

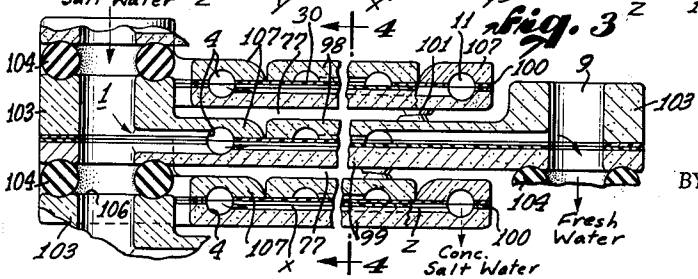
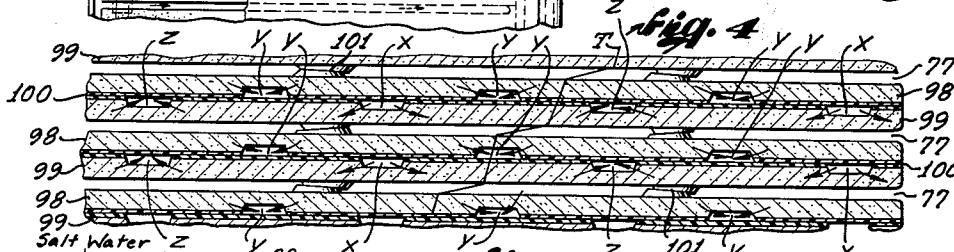
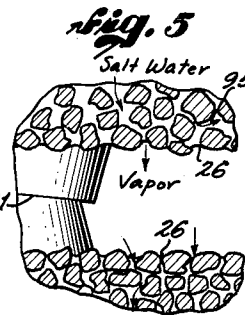
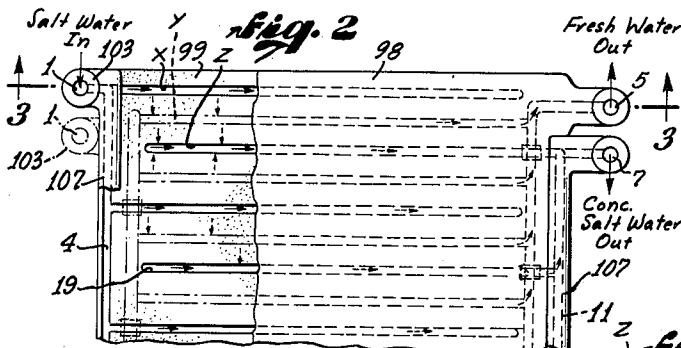
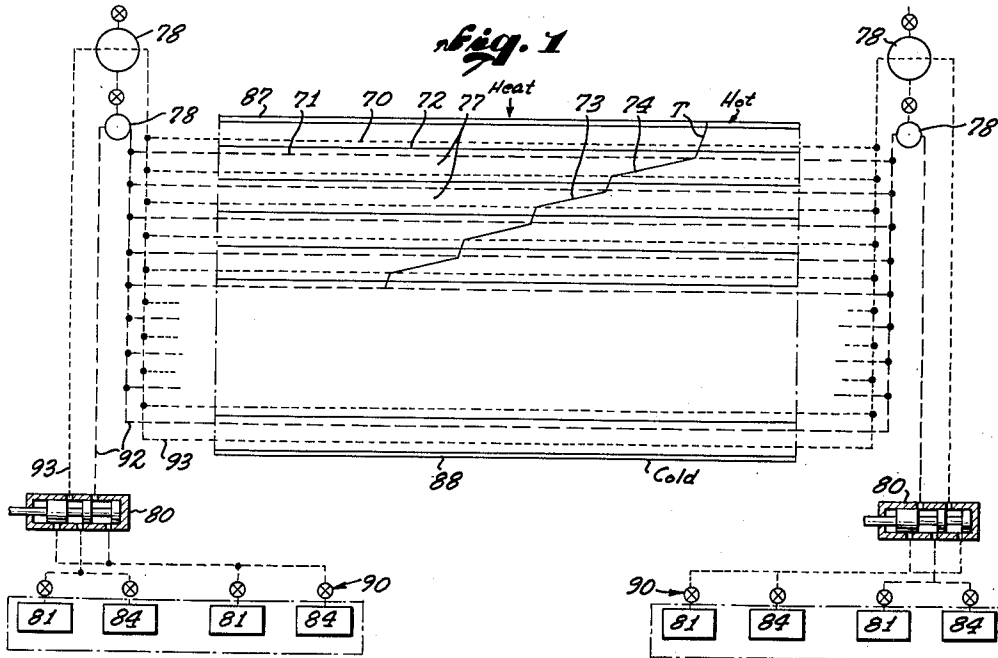
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MEANS AND METHOD FOR MASS AND HEAT TRANSFER

