July 23, 1935. H. E. A. GÖTH 2,009,175

METHOD AND APPARATUS FOR HEAT TRANSMISSION

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Fig. 1.

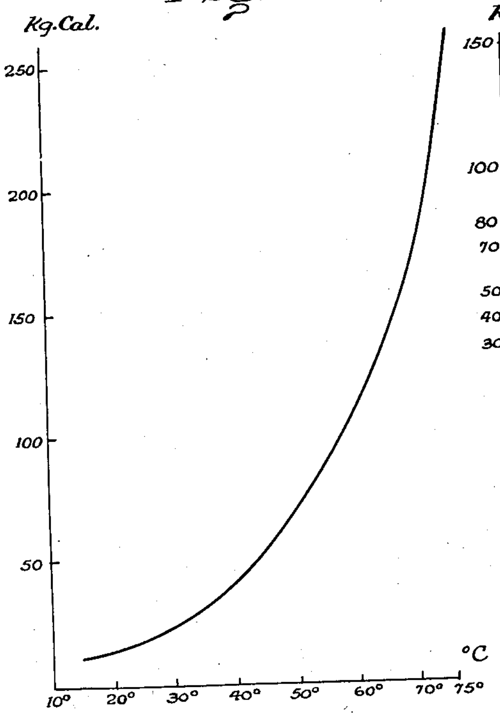


Fig. 2.

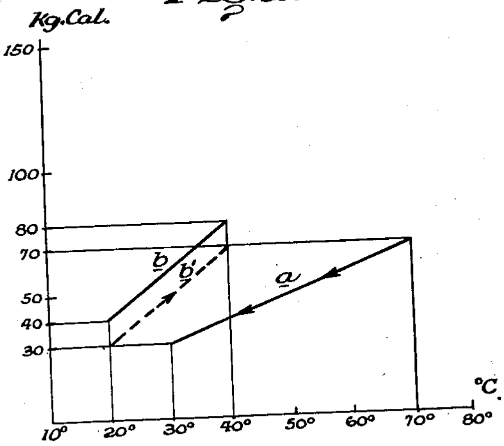


Fig. 3.

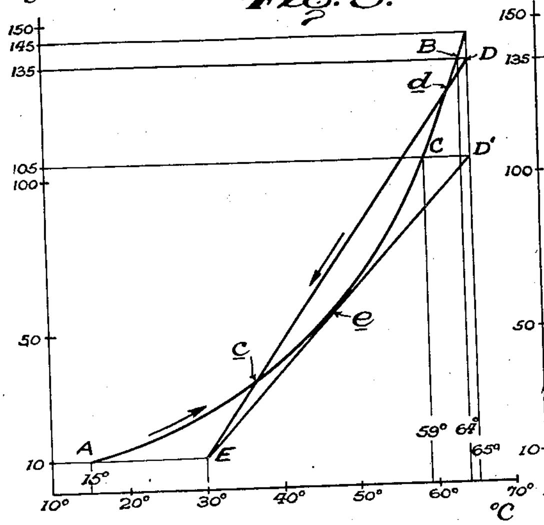
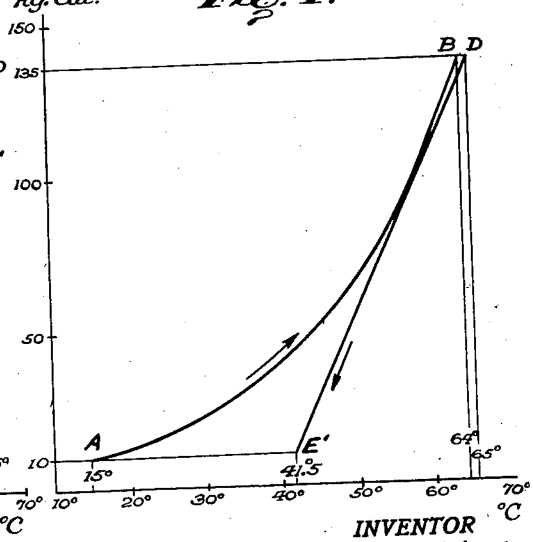


Fig. 4.



INVENTOR

Hans Elis Abraham Göth

BY

Cameron, Kerkam & Sutton ATTORNEYS

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METHOD AND APPARATUS FOR HEAT TRANSMISSION

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Fig. 5.

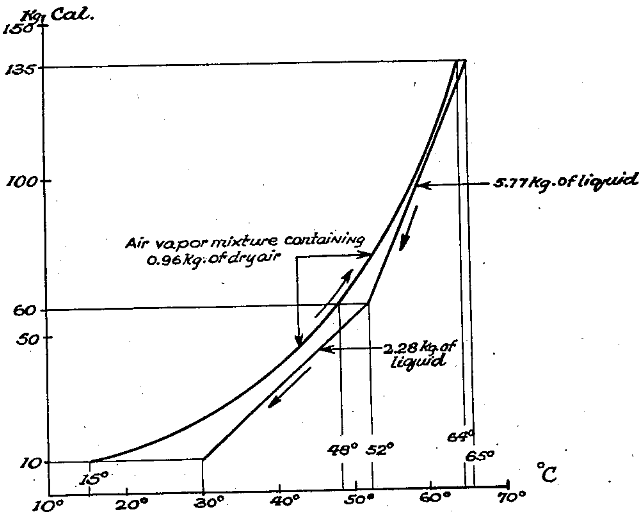


Fig. 7.

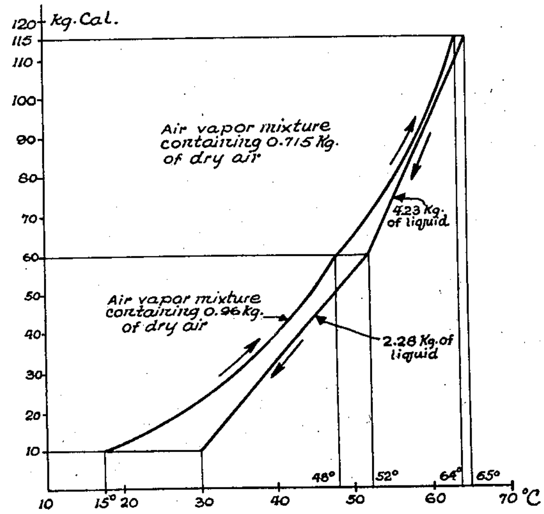
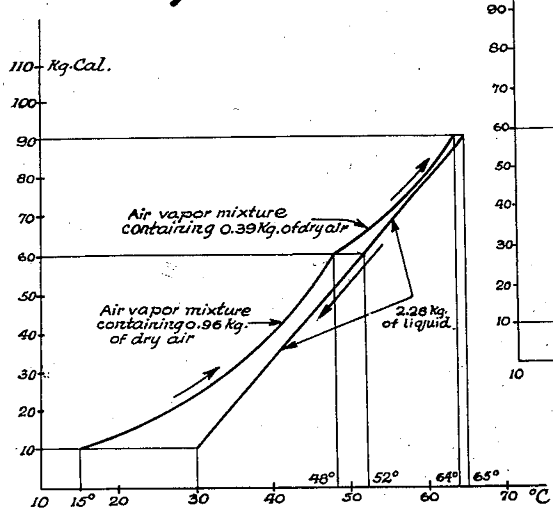


Fig. 6.



