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REVERSIBLE HEAT PUMP CYCLE WITH MEANS FOR ADJUSTING THE EFFECTIVE CHARGE

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Fig. 1

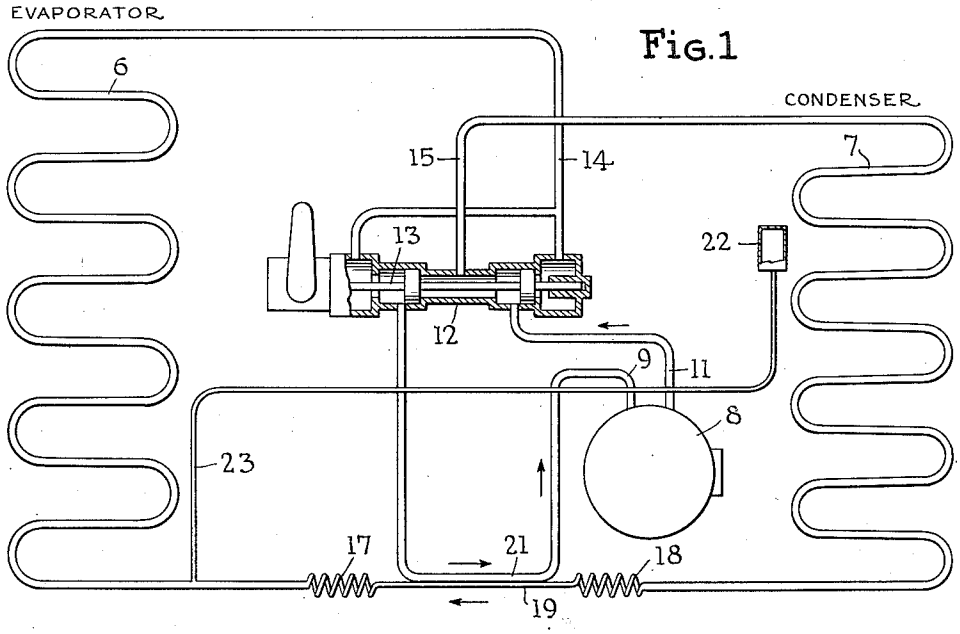


Fig. 2

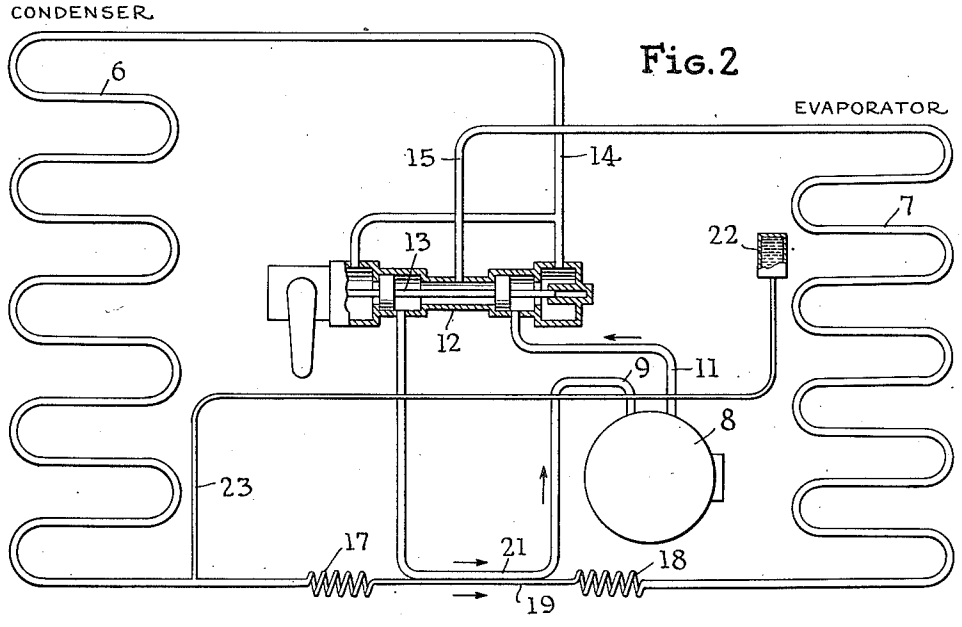
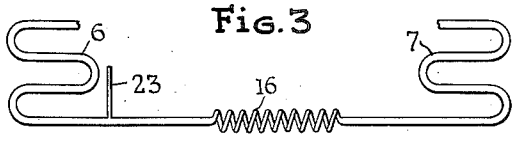


Fig. 3



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REVERSIBLE HEAT PUMP CYCLE WITH MEANS FOR ADJUSTING THE EFFECTIVE CHARGE

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This invention relates to refrigeration and particularly to reversible heat pumps.