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3,129,145 MEANS AND METHOD FOR MASS AND HEAT TRANSFER

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7 Claims. (Cl. 202—51)

This invention relates basically to a method and means for promoting heat transfer between an impermeable wall and a body of liquid flowing across the surface of such wall. Also, the present invention, in general, relates to an improved mass and heat transfer between a flowing body of liquid and a body of gas in contact with the surface of the liquid. More specifically, the present invention relates to an improved distillation process utilizing small temperature differences. A practical application of this invention, as will be described hereinafter, resides in the distillation of sea water to produce pure water. The present application is a continuation of the application, Serial No. 817,538, filed June 2, 1959, and now abandoned, entitled Means and Method for Capillarity Heat Transfer and Applications Thereof. Such earlier application was itself a continuation-in-part of application, Serial No. 436,396, filed June 14, 1954, now abandoned.

The problem of heat transfer through a wall to supply heat to a vaporizing liquid surface or, conversely, to withdraw heat through a wall from a condensing liquid surface is essentially the problem of heat transfer through a thin film of fluid lying next to the wall. Methods previously used to reduce the resistance to heat flow encountered in the film include the use of very rapid flow of the film induced by pumps so that the high shear near wall will keep the film thin; the use of rapidly spinning metal surfaces to reduce the film thickness by centrifugal force and the use of drop-wise condensation or nucleated boiling. These methods are often very disadvantageous in that the power need for rapid flow costs too much and to much heat energy is degraded by mixing within the stream. The spinning boiler surfaces cost energy, are complicated to feed and have a high initial cost. The drop-wise or nucleated flows require a knowledge of surface chemistry that is often unavailable, so that the water repellant surfaces may be fouled or corroded.

In general, the purpose of the designer is to use convective flow as far as possible, but he is normally limited by the existence within a film of fluid commonly called "laminar" film which lies against every phase boundary. Heat and mass must pass through this film by the relatively inefficient process of diffusion. The present invention teaches methods and means for greatly reducing the resistance within laminar films by utilizing a flow of liquid within conducting porous material placed where the laminar film ordinarily would occur. Thus applicant arranges a convective flow of liquid within the porous material which promotes high rates of heat and mass transfer. By choosing porous materials of high thermoconductivity to augment the heat conduction which ordinarily would be carried by stagnant liquid alone and by using the tortuosity of the porous material to force a convective flow having a component in the direction of the heat or mass transfer, the usual diffusion resistance to either heat or mass can be greatly reduced.

In the known prior art of distillation, it has generally been necessary to place a rigid, impermeable wall between the two liquids having different temperatures and pressures so that the laminar film resistance occurred on each side of the pressure wall. The present inven-

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tion teaches how to support large pressure differences between two liquid phases separated by a gas boundary without any impermeable solid wall. By using a higher pressure in the gas boundary, the capillary forces hold the liquid in the porous material. In this way, a barrier is formed which freely passes vapor and heat but selectively blocks the flow of solution. A stagnant film need not accompany such barrier because, according to this invention, a convective flow can be established by a pressure gradient directed parallel to the porous surface, which convective flow contains components of flow normal to the porous surface even at distances from the porous surface. In other words, the convective flow has components normal to the surface which would otherwise be a laminar film.

