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54 An absorption cycle heat pump.

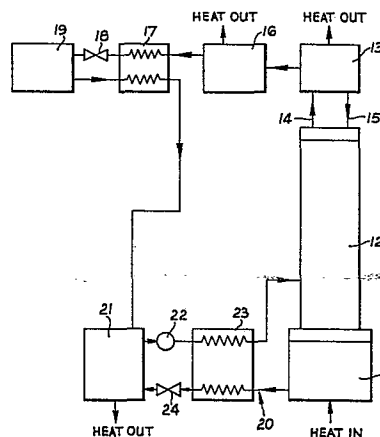
57 An absorption cycle heat pump includes a generator 11 which contains a refrigerant and a solvent for the refrigerant and to which, in use, an external source of heat is applied to raise the temperature thereof such that a vapour rich in the refrigerant is expelled from the generator 11. A condenser 13, 16 is connected to the generator 11 so as to receive and condense the vapour expelled from the generator 11 in use, and an evaporator 19 is connected to the condenser 13, 16 through a heat exchanger 17 and valve means 18 so as to re-evaporate the condensed vapour into the evaporator 19. An absorber 21 is connected through the heat exchanger 17 to the evaporator 19, the absorber 21 and the generator 11 forming part of a series circuit 20 through which, in use, a liquid rich in the solvent flows from the generator 11 to the absorber 21 for recombination with the fluid from the evaporator 19. A pump in the series circuit 20 returns the recombined refrigerant and solvent from the absorber 21 to the generator 11.

In order to ensure maximum thermodynamic efficiency when operating as a heat emitting device, the heat pump is arranged so that the normal boiling points difference of the solvent and the refrigerant is less than or equal to 200°C and so that:

a) evaporation of the condensed vapour into the evaporator is incomplete and the fluid leaving the eva-

porator 19 contains 5 to 30% by mass of liquid, and

b) the refrigerant liquid in the fluid flowing from the evaporator 19 is evaporated in the heat exchanger 17 so that the fluid leaving the heat exchanger 17 is at between a maximum superheat of 2°C and a flash ratio of 2%.



This invention relates to an absorption cycle heat pump of the kind including a generator which contains a refrigerant and a solvent for the refrigerant and to which, in use, an external source of heat is applied to raise the temperature thereof such that a vapour rich in the refrigerant is expelled from the generator, a condenser which is connected to the generator so as to receive and condense the vapour expelled from the generator in use, an evaporator connected to the condenser through a heat exchanger and valve means arranged to re-evaporate the condensed vapour into the evaporator, and an absorber connected through said heat exchanger to the evaporator; the absorber and the generator forming part of a series circuit through which, in use, a liquid rich in the solvent flows from the generator to the absorber for recombination with the fluid from the evaporator, and a pump in said series circuit for returning the recombined refrigerant and solvent from the absorber to the generator.

In the heat pump described in the preceding paragraph, it is of course well known that heat is emitted to the environment at the condenser and is extracted from the environment at the evaporator. Generally, however, in any given practical application, only one of the heat transfer modes of the pump is effectively utilised and in the past this mode has normally been the heat extraction mode in, for example, refrigeration and air conditioning applications. The present invention is, on the other hand, concerned with a heat pump of the kind specified designed solely as a heat emitting device, for example a water and space heater.

As a result of examining the problem of operating an absorption cycle heat pump of the kind specified as a heat emitting device, it has now been found that the optimum thermodynamic performance can be obtained when the normal boiling points difference of the solvent and the refrigerant is less than or equal to 200°C and the pump is operated so that:-

a) there is incomplete evaporation of the condensed vapour into the evaporator so that at least some liquid refrigerant flows from the evaporator, and

b) the evaporation of the condensed vapour is continued in said heat exchanger so that the fluid leaving the heat exchanger is as near as possible to a saturated vapour state.

Accordingly, the invention resides in an absorption cycle heat pump of the kind specified in which the normal boiling points difference of the solvent and the refrigerant is less than or equal to 200°C and which is adapted to operate so that:-

a) evaporation of said condensed vapour into the evaporator is incomplete and the fluid leaving the evaporator contains 5 to 30% by mass of liquid, and

b) the refrigerant liquid in the fluid flowing from the evaporator is evaporated in said heat exchanger so that the fluid leaving the heat exchanger is at between a maximum superheat of 2°C and a flash ratio of 2%.

