

[54] **EVAPORATOR-CONDENSER**

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[22] Filed: **Mar. 1, 1972**

[21] Appl. No.: **230,729**

[30] **Foreign Application Priority Data**

Mar. 8, 1971 Germany..... 2111026

[52] U.S. Cl. **165/167, 158/28 P, 202/187**

[51] Int. Cl. **F28f 3/08**

[58] Field of Search **165/165, 155.7; 202/185, 202/188 B, 187, 189; 159/28 P**

[56] **References Cited**

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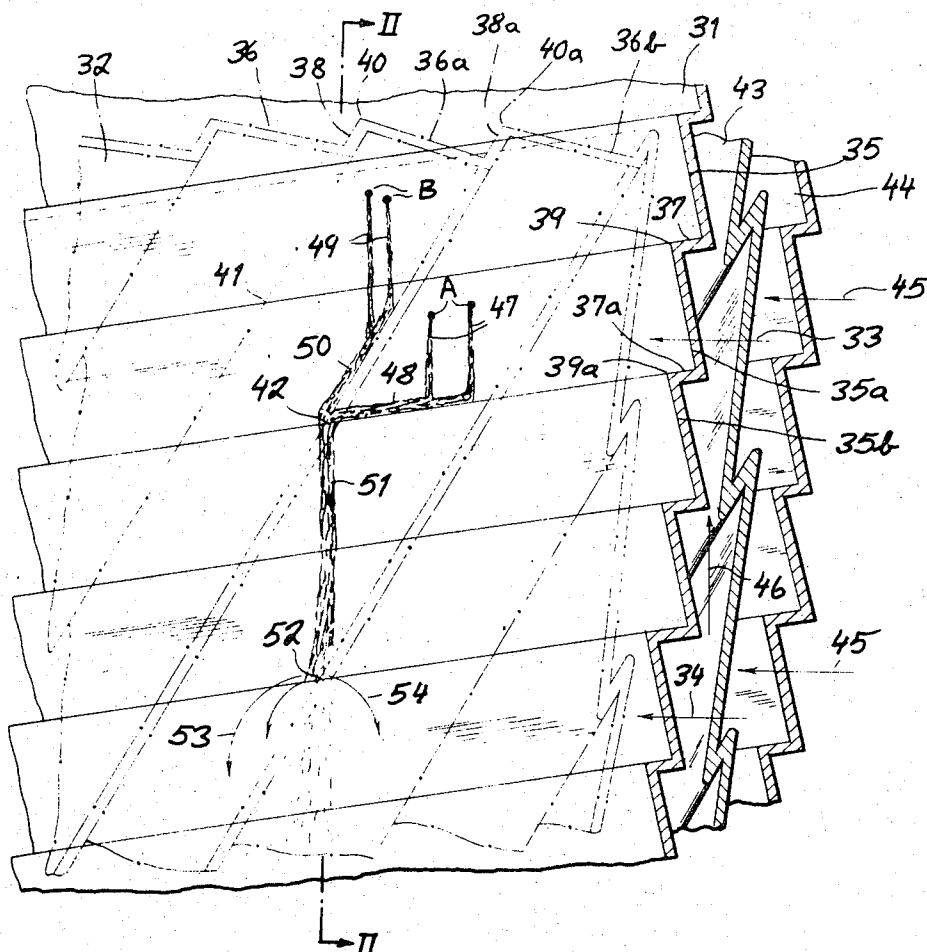
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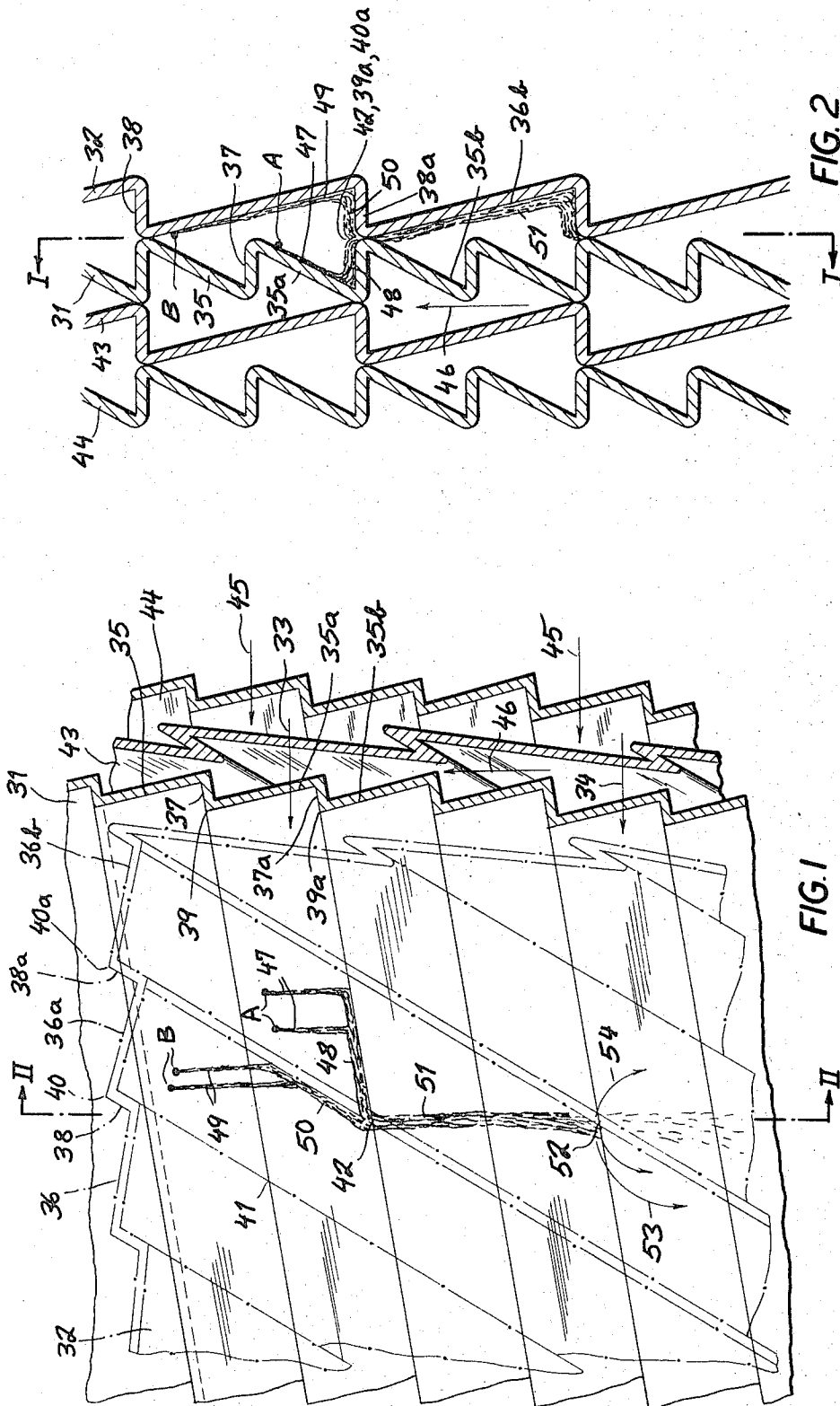
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[57] **ABSTRACT**