An example of such prior art heat exchangers which can be replaced by the present invention are the terminal heat exchangers used to heat entering sea water and systems for recovery of fresh water from sea water by distillation. The terminal heat exchangers in such systems are used to heat the entering sea water by arranging the returning heated brine on the opposite side of a metal wall in countercurrent flow therewith. Available energy is dissipated in such process and such exchangers are costly, both as to capital outlay and energy costs. The present invention provides means for recapturing some of the energy loss by this terminal heat flow by causing the heat to pass as a latent heat of vapor moving between an evaporating brine surface and a condensing fresh cool water surface. Thus capital outlay is avoided by combining into one unit the functions of distillation and terminal heat exchange.

Because thin films of liquid capable of conducting heat readily will support high pressure when microscopically supported within a porous layer, this invention will greatly relieve the problems of corrosion and cost of the metal pressure walls previously required to pass heat while supporting pressure. A further advantage lies in that a vaporizing or dissolving surface and a condensing surface can be closely juxtaposed and placed upside down or at any angle with the gravity, while free surfaces of liquid in known devices generally in use, such as sprayed or flowing surfaces, cannot be closely juxtaposed without danger of intermingling. Furthermore, the porous layers of the present invention may be comprised of sheets adapted to have a condensing interface surface on one side and an evaporating interface surface on the other side. Such sheets can be fabricated from extremely inexpensive, but yet durable and effective materials so as to make possible the fabrication and production at relatively small capital outlay of a plant for the recovery of fresh water from sea water.

In accordance with the foregoing general outline, the objects of the present invention include as a primary object improved and simplified method and means for mass and heat transfer.

Another object of the present invention is to eliminate the problem of resistance to mass and heat transfer across laminar films by providing means having a layer of porous material adapted to sustain a liquid-vapor interface within itself. Such porous material forces a convective flow having a component in the direction of the needed heat or mass transfer. Also, such porous material separates a gas and liquid phase without any impermeable wall by utilizing the capillary force of the liquid in the porous material.

Another object of the present invention is to obtain a low-cost distillation unit by accomplishing in one unit both vapor exchange and terminal heat exchange.

Another object of the present invention is to provide heat exchange units comprising several layers spaced by vapor or air gaps, the layers each consisting of an im-

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permeable barrier having porous layers on opposite sides thereof whereby to provide a condensing interface on one side of the impermeable barrier and an evaporating interface on the opposite side.

Further objects and additional advantages of the present invention will become apparent from the following detailed description and annexed drawing, wherein:

In the drawing:

FIG. 1 is a schematic view of a vertical elevation of a multiple evaporator stack used in the distillation of sea water;

FIG. 2 is a schematic plan view of one of the heat exchange units utilized in the assembly of FIG. 1;

FIG. 3 is a sectional view taken along the line 3—3 of FIG. 2;

FIG. 4 is a sectional view illustrating a form of the layered heat exchange assembly which may be utilized in the stack of FIG. 1;

FIG. 5 is an enlarged view of a portion of the assembly in FIG. 4.

Basically, the present invention involves a structure adapted to promote heat transfer between an impermeable wall and a body of liquid flowing over the surface of the wall or heat and mass transfer between a body of gas and a body of liquid flowing in contact with said body of gas. For example, in the case of heat transfer between an impermeable wall and a body of liquid, the present invention involves a porous layer on at least one surface of the wall. Liquid is then conducted in sequence into contact with the surface of the porous layer contacting the wall, at spaced intervals, through the porous layer substantially parallel to the wall and then away from the surface of said porous layer contacting the wall at spaced intervals. A gas pressure is maintained on the surface of the porous layer remote from said wall higher than the liquid pressure in the said porous layer.