It is to be appreciated that the term "flash ratio" is used herein in its commonly accepted sense as defining the ratio of the mass of a liquid in a flowing fluid to the total fluid mass flow rate.

Preferably, the refrigerant is ammonia and the solvent is water, in which case the normal boiling points difference is 133.6°C .

In a further aspect, the invention resides in an adsorption cycle heat pump of the kind specified in which the refrigerant is ammonia and the solvent is water and which is adapted to operate such that:

(a) the pressure in the evaporator is 30-65 p.s.i., absolute;

(b) the ammonia concentration of the vapour flowing from the condenser to the heat exchanger is 97-99% by weight; and

(c) the temperature of the condensed vapour flowing from the heat exchanger is $5-10^{\circ}\text{C}$ below that of the condensed vapour entering the heat exchanger from the condenser; or/and

(d) the fluid flowing from the heat exchanger to the absorber is at between a maximum of 2°C superheat and a flash ratio of 2%.

In particular, it is found that the coefficient of performance of the heat pump of said further aspect of the invention can be maximised by maintaining the operational conditions (a), (b) and (c) or (a), (b) and (d). More preferably, the heat pump is controlled so that all the conditions (a) - (d) are maintained.

In yet a further aspect, the invention resides in a method of operating an absorption cycle heat pump of the kind specified wherein the refrigerant is ammonia and the solvent is water, the method comprising the steps of:

(a) maintaining a pressure of 30-65 p.s.i., absolute in the evaporator;

(b) controlling the ammonia concentration of the vapour flowing from the condenser to the heat exchanger at 97-99% by weight; and

(c) maintaining the temperature of the condensed vapour flowing from the heat exchanger at $5-10^{\circ}\text{C}$ below that of the condensed vapour entering the exchanger from the condenser; or/and

(d) controlling the heat exchanger so that the fluid flowing therefrom to the absorber is at between a maximum of 2°C superheat and a flash ratio of 2%.

In the accompanying drawings,

Figure 1 is a block diagram of an absorption cycle heat pump according to one example of the invention; and

Figure 2 is a graph showing the variation in the optimum values of evaporator pressure (curve A), the refrigerant concentration in the fluid leaving the condenser (curve B), and the heat exchange rate of the heat exchanger (curve C) with changes in the ambient air temperature for the heat pump shown in Figure 1.

Referring to Figure 1, the heat pump of said one example includes a still 11 which contains a mixture of ammonia and water and which, in use, is heated by a fossil fuel burner (not shown) so that an ammonia-rich vapour is driven from the still to a packed column 12 mounted above the still. In one practical embodiment, the column 12 is 4 inches in diameter, 3 feet in length and is filled with 0.375 inch Raschig rings. Such a column is equivalent to 2 mass transfer units and is adequate for a heat pump with a total heating output of 10kW.

The column 12 is connected by a vapour conduit 14 and a liquid return conduit 15 to an equilibrium partial condenser 13 (i.e. the saturated vapour leaving the condenser 13 is in equilibrium with the reflux liquid flowing back through the conduit 15). The partial condenser 13 is in turn connected to a main condenser 16, each of the condensers 13, 16 conveniently being in the form of a tube-in-shell heat exchanger through which liquid to be heated by the pump is circulated. The outlet of the condenser 16 is connected to a heat exchanger 17, which is conveniently a tube-in-tube heat exchanger and which, in said one practical embodiment has a maximum heat exchange of 850 watts. The heat exchanger 17 is in turn connected through an automatic expansion valve 18 to the input of an evaporator 19, the outlet of which is connected

through the heat exchanger 17 to an absorber 21. The absorber 21 is arranged so that there is counterflow between the incoming vapour from the heat exchanger 17 and a weak ammonia solution flowing through a series circuit 20, heat of solution generated in the absorber being extracted internally. The series circuit 20 includes the absorber 21, a pump 22, the low temperature side of a heat exchanger 23, a liquid inlet conduit to the column 12, a liquid outlet conduit from the still 11, the high temperature side of the heat exchanger 23 and a throttling valve 24. The heat exchanger 23 is conveniently a tube-in-tube heat exchanger and in said one practical embodiment has a capacity of 3,500 watts.