An evaporator-condenser for at least two fluids passed in indirect heat-exchanging relationship through respective flow passages of the heat exchanger. The latter is constituted by pairs of plates defining the flow passages. Alternating pairs of plates are sealed together at opposite sides of the rectangular array from the sides of each neighboring pair whereby each pair of plates defines one fluid passage and the next pair of plates defines the other fluid passage. The plates are of corrugated or wrinkled (profiled) configuration so that, at least in the flow path of the condensable fluid, the corrugations or undulations define flanks which are inclined to the outlet of the condensate and form chutes or ramps along which the liquid is guided.

9 Claims, 5 Drawing Figures





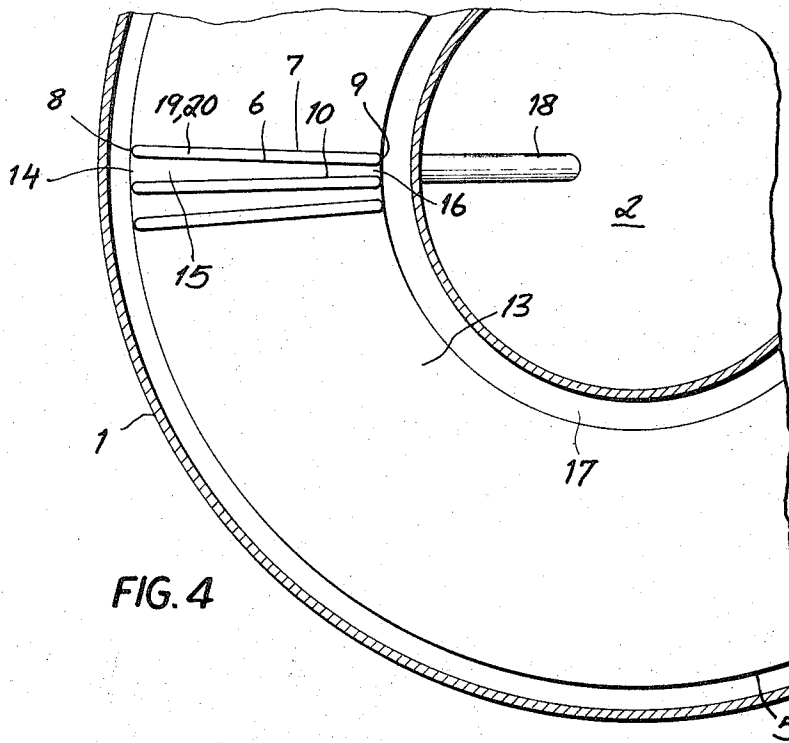


FIG. 4

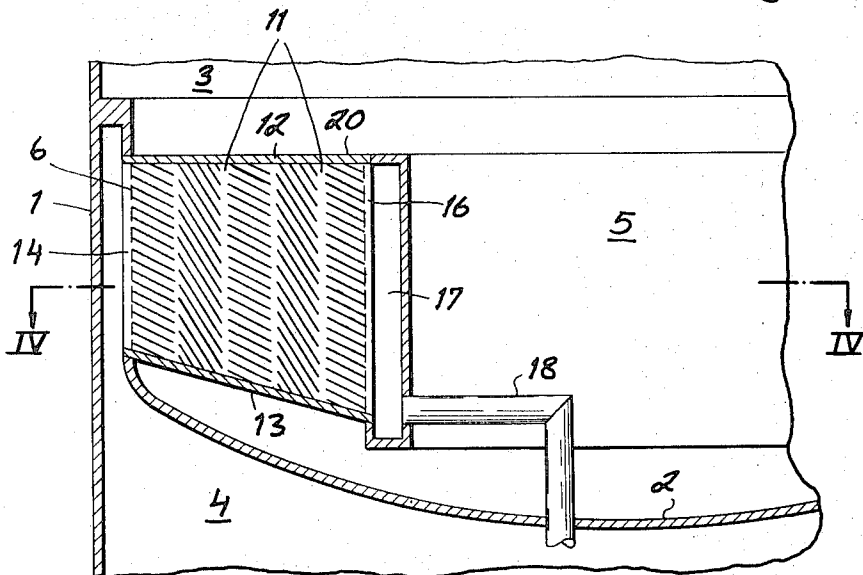


FIG. 3

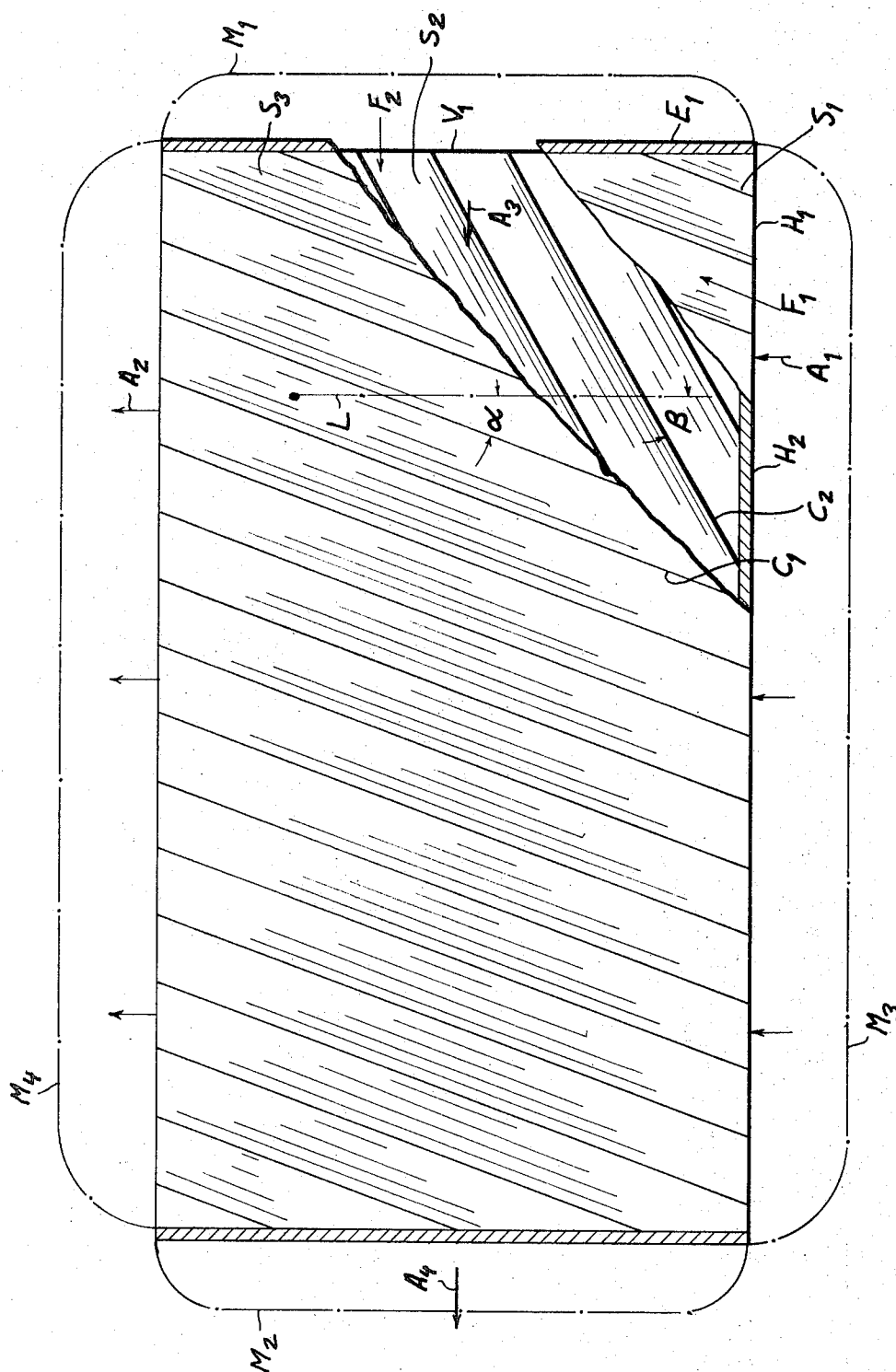


FIG. 5

EVAPORATOR-CONDENSER

FIELD OF THE INVENTION

The present invention relates to heat-exchanger systems of the plate type generally and, more particularly, to an evaporator-condenser heat exchanger as may be used in refrigerating or low-temperature systems, especially in air rectification and low-temperature separation of gases.

BACKGROUND OF THE INVENTION

In many low-temperature applications and elsewhere, two or more fluids must be passed in heat-exchanging relationship so that one of the fluids is cooled while the other fluid is heated. An indirect heat exchanger, for example, leads the fluids through respective flow passages on opposite sides of a thermally conductive barrier or wall through which heat transfer takes place. In this system, as opposed to heat exchange wherein the two fluids contact one another directly and effect a mutual transfer of heat without any intervening barrier and regenerative heat exchange wherein a first fluid transfers heat to a high heat capacity body and the second fluid traverses the same fluid-passageway to abstract heat from this body, indirect heat exchange techniques maintain a separation of the fluids and nevertheless are capable of high rates of heat transfer. It will be apparent that heat-transfer efficiency increases as the thermal conductivity of the plates increases, as the thickness of the plates decreases and as the insulating laminar or boundary layers of fluid along the walls of the passage are disrupted and random movement of the fluid along the passage is ensured.

