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(54) HEAT EXCHANGER AND METHOD OF MANUFACTURE

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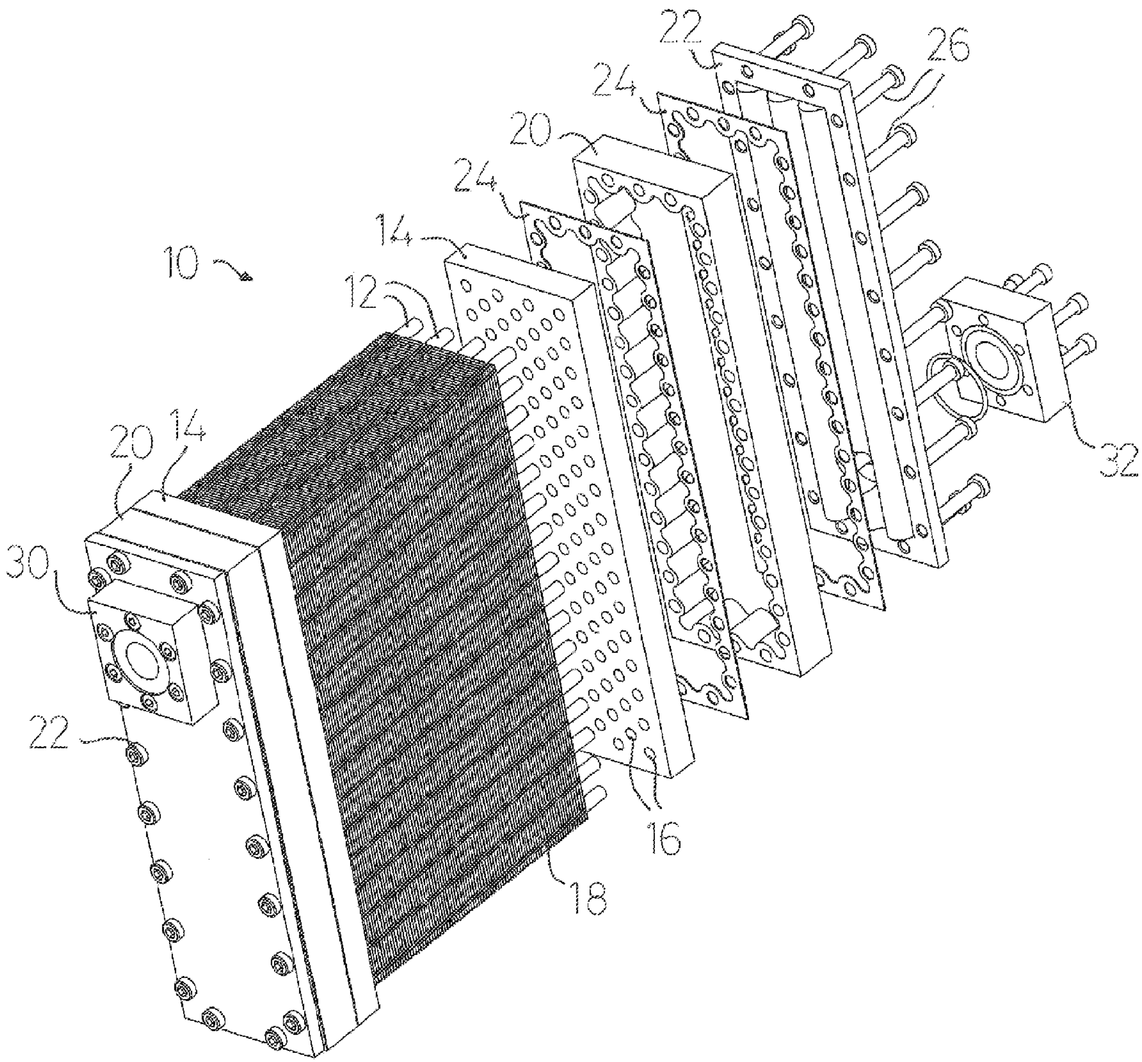
(57) ABSTRACT

This invention relates to a heat exchanger and to a method of manufacturing a heat exchanger. The heat exchanger has a number of tubes and at least one tube plate. The ends of each tube are located in a respective opening in the tube plate(s). The ends of each tube contain a respective insert, the insert acting to expand the end of the tube into sealing engagement with the tube plate.