The gas pressure is also sufficient to contain the liquid in the porous layer when the porous layer has a body of liquid contacting its surface contacting the wall. Thus, when the impermeable wall is heated, such heat is readily transferred to the body of fluid due to the conductivity of the porous material and the convective flow in the direction of the desired heat transfer, i.e. normal to the wall surface.

The principle of the use of flow in thin conducting porous layers can be applied in low temperature difference distillation and/or in mass transfer with small differences in the thermo-dynamic potential. The recovery of fresh water from sea water is a specific example of the utilization of the present invention and apparatus and process involving such specific example is illustrated in FIGS. 1-5.

FIG. 1 is a schematic drawing of a vertical elevation of a multiple evaporative stack of porous doublets showing schematically the manner of fluid connections between the evaporative stack and the pressure reservoirs. A preferred type of unit for use in the stack is described hereinafter in which the unit comprises an impermeable barrier having a porous layer closely juxtaposed on each side of it. In FIG. 1 the dotted lines 70 represent fresh water, dashed lines 71, sea water, and the solid line 72 is a thin salt barrier, such as copper or polyethylene. Zigzag diagonal 73, 74 represents a plot of temperature caused by the downward flow of heat applied to the stack. The 73, 74 curve shows a relatively large temperature drop through the vapor diffusion gaps, a relatively small temperature drop through the saturated porous films and salt barriers.

It is desirable to minimize the formation of bubbles within the pores. Thus, the fluid may be stripped of air before entering the zone of porous flow by exposing the fluid to a pressure less than that to be encountered in the vapor exchange stack, as in the tanks 78 of FIG. 1. In FIG. 2, the higher pressure inlet passage 1 for inlet

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liquid, such as salt water feed, communicates, by way of a manifold passage 4, to the feeder passages x. The concentrated salt water passes out of feeder passages z to the lower pressure terminal 7 by way of manifold 11. The fresh water is collected in passages y and passes to terminal 5. The flow of the salt water is thus directed through the porous material from the inlet 1 to the terminal 7 while the fresh water exits from terminal 5. Such exposure may be either continual or at regular intervals adapted to dissolve such bubbles as may form in the stack. The feeder passages, such as x and z of FIG. 2, may be shaped in triangular form (for example), so as to permit enough flow of water even when all the passages contain as much air as they will hold. The general requirements for avoiding bubbles are represented schematically by the trap 78 which removes bubbles at a higher level than the level of the stack by the interchange valves 80. The distillate receivers 81 are adjusted as to level and pressure to assure that the pore fluids are at a lower pressure than the air in the diffusion gap 77. The salt water feed tanks 84 are at pressures which are different enough to cause sufficient lateral flow and long enough to assure that the water in the porous material is everywhere under lower pressure than the pressure of the gaseous material in the diffusion gap 77. The curvature of the vaporizing and condensing liquid surfaces in the exchange unit is as indicated by 26 in FIG. 5.

The purpose of the interchange valves 80 is to reverse the flow of both sea water and fresh water through the unit which is accomplished by appropriate adjustment of the sets of valves designated at 90. Heat is applied to the stack by a heat source 87 at the top cooperating with the heat sink or cooler 88 at the bottom of the unit.

Referring to the operation of FIG. 1, it may be seen that the vaporizing salt water layers 71, fed with salt water by fluid connections 92, are caused to flow under suction above each air gap 77, while fresh water layer 70 under each air gap 77 continually receive distillate which diffuses across the air gap 77. The distillate is removed under suction through the fluid connections 93. The distillation across 77 is caused by the excess of temperature in the salty flow 71 as compared with the temperature of the fresh water surfaces 70 on the lower side of each doublet. This temperature excess rises from the source of heat placed above the stack at position 87 and the heat sink or cooler placed at the bottom of the stack 88. The temperature plot 73, 74 shows a relatively small temperature drop downward through the saturated porous materials because these are made thin and of heat conducting material. Also, they contain moving fluid having a random component of motion in the direction of heat flow, as shown at 95 in FIG. 5.