An evaporator-condenser of the plate-type is, of course, only a special case of a heat exchanger of the indirect type. In this specific heat exchanger, at least one fluid is condensable or contains a condensable component such that, when latent heat of condensation is transferred through the wall of the heat exchanger to the other fluid, the component condenses and is drawn off as a liquid from the system. On the evaporator side, a liquid is vaporized with the thermal transfer to it of latent heat of condensation by heat exchange through the wall. Evaporator-condensers are used, for example, in air-rectification installations of the Linde-Fränkl type, as boilers for low-temperature liquids and as gas condensers in similar applications.

It has been proposed to provide plate-type evaporator-condenser units in which the flow passages are defined between adjoining plates which effect heat exchange between them. In this case, the corrugated, wrinkled or otherwise deformed or profiled plates bear against the adjoining plates on opposite sides so as to create a stack of only limited deformability and provide formations within the passages which may interrupt any efficiency-reducing boundary layers which may develop along the faces of the plates defining the respective passage. The alternate pairs of plates, e.g., of rectangular configuration, may be sealed together at different pairs of opposing sides so that the unsealed edges or sides form inlets and outlets for the fluids. Hence the inlet and outlet of one pair of plates will permit the general flow of fluid in a direction perpendicular to the flow of fluid between the next pair of plates, the heat-exchange wall between the fluids of these two passages being common to both pairs. The advantages of such

plate-type heat exchangers include a high specific heat-exchange surface area, low volume per unit of throughput or heat transfer, low material cost and simple construction methods. Some problems, however, do arise when the system is used as an evaporator-condenser, especially with respect to the manner in which the condensate is led from the system.