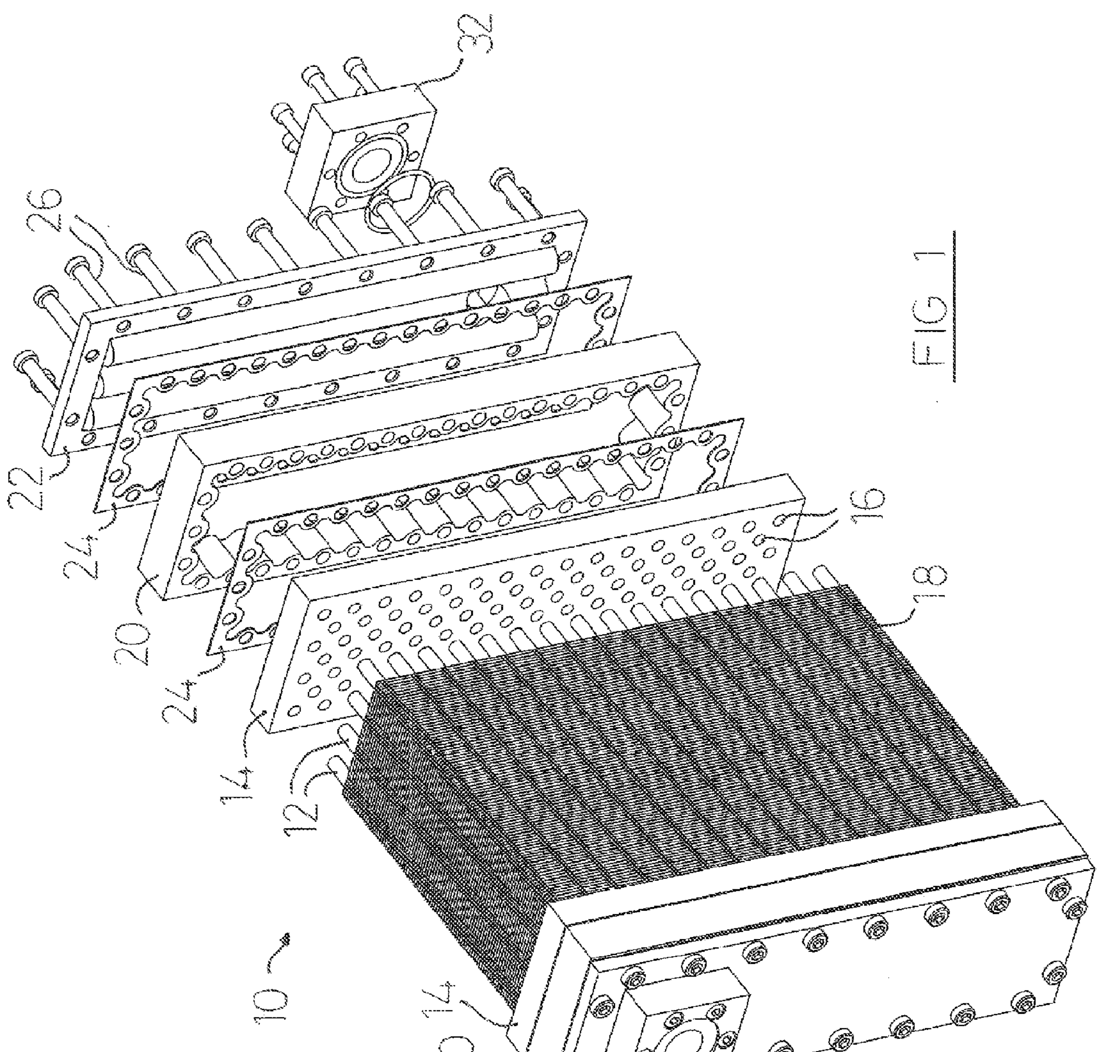


FIG 1

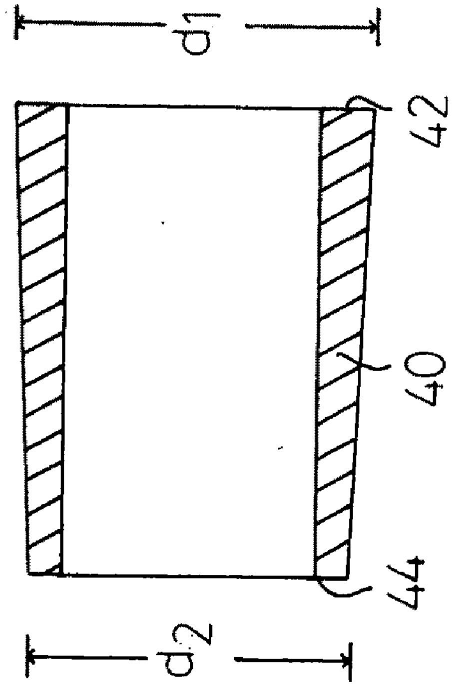


FIG 3

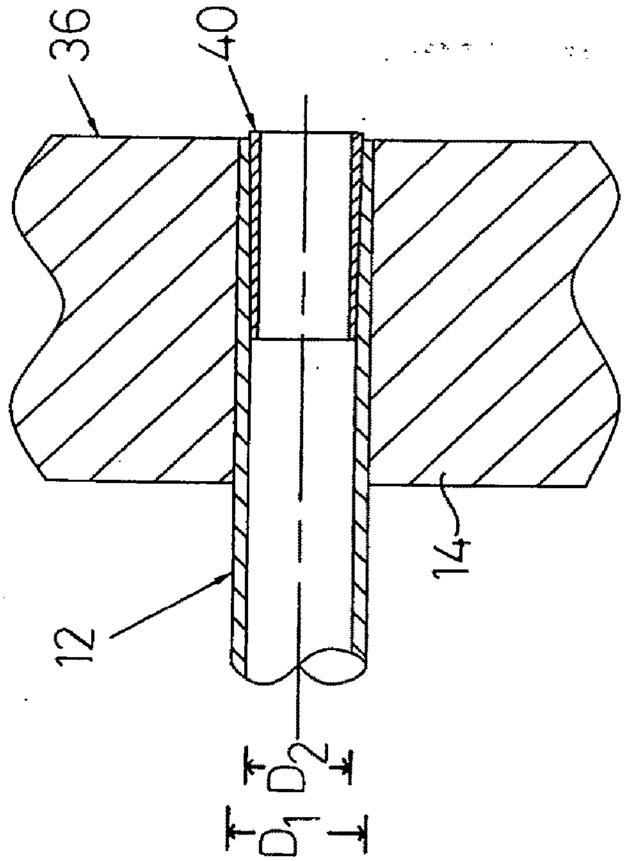


FIG 2

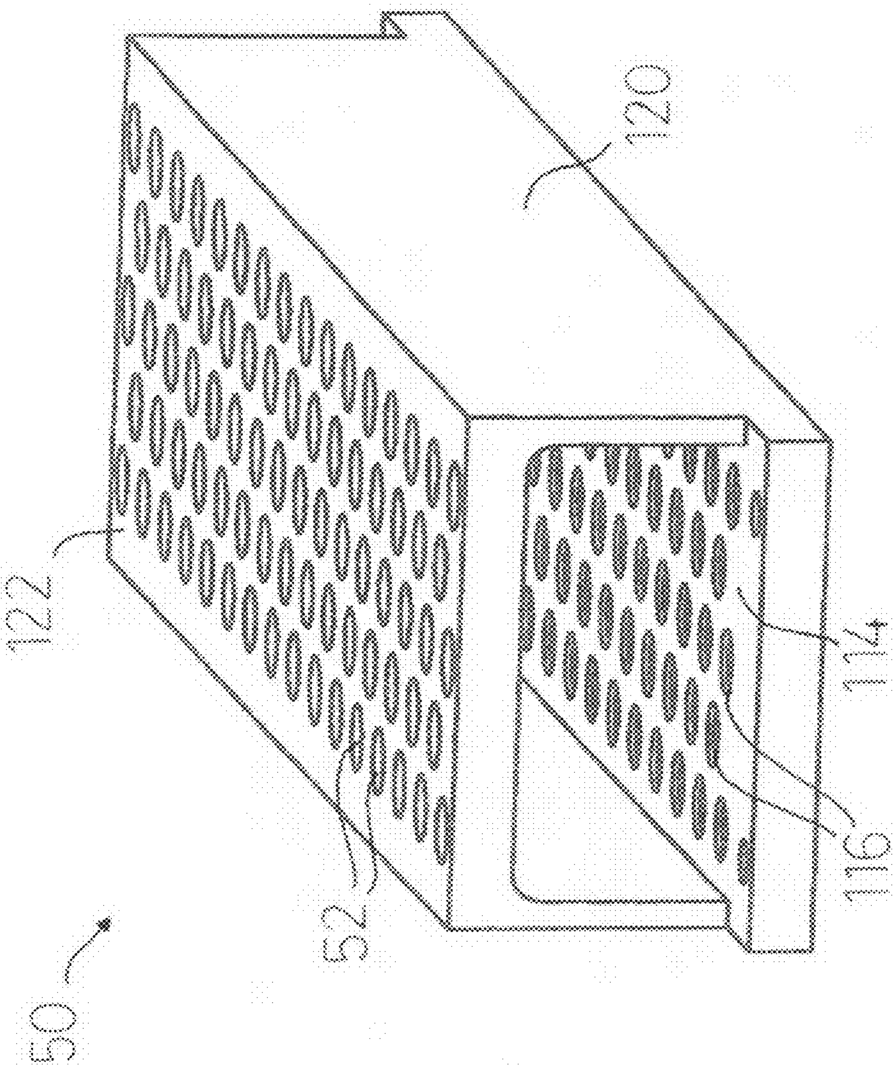


FIG. 4

HEAT EXCHANGER AND METHOD OF MANUFACTURE

FIELD OF THE INVENTION

[0001] This invention relates to a heat exchanger and to a method of manufacturing a heat exchanger.

