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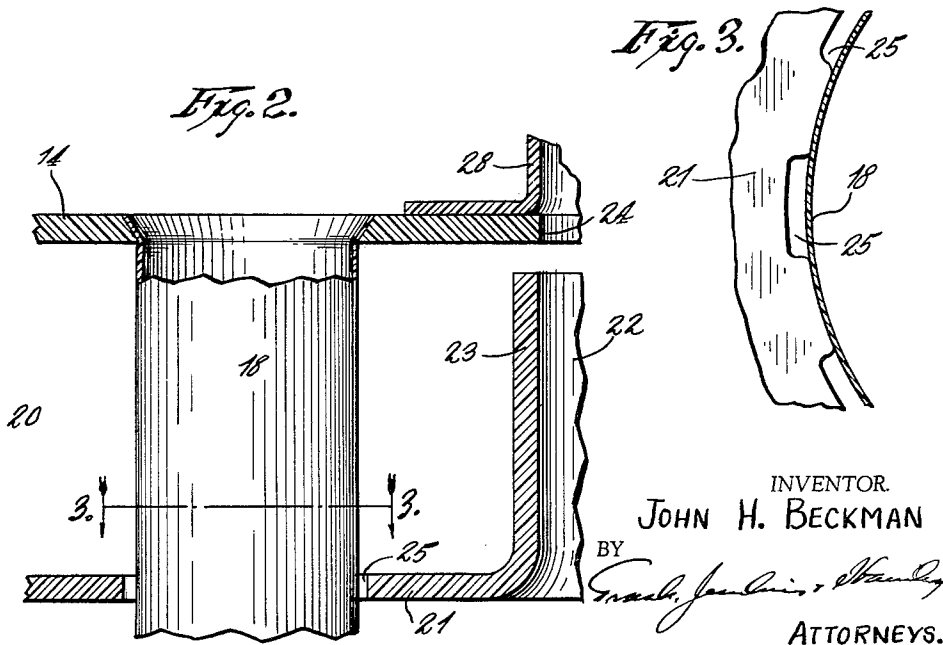
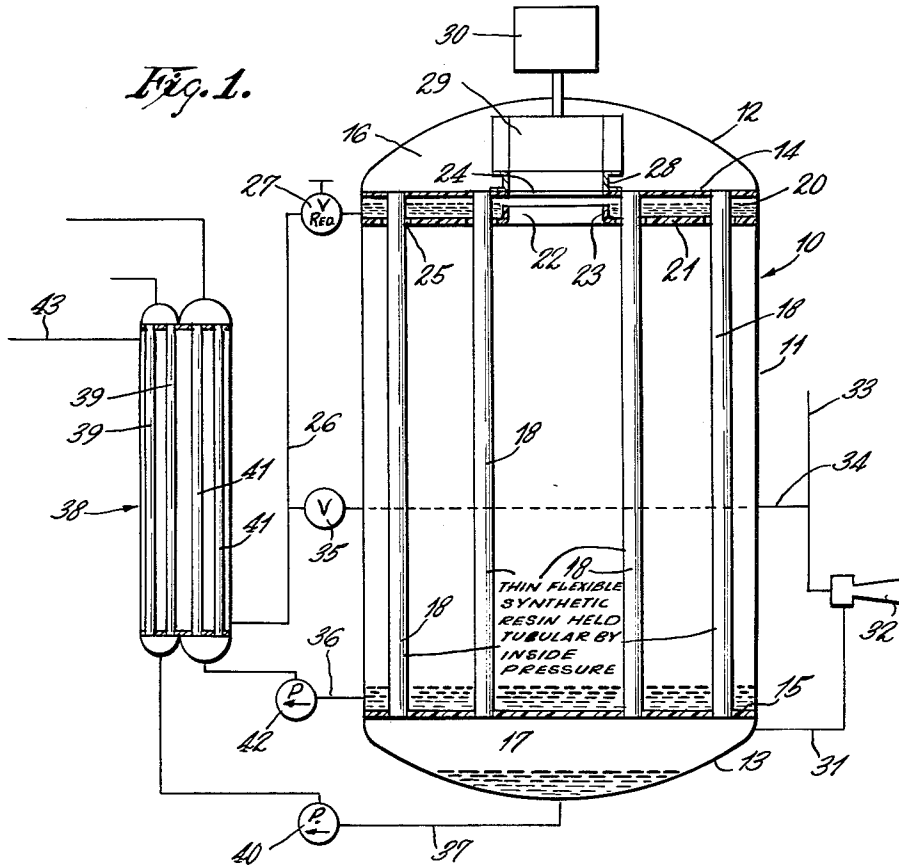
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FLEXIBLE THIN-WALLED TUBULAR HEAT EXCHANGER AND STILL