INVENTOR
Hans Elis Abraham Göth
BY
Cameron, Kerkam & Sutton ATTORNEYS

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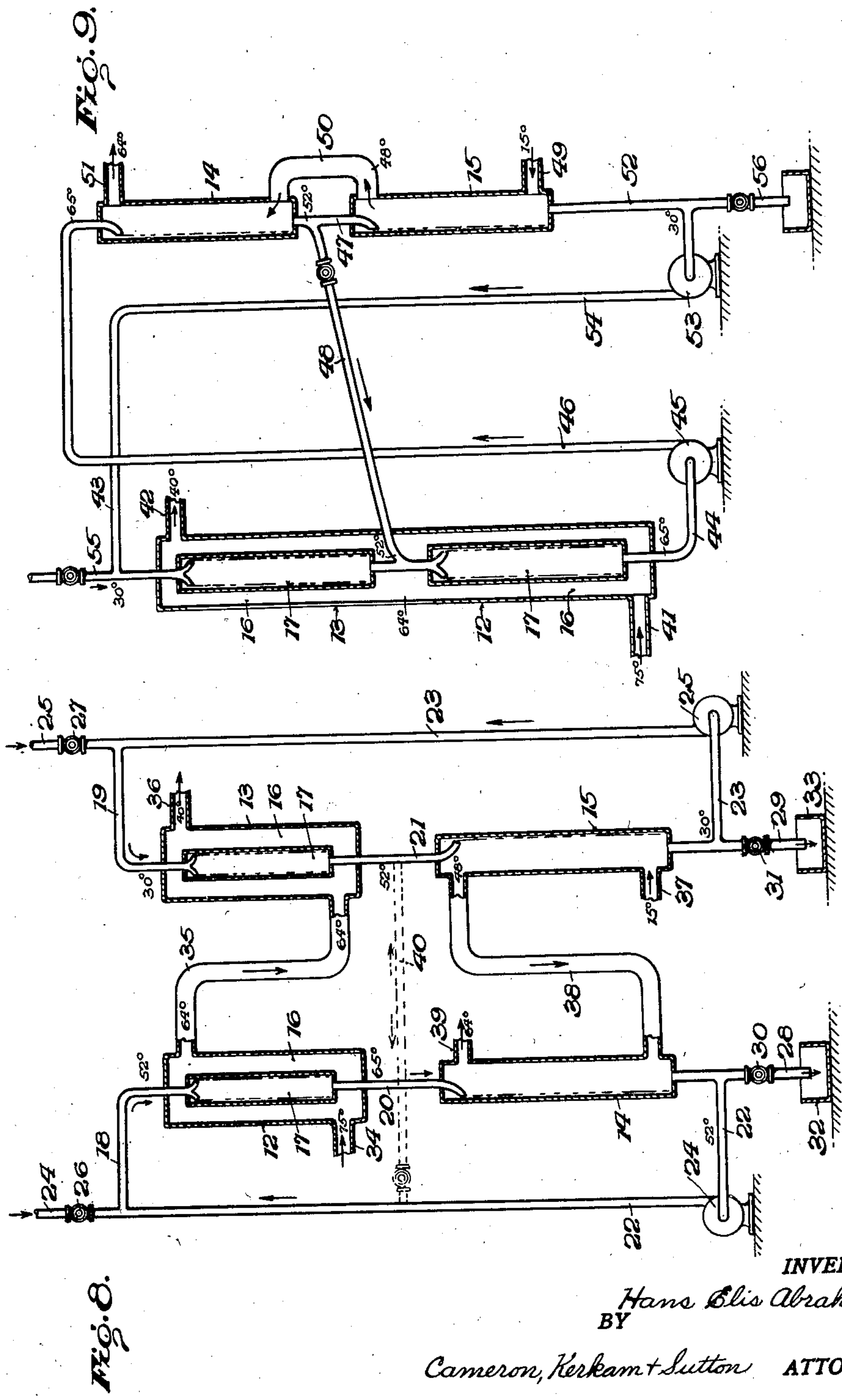

INVENTOR

Hans Elis Abraham Göth,

BY

Cameron, Kerkam + Sutton ATTORNEYS

METHOD AND APPARATUS FOR HEAT TRANSMISSION

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Fig. 11.

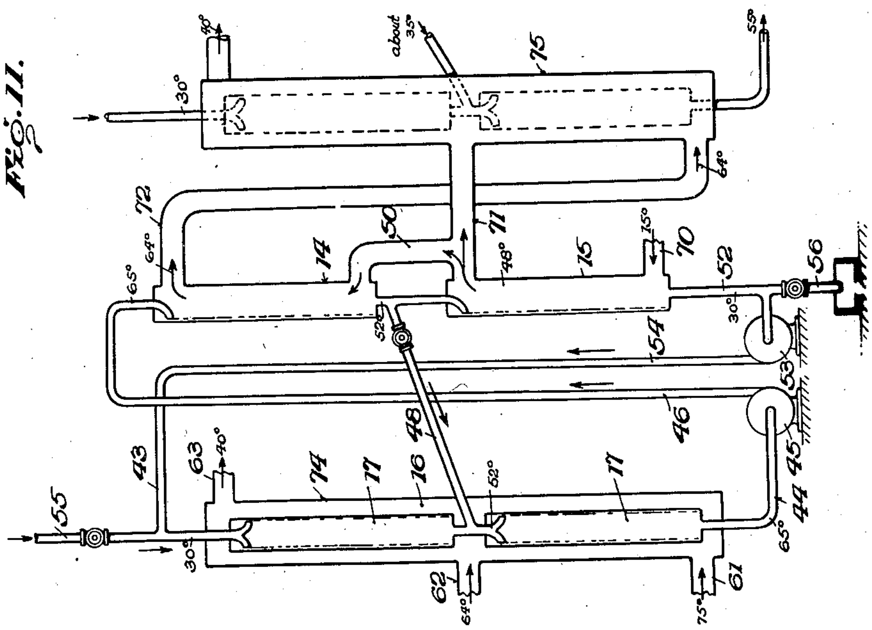
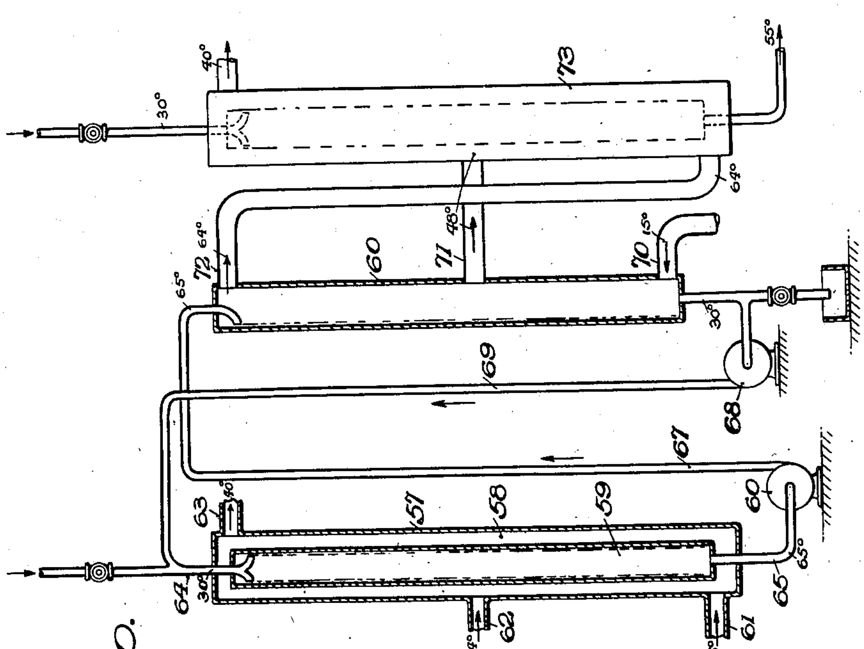


Fig. 10.



INVENTOR
Hans Elis Abraham Göth
BY
Cameron, Kerkam + Sutton ATTORNEYS

Patented July 23, 1935 2,009,175

UNITED STATES PATENT OFFICE

2,009,175

METHOD AND APPARATUS FOR HEAT TRANSMISSION

Hans Elis Abraham Göth, Stockholm, Sweden, assignor to Industrikemiska Aktiebolaget, Stockholm, Sweden, a Swedish joint-stock company

Application April 2, 1934, Serial No. 718,737
In Sweden May 22, 1930

22 Claims. (Cl. 159—16)

This invention relates to methods and apparatus for the transmission of heat, and more particularly to methods and apparatus of this character that involve the evaporation of liquids.

It is known that evaporation can be effected at atmospheric pressure by circulating the liquid to be evaporated alternately through an apparatus wherein it is heated by indirect contact with a condensible medium and through an apparatus wherein it is cooled by direct contact with a permanent gas or a vapor mixture containing a permanent gas. It has also been found that the gas vapor mixture obtained as a result of the cooling or evaporating step may be used as the condensible heating medium in the heating step of another phase of a multiple effect process, and that the relatively dry gas which results from the indirect heating step of any particular phase may likewise be utilized as the cooling or vapor absorbing medium in the evaporating step of some other phase.