In use, the heat pump described above is operated as follows:

Heat is supplied to the ammonia/water mixture in the still so that a stream of ammonia-rich vapour rises through the column 12, water in the vapour being condensed during passage through the column so that a vapour with an increased ammonia concentration flows through the conduit 14 to the partial condenser 13. Further concentration of the vapour occurs in the partial condenser 13, the degree of concentration being controlled by varying the heat load of the condenser (for ambient air of 0°C this load is about 700 watts) through adjustment of the flow rate of the cooling water with, for example, a needle flow control valve. Latent heat of condensation is of course extracted by the cooling water flowing through the condenser 13 and any water and ammonia condensed from the vapour in the condenser is returned by way of the conduit 15 and the column 12 to the still 11.

The partially and differentially condensed vapour issuing from the condenser 13 is at a temperature of about 80°C and passes to the main condenser 16, which is maintained at a pressure of about 250 p.s.i., so that condensation is completed and the majority of the latent heat is extracted.

by the cooling water.

The condensed vapour issuing from the main condenser 16 is at a temperature of about 45°C and consists of a saturated aqueous ammonia solution containing 97-99% by weight of ammonia. From the main condenser 17, the condensed vapour flows through the heat exchanger 17, where it is cooled to about 0°C by the vapour flowing from the evaporator 19 to the absorber 21. On leaving the heat exchanger 17, the cooled liquid flows through the valve 18, which is set to maintain the evaporator 19 at 30-65 p.s.i., absolute so that the fluid (liquid and vapour) is partially re-evaporated into the evaporator and heat is extracted from the ambient air. The fluid leaving the evaporator 19 is at about -5°C but the heat exchanger 17 is arranged so that, after the passage therethrough, the vapour is at a temperature of about 40°C (i.e. 5°C below the temperature of the fluid leaving the condenser 16) and is as close as possible to a saturated vapour state.

When heat is supplied to the still 11, the pump 22 is operated so that water-rich liquid is pumped from the still 11 around the series circuit 20, the liquid leaving the still 11 being at a temperature of about 165°C and being in equilibrium with the rising vapour from the still. After flowing through the heat exchanger 23 and valve 24 the water-rich liquid from the still has decreased in temperature to about 75°C and flows into the absorber 21, where it is mixed with the ammonia-rich vapour from the heat exchanger 17. Heat of solution generated in the absorber 21 is extracted by the cooling water stream so that the recombined water/ammonia mixture leaving the absorber is at about 45°C . After flowing through the heat exchanger 23, the temperature of the mixture has increased to 110°C so that the provision of the heat exchanger 23 reduces the thermal energy which must be supplied to the still 11. The liquid flowing from the exchanger 23 to the column 12 is water saturated with ammonia.

Operating the heat pump of said one practical embodiment in the manner described achieves a high coefficient of performance over an ambient temperature range of -10°C to $+10^{\circ}\text{C}$. In practice, the evaporator pressure and the ammonia concentration of the vapour leaving the condenser 16 would be adjusted to give optimum efficiency at a median temperature in this range, for example, 0°C . These values could then be retained over the working temperature range of the pump or could be varied to maintain the efficiency as near as possible to the optimum. Thus, referring to Figure 2, it can be seen from curves A and B, that in order to maintain optimised operation of the evaporator, the evaporator pressure and the refrigerant (ammonia) vapour concentration will have to be reduced with falling ambient temperature. The change in the evaporator pressure can be accomplished by using an adjustable automatic expansion valve, such as the outlet pressure regulator valve supplied by the Refrigerating Specialties Company of USA as type A2B0. The decrease in the ammonia vapour concentration is reflected (combined with the change in the evaporator pressure) in an increase in the load on the partial condenser 13,

with

falling ambient temperature. This increase in the partial condenser load can be effected by increasing the cooling-water flow rate through the partial condenser.

Curve C in Figure 2 shows that the heat exchange rate of the heat exchanger 17 increases with decreasing ambient air temperature. This reflects the fact that at the minimum air temperature at which the pump is designed to operate, a considerable proportion of the fluid (typically 30%) passes unevaporated from the evaporator. The heat exchanger could be designed and sized to complete the evaporation of this amount of liquid carried over at the minimum ambient air temperature. However, this would mean that at higher ambient air temperatures, the vapour emerging from the heat exchanger could be highly superheated so that, throughout the operating temperature range of the pump,

there would be a departure from optimum operation. Alternatively, the heat exchanger 17 could be designed to effect complete evaporation of the mixture of refrigerant liquid and vapour emerging from the evaporator at the design air temperature. At higher ambient temperatures the vapour leaving the heat exchanger could become slightly superheated. At lower ambient temperatures, however, part of the refrigerant liquid might pass to the absorber without evaporation.