Filed Jan. 16, 1963

2 Sheets-Sheet 1



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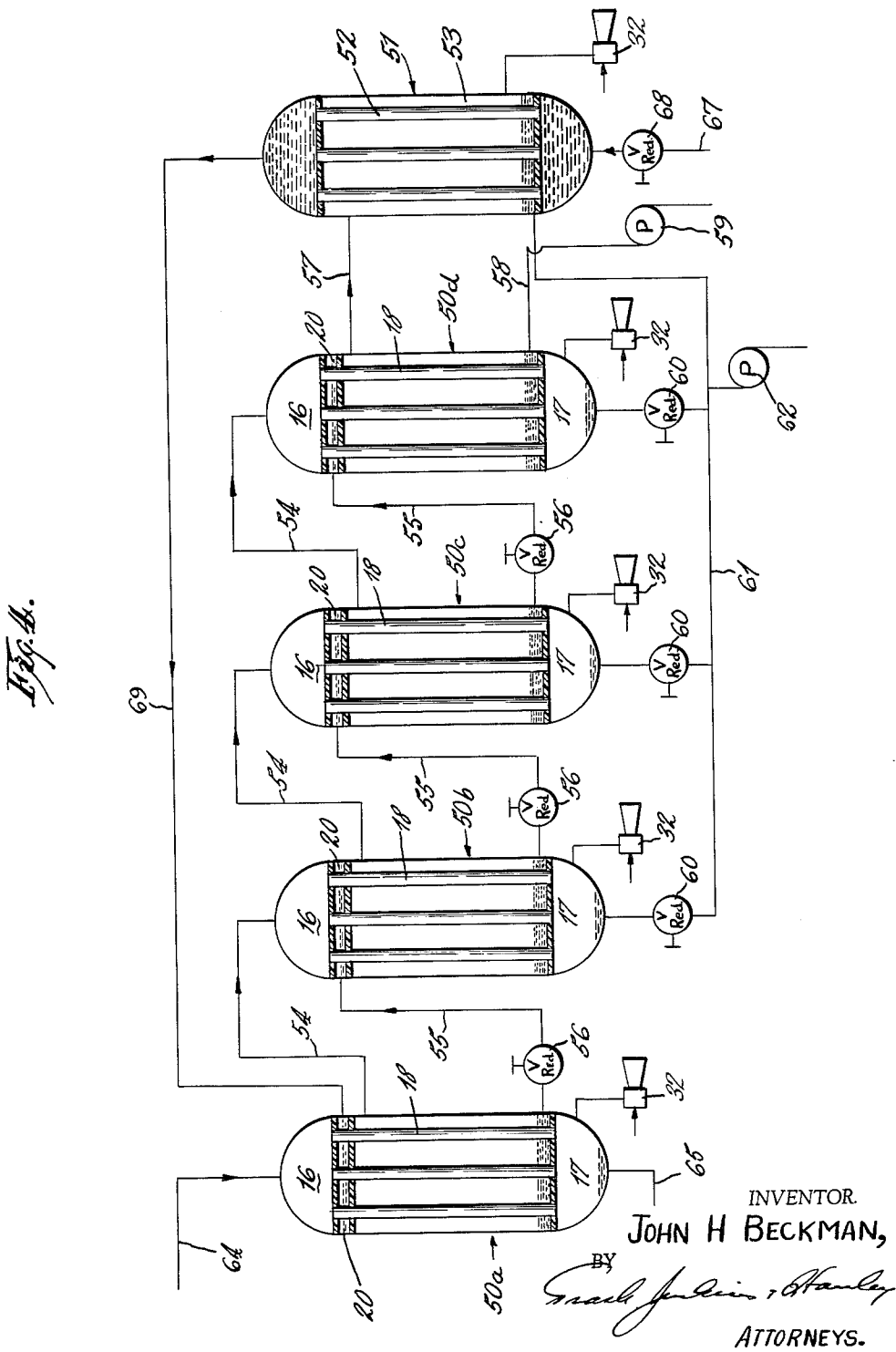
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2 Sheets-Sheet 2