For example, the application for United States Letters Patent of Erik Oman, Serial No. 362,976, filed May 14, 1929, discloses a simplified multiple effect evaporating process wherein the whole apparatus is rendered operable under one and the same total pressure, such as atmospheric pressure, by the use of a permanent gas, or gases, in mixture with vapors in giving off heat to a liquid and in evaporating the same. Furthermore, my own prior application, Serial No. 513,240, filed February 4, 1931, discloses how, in order to obtain high efficiency from the standpoint of heat economy, such an evaporating process should preferably be divided into two stages: first, the heating of the liquid to be evaporated, and, second, the cooling of the same by evaporation, both of these heat exchanging operations preferably taking place during a counterflow of the respective bodies of liquid and gas or gas vapor mixture between which the exchange of heat takes place.

As is disclosed in the last mentioned application, it may be stated, as a general rule, that in the heating of the liquid by indirect contact with a condensing gas vapor mixture it is important that the mixture be cooled down to as low a temperature as possible, a result which is attained by maintaining the initial temperature of the liquid also as low as possible. At the same time, it is also important, particularly where multiple effect evaporation is the object, that the saturation temperature of the new gas vapor mixture which is obtained at the subsequent evaporation of the heated liquid should be as high as possible.

When the liquid is circulating, and is alternately cooled by evaporation and heated by indirect heating, the initial temperature of the liquid at the beginning of the indirect heat exchange will depend ultimately upon how far the cooling by evaporation is carried. Consequently, the heat economy of the whole method will be dependent upon the manner in which the evaporation is effected. Since the amount of vapor which can be taken up by a cooling medium containing a certain amount of a permanent gas, such as air, before saturation depends upon the temperature prevailing during the evaporation (increasing where the temperature is rising), and since the prevailing temperature is greatest at the point of entrance of the hot liquid into an evaporating apparatus, the evaporative process would be substantially improved in efficiency if the difference between the temperature of the liquid and the saturation temperature of the gas were to be increased where cold gas is entering the liquid cooling or evaporating step, and, on the other hand, decreased where hot liquid is entering the same step.

The present invention relates to a novel method and apparatus for carrying out such an improved evaporating process. However, before proceeding with a detailed description of the method and apparatus forming the subject matter of the invention, it is deemed advisable to first explain the theoretical aspects of the process of evaporation of a liquid by direct contact with a permanent gas which preferably flows in countercurrent to the liquid, reference being had for this purpose to Figs. 1–4 of the accompanying drawings wherein are graphically illustrated the phenomena in question.

In connection with this explanation, it is assumed that the liquid to be evaporated consists of water and that the permanent gas is air, although it will be understood that the fundamental principles are the same for other liquids and gases. It is also assumed that a certain quantity of water of a constant initial temperature is passed in direct contact with and in countercurrent to a certain quantity of air also of constant initial temperature, whereupon evaporation takes place, the water is cooled and the air is saturated to a higher temperature. The contact surface between the air and water is assumed to be infinite in extent. All temperatures are expressed in degrees centigrade.

The calculations involved are based upon known tabular values of the content of water vapor in saturated air at a total pressure of 760 mm. of mercury and at different temperatures, and upon other known values of the specific heat, etc., of air and water. The calculations always relate to air vapor mixtures containing 1 kilogram of dry air.

Referring now to Fig. 1 of the drawings, the curve shown therein indicates the total heat (calculated from 0° C.) of 1 kilogram of air saturated with steam at temperatures between 15° and 75°, the temperature of the air vapor mixture being plotted on the abscissa in degrees centigrade, the heat content of the mixture being plotted on the ordinate in kilogram calories. It will be recognized that the curvature of the line of Fig. 1 is due to the similar shape of the steam pressure curve.

If the process of cooling or heating a certain quantity of liquid should be reproduced in a diagram of this character, such a process would be represented by a straight line (the inconsequential changes in the specific heat of the liquid being disregarded). For example, in the diagram shown in Fig. 2, line *a* represents the process of cooling 1 kilogram of water from 70° to 30°, or heating the same from 30° to 70°, while line *b* indicates a similar cooling or heating of 2 kilograms of water between the temperatures of 40° and 20°.

The calculation of the quantity of liquid represented by such a line is relatively simple. Line *b* gives, for instance:

Fall of temperature: 40°−20°=20°

Quantity of heat given off (or absorbed)=40 cal.

Specific heat of water=1

$$\text{Quantity of liquid}=\frac{40}{20}=2 \text{ kilograms}$$

If line *b* in Fig. 2 is shifted parallel to itself in the vertical direction, the new line *b'* thus obtained indicates only the rate of variation in the heat content of the liquid in heating or cooling, and differs from the line *b* in that the end points thereof no longer indicate the total heat content of that particular quantity of liquid at the respective temperatures. In other words, in a diagram such as Fig. 2, the line *b* or *b'* represents a quantity of liquid wherein the heat content varies according to the heat variation of the quantity represented by line *a*; however, as line *b'* does not pass through the same zero point as do lines *a* and *b*, the total heat content of the quantity of liquid represented by *b'* at any particular temperature cannot be determined by a simple observation of the ordinate of a point on that line corresponding to the temperature in question.

Actually, lines *a* and *b* under these conditions represent the heat exchange which would take place between the two liquid quantities referred to in the diagram when flowing in indirect contact with and countercurrent to one another. In other words, Fig. 2 is a graphical illustration of the exchange of heat which takes place when 1 kilogram of water is cooled from 70° to 30° by indirect heat exchange with 2 kilograms of water the temperature of which is thereby raised from 20° to 40°.

Now let it be assumed that the initial temperature of the water is 65°, that the initial temperature of the saturated air is 15°, and that the water is to be cooled by evaporation to 30°. Under these conditions, the problem is to ascertain whether it would be possible to obtain a final saturation temperature of the air of 64°, for example.

Fig. 1 shows that the total heats of saturated air at 64° and 15° are 137 and 10 cal./kg., respectively. Accordingly, in order to raise the temperature of 1 kilogram of saturated air from 15° to 64° by heat exchange with water, the water would be required to give off 137−10=127 calories during the process. The initial and final temperatures of the liquid having been fixed at 65° and 30°, the quantity of liquid required for the process would be

$$\frac{127}{65-30}=3.65 \text{ kilograms.}$$

Under these conditions, the process of the evaporation would be represented by the curve A—B and the line D—E in the diagram shown in Fig. 3 of the drawings. The line D—E is obtained by shifting a line corresponding to the above mentioned quantity of liquid between the temperatures of 30° and 65° parallel to itself, as discussed above in connection with Fig. 2, until point E coincides with the point having the coordinates $t=30°$, cal.=10, corresponding to the initial condition of the air, $t=15°$, cal.=10.

It will be seen that line D—E intersects the curve at two points, *c* and *d*. If the process of evaporation were really that indicated in the diagram, then, during that portion of the process which takes place between the points *c* and *d*, heat would be transmitted from a colder to a warmer medium, an obviously impossible condition. Therefore, if transmission of heat from the water to the air vapor mixture is to be actually possible, the straight line representing the cooling of the liquid must obviously never intersect the curve A—B, but must pass to the right thereof, or at the most be tangent thereto.

Thus it follows that is is not possible in a process of this kind, where the initial and final temperatures of the water and the initial temperature of the air are fixed, to choose arbitrarily the final temperature of the saturated air; but the latter is limited to a certain temperature, less than the highest temperature of the liquid, which is determined by the temperature drop which the liquid is to undergo during the evaporation (in the above example, cooling from 65° to 30°).

If, in Fig. 3, a straight line is drawn from the point E tangent to curve A—B, as at *e*, said line will intersect a vertical line corresponding to $t=65°$ at D'. A horizontal line drawn through D' will then intersect curve A—B at C, a point corresponding to $t=59°$. Point C (59°) therefore represents the highest saturation temperature to which 1 kilogram of air can be raised during the evaporative cooling from 65° to 30° of the quantity of water represented by line D'—E, assuming an infinite contacting surface between the air and liquid.

Since the line D'—E, by reason of its smaller inclination, represents a smaller quantity of liquid than the line D—E, it is obvious that with the larger quantity of liquid represented by D—E a larger quantity of air than 1 kilogram could be saturated to 59°.

