Dec. 8, 1970 J. M. CHAWLA 3,545,216

REFRIGERANT CYCLE FOR REFRIGERATION UNITS

Filed May 31, 1968 2 Sheets-Sheet 1

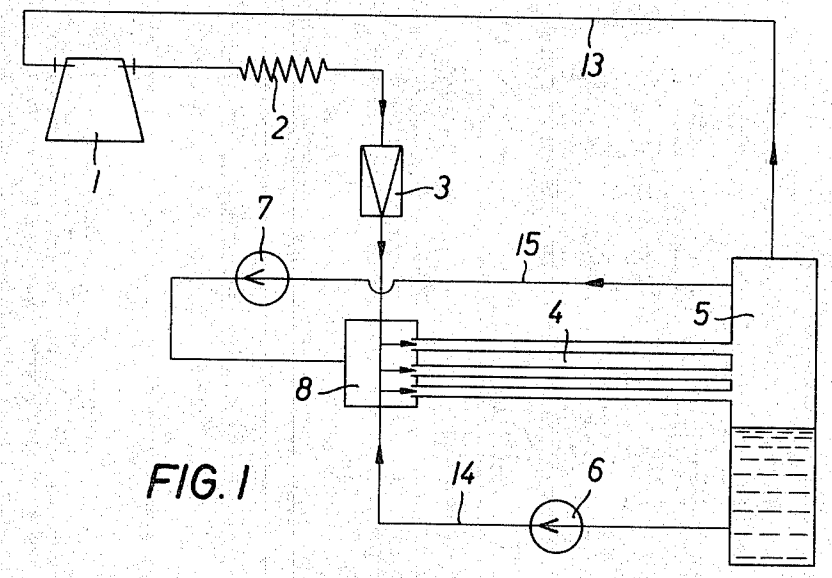


FIG. 1

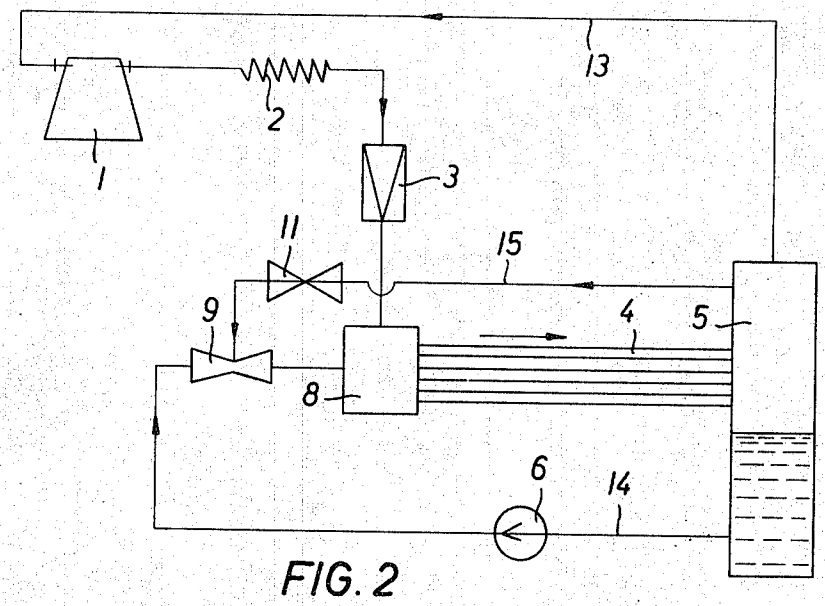


FIG. 2

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REFRIGERANT CYCLE FOR REFRIGERATION UNITS

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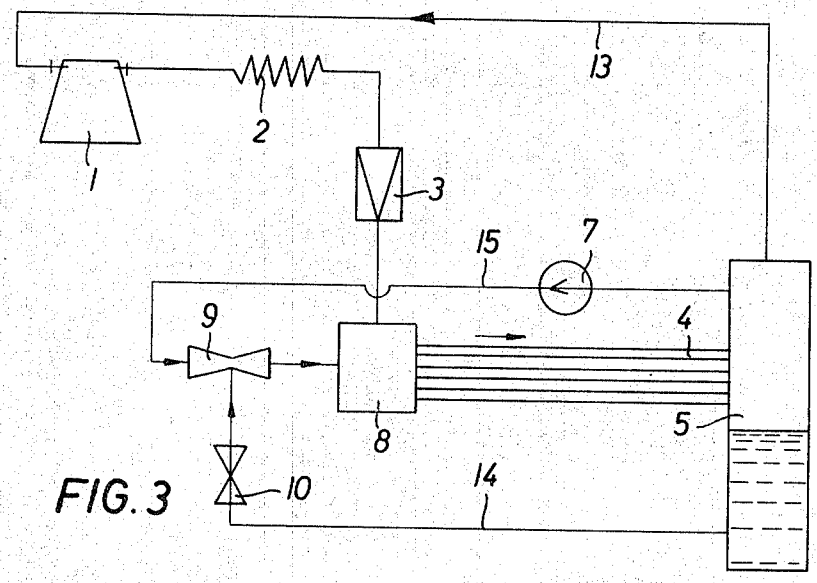