3,227,630 FLEXIBLE THIN-WALLED TUBULAR HEAT EXCHANGER AND STILL

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Filed Jan. 16, 1963, Ser. No. 251,798
6 Claims. (Cl. 202—205)

This invention relates to heat-exchangers of a type suitable for use in the conversion of sea-water into fresh water by distillation. One form of apparatus used in effecting that conversion embodies a heat-exchanger, the heat transferring walls of which separate spaces in which different fluid pressures are maintained by a compressor. Water vapor given off by sea-water supplied to the space of lower pressure is delivered to the compressor, which discharges into the space of higher pressure where the vapor condenses and gives off heat condensation, which is transferred through the heat-exchanger walls to the sea-water. Commonly, the operation is conducted in a partial vacuum in order to permit use of lower temperatures and thereby reduce scaling. The temperature-differential maintained between the condensing water vapor and the evaporating sea-water determines the capacity of any specific apparatus of this type and also determines the pressure-differential which must be maintained between the evaporating and condensing spaces.

The cost of conventional forms of heat-exchangers is such a large factor in the over-all cost of distilling sea-water that it is advisable, in apparatus of the type referred to, to operate at relatively high pressure and temperature-differentials even through the maintenance of high differentials may require multi-stage compressors and involve relatively high power costs. If the cost of heat-exchangers could be reduced, it would be economically practical, by multiplying or enlarging them, to obtain a given capacity with lower temperature and pressure differentials, thus reducing power consumption and lowering over-all costs.

It is therefore an object of this invention to provide a relatively low-cost heat-exchanger. Another object of the invention is to produce a low-cost heat-exchanger especially suited for, although not limited to, use in the distillation of sea-water. Still another object of the invention is to produce a heat-exchanger which will be self-descaling in operation.

A heat-exchanger in accordance with my invention is of the tube and tube-sheet type and, in its preferred form, is characterized in that the tubes are thin-walled tubes formed of a flexible synthetic resin, such as polyethylene. The tube-sheets are desirably also of synthetic plastic and are provided with holes receiving the ends of the tubes, which are conveniently united with the tube-sheets by heat-sealing. In a heat-exchanger so constructed and adapted for use in the distillation of sea-water, the tubes may extend vertically and the tube-sheets cooperate with heads on the ends of a casing to define an upper, or vapor, chamber and a lower, or condensate chamber. Sea-water supplied to the heat-exchanger just below the upper tube-sheet is caused to run down the outer surfaces of the tubes in the form of falling films from which water is to be distilled. In single-stage apparatus, vapor distilled from the falling films passes upwardly into a blower or compressor which discharges into the vapor chamber and therethrough into the upper ends of the tubes. In multi-stage apparatus, vapor from the falling films of each stage is passed to the vapor chamber of the next stage. The vapor condenses in the tubes, and the condensed fresh water runs downwardly into the condensate chamber, while the concentrated sea-water collects in the casing above the lower tube-sheet. Pressures and temperatures

within the heat-exchanger are maintained at the values necessary to effect such vaporization and condensation. Fresh water and concentrated sea-water separately withdrawn from the apparatus may be passed in heat-exchanging relationship with the entering sea-water to be distilled.