As an alternative to the example described above using ammonia and water as the working fluids, the refrigerant could be methylamine, again with water as the solvent. In this case, the normal boiling points difference of the solvent and refrigerant would be 107°C .

C L A I M S :

1. An absorption cycle heat pump including a generator which contains a refrigerant and a solvent for the refrigerant and to which, in use, an external source of heat is applied to raise the temperature thereof such that a vapour rich in the refrigerant is expelled from the generator, a condenser which is connected to the generator so as to receive and condense the vapour expelled from the generator in use, an evaporator connected to the condenser through a heat exchanger and valve means arranged to re-evaporate the condensed vapour into the evaporator, and an absorber connected through said heat exchanger to the evaporator; the absorber and the generator forming part of a series circuit through which, in use, a liquid rich in the solvent flows from the generator to the absorber for recombination with the fluid from the evaporator, and a pump in said series circuit for returning the recombined refrigerant and solvent from the absorber to the generator, wherein the normal boiling points difference of the refrigerant and the solvent is less than or equal to 200°C and the pump is adapted to operate so that:-

a) evaporation of said condensed vapour into the evaporator is incomplete and the fluid leaving the evaporator contains 5 to 30% by mass of liquid and,

b) the refrigerant liquid in the fluid flowing from the evaporator is evaporated in said heat exchanger so that the fluid leaving the heat exchanger is at between a maximum superheat of 2°C and a flash ratio of 2%.

2. A pump as claimed in Claim 1, wherein the refrigerant is ammonia and the solvent is water.

3. An absorption cycle heat pump including a generator which contains ammonia and water as the working fluids and to which, in use, an external source of heat is applied to raise the temperature thereof such that a vapour rich in ammonia is expelled from the generator, a condenser which is connected to the generator so as to receive and condense the vapour expelled from the generator in use, an evaporator connected to the condenser through a heat exchanger and valve means arranged to re-evaporate the condensed vapour into the evaporator, and an absorber connected through said heat exchanger to the evaporator; the absorber and the generator forming part of a series circuit through which, in use, a liquid rich in water flows from the generator to the absorber for recombination with the fluid from the evaporator, and a pump in said series circuit for returning the recombined ammonia and water from the absorber to the generator, wherein the pump is adapted to operate so that:-

(a) the pressure in the evaporator is 30-65 p.s.i., absolute;

(b) the ammonia concentration of the vapour flowing from the condenser to the heat exchanger is 97-99% by weight; and

(c) the temperature of the condensed vapour flowing from the heat exchanger is 5-10°C below that of the condensed vapour entering the heat exchanger from the condenser; or/and