While in the above example it is not possible to reach a saturation temperature higher than 59°, it is evident that under other conditions it would be possible to obtain a higher saturation temperature. For example, this may be effected by maintaining the final temperature of the liquid higher; that is, by using a comparatively smaller quantity of air for the evaporation. Such a process is illustrated by the following example.

Assuming that a final saturation temperature of 64° is desired, and that the initial temperature of the air is 15°, then 127 calories must be exchanged per kilogram of air, as above indicated. The problem is then to determine how far the liquid can be cooled.

Referring to the diagram shown in Fig. 4, the curve A—B represents the process of raising the temperature of saturated air from 15° to 64°. A horizontal line passing through point B intersects a vertical line corresponding to $t=65°$ at D. If a line is then drawn tangent to curve A—B, it will intersect a horizontal line through point A at E', corresponding to $t=41.5°$. The slope of line D—E' indicates the quantity of liquid that would be required for the process, and the point E' indicates that the lowest attainable exit temperature of the liquid will be 41.5°.

When the liquid is to be circulated in the evaporating apparatus—that is, to be cooled by evaporation in one step and then heated in a subsequent step preparatory to a second evaporation—this higher exit temperature after cooling or evaporation naturally results in an initial temperature at the subsequent heating which is higher than that originally assumed. This condition in turn limits the point to which the gas vapor mixture used for indirect heating of the liquid can be cooled, and hence prevents the attainment of maximum efficiency in the utilization of the heat content of said mixture.

The peculiar conditions that have been shown to prevail in the evaporation of a liquid with the aid of a gas obviously originate in the curved character of the steam pressure curve. As the steam pressure curves of all liquids are of similar form, the same conditions will always prevail, no matter what liquid and what gases are under consideration.

In view of the facts and phenomena set forth above, it should be clear that, in the evaporation of a fixed quantity of a liquid by means of another fixed quantity of a gas in direct contact therewith and flowing in countercurrent thereto, it will not be possible, if the initial temperatures of the liquid and the gas are fixed, to arbitrarily vary both exit temperatures. If one of the exit temperatures is fixed, there will be an inherent limiting value for the other beyond which it is physically impossible to go with the character of process thus far disclosed. It should be obvious from the above values of attainable temperatures, however, that, even if it is not possible to reach the extreme limits of cooling and heating which at first seem possible, it is nevertheless possible to effectually utilize the source of heat and simultaneously obtain a useful air vapor mixture. Thus it is always possible on this basis to construct a multiple effect system.

However, the difficulties of effectively lowering the temperature of the liquid in the evaporation process, without at the same time lowering the exit saturation temperature of the air vapor mixture too much below the initial temperature of the liquid, become greater the higher the temperature of the entering liquid.

It is therefore the principal object of the present invention to overcome these difficulties which are inherent in evaporation processes utilizing fixed quantities of liquid and gas, and to provide both a method and apparatus for carrying out the evaporative process wherein the exit temperature of the liquid and the exit saturation temperature of the gas vapor mixture are materially lower and higher, respectively, than the corresponding temperatures which are attainable in processes hitherto known to the art, thereby substantially improving their over-all efficiency. More broadly, it is the object of this invention to provide a novel method and apparatus for the transmission of heat between a liquid and a gas or a gas vapor mixture wherein the ratio of the quantity of liquid to the quantity of gas or gas vapor mixture is varied during the heat transmission.

The invention is particularly applicable to evaporating processes, and more especially to processes in which the evaporation is carried out with the aid of a permanent gas or gas mixture, and in which the liquid which is being evaporated may be alternately indirectly heated and cooled by evaporation. In such processes, the variation in the ratio of the quantity of liquid to the quantity of gas or gas mixture may be effected in various ways. For example, the variation may take place by steps at two or more different stages during the evaporative heat exchange, and may be effected either by a reduction in the quantity of liquid with respect to a fixed quantity of gas or gas vapor mixture, or by a reduction in the quantity of the gas or gas vapor mixture with respect to a fixed quantity of liquid, or by a combination of both of these procedures. The variation may also be accomplished by using separate, different quantities of either liquid or gas vapor mixture in successive stages of the process, or each stage may have its own individual quantities of both liquid and gas vapor mixture.

If the variation in ratio is effected by withdrawing some of the liquid and thereby reducing its quantity as compared with the quantity of the gas or gas vapor mixture, and the process contemplates the subsequent reheating of the liquid after cooling by evaporation, the quantity of liquid withdrawn at any stage may be added to some other quantity of liquid which is in the process of being heated, preferably at a stage of heating of the latter where its temperature corresponds to the temperature of the liquid withdrawn, the heating of both quantities thereafter continuing together.

The invention will be more clearly understood by reference to the accompanying drawings wherein several different embodiments of the method and apparatus constituting the present invention are disclosed, it being distinctly understood, however, that these drawings are for the purpose of illustration only and are not to be construed as defining the scope of the invention, reference for the latter purpose being had to the appended claims.

In the drawings, wherein like reference characters indicate like parts throughout the several views:

Figs. 5, 6 and 7 are diagrams, somewhat similar to Figs. 3 and 4, graphically illustrating three different embodiments of the method of the present invention as applied to the evaporation of a liquid by direct contact with and in counterflow to a gas or a gas vapor mixture;

Fig. 8 is a schematic diagram of one form of apparatus embodying the present invention wherein separate, different quantities of liquid are successively indirectly heated and cooled by evaporation by the same quantities of heating medium and gas or gas vapor mixture, respectively;

Fig. 9 is a diagram similar to Fig. 8 of another form of apparatus embodying the present invention wherein the heating and evaporating processes are carried out in two stages with a variation in the quantity of the liquid between said stages;

Fig. 10 is a diagram similar to Fig. 8 of still another form of apparatus embodying the present invention wherein the variations in the ratios above mentioned are effected by adding to or withdrawing from the quantity of gas or gas vapor mixture which is being used for heating or evaporating a fixed quantity of liquid; and

Fig. 11 is a diagram of an apparatus embodying the features of both Figs. 9 and 10.

Referring first to Fig. 5, there is indicated therein a two-stage evaporative process whereby water may be cooled from 65° to 30° by direct contact with air having an initial saturation temperature of 15° and a final saturation temperature of 64°, the conditions which it was found could not be met in a single step process such as that indicated in Fig. 3. As shown, in the first stage of the process a certain quantity of air having an initial saturation temperature of 15° is flowed in direct contact with and countercurrent to a quantity of water having an initial temperature of 52°. During the counterflow evaporation takes place which lowers the temperature of the liquid to 30° and at the same time raises the saturation temperature of the air to 48°. The air is then brought into contact with and continues its flow counter to that of another and larger quantity of liquid, evaporation of which raises the saturation temperature of the air to 64° while the liquid is cooled from 65° to 52°.

In the first stage, the heat content of the liquid is reduced by 60—10=50 calories while the temperature of the liquid is lowered 52°—30°=22°. Hence the calculated quantity of liquid which is supplied to the first stage is

$$\frac{50}{22}=2.28 \text{ kilograms}$$

Computed in the same manner, the quantity of liquid which can be cooled by evaporation in the second stage of the process is

$$\frac{75}{13}=5.77 \text{ kilograms}$$

Since it is assumed that the amount of heat given off by the liquid is absorbed without loss by the air during the evaporating process, the total heat content of the air during its heating from 15° to 64° increases from 10 to 135=125 kg. cal. Since, according to Fig. 1, 1 kilogram of dry air takes up approximately 140—10=130 kg. cal. in being heated from 15° to 64°, a gas vapor mixture containing

$$\frac{125}{130}=0.96 \text{ kilogram}$$

of dry air is necessary for cooling the above quantities of liquid by evaporation between the stated temperatures.

Carrying out the evaporation in this manner involves a decided advantage over and results in a greater efficiency than the single step evaporative processes hitherto known. It will be seen from the diagram and the above numerical example that the air vapor mixture obtained in the evaporating process has an exit saturation temperature of 64°, and also that a portion of the liquid can be cooled down to an exit temperature of 30°. Thus, by drawing off a portion of the liquid after it has been cooled from its initial temperature by a certain amount, and then continuing the cooling evaporative process with the reduced amount of liquid but with the same amount of air—that is, by reducing the ratio of the quantity of liquid to the quantity of the air vapor mixture during the course of evaporation—it is possible to accomplish results which are shown in Fig. 3 to be impossible of achievement with fixed quantities of both liquid and air. The quantity of liquid cooled to 30° also makes possible a more effective utilization of the source of heat in the subsequent repeated heating of the liquid in processes where alternate heating and cooling are employed and where the heating medium comprises a condensible gas vapor mixture.

