbore 20 so that the charge 50 can be placed within the end of the tube 18 with the inner end of the annular main charge 55 slightly recessed within the tube sheet 10 from the inner surface 15. This prevents the full explosive force from being applied to the tube walls outside of and thus not supported by the surrounding tube sheet 10, which might otherwise be puffed outward and possibly even

ruptured. When an actuating current pulse from the source 62 is applied to the detonator cap 58, or the detonation shock from the "Primacord", the disc initiation charge 56 burns rapidly outward from its center at a substantially uniform rate in all directions to ignite the bonded outer end surface of the annular main charge 55 about its entire circumference at approximately the same time. The main charge 55 then burns longitudinally propagating a shock wave along the tube inwardly from its end. This shock wave forces the surrounding tube walls radially outward against the inner surface of the enlarged counter bore portion of the tube sheet orifice 12 with the shock generated jet from the outer surface of the tube effecting the metallurgical bonding between the abutting metal surfaces of the outer tube wall and inner wall of tube sheet hole. To achieve the jetting effect, the outer tube walls should be spaced from the inner bore surfaces, as by use of a separator tape around the tube end or, as illustrated, a spacer ridge 57 within the bore.

In a tube sheet assembly, such as shown in FIG. 1, containing a number of closely spaced tubes, the explosive welding charge 50 for all or a substantial number of the tubes can be inserted to be detonated simultaneously welding all of the tube ends to the tube sheet 10 in a single operation, as compared with the time consuming and tedious individual welding of each tube required heretofore. Shock waves radiated outward from surrounding tube positions would be transmitted through the tube sheet 10 forcing the surrounding orifice walls inward against the respective ends to further assist the welding operation. However, in larger tube sheet assemblies containing great numbers of tubes, the number of tubes welded in a single simultaneous operation may have to be limited if the total blast force from the tube sheet might cause damage or injury in the vicinity, particularly when such welding operations are to be conducted indoors.

As shown in FIG. 3, at the detonation of the explosive welding charge 50, the tube walls within the tube sheet orifice 12 are forced outwardly against the inner walls of the enlarged counter bore section 20 filling the previously surrounding spaces. The cut end surfaces 24 of the tubes 18 are expanded outwardly to be shielded by the shoulder 42. This removes any rough tube end surfaces from the flow path between the tube sheet 10 and tube 18 to keep it virtually free of discontinuities that might otherwise cause turbulence and non-laminar flow at the tube entrances to erode the interior tube surfaces.

Moreover, as compared with the prior use of single fillet welds between each tube and the inner surface of the tube sheet, the weld provided by the method of this invention is much stronger since a greater weld area between the tube sheet and the tube end exists and thus provides an overall improvement in the structural strength of the tube sheet assembly. Also, the tedious task of individually welding each tube into the tube sheet is avoided, and numerous tubes can be welded in a closely spaced pattern without irregular contours in the flow path or having to manipulate welding equipment to reach points on the inner surface surrounding interior tubes. Of course, the advantages of the invention are equally applicable with minor modification to diverse types of tube sheet assemblies and the like which, for example, might include the welding of boiler tubes into the cylindrical surface of a header, instead of a flat tube sheet as shown in FIG. 1.

In one particular tube sheet assembly constructed in accordance with the invention for use in a high pressure boiler preheater, a carbon steel tube sheet had about 2,000 orifices drilled through an approximately 5-inch sheet thickness. The enlarged counterbore portion had a diameter of 0.630 inch to a depth of approximately 1 inch. U-shaped steel tubes 18 each having an internal diameter of 0.445 inch and an external diameter of 0.625 inch were each cut to a length of approximately 10 ft. The explosive welding charge 50 consisted of an annular shaped main charge 55, approximately 0.750 inches long cut from a 1/8-inch thick sheet of conventional PETN impregnated flexible plastic and rolled into a cylinder. A circular ignitor disc cut from the same 1/8-inch sheet was bound by ad-

hesive to one end of the rolled cylinder with the initiating explosive cord strand in lieu of the detonator cap affixed by adhesive at its center. The explosive welding charge so formed was positioned in each tube with the inner surface of the annular main charge 55 recessed approximately 0.125 inches from the tube sheet inner surface 15. Because the work was performed in an indoor factory facility, only two hundred of the explosive charges were ignited at one time to limit the blast effect within the confined space. To avoid the need for a separate initiator cap 58 for each charge, only a single cap was used with the remainder of the 200 charges being linked to it by high speed explosive cord extending between and affixed to the center of the discs 56. Thus, the approximately two thousand tube ends could be welded to the tube sheet in several operations each involving a maximum of 200 tubes at a time. The resulting welds between each tube and the tube sheet were found to have greater strength than conventional fillet welds and provided a flow path at the tube ends having a substantially uniform surface without detectable surface discontinuities to cause turbulence or non-laminar flow.

What is claimed is:

1. A method of forming a tube sheet assembly having a plurality of tubes extending therefrom comprising:
 - forming a tube sheet with a plurality of orifices extending therethrough each having an enlarged inner counterbore portion and a smaller outer bore portion;
 - inserting one end of each of the plurality of tubes into the enlarged counterbore portion of a respective one of the orifices of the tube sheet.
 - positioning an explosive welding charge within said one end of each tube and within said counterbore portion of each said orifice; and
 - simultaneously detonating each of a plurality of said explosive welding charges to weld the outer surfaces of each tube at its end to the interior tube sheet surfaces within said counterbore portion.
2. The method of claim 1 wherein: the diameter of each

smaller outer bore portion is formed to correspond to the inner diameter of the end of the tube inserted therein, and the diameter of said enlarged counterbore portion is formed to be slightly larger than the outer diameter of the end of the tube inserted therein.

3. The method of claim 1 wherein:

the explosive welding charge comprises an annular shaped cylinder of explosive material positioned concentrically within the end of each tube to extend longitudinally wholly within the enlarged counterbore portion of the respective orifice in the surrounding tube sheet.

4. A method of forming a tube sheet assembly comprising:

forming opposing tube sheets each having inner and outer surfaces with a plurality of cylindrical orifices extending between said surfaces in each said tube sheet, each orifice having an enlarged counterbore portion extending from said inner surface and intersecting with a coaxial smaller bore portion extending from the outer surface;

inserting the ends of each of a plurality of tubes into the enlarged counterbore portion of each of the corresponding orifices in the opposing tube sheets to extend therebetween with each tube having an annular end surface abutting an annular shoulder within its orifice at the intersection of said portions;

positioning an annular shaped explosive charge coaxially within each tube end and recessed from said inner surface within the surrounding counterbore portion; and simultaneously detonating the explosive charge within each of a plurality of tube ends to form a metallurgical bond between the outer tube surfaces and the abutting tube sheet surfaces within the corresponding ones of said orifices.

5. The method of claim 1 wherein said enlarged inner counterbore extends into said tube sheet from an inner surface of said tube sheet and wherein said explosive welding charge is recessed from said inner surface.

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