OBJECTS OF THE INVENTION

It is, therefore, the principal object of the present invention to provide an improved plate-type heat-exchanger structure which possesses all of the advantages of the plate-type heat-exchange systems mentioned earlier but yet affords advantages in several important operational and technological respects.

Another object of the invention is to provide an evaporator-condenser which advances the art of plate-type heat-exchangers and provides improved direction of the fluids traversing the respective flow passages.

It is also an object of the invention to provide a generally improved plate-type evaporator-condenser with highly desirable condensate-flow characteristics.

SUMMARY OF THE INVENTION

These objects and others which will become apparent hereinafter are attained, in accordance with the present invention, with an arrangement in which each pair of plates of a fluid with at least one plate of two adjoining pairs being common to both and forming the heat-conducting partition between the passages. The plates are, according to the invention, corrugated, wrinkled, profiled or otherwise deformed to provide mutually parallel rectilinear crests or ribs and troughs alternating with the crests, the crests of the plates defining each flow passage bearing against one another at intersection or crossing points distributed substantially over the entire area of the plate, with the crests of the two plates of each pair being inclined at different angles to a liquid-fall line e.g. plumb line or "vertical," as will be described in greater detail hereinafter; at least one of the inclined ramps, ledges or flanks discharging the condensate being inclined sharply to the horizontal but slightly relative to the verticle so as to approximate the fall line. This configuration with the juxtaposed plates defining the passage for the condensable fluid having different inclinations with respect to the plumb line, has been found to greatly improve the efficiency of discharge of the condensate and also eliminates boundary layers of condensate which tend to insulate the passage against efficient heat exchange.

The present invention thus resides in a plate-type heat exchanger, adapted to operate as a condenser, in which the profiles or formations of the plates extend linearly and parallel to one another and preferably are formed with continually contacting crests at least engaging one another in the passage for the condensable fluid, the crests forming flumes or ramps leading downwardly to the condensate outlet, at least one such ramp being at a steep angle approximating the natural fall line. The essential characteristic of this structure is that the profiles or crests of the juxtaposed plates defining the condensable-fluid passage are inclined to different extents to the aforementioned fall or plumb line and form troughs for the condensate which reach at least to the vicinity of the contact point at the steep inclination mentioned. The profiles form the aforementioned troughs or ramps and can be of sawtooth cross-section

with the sawtooth pitch of one plate being twice the sawtooth pitch of the opposite plate.

This arrangement, wherein the contact points are spaced along the crests, results in a system whereby each condensate streamlet descends originally generally along a plumb line or fall line until it reaches the respective flank of the crest and thereupon travels downwardly along the flank at an inclination determined by the corresponding angle which differs between the two plates defining the condensate chamber, but nevertheless leading toward the condensate outlet. At the contact point, the streamlets from both plates join and, if of sufficiently high flow rate (by virtue of steep inclination), cascade downwardly in a torrent which may be intercepted at some lower portion of the plate or will reach the bottom of the plate whereby the liquid is led to the outlet. Where the torrent is intercepted, it is guided again downwardly and in the direction of the outlet until it meets another contact point and thereupon forms a further cascade. In this manner the condensate is led to the outlet rapidly and is promptly joined into cascading streams, thereby eliminating films of liquid upon the plates which have a tendency to reduce the heat exchange efficiency.

Another advantage of the system of the present invention is that the profiles or crests which extend at a slight angle to the principal flow direction according to the present invention, do not significantly interfere with throughflow and hence give rise to a minimal pressure drop between the inlet and outlet sides of the stack. It is possible in accordance with the aforementioned principles to have one fluid pass through chambers in which the ribs, profiles or crests form relatively large angles with the main flow direction while the throughflow in the other passages occurs at a minimal angle to the crests as already noted. In this case, the low-pressure-drop passages may be used for the condensable fluid while a gas traverses the passages in which the crests run at large angles to the main flow direction and hence undergo intensive mixing. Advantageously, the profiles of each plate may be at both large and small angles to the main flow direction so that the optimum balance between pressure drop and turbulence is attained. A turbulence or intensive mixing, of course, corresponds to greater heat transfer. Advantageously, the rectangular plate is subdivided into parallel zones whose crests alternately lie at a small and a large angle to the main flow direction and we may provide crest-free strips between these zones to facilitate the cascading of the condensate toward the outlet.