It may be desirable to occasionally change the direction of heat flow and interchange the fresh water and the salt bearing porous flow in order to dissolve away any calcareous deposit which may form when sea water evaporates. In such case, the salt water flow would be "below" each air gap, while the fresh water would be "above."

Porous flow occurs in short paths between the feeder and drain passages. As indicated in FIG. 4, the salt solution flows within the fine pores through a relatively short path and thence away from the porous sheet through the outlet passages and outlet main passages as described. Such a construction is useful, but where filterable solids are present, these blind ends will be difficult to flush clean by reversing the flow since flow through the fine porous path is necessarily slow. It is, therefore, desirable to arrange two fluid connections for the inlet path so that a high-velocity flow in the channels, as well as back flow through the porous material can be used to clean out any plugging. In the case of the fresh water plate, distillate will leave no deposit and will remove slightly soluble deposits, such as the calcareous residue that may be left on the evaporating salt water layer. In many cases, it will be desirable to charge the water and diffusion gaps with

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a portion of carbon dioxide to keep the bicarbonate in solution, and in this event special passages are provided to feed gases into or through the diffusion gaps as necessary.

FIG. 4 is an enlarged cross-sectional view showing the layer and gap construction of a preferred type of unit to be used in the stack of FIG. 1. FIG. 3 is an enlarged sectional view showing the construction at the terminal portions of the assembly of FIG. 4 illustrating the manner of assembly of the adjacent units in the stack of FIG. 1. FIG. 3 is a sectional view taken along the line 3—3 of FIG. 2. FIG. 2 is a plan view of one layer of the stack of FIG. 1 illustrating the fluid connections, the manifolding, and the grid networks within the stack.

In FIG. 4, this enlarged section shows adjacent cemented pairs of porous plates separated by a vapor gap 77. The plates are designated at 98 and 99 and are separated by an impermeable salt barrier 100 which may preferably be provided by a lacquer film suitably deposited on the surface of the porous layers. The groove channels as shown are formed in the porous layers. The vapor gap is held open by an array of thin, impermeable spots or members 101 shown as pyramids having an incline truncation. The flow arrows of FIG. 4 indicate a transverse flow from inlet passages to outlet passages for a warm salt water layer and flow of distillate outward to all the passages in other layers. The salt barrier 100 may be provided by cementing the two porous layers together so that the cement itself forms the barrier.

FIG. 3 shows the structural formation of the assembly of FIG. 4 whereby the layers are assembled into a stack as exemplified in FIG. 1. In FIG. 3, to prevent intermingling of the liquids at those places along the edge where the juxtaposed grooves overlap, an impermeable tape may be used as shown at 30 which blocks off the manifold at the points of cross-over of the grooves. The grooves terminate in a thickened fluid manifold passage, that is, a manifold which extends only half way along the edge. FIG. 3 shows how the double thickness of the porous plate when cemented back-to-back with grooves between equals the thickness of the thickened passage part above the groove. A pierced terminal lug 103 sealed by O-rings 104 is again doubled in thickness, but since two or more positions for the terminals are provided in the design of the plan these terminal lugs may be sealed by gaskets without imposing unwanted thickness on the main area.

The need to concentrate the feeder flow and the distillate flow into terminal lugs where leak-proof connections can be made, together with the requirement that the thickness of the porous sheet be held at a minimum, imposes a restriction on the arrangement in the plan of the passages for the regions of concentrated flow, i.e. the manifolds, must be thicker than the main area of the sheet. FIG. 3 shows how the thickened parts 107 are made twice as thick as the main diffusion area of the sheet, while the corresponding area of the sheet is reduced by one-half. The plan of the thickness area is so made that when similar sheets are turned over and stacked there is no interference. A further state of thickening of the liquid terminals is required to provide room for the gasket seal, such as 104. The terminal lugs which connect through the gaskets or other seals need not have a large area and, therefore, can be arranged to fall in one of the sets of edged positions (not shown). Where large temperature differences are used in this distillation process, it will be advantageous to provide separate connections to heat exchangers or economizers so that heat can be returned from the waste water or distillate to the sea water of those layers which under vertical heat flow operate at a higher temperature.