In the refrigerating art it is standard practice to use long-path slender restrictors in lieu of conventional expansion valves. These restrictors are not just a cheap expedient, for when properly used they have a considerable self-regulating action. Successful use requires that the quantity of refrigerant in the circuit be carefully proportioned to the restrictor and to the thermodynamic characteristics of the circuit. Manufacturers have established standards in this connection and adhere to them closely.

It is characteristic of reversible heat pumps that compressing means are operated alternatively in two opposite senses to draw refrigerant from a chosen one of two exchangers (which then functions as an evaporator) and compress it into the other of the two exchangers (which then functions as a condenser). Nothing could be more attractively simple than the connection of the two exchangers by a long-path flow restrictor. It has no moving parts, and is indifferent to the direction of flow. Not even a valve is needed.

Attempts to avail of the idea have met with the serious difficulty that in almost any commercially useful unit reversal of the heat pump so changes the thermodynamic characteristics of the circuit that a refrigerant charge which is correct for one direction of pumping is wrong for the other.

The invention solves that problem by inherently automatic means involving no moving parts.

The charge is proportioned for that direction of pumping which requires the larger charge, all according to principles known in the art. The proper charge for the other direction of pumping is determined according to the same principles. A receptacle whose volume equals the difference in liquid volume between the two charges is connected to the system in such a way that when the system is pumping in the direction requiring the smaller charge, liquid refrigerant collects in and fills said receptacle, whereas pumping in the reverse direction causes the liquid to leave the receptacle and resume active circulation.

To accomplish this result the receptacle is so located that it is subject to the temperature of that one of the two heat exchangers which functions as the condenser when the larger charge is needed, and is connected to the circuit in such a way that it will collect liquid refrigerant when cold, but heating of the receptacle to approximately condenser temperature causes the refrigerant to flow back into the circuit. Attempts to

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embody this concept in specifically different forms have met with different degrees of success. In the best embodiment of the invention developed so far, the bottom of the receptacle is connected by a tube with a part of the circuit which is at the pressure of the other heat exchanger, desirably the lower connection of that exchanger.

Thus when the receptacle is at condenser temperature it is at evaporator pressure and so empties itself. Conversely, when the receptacle is at evaporator temperature and condenser pressure vaporous refrigerant flows to it and condenses, until the receptacle is full.

It is advantageous for reasons of economy to provide for recuperative heat exchange between warm liquid leaving the condenser and cold vapor leaving the evaporator. Where the cycle is not reversible, it is simple to do this but there are obvious difficulties where flow must be reversed.

According to the invention the exchanger is associated with the long-path restrictor in such a way that the regulatory action of the restrictor is improved and its performance stabilized. It is even possible to secure (within limits) different regulartory effects for the two opposite directions of flow.

Preferred embodiments of the invention will now be described by reference to the accompanying drawing.

Fig. 1 is an elevation largely diagrammatic showing the improved reversible heat pump circuit set to absorb heat through the left-hand one of the two coils and reject it through the right-hand coil. The reversing valve (four-way valve) is shown in diagrammatic section.

Fig. 2 shows the reverse setting in which heat is absorbed through the right-hand coil and rejected through the left.

Fig. 3 is a fragmentary view showing a modification.

The numerals 6 and 7 identify two coil heat exchangers. These are diagrammed, for simplicity, as single pass coils without fins, but the two can be of any type and need not even be of the same type. They are diagrammed as being of different effective surfaces, though they need not be, since differences in thermal loading ordinarliy will cause asymmetry of performance such as creates the need for the invention.

A motor driven compressor is digrammed at 8. It is assumed to be of the type in which the electric driving motor and the compressor driven thereby are both enclosed in a gas-tight casing.

The suction connection is shown at 9 and the discharge ("hot gas") connection at 11.

A four-way valve diagrammed as of conventional form having a casing 12 and an axially-shiftable piston valve unit 13 is connected to the lines 9 and 11 and to the lines 14 and 15 which serve as the upper connections to the coils 6 and 7 respectively. The drawings will make clear that in Fig. 1 the four-way valve is set to cause compressor 8 to draw vapor from coil 6 (which is then the evaporator) and deliver it under pressure to coil 7 (which is then the condenser). In Fig. 2 the valve is in its opposite setting and the compressor draws vapor from coil 7 (evaporator) and delivers it under pressure to coil 6 (condenser).