Further objects and features of the invention will become apparent from the following more detailed description and from the accompanying drawing, in which:

FIG. 1 is a vertical sectional view, largely diagrammatic in character, illustrating a single-stage apparatus, including heat-exchangers embodying my invention, suitable for use in distilling sea-water;

FIG. 2 is a fragmental view similar to FIG. 1, but on a greatly enlarged scale, illustrating details of construction;

FIG. 3 is a fragmental section on the line 3—3 of FIG. 2; and

FIG. 4 is a diagrammatic view illustrating a multi-stage distillation apparatus employing heat-exchangers embodying my invention.

The apparatus illustrated in FIG. 1 comprises a main heat-exchanger designated in its entirety by the reference numeral 10. Such heat-exchanger embodies a cylindrical shell or casing 11 closed at its ends by upper and lower heads 12 and 13. Secured in the shell 11 close to the heads 12 and 13 are upper and lower tube-sheets 14 and 15 which, with the respective heads 12 and 13, define vapor and condensate chambers 16 and 17. The tube-sheets 14 and 15 are provided with openings which receive the ends of tubes 18 formed, as previously indicated, of a synthetic resin such as polyethylene and having walls which are thin and flexible. Wall-thicknesses in the neighborhood of two mils are appropriate. If, as is preferred, the tube-sheets 14 and 15 are of synthetic plastic, the tubes 18 may be united with them by heat-sealing. To facilitate the heat-sealing operation, the holes in the tube-sheet may be countersunk as indicated in FIG. 2, thus permitting the sealing to be effected by insertion of a heated, conical element into the end of the tube.

While the synthetic resins suitable for use in forming the tubes 18 have relatively poor heat-transmitting qualities, that characteristic is in large part offset by the extreme thinness of the tube wall. Because of that thinness, it is necessary that the pressure maintained within the tube be at least as great as that outside the tube in order to prevent the tube from collapsing. Preferably the internal pressure is slightly greater than the external pressure, but the differential should of course not be great enough to incur danger of tube-rupture.

In the complete distillation apparatus shown in FIG. 1, the heat-exchanger 10 is provided with an annular liquid-receiving chamber 20, the bottom of which is formed by a horizontal partition 21 having a large central opening 22 around and spaced outwardly from which the tubes 18 are arranged. The inner wall of the chamber 20 may be an annular flange 23 that surrounds the opening 22 and extends upwardly toward the upper tube-sheet 14 which, like the partition 21, has a large central opening designated by the reference numeral 24. The partition 21 is provided with openings through which the tubes 18 respectively pass, each of such openings having a diameter corresponding to the outer diameter of the tube and provided with a circumferential series of shallow grooves 25 through which sea-water in the chamber 20 may escape to run down the outside of the tube as a thin film. Sea-water is supplied to the chamber 20 through a conduit 26 containing a pressure-reducing valve 27.

The space within the casing 11 and between the tube-sheets 14 and 15 communicates through the openings 22 and 24 and a short conduit 28 with the inlet opening of a blower 29 mounted in the vapor chamber 16. As shown,

the blower 29 is driven by a motor 30 located outside the heat-exchanger.

To maintain the desired sub-atmospheric pressure within the heat-exchanger 10, the condensate chamber 17 may be connected through a conduit 31 to any suitable type of vacuum producing device. As shown, the conduit 31 is connected to the throat of a steam ejector 32 supplied with steam from a line 33, a branch 34 of which communicates through a valve 35 with the sea-water supply conduit 26. By admitting steam into the conduit 26, the incoming sea-water may be preheated to, or approximately to, the temperature it is to have within the heat-exchanger.