According to a further feature of the invention, the profiles are of the sawtooth shape mentioned above and consist of a generally horizontal flank defining the ramp and facing upwardly in the condensate compartment and an upwardly and inwardly directed wall rising from the horizontal flank. This construction has been found to offer both the most desirable utilization of surface area and most rapid discharge of condensate. It has been found to be advantageous, moreover, to provide the aforementioned zones as vertically extending strips of profiled plate separated by vertically extending nonprofiled strips of smaller horizontal width. The condensate fluid is preferably introduced in the horizontal direction through passages formed by openings of the plate pair along the vertical edges thereof when the plates are upright. For the pair of plates through which

the condensable fluid is passed, we seal the horizontal sides of the plate pair together, e.g., by welding.

According to yet another feature of the present invention, the stack of plates is provided in the form of a ring, with each pair of plates lying generally along a radial plane and extending vertically. The condensable fluid is then passed radially through the heat exchanger while the vaporizable fluid may be passed axially there-through. The evaporator-condenser so constructed can be provided with a generally cylindrical housing having upper and lower annular dome portions through which the fluids are conducted axially through the array of plates and an annular trough along a periphery of the annular along which the condensate is collected.

DESCRIPTION OF THE DRAWING

The above and other objects, features and advantages of the present invention will become more readily apparent from the following description, reference being made to the accompanying drawing in which:

FIG. 1 is an elevational view of a portion of a plate stack according to the present invention, partly broken away and corresponding generally to a view taken along the line I — I of FIG. 2;

FIG. 2 is a cross-sectional view taken along the line II — II of FIG. 1;

FIG. 3 is a vertical cross-sectional view through a portion of an evaporator-condenser embodying the invention;

FIG. 4 is a cross-section taken generally along the line IV — IV of FIG. 3; and

FIG. 5 is an elevational view illustrating another set of plates according to the present invention.

SPECIFIC DESCRIPTION

Referring first to FIG. 5 of the drawing, from which the operating principles of the present invention will become clearer, it can be seen that a stack of sheet-metal plates S_1 , S_2 and S_3 , all of rectangular configuration, can be joined along opposite edges to form pairs of plates defining respective fluid-flow compartments. Thus plates S_1 and S_2 may be sealed along their vertical edges E_1 to define a flow compartment F_1 between these plates which is open along the horizontal edges H_1 . A fluid, e.g., a vaporizable liquid or a heat-absorbing gas, may then be introduced into the flow compartment F_1 in the direction of arrow A_1 and will emerge as represented at A_2 .

The next pair of plates S_2 , S_3 having the plate S_2 in common with the previously described pair of plates, defines a flow compartment F_2 which is open at V_1 along its vertical edges but is sealed at H_2 along its horizontal edges. Thus, a condensable fluid may be introduced horizontally (arrow A_3) and will emerge as shown at A_4 . The vertical openings of the entire stack of plates may be provided with a manifold M_1 , into which the condensable fluid is fed while, on the opposite side of the plates, a collecting manifold M_2 , preferably including a condensate trough as described subsequently, is provided to collect the fluid traversing the stack of plates in the horizontal direction. A further manifold M_3 communicates with all of the passages open along the lower horizontal edge and feeds a gas upwardly through the stack of heat-exchanger plates, the fluid being collected by the upper manifold M_4 .

It also will be apparent from FIG. 5 that the juxtaposed faces of each pair of plates defining a flow pas-

sage is formed with profiles or crests C_1 and C_2 which extend at different angles to a plumb line or fall line which has been illustrated as a dot-dash line L in FIG. 5. For the purposes of the present invention, this plumb line (vertical) or fall line is defined as the line described by a free-fall body upon which the gravitational force acts. It is the line along which a stream of liquid will cascade or a trickle of liquid will flow if not intercepted. Thus, crests C_1 are shown to include a relatively small angle α with the fall line while the crests C_2 include the angle β with the fall line, β being greater than α . However, all of the crests extend generally in the same direction, i.e., they run downwardly and outwardly to the left or upwardly and inwardly to the right. It is thus apparent that, within each compartment, the crests of the two plates intersect and bear upon one another. Furthermore, each stream of fluid encounters an array of crests which have a small inclination to the main flow direction and are responsible for only a small pressure drop and an array of crests intercepting the flow at a large angle and responsible for augmented turbulence.

