Plate-type cross-flow heat exchanger.

A plate-type cross-flow heat exchanger having a core (20) which is constituted by a stack of flat metal plates (23 and 24) which are diffusion bonded in face-to-face contact. Some of the plates (23) are formed with a first group of channels (25) which extend between a first pair of opposed edges (26A and 26B) of the plates, and others of the plates (24) are formed with a second group of orthogonally disposed channels (27) which extend between a second pair of opposed edges (28A and 28B) of the plates. First and second headers (35 and 36) are bonded to opposite edges of the core and are in fluid passage communication with the first group of channels (25), and conduits (37) are provided for directing a first fluid to and from the first group of channels (25) by way of the first and second headers (35 and 36). A vessel (51 or 54 or 55) contains the core (20) and the headers (35, 36), with the interior of the vessel being in fluid passage communication with the second group of channels (27) in the core. A conduit (39 or 52) is provided for admitting a second fluid to the second group of channels in the core and to the interior of the vessel (51 or 54 or 55) whereby, in passing through the vessel, the second fluid contacts the exterior surface of the first and second headers (35 and 36) within the vessel. A further conduit (53 or 57) is provided for conveying the second fluid from the interior of the vessel (51 or 54 or 55) after it has contacted the headers (35 and 36).
PLATE-TYPE CROSS-FLOW HEAT EXCHANGER

This invention relates to a plate-type heat exchanger and, in particular, to a heat exchanger which is configured to provide for cross-flow thermal contact between fluids which pass through the heat exchanger.

Although the heat exchanger does have broader application, it has been developed particularly for use in refrigeration and air conditioning applications where a need exists for a unit which is very compact, which can be produced economically and which will meet seemingly incompatible working requirements. Thus, the heat exchanger has been developed such that it will accommodate various types of working fluids (including gases, liquids, two-phase fluids, refrigerants, oil, water and glycol) such that it may be manufactured in a range of capacities (from a few kilowatts to hundreds of kilowatts) and such that it can accommodate various temperature conditions, including conditions under which thermally contacting fluids are at widely different temperatures.

A heat exchanger which provides for cross-flow thermal contact between fluids and which has some relevance in the context of the present invention is disclosed in the publication Chemical Engineering.
December 1974, pages 80-83, in an article entitled "Graphite Heat Exchangers". This article describes a rectangular block-type cross-flow heat exchanger which is constructed from graphite plates and which incorporates two groups of orthogonally disposed parallel holes. The graphite plates are bonded together with a thermosetting resin and the composite block is permanently compressed between cast iron clamping plates. Headers are bolted to four faces of the block for carrying fluids to and from the respective groups of holes in the blocks and, whilst resident in the holes, the fluids exchange heat through the surrounding portions of the graphite blocks.

United States Patent No. 1,662,870 also discloses a cross-flow heat exchanger which is constructed from a stack of orthogonally grooved plates. The plates are bolted together to form a core and, as in the case of the graphite heat exchanger, fluid is delivered to and taken from the respective grooves by headers which are bolted to four faces of the core.

The two above mentioned prior art heat exchangers are constructed in a way which does not lend to compactness and, whilst this aspect of the heat exchangers might be improved by adopting modern fabrication techniques, it is important to note that in neither case is any thermal contact established between the fluid streams other than when the streams are resident within the cores of the heat exchangers. This may be contrasted with the present invention which, as hereinafter described, is directed to a heat exchanger in which one fluid stream is thermally contacted with the other through walls of headers in order to reduce thermally induced stresses which otherwise would occur in the region of the interface between the headers and the core.

When headers or manifolds (referred to herein only as "headers" for convenience of reference) are attached
to a heat exchanger core, if no measures are taken to avoid the problem the headers will tend to attain the temperature of the fluid passing therethrough, whereas the core temperature will lie somewhere between the inlet temperatures of the fluids. Therefore, if the core-header attachment is solid (e.g., effected by welding, brazing or soldering), severe stresses will be induced in the vicinity of the core-header attachment region because of differential expansion between the header and the core. This may lead to fatigue failure of the assembly following a number of operating cycles when ductile materials are employed or to immediate failure if brittle materials are employed.