BACKGROUND OF THE INVENTION

[0002] Often it is necessary to cool a working fluid, and it is known for this purpose to use a heat exchanger. Heat exchangers are made in many different sizes, are used with many different working fluids, and utilise many different fluids as the coolant.

[0003] Heat exchangers usually comprise a number of tubes suspended between two tube plates, though it is known to use U-shaped tubes with each tube connected at opposite ends to a single tube plate. Typically, the working fluid flows through the tubes, whilst the coolant passes around and between the tubes, the working fluid giving up latent heat (by way of the tubes) to the coolant flowing around the tubes. Each tube may carry external fins (mechanically coupled to or integral with the respective tube) to increase the available surface area for heat transfer.

[0004] The present invention is primarily directed to industrial heat exchangers such as those used on compressors for example. However, the invention also has utility for marine heat exchangers, and the oil coolers for some motor vehicles.

[0005] It is becoming increasingly desirable to reduce the weight of industrial components, and there is a general desire amongst most heat exchanger manufacturers to use less material and lighter-weight materials where these meet the performance and cost requirements of the heat exchanger. If the heat exchanger is an oil cooler for a motor vehicle for example, or the heat exchanger for the engine of a ship, reducing the weight of the heat exchanger can have a direct effect upon the efficiency of the vehicle or ship.

[0006] Many heat exchangers operate with a considerable pressure differential between the working fluid and the coolant. A heat exchanger for some compressors for example can operate at a pressure differential of 500 p.s.i. (approx. 3.4×10^6 Pa), and there is an increasing trend in the pressure differential of vehicle oil coolers, many of which now operate with pressure differentials of 200-300 p.s.i. (approx. $1.4\text{-}2.1\times10^6$ Pa). Also, many heat exchangers operate with a significant heat differential between the working fluid and the coolant. In an oil cooler for a vehicle the oil may be at 300° C. whilst the coolant (air) may be at 20° C., for example. Few heat exchangers operate continuously, and so the heat exchanger must be able to operate at the required differential pressures and temperatures, and must also be able to withstand cycles of operation and non-operation, parts of the heat exchanger being subjected to large variations of pressure and temperature during those cycles.

DESCRIPTION OF THE PRIOR ART

[0007] Heat exchangers are most often constructed from metallic materials, i.e. metallic tubes fitted to metallic tube plates. Metals are commonly used because of their good thermal transfer properties. To secure a tube to the tube plate it is known to provide an aperture in the tube plate and to weld or braze the end of the tube into the tube plate, the welded or brazed joint providing the required seal for the temperature differential and pressure differential involved. Many heat exchangers, including for example the oil coolers for motor vehicles, utilise aluminium tubes and aluminium tube plates, with the tubes being welded to the tube plates.

[0008] In an alternative known method of construction the tube is mechanically expanded by a specialised expanding machine into sealing engagement with the aperture. This arrangement is not always suited to heat exchangers which will incur a large pressure differential, however, as the seal is not as effective as a welded or brazed joint.

DISCLOSURE OF THE INVENTION

[0009] The present invention seeks to provide a heat exchanger which can be manufactured without welding, brazing or any other heating process, and can use lightweight materials to provide a weight and efficiency saving.

[0010] According to the invention, there is provided a heat exchanger comprising a number of tubes and at least one tube plate, the ends of each tube being located within respective openings in the tube plate(s), the ends of each tube containing a respective insert, the insert acting to expand the end of the tube into sealing engagement with the tube plate.

[0011] Thus, in the present invention the tubes are put into sealing engagement with the tube plate by the insert rather than by welding, brazing, or a separate expansion step. It is arranged that the tube wall is sufficiently thin, and the insert is sufficiently rigid, that the tube can be deformed outwardly by the insert.

[0012] The inventors have appreciated that there is a practical lower limit to the wall thickness of aluminium tubes which are welded or brazed to the tube plate of a heat exchanger. The heat generated by the welding or brazing process softens the aluminium of the tube and if the tube wall is too thin it will subsequently fail in use. In any event, the tubes will not be able to withstand as great a pressure differential as a similar tube which has not been subjected to the heat of welding or brazing. Accordingly, and despite the general desire to reduce the weight of the heat exchanger, manufacturers of heat exchangers where the tubes are welded or brazed to the tube plate are required to use thicker tubes than would be necessary to withstand the differential pressures involved.