The operation of the equipment (FIGS. 1-5) is as follows: salt water enters the equipment through passage 1 and feeds in parallel through passage x to each individual distillation chamber. The salt water feeds into and per-

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meates through the porous layer 99 from parallel grooves and water distills therefrom across gap 77 and condenses in porous layer 99. Finally, the concentrated salt water exits out of passage 7 while the fresh water goes out passage 5.

The pressure excess within the air gap which determines the interface curvatures at 26 in FIG. 5 is needed to keep the vapor gap dry in order that it may effectively block the flow of liquid. If in some way a drop of liquid is placed within the gap, the drop will be drawn out of the gap only if the excess pressure in the gap is sufficient to oppose the capillary forces in plates 98 and 99. This restriction implies a gap pressure excess about equal to the capillary pressure rise within the plates. A second consideration arises from the possibility that separating spots may unavoidably have surfaces that absorb water and to some degree serve as leakage paths for salt water. Excess pressure within the gap will cause such absorbed films to shrink by driving away liquid and by activating a vapor transfer from the separator surface toward the lower pressure porous material.

The choice of thickness of the selective vapor transfer gap depends upon the gap pressure, the available temperature difference, and the associated thermal resistance, as indicated below, but it is guided by the need to balance the loss of energy due to direct heat transfer across the gap against the accompanying favorable transfer of vapor. If, for example, the rate of heat flow through the stack be fixed, as by the rate of passage of solar energy, it is possible to make the gap so unfavorably thin that direct heat conduction through the gap will carry all of the heat at a temperature difference so low that the sea water vapor pressure does not rise to the fresh water vapor pressure and thus no distillation will occur. It is then necessary to spread the gap to several thousands of an inch in order to increase the gap temperature difference and cause a useful portion of the heat to be transferred as latent heat and hence to transfer a mass of water vapor. The inclined plains 101 (FIG. 3) may be provided to adjust the thickness of the gap to the most efficient value. The adjustment is made by sliding alternate layers with respect to one another in the direction of the incline.

An important advantage of the present invention is its ability to use low temperature differences of the order of about 2 degrees per stage of distillation by comparatively inexpensive means.

While the above illustrative description deals with a separating diffusion gap of gaseous nature, I do not intend to restrict my claims or teaching in this way. Any choice of fluids which form phase boundaries subject to control by a porous material may be useful for selective transfer of one or a class of components. Any adjustment of temperature by flow of heat vertically through a polarized sequence of layers which results in a favorable concentration gradient within the separating diffusion gap will be useful.

In general, any adjustment which increases the difference in the thermodynamic potential, as by temperature, and any adjustment of composition of the thin separating phase which reduces the heat of transfer or the transfer irreversibilities, as by use of a vacuum of a phase having low heat of solution, is contemplated herein. By providing two terminals for inlet flow and terminals for outlet flow (of both solution and solvent layers), it will be expedient to activate transfer by composition adjustment, as well as by the use of heat. Similarly, a pair of terminals for each transfer gap permit the adjustment of the selective properties and diffusion resistance of the transfer gap.

Effective use of this invention will depend on the construction of thin porous layers of low cost, having a high ratio of permeability to air entry pressure, and having very closely matched surfaces so that they can be closely juxtaposed in a book or stack. Another important structural feature of some forms of the present invention is the

provision of an alternate flow path, suitable for high velocity flushing, for removal of filtrate that may unavoidably form on the passages.