The lower ends of the coils 6 and 7 can be connected through a single long-path restrictor 16 without any heat exchanger, such an arrangement being indicated in Fig. 3. It is practicable to use with such an arrangement the parts 22 and 23 hereinafter described, but better results can be secured by adhering to the general scheme illustrated in Figs. 1 and 2.

In Figs. 1 and 2 the restrictor is made of a single length of tubing and can be regarded as comprising three successive portions, a portion 17 which is the entrance or exit portion depending on the direction of flow, a portion 18 which can be considered as the exit or entrance portion according to the direction of flow, and an intermediate heat exchanger portion 19 which is in thermal contact with the tube 21. The tube 21 is always a part of the suction line leading to the compressor and as illustrated is interposed between the four-way valve and the suction connection 9 of compressor 8.

In Figs. 1 and 2 the portion 17 of the restrictor is equal in length with the portion 18 and this condition ordinarily would exist. However, it is not essential, as in particular cases the portions 17 and 18 may differ in length as will be explained hereinafter.

To change automatically the amount of refrigerant in effective circulation in the system, the invention provides a receptacle 22 closed except for at least one flow connection 23 which leads to a point in the system. The location of the receptacle 22 is important. In Figs. 1 and 2 it is shown adjacent the coil 7, it being assumed for purposes of discussion that coil 7 is that one of the two coils 6 and 7 which functions as the condenser when the larger charge of refrigerant is needed.

At such time heat from the condenser causes vaporization of any liquid refrigerant present in receptacle 22. In this way the receptacle 22 is emptied of liquid and the refrigerant becomes a part of that circulating in the system (see Fig. 1). The best known arrangement is to lead the connection 23 from the bottom of the recpetacle 22 to some point in the circuit which is at the pressure of the other coil 6 and advisably the point selected is one at the lower end of the coil 6.

Refrigerant flows from receptacle 22 to the system under the conditions diagrammed in Fig. 1. At that time the coil 6 is the evaporator and it is best to lead the liquid refrigerant to the lower or entrance end of the evaporator.

This arrangement assures a rapid transfer of liquid to and from the receptacle 22. When coil 6 is the evaporator and receptacle 22 receives heat from the condenser, a vapor pressure in receptacle 22 will develop quickly and will purge

the receptacle of liquid. Conversely (see Fig. 2) when coil 7 is cold (evaporator) and the coil 6 is warm (condenser) vaporous refrigerant will condense in receptacle 22 and thus create a partial vacuum sufficient to draw liquid refrigerant into the recptacle. As a consequence, the receptacle is quickly filled with liquid. This action is reliable and rapid and is attained without the addition to the system of any moving parts or any joints of a type which could leak.

By the use in a single system of a restrictor, a compressor of the hermetically sealed type, and a four-way valve also of the hermetically sealed type, leakage to and from the atmosphere is precluded. This arrangement brings to the field of reversible circuits the same degree of reliability as has heretofore been available in one-way circuits.

As already stated, in cases where the economy offered by the heat exchanger 19, 21 is not desired, one can have recourse to the arrangement shown in Fig. 3 and secure variation of effective refrigerant charge characteristic of the use of the receptacle 22 and its connection 23. However, the arrangement described with reference to Figs. 1 and 2 affords in addition to the advantages characteristic of the recuperative heat exchange, the advantage of enhanced stability, the reason for which can now be explained.

When the system is operating, the operating conditions will change. The rate at which heat is delivered to the evaporator may change. The rate at which heat is dissipated by the condenser may change and the action of the restrictor must change if the system is to remain in balance. The conditions in the system vary progressively but there are three typical conditions requiring discussion.

The condenser may be operating so that it just condenses all the refrigerant which it receives and so delivers refrigerant completely condensed but not sub-cooled.

The second condition which is caused by high head pressure or low back pressure or both results in a condition under which the capacity of the compressor does not equal the liquid flow capacity of the restrictor. As a consequence, the restrictor delivers a mixture of liquid and vapor.

The third condition exists as the result of low head pressure or high back pressure or both. The pumping capacity of the compressor in pounds of refrigerant per minute increases so that the restrictor is unable to discharge the entire amount of condensed liquid. There is an inherent tendeny for rebalance to occur first because obstruction of flow from the condenser will cause a rise in head pressure and a fall in back pressure. A more important effect is the tendency of liquified refrigerant in the condenser to become sub-cooled. The sub-cooled liquid flows through the restrictor much more freely. How much more freely is indicated by the fact that 20° of liquid sub-cooling will increase the flow capacity of a restrictor by as much as 40 percent.