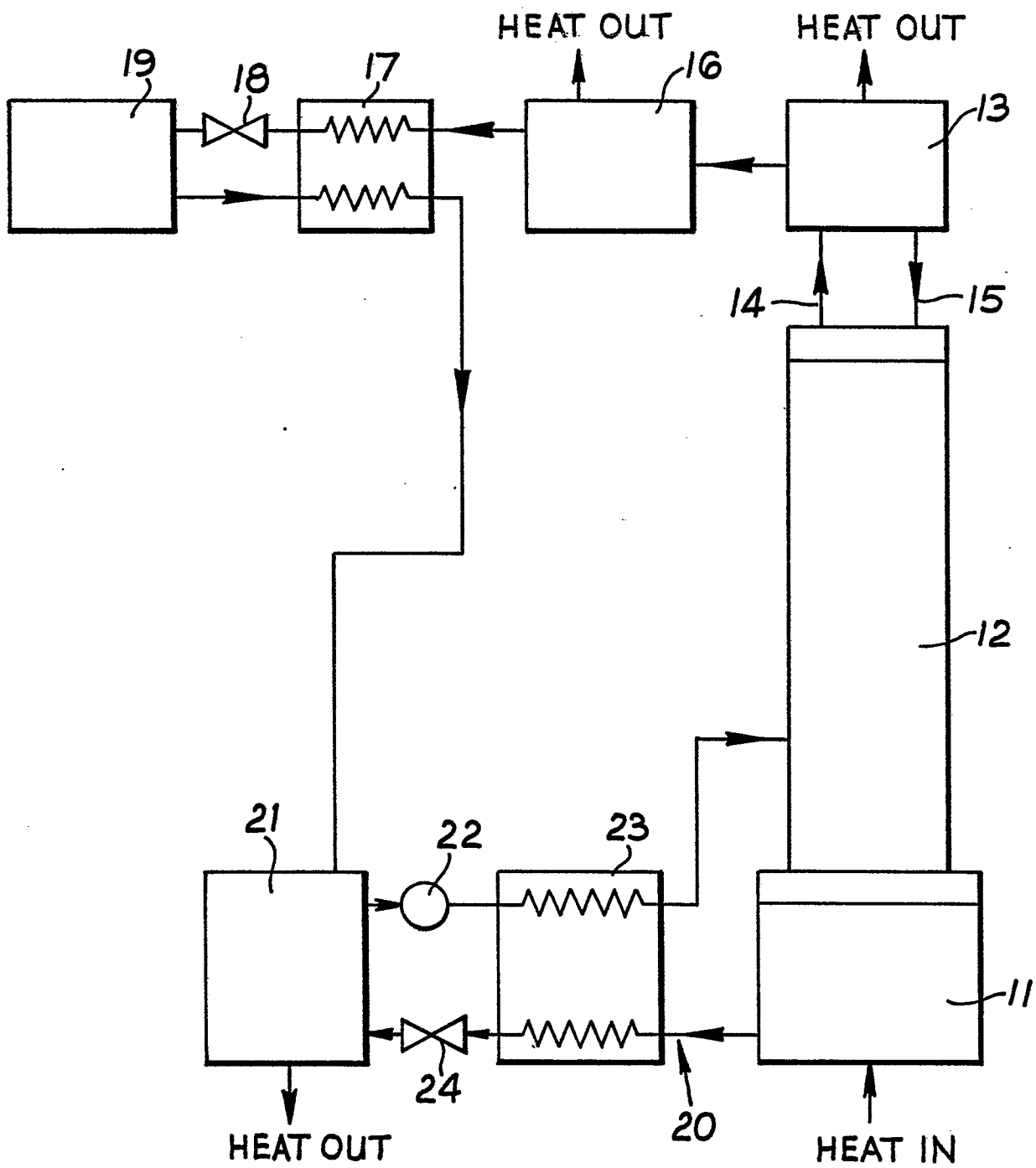
(d) the fluid flowing from the heat exchanger to the absorber is at between a maximum of 2°C superheat and a flash ratio of 2%.

4. A pump as claimed in Claim 3, and adapted so that only conditions (a), (b) and (c) apply.

5. A pump as claimed in Claim 3, and adapted to operate so that only conditions (a), (b) and (d) apply.
6. A pump as claimed in Claim 3, and adapted to operate so that all of conditions (a), (b), (c) and (d) apply.
7. A method of operating an absorption cycle heat pump including a generator which contains ammonia and water as the working fluids and to which, in use, an external source of heat is applied to raise the temperature thereof such that a vapour rich in ammonia is expelled from the generator, a condenser which is connected to the generator so as to receive and condense the vapour expelled from the generator in use, an evaporator connected to the condenser through a heat exchanger and valve means arranged to re-evaporate the condensed vapour into the evaporator, and an absorber connected through said heat exchanger to the evaporator; the absorber and the generator forming part of a series circuit through which, in use, a liquid rich in the water flows from the generator to the absorber for recombination with the fluid from the evaporator, and a pump in said series circuit for returning the recombined ammonia and water from the absorber to the generator, the method comprising the steps of:-
- (a) maintaining a pressure of 30-65 p.s.i., absolute in the evaporator;
 - (b) controlling the ammonia concentration of the vapour flowing from the condenser to the heat exchanger at 97-99% by weight; and
 - (c) maintaining the temperature of the condensed vapour flowing from the heat exchanger at 5-10°C below that of the condensed vapour entering the exchanger from the condenser; or/and
 - (d) controlling the heat exchanger so that the fluid flowing therefrom to the absorber is at between a maximum of 2°C superheat and a flash ratio of 2%.
8. A method as claimed in Claim 7 and comprising only steps (a), (b) and (c).