The process of this invention can be carried out with any porous materials. In general, organic materials, such as paper or felted fiber with gelatin, or cemented powder coatings, will be easiest and cheapest to manufacture. However, they are subject to attack by bacteria and fungi and, moreover, have unfavorably low thermal conductivity. A recommended material for producing the vapor exchange sheets, such as shown in FIGS. 3-5, is the type of investment used in the well known lost wax casting process, and consisting of ethyl silicate binder and sand placed with fiber glass cloth as reinforcing, against a waxed flexible mold. A grog consisting of six parts of 100 mesh sand and five parts of 320 mesh sand mixed ethyl silicate solution according to the instruction, for example, of Carbide and Carbon Company's instruction manual on the subject, can be trowelled against very fine glass cloth of weave, such as marquisette or cheesecloth, which cloth is held against a cylindrically curved, wax-coated rubber mold and finished by pressing against an opposing waxed rubber mold. The flexible molds may be stripped away by warming the way, and the hard sheet may then be finished and sized by light sanding. The separating spots 101 may be printed or rolled on from a rubber roll deeply changed with epoxy wax. The impermeable cement may be printed on, but it is preferably applied, to prevent penetration, by utilizing a hot thermoplastic, such as hard asphalt, applied with hot rollers to a cold porous sheet, and then pressed together instantaneously after rapid passage of flame or hot blast to reactive a tacky surface. Closure face 106 of the terminal lugs may be formed of pressed hot glass or molded resin and cemented in place. The grog may also be made of such more expensive and more conducting materials as graphite and alundum.

One advantage of the present invention is apparent by comparing it with prior art conventional apparatus. When using conventional apparatus of the prior art, such as metal tubes, that flow streams of fluid while the temperature changes in the direction of flow, the mixing losses are serious. When the hot central core of the stream contained within cold walls is continually mixed with and exchanges heat with the colder outer parts of the same extreme, entropy is increased and available energy is wasted. It is an advantage of the heat exchange process of the present invention that such mixing losses are greatly reduced because within the porous grains there is only a short path, microscopic over-running of a hotter or colder central part followed by internal mixing. Effectively, the fluids advance in a more coherent, uniform, progressive encroachment with a maximum of heat exchange with the other heat exchange stream and a minimum of heat exchange between the parts of a single stream. Smaller temperature differences occur between the two streams, corresponding to the low values of the heat transfer coefficient commonly called U, because of the good conductance through the grains, and because of the very much smaller heat exchange and temperature degradation between the parts of a single stream. The flow of thin sheets of fluids, physically isolated but spaced within the range of selective diffusion while they exchange vapor through thin gaps and small temperature differences, as taught in this invention, provides means whereby new and useful process of heat exchange can be applied to the use of streams of fluid at different temperatures. The energy is provided and used as a multitude of separate streams having small temperature differences.

The foregoing disclosure is representative of the preferred form of invention and is to be interpreted in an illustrative, rather than a limiting sense. The invention is to be accorded the full scope of the claims appended hereto,

I claim:

1. A distillation structure comprising:

- (a) first and second closely spaced porous layers, each having inner and outer surfaces, the layers being separated by a gap, with the layers inner surfaces being opposed;
- (b) first barrier means adjacent the outer surface of said first porous layer, incorporating means to conduct feed liquid into contact with the outer surface of said first porous layer at spaced intervals; said liquid passing therefrom through said first porous layer to the inner surface thereof;
- (c) means for maintaining a gas pressure in said gap higher than the liquid pressure in said first and second porous layers, whereby a quantity of said liquid vaporizes across said gap, and forms a condensate on said second porous layer which passes to the outer surface of said second porous layer;
- (d) second barrier means adjacent the outer surface of said second porous layer incorporating means to conduct the condensate away from the outer surface of the second porous layer; and
- (e) means for applying heat to the first barrier means and means to withdraw heat from the second barrier means.

2. A structure according to claim 1 wherein the means to conduct feed liquid comprises a plurality of substantially parallel feed grooves, and the first barrier is also provided with a second plurality of parallel grooves interspaced between the feed grooves, said second grooves being adapted to conduct liquid away from the outer surfaces of the first porous layer.