The problem will be especially severe in cases where the inlet temperature of one of the fluids is remote from that of the core and if the header must have heavy walls to withstand a relatively high fluid pressure. This situation may arise when one of the fluid streams has a much lower heat capacity than the other stream, and so is subjected to a large temperature change in passing through the heat exchanger, and/or has a much lower heat transfer coefficient within the core than the other stream, perhaps because it has a low thermal conductivity.

Both of these factors apply in the case of an oil cooler for a refrigeration screw compressor, for example, where oil is cooled from about 90°C to 40°C by water which increases in temperature from about 30°C to 35°C. The heat transfer coefficient for water within the core is almost a factor of ten times higher than that for oil, because the thermal conductivity of water is much higher and heat transfer is further enhanced by turbulence. The core temperature, therefore, is probably less than 40°C everywhere and, during start-up and shut-down, the header conveying the oil to the inlet side of the core undergoes a 50°C temperature change relative to the
core. This can lead to exceptionally severe stresses in the core-header attachment region.

The present invention seeks to avoid the above problems by providing a heat exchanger which comprises a core which is constituted by a stack of flat metal plates which are diffusion bonded together in face-to-face contact. At least some of the plates are formed with a first group of channels which extend between a first pair of opposed edges of the plates, and at least some of the plates are formed with a second group of channels which are transversely disposed with respect to the first group, which extend between a second pair of opposed edges of the plates and which do not communicate with the first group of channels. The channels in each plate are formed within the thickness of the plate and have a depth falling within the range 0.2 mm to 1.5 mm. First and second headers are bonded to opposite edges of the core and are in fluid passage communication with the first group of channels, and means are provided for directing a first fluid to and from the first group of channels by way of the first and second headers. Also, the core, together with the first and second headers, is located within a vessel, and the interior of the vessel is in fluid passage communication with the second group of channels. Means are provided for admitting a second fluid to the second group of channels in the core and to the interior of the vessel, whereby the second fluid contacts the exterior surface of the first and second headers, and for conveying the second fluid from the vessel after it has contacted the headers.

Heat exchange between the first and second fluids occurs whilst the fluids are passing through the core and additionally, the first and second headers are exposed (at their inner and outer surfaces respectively) to the first and second fluids. This results in the temperature of the core and the headers
settling to a temperature between that of the two fluid 
streams, and the core and header temperatures will 
normally tend to settle closer to that of the fluid 
with the higher thermal conductivity. Because the 
temperatures of the core and headers are brought closer 
together than they would otherwise be, thermal stresses 
are minimised. The second fluid preferably is chosen 
as that having the higher thermal conductivity, in 
which case the core, headers and vessel will attain a 
similar temperature.

When the Reynolds Number is sufficiently high to 
enable inducement of turbulence in one or the other or 
both of the groups of channels, then the channels 
preferably are formed to follow a zig-zag, serpentine 
or other tortuous path which has the effect of inducing 
turbulence in a fluid stream flowing through the 
channels.

In all cases the channels connect with the edges 
of the plates and preferably are in the form of grooves 
which extend for the full length or width of the 
plates. However, the longitudinally extending channels 
do not cover the full width of the surface of the plate 
in which they are located, and the transversely 
extending channels do not cover the full length of the 
plates in which they are located.

The two groups of channels may be formed in each 
of the plates, the first group being formed in one face 
and the second group being formed in the other face of 
each plate. However, the first (longitudinally 
extending) group of channels preferably are formed in 
one set of the plates and the second (transversely 
extending) group of channels preferably are formed in 
another set of the plates, with plates of the 
respective sets being alternatingly placed in the 
stack. In either case, spacer plates may be located 
between adjacent channelled plates. The spacer plates, 
when used, preferably have a thickness in the range 0.4 
mm to 1.0 mm.
The channels in each plate preferably are formed by a chemical or electrochemical machining process. Also, the plates each preferably have a total thickness which provides a metal thickness in the order of 0.4 mm to 1.0 mm below or between the channels.