In the arrangement shown in Figs. 1 and 2, regardless of the direction of flow, there is an entrance restrictor of some length which delivers to the inter-cooler and then there is an exit portion of the restrictor which leads from the inter-cooler to the evaporator. Assuming the device is operating as diagrammed in Fig. 1, the portion 18 acts as a stabilizer in conjunction with the heat exchanger 19, 21 because it tends to con-

trol flow to the interchanger so that over a wide range of load, the liquid refrigerant is sub-cooled. Thus, whether the system is operating under the first, second or third condition above outlined, the effect is to deliver sub-cooled liquid to the exit portion 17 for a wider range of load conditions than could be possible with an arrangement such as that shown in Fig. 3. As a consequence, the arrangement of Figs. 1 and 2 affords two advantages—better thermal performance and stability over a wide load range.

It has been suggested that the portions 17 and 18 need not be of the same length. If the coils 6 and 7 were of widely different thermal characteristics, or if the heat load when pumped in one direction (Fig. 1) were materially different from the heat load when pumped in the opposite direction (Fig. 2), the desired amount of entrance restrictor stabilization could be sufficiently different to make it advisable to differentiate the length of the portions 17 and 18. It is believed that in extreme cases, better performance can be secured in this way but whether it is or not, the invention is not limited to arrangements in which the lengths of the portions 17 and 18 are equal.

The advantages offered by the arrangement of the parts 17, 18, 19 and 21 as above described are not strictly dependent upon the presence of the receptacle 22 and connection 23, for it is possible to imagine a reversible circuit in which the optimum charges for the two directions of operation were the same. In such case, one would not need the parts 22 and 23 and still the parts 17, 18, 19 and 21 would perform their characteristic stabilizing functions.

Conversely, the parts 22 and 23 can, as indicated in Fig. 3, perform their charge varying functions in the absence of the parts 17, 18, 19 and 21. However, when all these parts are present, they have a co-active relation because anything that stabilizes flow conditions through the restrictor, makes the amount of the refrigerant charge less critical than it otherwise would be. Also the adjustment of the charge makes the system less sensitive to load changes such as might affect the performance of the restrictor.

It follows that the features described do cooperate to produce, when all are present, the best and most stable operation, but useful results can be had by the independent use of each of the two features.

In the claims the terms "long-path restrictor" will be used and since the word "long" is a relative term, a definition is desirable. In the early days of the use of long-path restrictors they were called "capillaries." This word is a misnomer but it is attractive because it implies in one word a slender path of considerable length, as contradistinguished from an orifice plate or needle valve which offers a slender path of no significant length. The term "long-path restrictor" as here used is intended to mean a slender path whose length is so much greater than its transverse dimension that it offers not only flow restriction but also the well-known regulatory action characteristics of what the art has commonly called "capillaries."

The broad general principle of the invention has been described and two useful embodiments thereof have been illustrated. Modifications within the scope of the claims are possible and are contemplated.

I claim:

1. A reversible heat-pump circuit comprising a first surface heat-exchanger capable of operating selectively as an evaporator or as a condenser; a second surface heat-exchanger capable of operating selectively as a condenser or as an evaporator; a long-path flow restrictor affording a reversible liquid-flow connection between said heat-exchangers; compressing means interposed between said exchangers and completing said circuit, said compressing means including reversing means whereby the compressing means may be caused to draw refrigerant from either of said heat exchangers while delivering it at a higher pressure to the other heat exchanger, the thermal characteristics of the circuit being such that one of said directions requires for efficient operation a larger effective charge and the other a smaller effective charge of refrigerant in the circuit; refrigerant in said circuit in quantity corresponding to said larger charge; a receptacle whose volume equals the difference between the liquid-phase volumes of said charges, said receptacle being so located as to be subject to the temperature of that heat exchanger which functions as a condenser when the larger effective charge is needed; and a two-way flow connection between said receptacle and the circuit.