[0013] With the present invention, however, no heating is applied to the tubes during the manufacturing process, and the tubes will only be required to withstand the (much lower) operating temperature of the heat exchanger. The tubes can be made of thinner (and lighter) material, and are therefore also more efficient in transferring heat from the working fluid to the coolant. Aluminium tubes having a wall thickness of as little as 0.05 mm have been found to be suitable for use with the present invention, and such tubes would fail at a very low pressure differential if subjected to the heat of welding or brazing. In addition, the invention is suitable for use with other materials such as titanium which can be used in particular applications.

[0014] Preferably the insert is metallic. The insert must be harder or more rigid that the tube material so that it is able to deform the tube into sealing contact with the tube plate, and to maintain that sealing contact at the temperature and pressure differentials incurred. Stainless steel is a suitable material for an insert for fitment into an aluminium tube, a stainless steel (e.g. "hastalloy") insert having a wall thickness of 1 mm being sufficiently rigid to be able to deform an aluminium tube having a wall thickness of 1 mm into sealing contact with a tube plate, and to maintain that sealing contact during use.

Thus, stainless steel maintains its hardness and rigidity to around 1,000° C., and can therefore be reliably used at a typical operating temperature of many heat exchangers (an oil cooler for example having an operating temperature of around 300° C.).

[0015] Desirably, the tube plate is of metal, which is a preferred material to provide the required mechanical rigidity for the heat exchanger. In heat exchangers designed to minimise weight the tube plate is ideally aluminium. If it is desired to avoid erosion or corrosion of the tube plate it can be fitted with a facade plate such as that described in GB 2 266 951. The facade plate can be chemically bonded to the tube plate, and/or it can be retained by the inserts. For use in such embodiments the inserts preferably have an enlarged end which can overlie a part of the facade plate and act to secure the facade plate to the tube plate.

[0016] The invention also provides a method of making a heat exchanger comprising the steps of:

providing at least one tube plate with a number of openings therethrough;

providing a number of tubes and locating an end of a tube into a tube plate opening;

providing a number of inserts and locating an insert into the end of a tube within a tube plate opening; and

driving the insert into the end of the tube whereby to expand the end of the tube into sealing engagement with the tube plate.

[0017] Preferably the method of making the heat exchanger includes the following additional steps:

providing a header; and

securing the header to the tube plate by releasable fastening means.

[0018] The releasable fastening means may be a number of bolts for example, and the releasable fastening enables disassembly of the heat exchanger, suitably on site, should repair or refurbishment be necessary.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] The invention will be further described, by way of example, with reference to the accompanying drawings, in which:—

[0020] FIG. **1** shows an exploded view of a heat exchanger;

[0021] FIG. **2** shows a sectional view of part of the tube plate and tube of the assembled heat exchanger;

[0022] FIG. **3** shows an enlarged view of the insert; and

[0023] FIG. **4** shows a perspective view of part of a tube plate and header used in a preferred method of manufacturing the heat exchanger.

DESCRIPTION OF EXEMPLARY EMBODIMENTS

[0024] In this description reference is made to the "diameter" of the tube, since in the preferred embodiments the tube is of circular cross-section. In other, less preferred, embodiments the tubes are a circular in cross-section, oval tubes being particularly preferred in some applications.

[0025] FIG. **1** shows a heat exchanger **10** in exploded view. All of the components which are required to make a heat exchanger according to the present invention are shown in FIG. **1** except for the inserts which are shown in FIGS. **2** and **3**.

[0026] The heat exchanger **10** comprises an array of tubes **12** which in this embodiment are linear, and have their ends mounted to respective tube plates **14**. The tube plates **14** are formed with a number of openings **16** therethrough, each opening being adapted to receive the end of a tube **12**.

[0027] In this embodiment, as is common with many heat exchangers, the tubes carry fins **18**, the fins having an array of holes therethrough, similar to the array of openings **16** in the tube plates. The fins are in thermal engagement with the tubes and can therefore enhance the heat transfer from the tubes to the coolant which in use flows between the fins.

[0028] The tube plates **14** are connected to headers which in this embodiment each comprise a header wall **20** and a header plate **22**. A sealing gasket **24** lies between the tube plate **14** and the header wall **20**, and another sealing gasket **24** lies between the header wall **20** and the header plate **22**. The header plate **22** and header wall **20** are sealingly secured to the tube plate by way of a number of bolts **26**.

[0029] In an alternative method of construction, some of the bolts **26** are replaced by studs fitted to the tube plate **14**. Thus, it is appreciated that some of bolts **26** can be removed from an assembled heat exchanger without inducing leaks between the tube plate **14** and the header wall **20**, or between the header wall **20** and the header plate **22**. However, in order to reduce the likelihood that the header wall can be distorted by the pressure differential the removed bolts can be replaced by studs projecting from the tube plate into the aligned holes within the header wall. In one practical alternative embodiment, an alternating sequence of bolts **26** and studs are located in the holes surrounding the header wall **20**. It will be appreciated that reducing the number of bolts **26** which must be fitted reduces the time taken to assemble and disassemble the heat exchanger.