Although the first fluid stream is conveyed into and from the core by way of the first and second headers, the second fluid stream may be induced to flow through the second group of channels in the core, as a consequence or under the influence of inertia, buoyancy or gravity, simply by exposing the core to the fluid stream.

However, in a preferred form of the invention, a third header is secured to one edge of the core with which the second group of channels communicate and the second fluid stream is directed into or from the core by way of the third header. Either prior to or after passing through the core, the second fluid flows into and from the vessel and, in so doing, contacts the external surface of the first, second and third headers. Whereas the first and second headers are both contacted on their inner and outer surfaces with the first and second fluids respectively, the third header is contacted on both of its (inner and outer) surfaces with the second fluid only. This is acceptable for the following reasons:

1. Either the inner or the outer surface of the third header is contacted by the second fluid after it has passed through the core.

2. The second fluid, if it has the higher thermal conductivity, would normally be near the temperature of the core.

3. The third header would normally be of lighter construction than the first and second headers (it being exposed to a lower pressure differential) and so would be less prone to thermal stress problems than the first and second headers.
4. If any fatigue cracks should occur in the third header it would not be critical because it would not result in mixing of two fluids or loss of fluid.

The headers may be bonded to the core by welding, brazing or soldering them to the respective edges of the core.

The invention will be more fully understood from the following description of a number of exemplary arrangements which embody the invention. The description is provided with reference to the accompanying drawings wherein:

Figure 1 shows a perspective view of a core portion of a cross-flow plate-type heat exchanger.
Figure 1A shows an enlarged view of a portion of the core and, in particular, plate portions of the core.
Figure 2 shows a plan view of one type of plate which is incorporated in the core and which has longitudinally extending channels.
Figure 3 shows a plan view of a second type of plate which is incorporated in the core and which has transversely extending channels.

Figures 4A to 4D show cross-sectional elevation views of the plate which is illustrated in Figure 3 and which show alternate cross-sectional forms of the channels in the plate.

Figure 5 shows a perspective view of the heat exchanger core with headers welded to first and second (opposed) edges of the core.
Figure 6 shows a similar core structure to that shown in Figure 5 but with a further header mounted to a third edge of the core.
Figure 7 shows a plan view of a structure which is similar to that shown in Figure 6 but with the third header being constructed to provide bidirectional flow.

Figure 8 shows a perspective view of a two-component core, each component being the same as that shown in Figure 1 and the two components being spaced-apart by spacer plates.
Figure 9 shows a perspective view of an alternative form of core, such core having three separate longitudinally extending channel regions and three separate transversely extending channel regions.

Figure 9A shows on an enlarged scale a portion of the core which is shown in Figure 9, including plate portions of the core.

Figure 10 shows a core of the type which is illustrated in Figure 1 but mounted within a vessel therefor.

Figure 11 shows an alternative arrangement of a core mounted within a vessel.

Figure 12 shows a perspective view of the exterior of a complete heat exchanger which incorporates (internally) a core of the type shown in Figure 6, and

Figure 13 shows a sectional end elevation view of the heat exchanger which is illustrated in Figure 12 and as viewed in the direction of section plane 13-13 shown in Figure 12.

As shown in Figures 1 and 1A of the drawings, the heat exchanger core comprises a stack of flat stainless steel plates 20 which are bonded together in face-to-face contact between a pair of end plates 21 and 22. The plates are diffusion bonded together at their contacting surfaces and, to effect such bonding, the plates are pressed together whilst subjected to a temperature approaching the melting point of the metal whereby interfacial crystal growth is promoted. A compression of 0.5% to 5.0% is applied to the stack of plates during the bonding process in order to assure a sound bond and to compensate for any lack of plate flatness.

The stack 20 is composed of two different types of plates 23 and 24 which are alternatingly placed in the stack. Each of the plates 23 is formed with longitudinally extending grooves or channels 25 which extend between a first pair of opposite edges 26a and
26b of the plate. The other plates 24 are formed with transversely extending grooves or channels 27 which extend between a second pair of opposed edges 28a and 28b of the plate.