In Fig. 6 there is diagrammatically illustrated an evaporating process wherein the same initial and exit temperatures of both liquid and gas are obtained as in the process of Fig. 5, but wherein the variation in the ratio between the quantities of liquid and gas or gas vapor mixture is attained by decreasing the quantity of the gas by withdrawing a portion thereof at a point intermediate the beginning and ending of the evaporative process while maintaining the quantity of liquid constant. It will also be noted that the total heat transferred during the process of Fig. 6 is less than in the process of Fig. 5.

As shown, a certain quantity of air having an initial saturation temperature of 15° is flowed in direct contact with and countercurrent to a quantity of the water to be evaporated until the saturation temperature of the air is raised to 48°. At the same time, the liquid is cooled from a temperature of 52° to 30°. At this point, some of the air vapor mixture is withdrawn and the evaporative process continues with the smaller quantity thereof in contact with the same quantity of liquid that was used in the first mentioned stage of the process. This second stage raises the saturation temperature of air to 64° while the liquid is cooled from 65° to 52°.

Since in the first mentioned interval of this process the conditions of temperature and variation in heat content of the air and liquid are the same as in the process illustrated in Fig. 5, the relative quantities of air and liquid will be the same as in the latter process, namely, 0.96 kilogram of dry air and 2.28 kilograms of liquid. In the second stage of the process of Fig. 6, however, the quantity of liquid remains the same as in the first stage (2.28 kilograms) but the quantity of dry air contained in the air vapor mixture is substantially reduced. In this second stage, the saturation temperature of the air vapor mixture is raised from 48° to 64°, during which increase in temperature the total heat content of 1 kilogram of dry air, as computed from Fig. 1, would increase 137—60=77 kg. cal. However, at the same time, the water gives up 90—60=30 calories, all of which it is assumed is absorbed by the air with which it is in contact. Consequently, a gas vapor mixture containing

$$\frac{30}{77}=0.39 \text{ kilogram}$$

of dry air is necessary for cooling the 2.28 kilograms of liquid from 65° to 52° during the second stage of the evaporative process.

The process illustrated by the diagram of Fig. 7 is a combination of the processes of Figs. 5 and 6 in that the variation in the ratio between the quantities of gas or gas vapor mixture and liquid is accomplished by varying both the quantity of gas and the quantity of liquid in the two stages of the process. In this instance, it will be noted that the total heat transferred during the cooling of the liquid from 65° to 30° is intermediate the quantities transferred in the processes of Figs. 5 and 6.

By computations similar to those above set forth in connection with the processes of Figs. 5 and 6, it can readily be established that by utilizing a gas vapor mixture containing 0.96 kilogram of dry air in the first stage wherein its saturation temperature is raised from 15° to 48°, and 0.715 kilogram of dry air in the second stage wherein the saturation temperature is further increased from 48° to 64°, 4.23 kilograms of water can be cooled by evaporation from 65° to 52°, and 2.28 kilograms thereof then cooled from 52° to 30°, thereby again attaining the advantages and improved results discussed above in connection with the process illustrated in Fig. 5.

Having now described in detail the concept of the present invention as applied to the process of evaporation, reference may now be had to Figs. 8–11 wherein there are disclosed various forms of apparatus by which the method of the present invention may be practiced. In general, such an apparatus comprises a suitable arrangement of means for flowing a liquid and a gas or gas vapor mixture in direct contact with but countercurrent to one another during which flow heat may be transmitted between the gas or gas vapor mixture and the liquid, as by evaporation of the latter, and means for varying the ratio between the quantities of gas or gas vapor mixture and liquid during the heat transmission by either drawing off a portion of the liquid or withdrawing a portion of the gas or gas vapor mixture at some point intermediate the beginning and ending of the heat transmission process. It is also preferable that the means for carrying out the heat transmission or evaporation be combined with a suitable heater or heaters wherein the liquid may be heated, preferably by indirect contact with a condensible gas vapor mixture, prior to entering the evaporating apparatus.

Referring first to Fig. 8, there is diagrammatically illustrated therein an evaporating system operating upon the principles above set forth, and corresponding to the evaporating process indicated in the diagram of Fig. 5. In the embodiment disclosed, the variation in the ratio between the quantities of gas or gas vapor mixture and liquid is attained by utilizing entirely separate, different quantities of liquid in the two stages of the evaporative process while at the same time maintaining the quantity of gas or gas vapor mixture constant in both of said stages. Furthermore, the heating of the liquid prior to evaporation is also divided into two stages in both of which the same quantity of heating medium is utilized with the different quantities of liquid, thereby increasing the efficiency of the heat transfer in the same manner as has previously been described in connection with the evaporating process.

As shown, the heating takes place in a pair of heaters 12 and 13 of any suitable character, while the evaporation is effected in evaporators 14 and 15. Preferably, each of the heaters comprises an outer chamber 16 for the heating medium and an inner separate chamber 17 through which flows the liquid to be heated, the heat transmission taking place through the relatively thin walls of inner chambers 17. Each of the evaporators, however, consists of a single chamber wherein the liquid and gas or gas vapor mixture are in direct contact with but flow in countercurrent to one another. Heater 12 and evaporator 14 form one system while heater 13 and evaporator 15 form another, and the two systems are so designed as to operate with different quantities of liquid.

Heaters 12 and 13 are provided with conduits 18 and 19, respectively, which supply different quantities of liquid to the tops of inner chambers 17 and direct the liquid against the walls thereof in such a manner that it flows downwardly thereover in relatively thin layers. From the bottoms of inner chambers 17 the two different quantities of now heated liquid are conducted by conduits 20 and 21, respectively, to the tops of the chambers of evaporators 14 and 15 where the liquid is again directed against the walls of the chambers and flows downwardly thereover in thin streams. The unevaporated quantities of liquid leaving evaporators 14 and 15 are returned through conduits 22 and 23, by means of suitable pumps 24 and 25, to conduits 18 and 19, respectively, for recirculation through the heaters and evaporators. Fresh liquid may be supplied to heaters 12 and 13 through conduits 24 and 25, respectively, controlled by valves 26 and 27. Concentrated liquid may be drawn off from evaporators 14 and 15 through conduits 28 and 29, respectively, controlled by valves 30 and 31, into suitable collecting vessels 32 and 33.

Heater 12 is also provided with a conduit 34 connected to the bottom thereof and leading into the outer chamber 16 through which a condensible gas vapor mixture may be supplied for heating purposes. The heating medium supplied through conduit 34 flows upwardly through outer chamber 16, giving up its heat to the counterflowing liquid in chamber 17, and passes from the top of heater 12 through a conduit 35 to the bottom of heater 13 at which point it enters outer chamber 16 thereof. After flowing upwardly through heater 13, the heating medium is drawn off from the top thereof through the conduit 36 whence it may be supplied to the evaporating apparatus of another unit or otherwise disposed of in any suitable manner.

The flow of the evaporating gas or gas vapor mixture is opposite to that of the heating medium in that it is first supplied to evaporator 15 where it comes into contact with the liquid from heater 13, the latter constituting the second stage of the heating process. As shown, the evaporating gas or gas vapor mixture is supplied to the bottom of evaporator 15 through a suitable conduit 37, flows upwardly through the chamber of said evaporator in direct contact with but counter-current to the liquid therein, is conducted from the top of evaporator 15 through a conduit 38 to the bottom of evaporator 14, and after upward flow therethrough is drawn off from the top thereof through conduit 39. The gas vapor mixture leaving evaporator 14 through conduit 39 is supplied to the heater of another unit and there utilized as the heating medium.