[0030] The heat exchanger **10** has an inlet housing **30** and an outlet housing **32**, which can be connected to respective conduits (not shown) forming part of a circuit for the working fluid, in known fashion.

[0031] The heat exchanger **10** is designed for air cooling, so that the fins **18** are not enclosed in use. In other heat exchangers, for example those for which the coolant is sea water, the tubes (and fins if fitted) are enclosed within a jacket for the coolant.

[0032] It will be understood that the header wall and the header plate could in other embodiments be integral, and in yet other embodiments (such as that of FIG. **4**) the tube plate, header wall and header plate are integral. Nevertheless, the two-part header construction and the separate tube plate of the embodiment shown in FIG. **1** is easy and cost-effective to manufacture.

[0033] In this embodiment the tubes **12**, tube plates **14**, header wall **20**, header plate **22** and inlet and outlet connectors **30** and **32** are all made of aluminium so as to minimise weight. No welded or brazed joints are required to assemble the heat exchanger **10**, and if a particularly hard grade of aluminium is used (such as C250, for example) for the tube plate **14**, header wall **20** and header plate **22**, a heat exchanger which is capable of operating with a working fluid at up to 500 p.s.i. (3.4×10^6 Pa) can be manufactured.

[0034] FIG. **2** shows part of one of the heat exchanger tubes **12** when assembled into the tube plate **14**. The tube **12** is manufactured with an external or outer diameter slightly less than the diameter of the opening **16** of the tube plate **14**, so that the tube **12** is a close but sliding fit into the opening **16**. The difference between the diameters is so small that it is not visible in the drawing, but allows the tube **12** to be slid into position with its end substantially flush with the header face **36** of the tube plate **14**.

[0035] The insert **40** is shown in enlarged scale in FIG. **3**. The outer wall of the insert is tapered slightly (in this embodiment at an angle of approximately 1°). Also in this embodiment the insert is of stainless steel and the heat exchanger tube **12** has an external dimension D_1 of 9.5 mm and an internal dimension D_2 of 7.5 mm (i.e. the tube **12** has a wall thickness of 1 mm). The insert **40** has an outer diameter which tapers from a diameter d_1 of 8 mm at end **42** to a diameter d_2 of 7.45 mm at end **44**.

[0036] It is desired that the smaller end **44** of the insert **40** be slightly smaller than the internal diameter of the tube **12**, so that the insert can readily be located into the end of the tube **12**, and in particular can be temporarily retained in the end of the tube. A suitable driving tool (not shown) can then be aligned with the end **42** of the insert **40** and the insert can be driven into the tube **12**, for example to the position shown in FIG. **2**.

[0037] The driving tool can be used to drive an individual insert **40** into a tube **12**, so that the heat exchanger is assembled by locating an insert into each tube and driving the inserts into the tubes sequentially. Alternatively, a driving tool such as a press can be used to drive a number (and perhaps all) of the inserts **40** into their respective tubes **12** at once.

[0038] The diameter d_1 of the larger end **42** of the insert **40**, plus the wall thickness of the tube **12**, is greater than the diameter of the opening **16**. In addition, the insert **40** is harder or more rigid than the wall of the tube **12**, so that as the insert **40** is driven into the end of the tube **12**, the tube wall expands into engagement with the opening **16**.

[0039] Sufficient force can be applied by the insert **40** so as to form a seal between the tube **12** and the tube plate **14**, and in tests undertaken by the inventors an aluminium heat exchanger tube with an outer diameter of 9.5 mm and a wall thickness of 1 mm, assembled to a tube plate as above described with a stainless steel insert with an average wall thickness of 1 mm, was able to withstand a pressure differential (i.e. a pressure within the tube and header greater than the pressure around the tube) of 2,000 p.s.i. (approx. 1.4×10^7 Pa). This pressure differential is far above the pressure differentials incurred by the vast majority of heat exchangers, so that the present invention has widespread applicability.

[0040] Aluminium tubes having an outer diameter of 9.5 mm and a wall thickness of 1 mm are often used in heat exchangers in which the tubes are welded to the tube plates, and such a tube has been used in the inventors' tests to compare with those prior art heat exchangers. A pressure differential of 2,000 p.s.i. (approx. 1.4×10^7 Pa) far exceeds that which would typically be possible with a welded or brazed heat exchanger using tubes and tube plates of the same materials and of the same dimensions.