A conduit 36 for the withdrawal of concentrated sea-water is connected to the interior of the shell 11 at a point just above the lower tube-sheet 15, while a second conduit 37, for withdrawal of fresh water, communicates with the condensate chamber 17. Desirably, the fresh water withdrawn through the conduit 37 and the concentrated sea-water withdrawn through the conduit 36 are passed in heat-exchanging relationship with the incoming sea-water which is to enter the heat-exchanger through the conduit 26. For that purpose, I have shown in the drawing an auxiliary heat-exchanger 38 having a first set of tubes 39 through which the fresh water withdrawn through conduit 37 is pumped by a pump 40 and a second set of tubes 41 through which the concentrated sea-water is pumped by a pump 42. The space surrounding the tubes 38 and 41 is supplied with sea-water through a conduit 43, and the sea-water so supplied is delivered to the conduit 26 for flow to the main heat-exchanger through the pressure-reducing valve 27. So far as its tubes and tube-sheets are concerned, the heat-exchanger 38 may be the same as the main heat-exchanger 10.

In operation of the system shown in FIG. 1, the blower 29 withdraws water vapor from the space surrounding the tubes 16 and delivers such vapor, under an increased pressure and temperature, to the vapor chamber 16, from which the vapor flows downwardly into the tubes 18. The sea-water delivered through the conduit 26 into the chamber 20 escapes through the grooves 25 and runs down the exterior surfaces of the tubes 18 in the form of thin films. In the tubes 18 the water vapor condenses giving off heat of condensation which is transmitted through the tube-walls to the sea-water on the outer surfaces of those walls, thus driving off vapor from such sea-water. As above indicated, the concentrated sea-water collects above the tube-sheet 15 for withdrawal through the conduit 36, while the condensed fresh water collects in the condensate chamber 17 for withdrawal through the conduit 37.

In a heat-exchanger, such as that indicated at 10, used to distill sea-water the tubes 18 may have a diameter of one inch and a length of ten feet or so. At temperatures in the neighborhood of 100° F., and at corresponding boiling-point pressures of about one pound per square inch operation of the apparatus in sea-water distillation is practical with a pressure differential on the order of one ounce per square inch. Under such operating conditions, polyethylene tubes 18 might have a wall-thickness of two mils, or even somewhat less, and still be of adequate strength. It is to be understood that these figures are set forth merely by way of example and that wide variation in them is possible.

In addition to reducing the cost of heat-exchangers, the thin-walled plastic tubes above described have a further advantage in their capability of inhibiting the build-up of scale. In the first place, the surface characteristics of the tube-walls are such that scale does not readily adhere to the walls. In the second place, distortion of the tube walls resulting from even slight variations in the pressure differential will tend to break loose any scale which might adhere to the tube surfaces. If desired, the pressure-differential may be intentionally

varied periodically to the extent necessary to produce such scale-dislodging distortion.

The multi-stage distillation apparatus shown in FIG. 4 embodies a series of heat-exchangers, 50a, 50b, etc., each generally similar in construction to the heat-exchanger 10 above described except for the omission of the blower 29 and the absence of communication between the vapor chamber 16 and the intermediate chamber in which vaporization occurs. Four of the heat-exchangers 50 are shown but it will be understood that in practice the number will usually be considerably higher. In addition to the heat-exchangers, the apparatus of FIG. 4 embodies a condenser 51 shown as of the tube-and-sheet type embodying liquid-conveying tubes 52 extending through a condensation chamber 53.