In operation, the liquid is supplied to the system comprising heater 12 and evaporator 14 in a relatively larger quantity than it is to the system comprising heater 13 and evaporator 15. As indicated by way of example in Fig. 8, the temperature of the liquid supplied to heater 12 may be approximately 52°, and in its downward passage therethrough may be heated to approximately 65°, while at the same time the heating medium may be cooled from an initial temperature of 75° to an exit temperature of 64°. This quantity of liquid at 65° is then supplied to evaporator 14 wherein it may be cooled by evaporation to 52° by a gas or gas vapor mixture having an initial saturation temperature of 48° and an exit temperature of 64°. On the other hand, the liquid supplied to heater 13 may have an initial temperature of 30° and be heated to 52° by the heating medium leaving heater 12, the temperature of which will be 64° at entrance and 40° at exit. This relatively smaller quantity of liquid leaving heater 13 at 52° may then be cooled by evaporation back to 30° in evaporator 15 by the same quantity of gas or gas vapor mixture which passes through evaporator 14, but during the time that the temperature thereof is first raised from 15° to 48°.

It will be obvious from a comparison of the temperatures of the various quantities of liquid and gas or gas vapor mixture above referred to that the apparatus thus described is capable of carrying out the process indicated in Fig. 5.

Suitable means, such as a cross connecting conduit 40 indicated in dotted lines in Fig. 8, may also be provided for transferring liquid from the system comprising heater 12 and evaporator 14 to the system comprising heater 13 and evaporator 15, and vice versa, for the purpose of regulating the ratio between the different quantities of liquid in the two systems, or for regulating the concentrations thereof. It will be noted that the transfer of liquid through conduit 40 preferably takes place between points where the liquid in the two systems is of the same temperature.

As pointed out above, heater 12 and evaporator 14, and heater 13 and evaporator 15, form two separate systems with respect to the circulating quantities of liquid. The only condition other than those already specified that must be met in order for the evaporating process to take place in accordance with the diagram of Fig. 5 is that the quantities of liquid circulating in the two systems conform to the ratio 2.28:5.77.

In Fig. 9 there is shown an evaporating system in which the temperatures are the same as in the apparatus of Fig. 8, but in which the variation in the ratio between the quantities of liquid and gas or gas vapor mixture is effected by drawing off a portion of the liquid during the evaporative process.

In the apparatus shown, 12 and 13 indicate the heaters, and 14 and 15 the evaporators, as in the embodiment of Fig. 8. However, it will be noted that, as a matter of expediency, the two heaters may be combined in a single, outer casing so that the two outer chambers 16 are continuous one with the other. The heating medium enters the bottom of the combined heating unit through a conduit 41 at a temperature of 75°, and leaves through a conduit 42 at a temperature of 40°. The liquid, which enters through conduit 43 and leaves through conduit 44, is raised in temperature from 30° to 65° by heat transmitted from the heating medium. The liquid thus heated is then supplied by a pump 45 through a conduit 46 to the evaporator 14. After passing through this evaporator, the liquid is divided into two parts, one of which passes through the conduit 47 to the evaporator 15, while the other passes through the cross connecting conduit 48 to the heater 12.

Air of a saturation temperature of 15° is introduced to the bottom of evaporator 15 through the conduit 49, passes through the evaporator 15 in counterflow to the liquid and is heated to a saturation temperature of 48°, then through the conduit 50 to the evaporator 14, and leaves the latter at 51 at a saturation temperature of 64°. That portion of the liquid which passes through evaporator 15 leaves through the conduit 52 and is supplied by means of a pump 53 through a conduit 54 to the top of heater 13. Fresh liquid may be supplied through conduit 55, when desired, while concentrated liquid may be drawn off at 56.

The temperatures shown in Fig. 9 correspond to a branching off of a quantity of liquid through the conduit 48 equal to

$$\frac{5.77-2.28}{5.77}\times 100=60.5\%$$

of the liquid quantity leaving the evaporator 14.

As previously stated, the variation in the ratio between the quantities of liquid and gas or gas vapor mixture may also be varied by decreasing the quantity of gas utilized in successive stages of the process while maintaining the quantity of liquid constant, or by varying the quantities of both liquid and gas. In principle, these procedures do not differ from those above described, inasmuch as the improved results which flow from the present invention are obtained because of the variation in the ratio between the gas and liquid quantities, irrespective of the specific manner in which that variation is effected.

For example, the method of the present invention may also be carried out in apparatus such as that disclosed in Fig. 10, wherein the variation in the ratio referred to is effected by varying the quantity of gas or gas vapor mixture which is utilized during different stages of the process, according to the process illustrated by the diagram of Fig. 6.

As shown, the apparatus comprises a heater 57 having a relatively long casing in which are provided an outer chamber 58 and an inner chamber 59, corresponding to the chambers 16 and 17 of Figs. 8 and 9, and an evaporator 60. A certain quantity of the heating medium at a temperature of 75° is supplied to the bottom of heater 57 through a conduit 61, while an additional quantity at a lower temperature of 64°, for example, is supplied through conduit 62 at a point intermediate the ends of the heater. All of the heating medium is withdrawn from heater 57 at the top thereof through conduit 63, at which point it has all been cooled to a temperature of 40°. The liquid to be heated is supplied to heater 57 at the top of chamber 59 through a conduit 64 at a temperature of 30° and leaves through conduit 65 at a temperature of 65°, whence it is supplied by means of a pump 66 through a conduit 67 to the top of evaporator 60. In passing downwardly through evaporator 60 in direct contact with and countercurrent to the cooling gas or gas vapor mixture, the liquid is cooled from 65° to 30°, and after leaving evaporator 60 is returned to the top of heater 57 by means of a pump 68 and through a conduit 69.

The cooling gas or gas vapor mixture is supplied to the bottom of evaporator 60 through conduit 70 at a temperature of 15° and passes upwardly in heat exchange contact with and countercurrent to the liquid until its saturation temperature has been raised to 48°, at which time a portion of the gas is drawn off through conduit 71. The remainder of the gas continues its flow through the evaporator to the top thereof at which point it is drawn off through conduit 72 at a temperature of 64°.

The temperatures thus indicated correspond to a branching off of a quantity of gas through conduit 71 equal to

$$\frac{.96-.39}{.96}\times 100=59.4\%$$

of the total gas quantity reaching the point where conduit 71 branches off from the evaporator 60.

Since the quantities of gas or gas vapor mixture leaving evaporator 60 through conduits 71 and 72 have been heated and saturated with steam by contact with the liquid, they are capable of use for indirect heating of liquid in the heater of another system of the same type. In such event, as is indicated in Fig. 10, the gas vapor mixture leaving evaporator 60 through conduit 72 will enter the heater 73 of the following system at the bottom thereof, while the quantity of said mixture which is drawn off through conduit 71 will be introduced at some suitable intermediate point. Similarly, the heating medium leaving heater 57 through conduit 63 at 40° may, if desired, be returned to the evaporator of the preceding system and introduced thereinto as the evaporating medium through a conduit corresponding to conduit 70.

The apparatus shown in Fig. 11 combines the features of both Figs. 9 and 10, and provides a system wherein the variation in the ratio of the quantities of liquid and gas or gas vapor mixture is effected by changing the quantities of both the liquid and the gas or gas vapor mixture. As shown, the heater 74 of the first system or unit is similar to that shown in Fig. 9 in that it has two separate liquid chambers 17 within a common casing which forms one elongated gas chamber 16. The liquid to be heated is supplied to heater 74 through a conduit 43 at a temperature of 30°, and after passing through both sections of the heater is withdrawn through conduit 44 at a temperature of 65°. The heating medium, however, is supplied to heater 74 in two portions, as in Fig. 10, one portion entering the bottom of the heater through conduit 61 at a temperature of 75° and another portion entering through conduit 62 at 64° at the point where the liquid passes from the upper to the lower inner chamber 17 and is increased in quantity by the portion which is withdrawn from the evaporator 14 through conduit 48. All of the heating medium leaves heater 74 through conduit 63 at a temperature of 40°. The heated liquid leaving the heater through conduit 44 is supplied by pump 45 through conduit 46 to the top of evaporator 14. After passing through evaporator 14, a portion of the liquid is drawn off through conduit 48, as previously mentioned, the remainder continuing the evaporative process in evaporator 15 and finally being drawn off through conduit 52 and recirculated by pump 53 through conduit 54 to the top of heater 74.