2. A reversible heat-pump circuit comprising a first surface heat-exchanger capable of operating selectively as an evaporator or as a condenser; a second surface heat-exchanger capable of operating selectively as a condenser or as an evaporator; a long-path flow restrictor affording a reversible liquid-flow connection between said heat-exchangers; compressing means interposed between said exchangers and completing said circuit, said compressing means including reversing means whereby the compressing means may be caused to draw refrigerant from either of said heat exchangers while delivering it at a higher pressure to the other heat exchanger, the thermal characteristics of the circuit being such that one of said directions requires for efficient operation a larger effective charge and the other a smaller effective charge of refrigerant in the circuit; refrigerant in said circuit in quantity corresponding to said larger charge; a receptacle whose volume equals the difference between the liquid-phase volumes of said charges, said receptacle being so located as to be subject to the temperature of that heat exchanger which functions as a condenser when the larger effective charge is needed; and a two-way flow connection between the bottom of said receptacle and a point in the circuit which is at the pressure of the other exchanger, whereby the receptacle is subject to the temperature of one and the pressure of the other heat-exchanger.

3. A reversible heat-pump circuit comprising a first surface heat-exchanger capable of operating selectively as an evaporator or as a condenser; a second surface heat-exchanger capable of operating selectively as a condenser, or as an evaporator; flow-restricting means affording a reversible liquid-flow connection between said exchangers; compressing means interposed between said exchangers and completing said circuit; a charge of volatile refrigerant in said circuit; means for operating said compressing means selectively to withdraw vaporous refrigerant from either of said exchangers and deliver it at increased pressure to the other exchanger; a closed container capable of holding a part of said charge and subject to the temperature at one of said exchangers; and a flow connection between said container and a part of the circuit

which is subject substantially to the pressure in the other exchanger.

4. A reversible heat-pump circuit comprising a first surface heat-exchanger capable of operating selectively as an evaporator or as a condenser; a second surface heat-exchanger capable of operating selectively as a condenser or as an evaporator; a long-path flow restrictor affording a reversible liquid-flow connection between said heat-exchangers; compressing means interposed between said exchangers and completing said circuit, said compressing means including reversing means whereby the compressing means may be caused to draw refrigerant from either of said heat exchangers while delivering it at a higher pressure to the other heat exchanger, the thermal characteristics of the circuit being such that one of said directions requires for efficient operation a larger effective charge and the other a smaller effective charge of refrigerant in the circuit; a refrigerant in said circuit in quantity corresponding to said larger charge; means for causing heat exchange between refrigerant vapor approaching the compressor and refrigerant flowing through the middle portion of the restrictor as contradistinguished from the two end portions thereof; a receptacle whose volume equals the difference between the liquid-phase volumes of said charges, said receptacle being so located as to be subect to the temperature of that heat exchanger which functions as a condenser when the larger effective charge is needed; and a two-way flow connection between said receptacle and the circuit.

5. A reversible heat-pump circuit comprising a first surface heat-exchanger capable of operating selectively as an evaporator or as a condenser; a second surface heat-exchanger capable of operating selectively as a condenser or as an evaporator; a long-path flow restrictor affording a reversible liquid-flow connection between said heat-exchangers; compressing means interposed between said exchangers and completing said circuit, said compressing means including reversing means whereby the compressing means may be caused to draw refrigerant from either of said heat-exchangers while delivering it at a higher pressure to the other heat-exchanger, the thermal characteristics of the circuit being such that one of said directions requires for efficient operation a larger effective charge and the other a smaller effective charge of refrigerant in the circuit; refrigerant in said circuit in quantity corresponding to said larger charge; means for causing heat exchange between refrigerant vapor approaching the compressor and refrigerant flowing through the middle portion of the restrictor as contra-distinguished from the two end portions thereof; a receptacle whose volume equals the difference between the liquid-phase volumes of said charges, said receptacle being so located as to be subject to the temperature of that heat-exchanger which functions as a condenser when the larger effective charge is needed; and a two-way flow connection between the bottom of said receptacle and a point in the circuit which is at the pressure of the other exchanger, whereby the receptacle is subject to the temperature of one and the pressure of the other heat-exchanger.

6. A reversible heat-pump circuit comprising a first surface heat-exchanger capable of operating selectively as an evaporator or as a condenser; a second surface heat-exchanger capable of operating selectively as a condenser or as an evaporator; compressing means; reversing means operable to reverse the action of said compressing means as to the first and second exchangers whereby it may be caused to draw from either exchanger while discharging into the other; a long-path flow restrictor connecting said first and second exchangers and completing said circuit; a charge of volatile refrigerant in said circuit; means for causing heat exchange between refrigerant vapor approaching the compressor and refrigerant flowing through the middle portion of the restrictor as contra-distinguished from the two end portions thereof; a closed container capable of holding part of said charge and subject to the temperature of one of said exchangers; and a flow connection between said container and a part of the circuit which is subject substantially to the pressure in the other exchanger.

7. The combination defined in claim 6 in which said flow connection extends between the bottom of the container and the lower end of said other exchanger.

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