One plate 23 which is formed with the longitudinally extending channels 25 is illustrated in Figure 2, from which it will be seen that the channels extend right to the edges 26a and b of the plate but do not cover the full width of the plate. Thus, unchannelled borders 29 extend along both sides of the plate.

Also, one of the plates 24 which is formed with the transversely extending channels 27 is illustrated in Figure 3 and, in this case, the channels can be seen to extend across the full width of the plate between the edges 28a and b. However, the transverse channels 27 do not cover the full length of the plate and, thus, unchannelled borders 30 extend along the ends of the plate.

The channels 25 within the plate 23 follow a zig zag path and they have a depth which is less than the full thickness of the plate. The channels 27 are linear and they too have a depth which is less than the full thickness of the associated plate 24.

The channels within each of the plate forms 23 and 24 may be profiled in cross-section as simple grooves, as shown in Figure 4A, or they may have the alternative profiles which are shown by way of example in Figures 4B to 4D. Thus, each channel may be formed with a longitudinally extending cusp 31, as shown in Figure 4B, or with a succession of transversely extending webs 32, as shown in Figure 4C. Alternatively, a series of staggered posts 33 may be left within each channel to create a tortuous path for fluid passing along the channels.

Metal is removed from the plates to form the channels 25 and 27 by a chemical or electro-chemical
machining process. The unremoved metal is protected by
a mask which is printed, screen-printed or
photographically applied (using a photoresist) to the
metal prior to exposing the plate surface to the
machining medium. This process permits the economical
use of various materials in the heat exchanger core,
including steel, stainless steel, brass, copper, bronze
and aluminium provided that, as in the case of the
present invention, the plates are relatively thin and
the channels are shallow.

When used in a heat exchanger in which water is
the first fluid, which passes through the channels in
the plate of Figure 2, and oil is the second fluid,
which passes through the channels in the plate of
Figure 3, the plates 23 and 24 might typically be 450mm
long, 70mm wide and 1.0mm thick. The channels 25 and
27 have a width in the range 1.0mm to 2.0mm and a depth
in the order of 0.3mm to 0.6mm. The end plates 21 and
22 have a thickness in the order of 10.0mm.

As shown in Figure 5, first and second headers 35
and 36 are welded to opposite edges of the core and
fluid inlet/outlet conduits 37 connect with the
interior of each header. When the core is embodied in
a complete heat exchanger, fluid is admitted to the
channels 25 by way of the header 35, the fluid then
flows through the channels 25 to exchange heat with a
second fluid passing through the other group of
channels 27, and the fluid exits from the core by way
of the header 36.

The core construction which is shown in Figure 6
is similar to that of Figure 5, but a further (third)
header 38 is welded to a third edge of the core for
delivering fluid to the transversely extending channels
27. Fluid is carried into the header 38 by a conduit
39.

The core which is shown in Figure 7 of the
drawings is constructed in a manner similar to that of
Figure 6, but it provides for bi directional fluid flow through the transverse channels 27. Thus, a third header 40 (which corresponds to the header 38 in Figure 6) is welded to the third edge of the core and the header is partitioned at 41 and provided with inlet and outlet conduits 42 and 43. When the core is embodied in a complete heat exchanger, fluid is admitted to the transversely extending channels 27 by way of the conduit 42 and, after passing through the channels at one end of the core, the fluid enters a surrounding vessel (not shown). The fluid contacts the headers 35, 36 and 40 whilst resident in the vessel and the fluid then flows back through a further group of the channels 27 to exit from the conduit 43. At the same time, another heat exchange fluid is passed straight through the core by entering the header 35, passing through the longitudinally extending channels 25 and exiting from the core by way of header 36.

The multi-pass arrangement that is illustrated in Figure 7 is appliable to both fluid streams, and arrangements may be made for one or the other or both streams to make more than two passes.

The core constructions which are illustrated in Figures 5, 6 and 7 would normally be embodied in different types of heat exchangers, some of which are to be hereinafter described with reference to Figures 10 to 13 of the drawings.