9. A method as claimed in Claim 7 and comprising only steps (a), (b) and (d).

10. A method as claimed in Claim 7 and comprising all of steps (a), (b), (c) and (d).



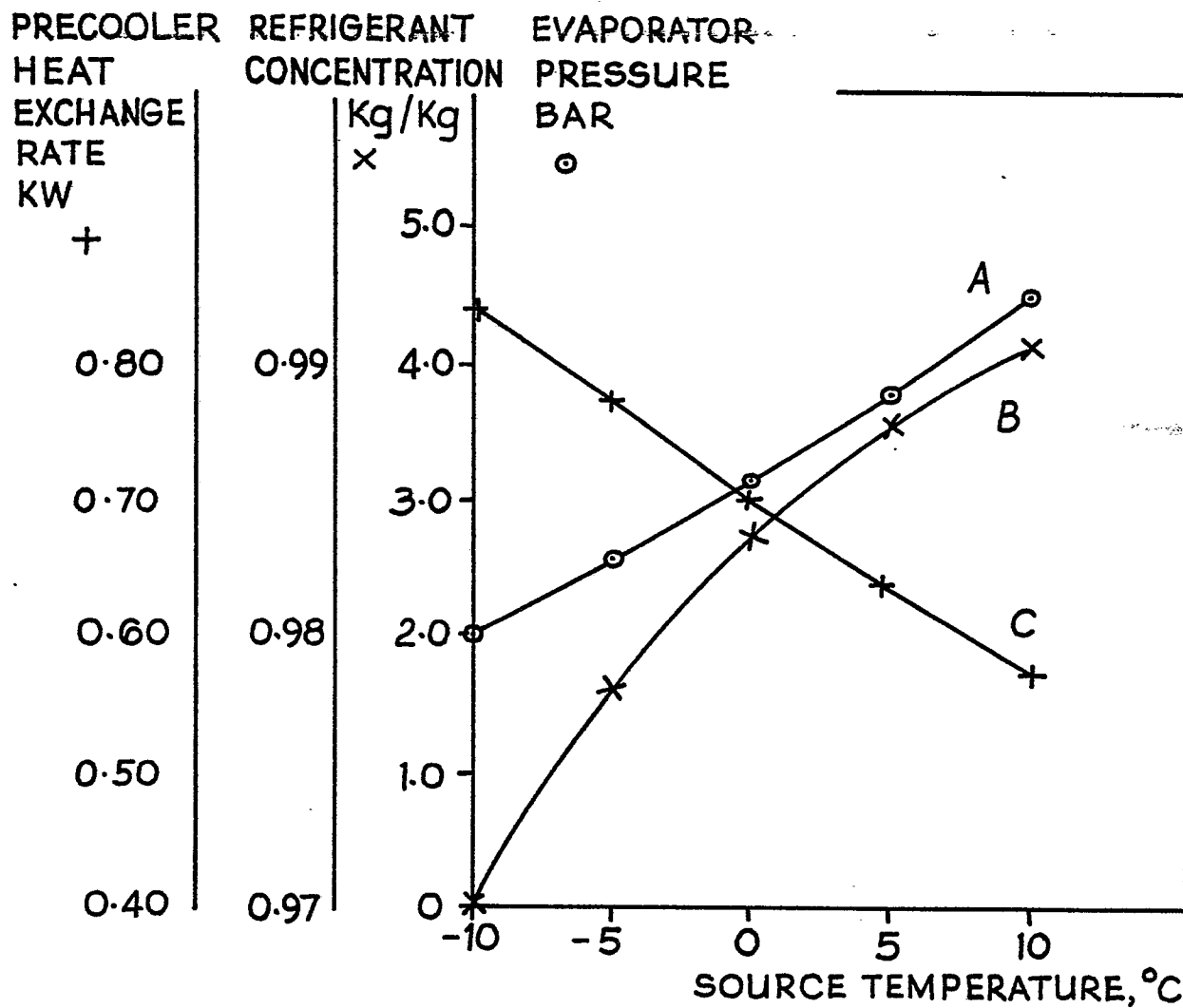


FIGURE 3-5. VARIATION OF OPTIMIZED EVAPORATOR PRESSURE, VAPOUR CONCENTRATION AND PRECOOLER LOAD WITH AIR TEMPERATURE