Except in the case of the last-stage heat-exchanger, designated 50d in the drawing, the upper portion of the intermediate, or vaporization, chamber of each exchanger is connected through a conduit 54 with the vapor chamber 16 of the next heat-exchanger in the series, while the lower portion of each vaporization chamber is connected through a conduit 55 and pressure reducing valve 56 with the receiving chamber 20 of the next heat-exchanger. Vapor given off in the last-stage heat-exchanger 50d flows to the condensation chamber of the condenser 51 through conduit 57, and the concentrated liquid collecting in the heat-exchanger 50d is withdrawn through conduit 58 by a pump 59. The condensation spaces of each of the heat-exchangers 50 as well as that of the condenser 51 are maintained under appropriate sub-atmospheric pressures as by being connected to the throats of ejectors 32. Except in the case of the first heat-exchanger 50a, the low points of the condensate chambers 17 are connected through pressure-reducing valves 60 to a distillate-header 61, which is also connected to the low point of the condensate chamber 53 in the condenser 51. Condensate is drawn off from the apparatus through the header 61 by a pump 62.

To provide the initial supply of heat for distillation in the several heat-exchangers 50, the vapor chamber 16 of the first heat-exchanger 50a receives steam from a boiler (not shown) through a supply line 64. Condensed steam accumulates in the condensate chamber 17 of that heat-exchanger and is returned to the boiler through a return line 65.

Sea-water or other liquid to be distilled enters the liquid spaces of the condenser 51 through a supply line 67 containing a pressure-reducing valve 68. From the condenser 51, the liquid flows through a conduit 69 to the receiving chamber 20 of the first heat-exchanger 50a, such liquid descending as falling films of the exterior surfaces of the tubes 18, as in the case of the apparatus shown in FIGS. 1-3. Vapor driven off from the falling films by heat transferred through the thin walls of the tubes 18 passes through the conduit 54 into the vapor chamber 16 of the next heat-exchanger 50b. The partially concentrated liquid collecting in the bottom of the vaporization chamber of the heat-exchanger 50a passes through the pressure-reducing valve 56 into the receiving chamber 20 of the heat-exchanger 50b, from which it descends as falling films on the outer surface of the tubes 18 of that heat-exchanger. In similar fashion vapor and liquid of progressively increasing concentration pass from one heat-exchanger to the next until the final heat-exchanger 50d is reached. From the vaporization chamber of the heat-exchanger 50d vapor passes into the condensation chamber 53 of the condenser while liquid at the bottom of the vaporization chamber of heat-exchanger 50d, in its state of final concentration is withdrawn from the pump 59.

It will be noted that in both forms of apparatus shown vaporization occurs from falling films. Vaporization from falling films in contact with heated surfaces is not broadly new; but so far as I am aware, the arrangement which provides falling films on the exterior surfaces of

heat-exchanging tubes is new and has the advantage both of providing an increase in the area of the surface from which vaporization occurs as well as making possible, in heat-exchangers of the type disclosed, a higher pressure inside the tubes than outside.

I claim:

1. In a heat-exchanger of the tube and tube-sheet type, a housing, spaced tube-sheets dividing the housing into a middle compartment and two end compartments, a plurality of tubes extending through said middle compartment and interconnecting said end compartments, each tube being a tube of substantially uniform diameter throughout its length with its ends connected in tubular configuration to said spaced tube sheets, and being formed of a thin, flexible wall of synthetic plastic resin, the thinness and flexibility and strength of the wall material being such that the tube is substantially incapable of maintaining its tubular shape in the absence of support but will be so maintained, without rupture, by a predetermined differential of inside pressure over outside pressure, and means for circulating through said middle compartment and tubes, respectively, fluids between which heat is to be interchanged through the tube-walls, said circulating means being so constructed and arranged as to maintain within the tubes a fluid pressure which exceeds that maintained in the middle compartment by a predetermined differential sufficient to maintain said tubes expanded in tubular shape.

2. A heat-exchanger as set forth in claim 1 with the addition that said tubes and tube-sheets are each formed of a synthetic plastic resin, said tube-sheets being provided with holes in which the ends of the tubes are respectively received, said tube-ends being heat-sealed to the tube-sheets.

3. A heat-exchanger as set forth in claim 1 with the addition of means to periodically vary said predetermined pressure differential to dislodge scale from the tube surfaces.