Whilst the heat exchanger core can most readily be fabricated in the manner shown in Figure 1, the core may be constructed in various other ways. For example, as shown in Figure 8, two cores 45 and 46 of the type shown in Figure 1 may be connected together at their ends by bridging bars 47. Then, whilst one heat exchange fluid is passed in the longitudinal direction through both of the core elements 45 and 46, that is in the direction of arrow A shown in Figure 8, a second heat exchange fluid may be
admitted to the space between the cores and be split into two separate (oppositely flowing) streams to pass in the transverse directions through the two cores 45 and 46.

If a large capacity heat exchanger is required and the total number of stacked plates exceeds that which can be bonded in a single operation, the core construction as shown in Figures 9 and 9a may be employed. In this case, the core is fabricated from three separate stacks of plates 49 and 50, and the respective stacks are then joined together (e.g. by welding) with intervening spacer plates 60. The alternate plates 49 and 50 in each stack are formed with orthogonally disposed channels 25 and 27 as indicated in Figure 9a and as shown by the dotted outlines in Figure 9. A first heat exchange fluid is directed through the core in the direction indicated by arrows A1, A2 and A3 and a second heat exchange fluid is directed through the core in the direction indicated by arrows B1, B2 and B3.

A composite core may be constructed by combining the structures which are shown separately in Figures 8 and 9.

A core of the type shown in Figure 5 may be embodied in a complete heat exchanger as shown in Figure 10, with the transversely extending channels 27 of the core being orientated in a vertical direction. The heat exchanger of Figure 10 comprises a vessel 51, having inlet and outlet conduits 52 and 53, and the core is located wholly within the vessel.

A first heat exchange fluid is directed through the core by way of the conduits 37 and heat is exchanged (in the core) with a second fluid which is passed through the vessel itself and which, as a consequence, washes the outside of the headers 35 and 36. Thus, the headers 35 and 36 are contacted by both the first and the second heat exchange fluids.
The heat exchanger which is shown in Figure 10 is intended for use principally with a second fluid which is at saturation temperature within the vessel and which will boil as it passes upwardly through the core 20. The second fluid makes one or more passes through the core as a consequence of the buoyancy effect created by the boiling action, and the vapour-liquid density difference separates the upstream and downstream levels of the fluid. Thus, no headers are required for directing the heat exchange fluid into or from the (vertical) transversely extending channels within the core.

Figure 11 shows a heat exchanger construction which is similar to that of Figure 10, but one which for which external pressure is required to move the second fluid stream through the core. In this case, the heat exchanger includes a vessel 54 in which the core 20, together with the headers 35 and 36, forms a baffle. A first heat exchange fluid passes through the core, from right to left as shown in the drawing, entering and exiting through the headers 35 and 36. The second heat exchange fluid passes upwardly through the (vertically orientated) transverse channels 27 in the core under the influence of a pressure differential across the core.

As in the case of the embodiment shown in Figure 10 of the drawings, in the construction shown in Figure 11 the headers 35 and 36 are exposed to both the first and the second heat exchange fluids.

In the heat exchanger shown in Figures 12 and 13, the core 20 is contained within a vessel 55 which has a cylindrical wall and dished end caps 56. The core is constructed in the manner shown in Figure 6 and, thus, has oppositely disposed headers 35 and 36 for directing a first heat exchange fluid longitudinally into and from the core 20. Conduits 37 are connected with the headers 35 and 36 and extend through the end cap 36 for
conveying the first heat exchange fluid into and from the heat exchanger.