In FIGS. 1 and 2, we have shown the principles of the invention in somewhat greater detail. In the plate stack of these Figures, it can be seen that plates 31 and 32, the latter being shown in phantom lines since the view has been taken behind, constitute a plate pair defining a flow path for the condensable fluid whose main flow direction has been indicated by the arrows 33 and 34. The plate 31 has a sawtooth profile which, in the direction of flow (arrows 33 and 34) runs at a relatively small angle downwardly. Plate 32 likewise has a sawtooth profile which, in the direction of flow (arrows 33 and 34) runs at a large angle downwardly. The surfaces of the plates 31 and 32 are divided by the sawtooth profiles into horizontal steps or flanks 37, 37a and 38, 38a, as well as inclined wall portions 35, 35a or 36, 36a intersecting at the crests of the formations.

The crests 39 and 40, defined at the junctions between the inclined wall portions 35, 35a, 36 and 36a with the respective steps 37, 37a, 38 and 38a constitute intersection ledges which bear upon one another at points such as are shown at 41. The other ledges, e.g., 39a and 40a, bear upon one another at point 42. Points equivalent to those shown at 41 and 42 are distributed in the form of a network over the entire area of both plates in substantially a lattice work so that the two plates bear against one another in force-transmitting relationship and defined at passages by spacing each other properly at the contact points. A further pair of sheet metal thermally conductive plates 43 and 44, essentially equivalent to those already described, define a flow passage for the condensable fluid as represented by arrow 45 and cooperate with the previously described pair of plates to define a flow passage 46 between plates 31 and 40.

As can best be seen in FIG. 2, each of the inclined wall portions of the surface of a plate defining the condensate passage, e.g., the wall portion 35a, constitutes a condensing surface. Assume then that condensate is formed at points A in the form of droplets which unite with other droplets as they move downwardly in a small streamlet under gravitational force along the fall lines 47. From each of the many sites of condensate precipitation, similar droplets trickle downwardly until they encounter the inwardly extending generally horizontal ledges or steps formed by the profiles and represented

by the ledge 37a. Several streamlets and the droplets thereof may unite at each ledge 37a and flow along the ledge as best seen in FIG. 1 to form a layer stream 48. During this interval, the condensate is traveling along the ramp in the direction of the condensate outlet in a downward direction. Similarly, droplets formed by condensation on the walls of the opposing plate, e.g., at 36a, trickle downwardly along the fall lines 49 at points B which have been illustrated solely by way of example. Again, the streamlet accumulates additional condensate drops until it forms a stream and is intercepted by the ledge 38a along which it is guided at high speed until the contact point or intersection point is reached.

As each streamlet reaches the ledge, the flow grows to form the stream 50 which continues downwardly and, at the junction 42, meets the stream 48. The streams unite and, because of surface tension and molecular-force phenomena and the high velocity and energy of the steeply traveling stream 50, entrain the slower stream 48 downwardly in a cascade and thus form a joint flow as shown at 51. In other words the high velocity stream 50, in part because of its high energy, entrains the low-velocity stream 48 in the downward direction and tears it away from its ledge. When the mass of cascade is insufficient, of course, the stream will continue along the steep ledge until it has gathered enough mass to plummet directly downwardly along the fall line represented at 51. A portion of either stream 48 or stream 50 may, of course, continue along the respective ledges. In general, however, the above-described cascades form rapidly and discharge condensate from the surface so that practically all of the condensate film is eliminated as soon as it is formed. The heat-exchange surfaces are thus exposed more rapidly and a more intensive heat transfer than has been possible heretofore is achieved. From time to time, the cascade will be intercepted by other contact points (e.g. as shown at 52) whereupon the main stream may be broken up and large droplets of condensate picked up by other streams in which the elevated energy of free fall is converted into an increasing downward velocity. Such breakup of the cascading liquid, moreover, interrupts any condensate film which may have the tendency to build up.

In FIGS. 3 and 4, we have shown the preferred embodiment of the evaporator-condenser according to the present invention. The evaporator-condenser comprises a cylindrical vessel 1 which is partitioned by an upwardly concave cup-shaped wall 2 into an upper portion 3 and a lower portion 4. The lower portion 4 of the receptacle can be a pressure column of an air rectification installation while the upper housing portion 3 may form a low-pressure column or upper column of the gas-separation unit. Within the partition 2, which forms a tray, according to the invention, there is provided a circular stack of heat-exchange plates represented generally at 5 and comprising a pair of plates 6 and 7 hermetically sealed at two opposing vertical edges 8 and 9. The neighboring plates 6, 10 are sealed to the plates of the first-mentioned pair at opposite horizontal edges as represented at 12 and 13. The plates thus lie in vertical planes through the axis of the cylindrical vessel and define generally radial passages between the plates sealed at the upper and lower edges. Accordingly, the other passages run generally axially.