[0041] In practice, the present invention permits the use of tubes with much thinner walls, and some heat exchangers are expected to utilise tubes of aluminium for example with an outer diameter of around 10 mm and a wall thickness as small as 0.05 mm. In alternative embodiments, titanium and stainless steel tubes having a wall thickness of 0.25 mm could be used. Despite their good heat exchange properties, titanium and stainless steel tubes are not presently used in heat exchanger applications because they cannot reliably be expanded by conventional methods, nor reliably welded or brazed to a tube plate, but they are suitable for use in the present invention. As the tube diameter increases the wall thickness would typically increase, and an (aluminium) tube with an outer diameter of 25.4 mm and a wall thickness of 1 mm or perhaps 1.2 mm could for example also be utilised with the invention.

[0042] Ideally, the driving tool exerts a predetermined maximum force upon the insert, the driving force being directly related to the seal provided. Preferably, the driving tool automatically stops when a predetermined maximum driving force is reached, so that (as shown in FIG. **2**) the insert **40** will remain projecting slightly from the end of the tube **12**. It is preferred that the insert **40** project from the end of the tube **12** once the maximum driving force has been reached as that ensures that the desired seal has been created. Alternatively stated, the desired seal would not necessarily be created if the driving tool pushed the insert **40** completely into the tube **12** and engaged the tube plate **14** before reaching the maximum driving force.

[0043] It will be understood that the projecting end of the insert **40** will induce turbulence in the working fluid within the header, and with certain working fluids that might lead to an increase in the erosion of the tube plate around the opening **16**. That erosion can be countered by providing a lip or flange upon the insert **40**, the lip overlying a part of the tube plate adjacent to the opening. There is no requirement for the lip to be of the same thickness as the cylindrical wall of the insert, and it may be desirable for the lip to be thicker (or thinner) than the wall in certain applications. In applications where it is desired to minimise the distance by which the lip projects from the tube plate (or façade plate if fitted) the tube plate (or façade plate) can be recessed to accommodate part or all of the lip.

[0044] In common with prior art heat exchangers, the openings **16** in the tube plate **14** are reamed to a very accurate diameter, and in particular a diameter only a fraction of a millimetre larger than the external diameter D_1 of the tube **12**. Accordingly, the insert **40** can be provided with the very shallow taper referred to. The openings **16** do not require any grooves to be provided, as are required with some prior art heat exchanger manufacturing methods.

[0045] Also, the small difference in diameter between the opening **16** and the tube **12** results in a relatively small expansion of the tube, and a consequently small reduction in wall thickness of the tube as the tube is expanded. A reduction in the wall thickness of 8% is generally acceptable in heat exchangers in which the end of the tube is expanded into contact with the tube plate by an expander tool, and the present invention can provide the desired seal with a reduction of wall thickness of around 5%.

[0046] FIG. **4** shows a part of a combined tube plate and header **50** (i.e. with the end parts of the header wall not present). The combined tube plate and header **50** comprises a tube plate **114**, a header wall **120** and a header plate **122**. The combined tube plate and header **50** is suitably made as an extrusion, with the remaining end parts of the header wall welded or otherwise secured as a subsequent manufacturing step.

[0047] The tube plate **114** includes openings **116** which in this embodiment have a counterbore to receive the lip or flange of the tube insert (not shown). The header plate **122** in this embodiment is also apertured, with a number of openings **52** aligned with the respective openings **116**. The openings **52** are provided to permit the insertion of a tube insert (such as **40**), i.e. after the tubes have been fitted to the tube plate opening **116** an insert is passed through the aligned opening **52** and into the end of the tube. A suitably tool is also passed through the aligned opening **52** so as to drive the insert into the tube and expand the tube into sealing engagement with the tube plate **114**.

[0048] The openings **52** can be threaded, or fitted with a bush, whereby a sealing plug can be fitted to each opening **52** as a final manufacturing step in order to close the header. If a sealing plug is screwed into the opening **52** it may be unscrewed therefrom at a later time as and when it is required to disassemble part or all of the heat exchanger.

[0049] Notwithstanding the tapering of the outer diameter of the insert **40** shown in FIG. **3**, the internal or inner diameter may be substantially uniform, or also tapered, as desired. An insert **40** with an internal diameter of uniform dimension would provide a minimum restriction to fluid flow along the tube, but may be more expensive to manufacture.

[0050] Whilst the wall thickness of the insert **40** could taper to zero at its end **44**, that is not preferred, nor therefore represented in the drawings. Reducing the wall thickness at the end **44** would reduce the turbulence created as the working fluid passes along the tube, but turbulence is not always disadvantageous as it increases heat transfer. Turbulence can be damaging to the tube in terms of erosion, however, and the heat exchanger must be made of materials able to provide a desired length of service without failure due to leaks caused by erosion within the tube.