While the treatment of the liquid in the evaporating process is similar to that shown in Fig. 9, the apparatus of Fig. 11 also includes means for varying the quantity of the evaporating gas or gas vapor mixture in the manner indicated in Fig. 10. Accordingly, gas or gas vapor mixture at a temperature of 15° is supplied to the bottom of evaporator 15 through a conduit 70, and, after passing upwardly through evaporator 15 and having its temperature raised to 48°, a portion thereof is withdrawn through conduit 71 and supplied to an intermediate point in the heater 75 of the next succeeding unit or system. The remainder of the evaporating gas or gas vapor mixture passes upwardly through conduit 50 and evaporator 14 to exit conduit 72 whence, at a temperature of 64°, it may be supplied to the bottom of heater 75, as in Fig. 10.

In order to carry out the process indicated in the diagram of Fig. 7 by means of the apparatus shown in Fig. 11, it is necessary that the quantity of liquid withdrawn through conduit 48 be equal to

$$\frac{4.23-2.28}{4.23}=46.1\%$$

of the total liquid quantity leaving evaporator 14, and that the quantity of gas withdrawn through conduit 71 be equal to

$$\frac{.96-.715}{.96}=25.5\%$$

of the total gas quantity leaving the top of evaporator 15.

Obviously, the above described methods and apparatus for effecting evaporation are applicable no matter what liquids or liquid mixtures or gases or gas mixtures are involved.

It will be understood that in actual practice the processes above described will be somewhat more complicated in so far as the computation of the exact temperatures and quantities is concerned because of the fact that the respective quantities of liquid are not actually constant throughout the evaporating process due to the evaporation itself. However, the small discrepancies which would therefore exist between the values shown in the drawings and above referred to and the actual values are immaterial for an understanding of the principle upon which the present invention is based and in no way affect the inventive concept.

It will be evident that the invention is not limited to processes of two stages but that the evaporating process may be subdivided into any suitable number of stages or intervals, each operating with a suitable quantity of liquid in the manner above described. Likewise, a plurality of systems or units may obviously be combined with one another in order to attain multiple effect evaporation.

While a number of embodiments of the method and apparatus of the present invention have been described and illustrated in the accompanying drawings, it is to be expressly understood that the invention is not limited to the use of the specific apparatus shown or to the exact procedural steps described, but that any suitable type of apparatus and any appropriate procedure may be used which will enable the invention to be carried into effect. It will also be apparent that the medium to be evaporated is not limited to water or to a pure liquid, but may be a suspension of solid in liquid or a mixture of liquids, for example. Likewise any suitable gas or gas vapor mixture may be utilized in place of air as disclosed. Various other changes, which will now appear to those skilled in the art, may be made in the details of construction and arrangement of the parts of the apparatus, and in the various steps of the process, without departing from the spirit of the invention. Reference is therefore to be had to the appended claims for a definition of the limits of the invention.

This application is a continuation in part of my application Serial No. 538,931, filed May 21, 1931.

What is claimed is:

1. In a method of transmitting heat between a liquid and a gas or gas vapor mixture, the steps

comprising flowing the liquid and gas or gas vapor mixture in heat exchanging relation with but countercurrent to one another, and increasing the ratio of the quantity of liquid to the quantity of gas or gas vapor mixture when the temperatures thereof reach predetermined points intermediate the desired initial and final temperatures.

2. In a process of evaporating liquids which consists in flowing the liquid to be evaporated in direct heat exchange contact with but countercurrent to a gas or gas vapor mixture having a relatively lower temperature, the step of increasing the ratio of the quantity of liquid to the quantity of gas or gas vapor mixture in contact therewith when the temperatures thereof reach predetermined points intermediate the desired initial and final temperatures.

3. The process step of claim 2 wherein the variation in the ratio of the quantity of liquid to the quantity of gas or gas vapor mixture is effected by withdrawing a quantity of liquid from the quantity initially brought into contact with the gas or gas vapor mixture.

4. The process step of claim 2 wherein the variation in the ratio of the quantity of liquid to the quantity of gas or gas vapor mixture is effected by withdrawing a quantity of gas or gas vapor mixture from the quantity initially brought into contact with the liquid.

5. The process step of claim 2 wherein the variation in the ratio of the quantity of liquid to the quantity of gas or gas vapor mixture is effected by withdrawing quantities of both liquid and gas or gas vapor mixture from the quantity of each initially brought into contact with the other.

6. The process of evaporating liquids which consists in flowing the liquid to be evaporated in direct heat exchange contact with but countercurrent to a gas or gas vapor mixture having a relatively lower temperature than said liquid until the temperature of said gas or gas vapor mixture is increased to a predetermined point, limiting the quantities of liquid and gas or gas vapor mixture in contact during the aforesaid portion of the process to a predetermined ratio, and then increasing the ratio of liquid to gas or gas vapor mixture and continuing the counterflow until the temperature of said gas or gas vapor mixture attains a still higher predetermined point, whereby the process of evaporation can be carried out at a materially higher efficiency than if said ratio were maintained constant throughout the process.

7. A method of evaporating liquids which consists in heating by indirect contact with a heating medium a certain quantity of liquid to be evaporated, then utilizing said same heating medium for indirectly heating another quantity of said liquid smaller in quantity and of lower initial temperature than said first named quantity, and conducting a quantity of gas or gas vapor mixture of lower temperature than said liquids into direct heat exchange contact with but counter-current to said last named and first named quantities of indirectly heated liquid successively to effect evaporation thereof.

8. The process of evaporating liquids which consists in flowing a certain quantity of the liquid to be evaporated at a relatively high initial temperature in direct heat exchange contact with but countercurrent to a gas or gas vapor mixture having a relatively low initial temperature until the temperature of said gas or gas vapor mixture is increased to a predetermined point, the temperature of said liquid being correspondingly lowered during the counterflow due to evaporation, and then bringing said gas or gas vapor mixture into direct heat exchange contact with a greater quantity of said liquid having an initial temperature higher than the initial temperature of said first named quantity and continuing the counterflow to effect evaporation of said last named quantity of liquid.

9. The process of evaporating liquids which consists in flowing the liquid to be evaporated at a relatively high initial temperature in direct heat exchange contact with but countercurrent to a certain quantity of a gas or gas vapor mixture having a relatively low initial temperature until the temperature of said liquid is decreased to a predetermined point, the temperature of said gas or gas vapor mixture being correspondingly raised during the counterflow due to evaporation, and then bringing said liquid into direct heat exchange contact with a greater quantity of said gas or gas vapor mixture having an initial temperature lower than the initial temperature of said first named quantity and continuing the counterflow to complete evaporation of the liquid.

10. The process of evaporating liquids which consists in flowing a certain quantity of the liquid to be evaporated at a relatively high initial temperature in direct heat exchange contact with but countercurrent to a gas or gas vapor mixture having a relatively low initial temperature until the temperature of said gas or gas vapor mixture is increased to a predetermined point, the temperature of said liquid being correspondingly lowered during the counterflow due to evaporation, then bringing said gas or gas vapor mixture into direct heat exchange contact with a greater quantity of said liquid having an initial temperature higher than the initial temperature of said first named quantity and continuing the counterflow to effect evaporation of said last named quantity of liquid, heating the unevaporated portions of said quantities of liquid to their initial temperatures, and recirculating said heated portions through their respective evaporating cycles.

11. The process of evaporating liquids which consists in flowing a certain quantity of the liquid to be evaporated at a relatively high initial temperature in direct heat exchange contact with but countercurrent to a gas or gas vapor mixture having a relatively low initial temperature until the temperature of said gas or gas vapor mixture is increased to a predetermined point, the temperature of said liquid being correspondingly lowered during the counterflow due to evaporation, then bringing said gas or gas vapor mixture into direct heat exchange contact with a greater quantity of said liquid having an initial temperature higher than the initial temperature of said first named quantity and continuing the counterflow to effect evaporation of said last named quantity of liquid, heating the unevaporated portions of said quantities of liquid to their initial temperatures, and recirculating said heated portions through their respective evaporating cycles, said heating step including the circulation of a quantity of heating medium of relatively high initial temperature in indirect contact with said unevaporated portions successively, the unevaporated portion of the last named greater quantity of liquid being the first to be heated by said heating medium.