The second heat exchange fluid is directed into the core by way of the conduit 39 and the header 38. After passing in a transverse direction through the core, the second heat exchange fluid then enters the interior of the vessel 55 and is conveyed away from the vessel by way of the exit conduit 57. Having passed through the core 20 and having entered the interior of the heat exchanger vessel, the second heat exchange fluid contacts the external surfaces of each of the headers 35, 36 and 38.
THE CLAIMS

1. A heat exchanger which comprises: a core (20) which is constituted by a stack of flat metal plates (23 and 24) which are diffusion bonded together in face-to-face contact, at least some of the plates being formed with a first group of channels (25) which extend between a first pair of opposed edges (26A and 26B) of the plates, and at least some of the plates being formed with a second group of channels (27) which are transversely disposed with respect to the first group, which extend between a second pair of opposed edges (28A and 28B) of the plates and which do not communicate with the first group of channels, the channels (25 and 27) in each plate being formed within the thickness of the plate and having a depth falling within the range of 0.2 mm to 1.5 mm; first and second headers (35 and 36) bonded to opposite edges of the core (20) and in fluid passage communication with the first group of channels (25); and means (37) for directing a first fluid to and from the first group of channels (25) by way of the first and second headers (35 and 36); characterised in that a vessel (51, 54 or 55) contains the core (20) and the headers (35 and 36), with the interior of the vessel being in fluid passage communication with the second group of channels (27) in the core (20), in that means (39, 52 or 54) are provided for admitting a second fluid to the second group of channels (27) in the core (20) and to the interior of the vessel (51, 54 or 55) whereby, in passing through the vessel, the second fluid contacts the exterior surface of the first and second headers (35 and 36) within the vessel, and in that means (53 or 57) are provided for
conveying the second fluid from the interior of
the vessel (51, 54 or 55) after it has contacted
the headers (35 and 36).

2. The heat exchanger as claimed in claim 1; further
characterised in that the second group of channels
(27) communicate directly with the interior of the
vessel (51 or 54), whereby the second fluid will
pass into and through the core (20) from the
interior of the vessel (51 or 54).

3. The heat exchanger as claimed in claim 1 or claim
2; further characterised in that the core (20),
together with the first and second headers (35 and
36), forms a baffle (Fig.11) which divides the
vessel (54) into two parts.

4. The heat exchanger as claimed in claim 1; further
characterised in that a third header (38) is
bonded to one edge of the core (20) and is in
fluid passage communication with the second group
of channels (27) in the core (20), and in that a
conduit (39) is provided for directing the second
fluid into or from the vessel (55) by way of the
third header (38) and the core (20).

5. The heat exchanger as claimed in any one of the
preceding claims; further characterised in that
the core (20) is constituted by two stacks (45 and
46) of the flat metal plates, each stack
incorporating plates (23 and 24) which are formed
with the first and second groups of channels (25
and 27), and in that the two stacks (45 and 46)
are joined by spacer bars (47) to permit fluid
flow between one group of corresponding channels
in the two stacks.

6. The heat exchanger as claimed in any one of claims
1 to 5 further characterised in that the core (20)
is constituted by at least two stacks (48) of the
flat metal plates (49 and 50), each stack (48)
incorporating plates which are formed with the first and second groups of channels (25 and 27), and in that the stacks (48) are connected end-to-end such that the first and second groups of channels (25 and 27) in the respective stacks lie parallel to one another.

7. The heat exchanger as claimed in any one of the preceding claims further characterised in that the channels (27) of the second group are disposed orthogonally with respect to the channels (25) of the first group.

8. The heat exchanger as claimed in any one of the preceding claims further characterised in that the channels (25 and 27) in the first and/or second group follow a non-linear path.

9. The heat exchanger as claimed in any one of the preceding claims further characterised in that the first group of channels (25) are formed in one set of the plates (23 or 49) and the second group of channels (27) are formed in a second set of the plates (24 or 50), with the plates of the respective sets being alternately placed in the stack.
**DOCUMENTS CONSIDERED TO BE RELEVANT**

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<td>GB-A-1 484 124 (ASSOCIATED ENGINEERING LTD.) * Page 1, lines 10-27; page 2, lines 45-83; claims 1,13-17; figure 2 *</td>
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The present search report has been drawn up for all claims.

Place of search: THE HAGUE
Date of completion of the search: 04-11-1986
Examiner: HOERNELL, L.H.
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The present search report has been drawn up for all claims.

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**Examiner:** HOERNELL, L.H.