4. In a heat-exchanging still, a vertically extending housing, upper and lower horizontal tube-sheets dividing said housing into upper, middle, and lower compartments, means including a horizontal partition disposed beneath said upper tube-sheet providing an annular receiving compartment for the reception of liquid to be distilled, said receiving compartment communicating above the level of liquid therein with said middle compartment, a plurality of tubes extending through said receiving compartment, partition, and middle compartment and interconnecting said upper and lower compartments, each tube being a tube of substantially uniform diameter throughout its length with its ends connected in tubular configuration to said spaced tube sheets, and being formed of a thin, flexible wall of synthetic plastic resin, the thinness and flexibility and strength of the material being such that the tube is substantially incapable of maintaining its tubular shape in the absence of support but will be so maintained, without rupture, by a predetermined differential of inside pressure over outside pressure, said partition being provided adjacent said tubes with openings through which liquid in the receiving compartment may escape to run down the outer surface of each tube as a thin film, means for supplying liquid to said receiving compartment, means for withdrawing liquid from said lower compartment and from the bottom of said middle compartment at rates to maintain not more than low heads of liquid at the lower ends of said tubes, means for maintaining a partial vacuum within all said compartments, and means for withdrawing vapor from said middle compartment and delivering it to the upper compartment under increased pressure at a predetermined pressure differential over that of the middle compartment sufficient to maintain said tubes expanded in tubular shape.

5. In a heat-exchanging still, a vertically extending housing, upper and lower horizontal tube-sheets dividing said housing into upper, middle, and lower compartments,

means including a horizontal partition disposed beneath said upper tube-sheet providing a receiving compartment for the reception of liquid to be distilled, a plurality of tubes extending through said receiving compartment, partition, and middle compartment and interconnecting said upper and lower compartments, each tube being a tube of substantially uniform diameter throughout its length with its ends connected in tubular configuration to said spaced tube sheets, and being formed of a thin, flexible wall of synthetic plastic resin, the thinness and flexibility and strength of the material being such that the tube is substantially incapable of maintaining its tubular shape in the absence of support but will be so maintained, without rupture, by a predetermined differential of inside pressure over outside pressure, said partition being provided adjacent said tubes with openings through which liquid in the receiving compartment may escape to run down the outer surface of each tube as a thin film, means for supplying liquid to said receiving compartment, means for withdrawing liquid from said lower compartment and from the bottom of said middle compartment, means for maintaining a partial vacuum within all said compartments, and means for withdrawing vapor from said middle compartment, the means for supplying and withdrawing fluids from the respective compartments being constructed and arranged to maintain a pressure in said tubes which has a predetermined differential over the pressure in the middle compartment sufficient to maintain said tubes expanded in tubular shape.

6. In a heat-exchanger of the tube and tube-sheet type, a housing, spaced tube-sheets dividing the housing into a middle compartment and two end compartments, a plurality of tubes extending through said middle compartment and interconnecting said end compartments, each tube being a tube of substantially uniform diameter throughout its length with its ends connected in tubular configuration to said spaced tube sheets, and being formed of a thin, flexible wall of synthetic plastic resin, the thinness and flexibility and strength of the material being such that the tube is substantially incapable of maintaining its tubular shape in the absence of support but will be so maintained, without rupture, by a predetermined differential of inside pressure over outside pressure, means for supplying liquid to the outer surface of each tube to run down such outer surface of each tube as a thin film, means for supplying heat-exchange fluid to an end compartment and said tubes, means for withdrawing liquid from a lower portion of at least one of said end compartments and from the bottom of said middle compartment, means for maintaining a partial vacuum within all said compartments, and means for withdrawing vapor from said middle compartment, the means for supplying and withdrawing fluids from the respective compartments being constructed and arranged to maintain a pressure in said tubes which has a predetermined differential over the pressure in the middle compartment sufficient to maintain said tubes expanded in tubular shape.

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