[0051] In addition, it is not uncommon to fit a turbulator into the tube **12** so as to increase turbulence within the working fluid. It is an advantage of the insert **40** than the inner diameter of the end **44** can be less than the dimension of the turbulator, so that the step or ledge created within the tube **12** by the end **44** prevents the turbulator passing out of the tube **12**. This avoids the widely recognised concern amongst users of heat exchangers incorporating turbulators that the turbulators may be forced out of the tube by the passage of working fluid, and might damage or adversely affect components of the working fluid circuit.

[0052] Also, if turbulence within the end of the tubes **12** is a concern in a particular application, the insert **40** can be increased in length, perhaps to cover more of the tube **12** where this lies within the tube plate **14**, or even to extend beyond the tube plate.

[0053] The step or ledge at the end **44** of the insert **40** has another advantage, in that a suitable tool can be passed through the insert to engage the step and permit the insert to be forced out of the tube **12**. Thus, it might be desired to remove or replace a tube **12**, perhaps because it has become damaged in use. Since there is no permanent connection between the tube **12** and the tube plate **14**, once the insert **40** is removed the resilience of the tube **12** will cause it to contract away from the tube plate **14**, enabling the tube **12** to be removed with little force. A suitable tool is a "butterfly" removal tool, similar to the tool provided for the removal of bearings.

[0054] The heat exchanger **10** of the invention is therefore particularly suitable for use in remote applications where it is desirable to quickly repair a heat exchanger, perhaps by replacing one or more damaged tubes, on site. Applications such as offshore wind farms would especially benefit from this advantage of the present invention. Thus, it will be understood that the tubes of the heat exchanger **10** are fully demountable, and in fact the heat exchanger **10** can be fully disassembled, on site if required.

[0055] Whilst the use of aluminium tubes, aluminium tube plates and stainless steel inserts has been described, the invention is not limited to these materials. Other materials which are used for heat exchangers, including for example copper, titanium, tantalum, and the many different alloys which are available, can be used for the tubes, tube plates and/or the inserts, provided that the insert material is harder than the tube material. Care must be taken, however, to use materials or combinations of materials which do not encourage galvanic or electrolytic corrosion. Also, whilst a stainless steel insert having an average wall thickness of 1 mm has been described, inserts having thinner walls could be used, and inserts having an average wall thickness of 0.5 mm can be suitable in some applications (a thinner-walled insert generally being suitable for use with thinner-walled tubes).

1. A heat exchanger comprising a number of tubes and at least one tube plate, the ends of each tube being located within a respective opening in the tube plate(s), the ends of each tube containing a respective insert, the insert acting to expand the end of the tube into sealing engagement with the tube plate.

2. A heat exchanger according to claim **1** in which the insert is metallic.

3. A heat exchanger according to claim **2** in which the insert is of stainless steel.

4. A heat exchanger according to claim **1** in which the external wall of the insert is tapered.

5. A heat exchanger according to claim **4** in which the taper angle is 1°.

6. A heat exchanger according to claim **1** in which insert has a wall thickness in the range 0.5 mm-1 mm.

7. A heat exchanger according to claim **1** in which the tube plate is of metal.

8. A heat exchanger according to claim **7** in which the tube plate is of aluminium.

9. A heat exchanger according to claim **1** in which the tubes are of metal.

10. A heat exchanger according to claim **9**, in which the tubes are made from a material selected from the group comprising: aluminium, copper, titanium, tantalum, and alloys containing these materials.

11. A heat exchanger according to claim **9** in which the wall thickness of the tubes is in the range 0.05 mm-1.2 mm.

12. A heat exchanger according to claim **1** in which the free end of the insert has a peripheral lip.

13. A heat exchanger according to claim **12** in which the peripheral lip of each of the inserts is located in a respective recess in the tube plate.

14. A method of making a heat exchanger comprising the steps of:

providing at least one tube plate with a number of openings therethrough;

providing a number of tubes and locating an end of each tube into a respective tube plate opening;

providing a number of inserts and locating an insert into the end of a respective tube within a tube plate opening; and

driving the insert into the end of the tube whereby to expand the end of the tube into sealing engagement with the tube plate.

15. A method according to claim **14** which includes the following additional steps:

providing a header; and

securing the header to the tube plate by releasable fastening means.

16. A method according to claim **15** which includes the following additional steps:

mounting a number of locating studs upon the tube plate; and

providing a number of apertures in the header, each of the apertures being adapted to receive one of a stud and a releasable fastening means.

17. A method according to claim **15** which includes the following additional steps:

providing a number of access openings in the header;

passing an insert through each of the access openings whereby the insert is located into the end of a respective tube by way of the access opening;

passing a driving tool through each of the access openings whereby the insert is driven into the end of the tube by the driving tool; and

sealing the access holes.

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