12. The process of evaporating liquids which

consists in flowing a certain quantity of the liquid to be evaporated at a relatively high initial temperature in direct heat exchange contact with but countercurrent to a gas or gas vapor mixture having a relatively low initial temperature until the temperature of said gas or gas vapor mixture is increased to a predetermined point, the temperature of said liquid being correspondingly lowered during the counterflow due to evaporation, then bringing said gas or gas vapor mixture into direct heat exchange contact with a greater quantity of said liquid having an initial temperature higher than the initial temperature of said first named quantity and continuing the counterflow to effect evaporation of said last named quantity of liquid, heating independently of one another the unevaporated portions of said quantities of liquid to their initial temperatures by indirect contact with another gas vapor mixture, and recirculating said heated portions through their respective evaporating cycles.

13. A method of evaporating liquids comprising simultaneously circulating in two separate systems two different quantities of the liquid to be evaporated, the liquid in each system first being heated by indirect contact with a quantity of heating medium and then being flowed in direct heat exchange contact with but countercurrent to a quantity of gas or gas vapor mixture of a temperature lower than that of said liquid to effect evaporation of the latter, the larger quantity of liquid being of the higher initial temperature, heating the different quantities of liquid in the two systems successively by the same heating medium by first utilizing the latter in the system containing the larger quantity of the liquid and then in the system containing the smaller quantity, and evaporating said quantities of liquid successively by the same gas or gas vapor mixture but in the reverse order to that in which said quantities are heated.

14. In the method of evaporating liquids of claim 13, the step of transferring liquid from one system to the other between points at which substantially the same liquid temperatures prevail.

15. The method of evaporating liquids which consists in heating by indirect contact with a heating medium a certain quantity of liquid to be evaporated, utilizing said same heating medium for indirectly heating another quantity of said liquid smaller in quantity and of lower initial temperature than said first named quantity, conducting a quantity of relatively cold gas or gas vapor mixture into direct heat exchange contact with but countercurrent to said last named quantity of indirectly heated liquid to effect evaporation of the latter by progressively decreasing the temperature of said liquid and increasing the temperature of said gas or gas vapor mixture, and subsequently conducting said gas or gas vapor mixture at its increased temperature into direct heat exchange contact with but countercurrent to said first named quantity of indirectly heated liquid to effect evaporation thereof.

16. The method of evaporating liquids which consists in heating by indirect contact with a heating medium a certain quantity of liquid to be evaporated, utilizing said same heating medium for indirectly heating another quantity of said liquid smaller in quantity and of lower initial temperature than said first named quantity, conducting a quantity of relatively cold gas or gas vapor mixture into direct heat exchange contact with but countercurrent to said last named quantity of indirectly heated liquid to effect evaporation of the latter by progressively decreasing the temperature of said liquid and increasing the temperature of said gas or gas vapor mixture, subsequently conducting said gas or gas vapor mixture at its increased temperature into direct heat exchange contact with but countercurrent to said first named quantity of indirectly heated liquid to effect evaporation thereof, and recirculating the unevaporated portions of said quantities of liquid through their respective heating and evaporation cycles.

17. Apparatus for the transmission of heat between a liquid and a gas or gas vapor mixture comprising a liquid receptacle having an inlet and an outlet, means for supplying a relatively cold liquid to the inlet of said receptacle, means for heating the contents of said receptacle, a pair of evaporating vessels each having a liquid inlet and outlet and an inlet and outlet for gas or gas vapor mixture, said evaporating vessels being arranged in series with the liquid outlet of the first vessel connected with the liquid inlet of the second and the gas outlet of the second connected with the gas inlet of the first, means for supplying relatively cold gas or gas vapor mixture to the gas inlet of said second evaporating vessel, means for supplying heated liquid from the outlet of said liquid receptacle to the liquid inlet of said first evaporating vessel, and means for varying the ratio of the quantity of liquid to the quantity of gas or gas vapor mixture in contact therewith as between said first and second evaporating vessels.

18. Apparatus for the transmission of heat between a liquid and a gas or gas vapor mixture comprising a liquid receptacle having an inlet and an outlet, means for supplying a relatively cold liquid to the inlet of said receptacle, means for heating the contents of said receptacle, a pair of evaporating vessels each having a liquid inlet and outlet and an inlet and outlet for gas or gas vapor mixture, said evaporating vessels being arranged in series with the liquid outlet of the first vessel connected with the liquid inlet of the second and the gas outlet of the second connected with the gas inlet of the first, means for supplying relatively cold gas or gas vapor mixture to the gas inlet of said second evaporating vessel, means for supplying heated liquid from the outlet of said liquid receptacle to the liquid inlet of said first evaporating vessel, means for varying the ratio of the quantity of liquid to the quantity of gas or gas vapor mixture in contact therewith as between said first and second evaporating vessels, and means for recirculating the liquid from the liquid outlet of said second evaporating vessel to the inlet of said liquid receptacle.

19. Apparatus for the transmission of heat between a liquid and a gas or gas vapor mixture comprising a liquid receptacle having an inlet and an outlet, means for supplying a relatively cold liquid to the inlet of said receptacle, means for heating the contents of said receptacle, a pair of evaporating vessels each having a liquid inlet and outlet and an inlet and outlet for gas or gas vapor mixture, said evaporating vessels being arranged in series with the liquid outlet of the first vessel connected with the liquid inlet of the second and the gas outlet of the second connected wth the gas inlet of the first, means for supplying relatively cold gas or gas vapor mixture to the gas inlet of said second evaporating vessel, means for supplying heated liquid from the outlet of said liquid receptacle to the liquid inlet of said first evaporating vessel, and means for reducing

the quantity of the liquid entering the liquid inlet of said second evaporating vessel below the quantity leaving the liquid outlet of said first evaporating vessel.

20. Apparatus for the transmission of heat between a liquid and a gas or gas vapor mixture comprising a liquid receptacle having an inlet and an outlet, means for supplying a relatively cold liquid to the inlet of said receptacle, means for heating the contents of said receptacle, a pair of evaporating vessels, each having a liquid inlet and outlet and an inlet and outlet for gas or gas vapor mixture, said evaporating vessels being arranged in series with the liquid outlet of the first vessel connected with the liquid inlet of the second and the gas outlet of the second connected with the gas inlet of the first, means for supplying relatively cold gas or gas vapor mixture to the gas inlet of said second evaporating vessel, means for supplying heated liquid from the outlet of said liquid receptacle to the liquid inlet of said first evaporating vessel, and means for reducing the quantity of the gas or gas vapor mixture entering the gas inlet of said first evaporating vessel below the quantity leaving the gas outlet of said second evaporating vessel.

21. Apparatus for the transmission of heat between a liquid and a gas or gas vapor mixture comprising a pair of liquid receptacles each having an inlet and an outlet and being arranged in series with the outlet of the first receptacle connected with the inlet of the second, means for supplying a relatively cold liquid to the inlet of said first receptacle, means for heating the contents of said receptacles, a pair of evaporating vessels each having a liquid inlet and outlet and an inlet and outlet for gas or gas vapor mixture, said evaporating vessels also being arranged in series with the liquid outlet of the first vessel connected with the liquid inlet of the second and the gas outlet of the second connected with the gas inlet of the first, means for supplying relatively cold gas or gas vapor mixture to the gas inlet of said second evaporating vessel, means for supplying heated liquid from the outlet of said second liquid receptacle to the liquid inlet of said first evaporating vessel, and means for cross connecting the liquid outlet of said first evaporating vessel and the inlet of said second liquid receptacle.

22. Apparatus for the transmission of heat between a liquid and a gas or gas vapor mixture comprising a pair of liquid receptacles each having an inlet and an outlet and being arranged in series with the outlet of the first receptacle connected with the inlet of the second, means for supplying a relatively cold liquid to the inlet of said first receptacle, means for heating the contents of said receptacles, a pair of evaporating vessels each having a liquid inlet and outlet and an inlet and outlet for gas or gas vapor mixture, said evaporating vessels also being arranged in series with the liquid outlet of the first vessel connected with the liquid inlet of the second and the gas outlet of the second connected with the gas inlet of the first, means for supplying relatively cold gas or gas vapor mixture to the gas inlet of said second evaporating vessel, means for supplying heated liquid from the outlet of said second liquid receptacle to the liquid inlet of said first evaporating vessel, and means for drawing off a portion of the gas or gas vapor mixture as it passes from the gas outlet of said second evaporating vessel to the gas inlet of said first evaporating vessel.

HANS ELIS ABRAHAM GÖTH.