The fluid to be condensed is, in the present embodiment, a gas which gathers at the head of column 4 and is in this case nitrogen. The gas passes through the slot-like openings 14 between the plates 6 and 10 and traverses horizontally through passage 15 in the radial direction inwardly, i.e., in the direction in which the chamber converges in a wedge configuration. The chamber constriction is proportional to the reduction in volume of the fluid with increasing condensation. As a consequence the passage creates a minimum flow resistance. The liquid (condensate) passes along the ledges of the plates through opening 16 into an annular collecting trough 17 and is led via the pipe 18 back to the tower 4, e.g. for refluxing. The other fluid collects as a liquid phase in tray 2 so that the space between plates 6 and 7 is filled with a boiling fluid. In general the boiling fluid passes from an inlet slot 19 to an outlet slot 20 in the upward direction. In the case of an air rectification installation, the liquid in the upper column is oxygen. Profile free zones 11 run vertically along the plates defining the condensable-fluid passage or chamber and separate the wider profiled zones from one another; the crests of the profiled zones are of alternating inclinations to the fall line.

I claim:

1. A heat exchanger for effecting heat transfer between at least two fluids including a condensable fluid, said heat exchanger comprising a stack of generally rectangular upright heat-exchanger plates of thermally conductive material defining between successive pairs of said plates respective flow compartments alternating for said fluids, means for passing said condensable fluid through the passages of first pairs of said plates, and means for passing another of said fluids through the passages of second pairs of said plates, adjoining first and second pairs of plates having one plate in common for heat transfer between said fluids, said plates of said first pairs having transversely spaced linearly extending mutually parallel sawtooth profiles of acute-angle vertices extending inwardly into the passage for the condensable fluid and running at different angles to a condensate fall line along the plates defining the condensable-fluid passages whereby crests of said profiles bear against one another at spaced locations over the areas of the plates defining the condensable fluid passages, said profiles forming liquid-flow ramps leading downwardly toward a condensate-discharge side of said stack.

2. The heat exchanger defined in claim 1 wherein at least some of said liquid-flow ramps extend at a steep angle to the horizontal approximating the condensate fall line and extend substantially to respective ones of said locations at which crests of said profiles bear against one another.

3. The heat exchanger defined in claim 2 wherein said profiles are provided in vertically extending horizontally spaced strips separated by narrow unprofiled

strips.

4. The heat exchanger defined in claim 1 wherein said ramps are formed by substantially horizontal flanks of the sawtooth.

5. The heat exchanger defined in claim 1 wherein the profiles of each plate are formed in a plurality of horizontally offset zones of different profile inclinations to the fall line.

6. The heat exchanger defined in claim 1 wherein said means for passing said condensable fluid through the passages of said first pair of plates is constructed and arranged so as to displace said condensable fluid generally horizontally through the passages between said first pair of plates and said means for passing said other fluid through the passages of said other fluid to traverse said passages of said second pair of plates in a generally vertical direction.

7. The heat exchanger defined in claim 6 wherein said stack has the configuration of a circular ring with said plates lying generally in radial planes, said condensable fluid traversing the respective flow passages generally radially inwardly.

8. The heat exchanger defined in claim 7 wherein the ring-shaped stack of plates is received in a pot-shaped tray, said heat exchanger further comprising a cylindrical receptacle receiving said tray and is divided thereby into an upper portion receiving a vaporizable liquid forming said other fluid and a lower portion receivable said condensable fluid, said passages of said one pair of plates being open along the exterior of said tray and communicating with said lower portion, and a condensate collecting trough along the inner periphery of said ring and communicating with said condensable fluid passages for conducting away from said stack.

9. A heat exchanger for effecting heat transfer between at least two fluids including a condensable fluid, said heat exchanger comprising a stack of generally rectangular upright heat exchanger plates of thermally conductive material defining between successive pairs of said plates respective flow compartments alternating for said fluids, means for passing said condensable fluid through the passages of first pairs of said plates, and means for passing another of said fluids through the passages of second pairs of said plates, adjoining first and second pairs of plates having one plate in common for heat transfer between said fluids, said plates of said first pairs having transversely spaced linearly extending mutually parallel profiles extending inwardly into the passage for the condensable fluid and running at different angles to a condensate fall line along the plates defining the condensable fluid passages whereby crests of said profiles bear directly against one another at spaced locations over the areas of the plates defining the condensable fluid passages, said profiles forming liquid-flow ramps leading downwardly toward a condensate-discharge side of said stack.

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