3. A method of distilling vapor from a warmer body of liquid to a cooler body of liquid at a high rate under a small temperature difference, comprising:

- (a) conducting the warmer liquid into contact with the outer surface of a first porous layer of a distillation apparatus comprising first and second closely spaced porous layers having opposed inner surfaces with a gap therebetween;
- (b) passing said liquid through the first layer both parallel to and away from the outer surface of said first porous layer;
- (c) maintaining a gas pressure in said gap higher than the liquid pressure in said first porous layer and sufficient to contain the liquid in said first porous layer, whereby only vapor passes across said gap to the inner surface of said second porous layer where it condenses to form the cooler body of liquid which passes through said second porous layer; and
- (d) maintaining a portion of the cooler liquid in contact with the outer surface of said second porous layer and conducting a portion of it away from the outer surface of said second porous layer.

4. A method of transferring heat between an impermeable wall and a body of liquid flowing over the surface of said wall, comprising:

- (a) providing an impermeable wall with a porous layer on at least one surface of said wall;
- (b) conducting a liquid in sequence:
 - (I) into contact with the wall-contacting surface of said porous layer at spaced intervals,
 - (II) through said porous layer substantially parallel to said wall, and
 - (III) away from the wall-contacting surface of said porous layer at spaced intervals; and
- (c) maintaining a gas pressure on the surface of said porous layer remote from said wall higher than the liquid pressure in said porous layer and sufficient to contain the liquid therein when said porous layer has a body of liquid contacting its wall-contacting surface; and
- (d) heating said impermeable wall.

5. A heat and mass transfer method adapted to promote heat and mass transfer between a body of gas and

a body of liquid flowing in contact with said body of gas, comprising:

- (a) contacting a body of gas with a porous layer;
 - (b) conducting a liquid in sequence;
 - (I) into contact with the surface of said porous layer remote from said body of gas at spaced intervals, 5
 - (II) through said porous layer substantially parallel to the surface of said porous layer adjoining said body of gas, and 10
 - (III) away from the surface of said porous layer remote from said body of gas at spaced intervals; and
 - (c) maintaining pressure in said gas higher than the liquid pressure in said porous layer and sufficient to contain the liquid therein when said porous layer has a body of liquid contacting its surface remote from said body of gas; and 15
 - (d) maintaining a temperature difference between said body of gas and body of liquid. 20
6. A heat transfer structure adapted to promote heat transfer between an impermeable wall and a body of liquid flowing over the surface of said wall, comprising:
- (a) an impermeable wall with means for heating said wall; 25
 - (b) a porous layer on at least one surface of said wall;
 - (c) means for conducting liquid into contact with the wall-contacting surface of said porous layer at spaced intervals whereby the liquid passes through said porous layer substantially parallel to said wall; 30
 - (d) means to conduct liquid away from the wall-contacting surface of said porous layer at spaced intervals; and

- (e) means for maintaining a gas pressure on the surface of said porous layer remote from said wall higher than the liquid pressure in said porous layer and sufficient to contain liquid in said porous layer when said porous layer has a body of liquid contacting its wall-contacting surface.
- 7. A heat and mass transfer structure adapted to promote heat and mass transfer between a body of gas and a body of liquid flowing in contact with said body of gas when a temperature difference is maintained between said body of gas and said body of liquid, comprising:
 - (a) means for enclosing a body of gas, said means including at least one porous layer;
 - (b) means for conducting liquid in sequence into contact with the surface of said porous layer remote from said body of gas at spaced intervals whereby said liquid passes through said porous layer substantially parallel to the surface of said porous layer adjoining said body of gas;
 - (c) means to conduct liquid away from the surface of said porous layer remote from said body of gas at spaced intervals;
 - (d) means for maintaining a pressure in said body of gas on the adjoining surface of said porous layer higher than the liquid pressure in said porous layer when said porous layer has a body of liquid contacting its surface remote from said body of gas.

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