FIG. 3

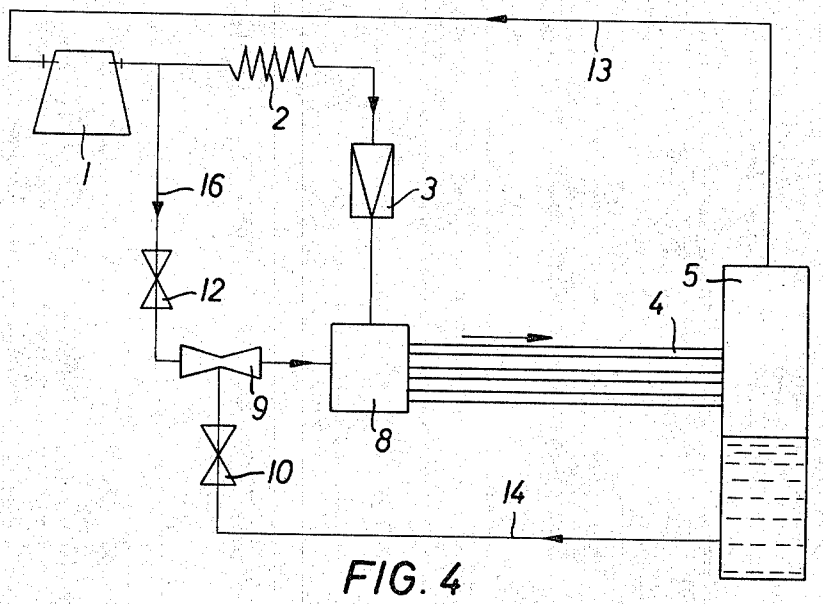


FIG. 4

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REFRIGERANT CYCLE FOR REFRIGERATION UNITS

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ABSTRACT OF THE DISCLOSURE

A refrigerant cycle includes a compressor that provides compressed refrigerant flowing to the high pressure end of an evaporator for evaporation and flow to a container and then back from the container to the compressor. A bypass is provided from said container to the high pressure end of the evaporator for moving controlled amounts of vapour directly to said evaporator high pressure end from said container. The container contains also a liquid refrigerant, and there is a second bypass circuit for feeding controlled amounts of the liquid refrigerant from the container to the high pressure end of said evaporator.

REFRIGERANT CYCLE FOR REFRIGERATION UNITS

The subject of the invention is a refrigerant cycle for refrigeration units consisting of a compressor which sucks the refrigerant from a low pressure space, a condenser, an expansion valve and an evaporator.

Two fundamental types of refrigeration units employing a refrigerant cycle are known so far. In one of them only one refrigerant cycle is employed. It consists of a compressor, a condenser, also a reservoir, an expansion valve, an evaporator having a single or more passes and a low pressure space at the end of the evaporator. Such refrigeration units are called dry expansion units where the refrigerant is almost completely evaporated at the end of the evaporator. The compressor sucks the refrigerant vapour from the low pressure space and compresses it in the condenser where it is colled and liquified. The condenser may be water- or air-cooled.

The high pressure liquid refrigerant flows through the reservoir to the expansion valve and is throttled here into the evaporator. A quality of the refrigerant vapour/liquid mixture of about $x_1=0.15$ to 0.2 is present at the beginning of the evaporator. The quality of the refrigerant liquid/vapour mixture is the ratio of the refrigerant vapour mass flow rate to the total refrigerant mass flow rate. This ratio has been designated by the letter x in this application so that x_1 represents the quality of the mixture at the beginning of the evaporator and x_2 the quality at the end of the evaporator. Thus $x=0$ means the refrigerant is in a liquid state, while $x=1$ means that the refrigerant is entirely vapour. Therefore $x=15$ means that 15% by weight of the refrigerant is flowing as vapour and 85% is in a liquid state. The refrigerant picks up heat in the evaporator thus increasing the quality of the mixture. The refrigerant is almost completely evaporated at the end of the evaporator in such dry expansion systems. Also a number of refrigerant passes come together in the low pressure space at the end of the evaporator.

The second system employs two refrigerant cycles which are connected by a container. The compressor sucks the refrigerant vapour from the container, compresses it into the condenser where the refrigerant is liquified. The liquid refrigerant passes through the expansion valve into the container. The second cycle begins on the liquid side of the container. Only the liquid refrigerant is pumped through the evaporator. Refrigerant liquid/vapour mixture leaves the evaporator and flows into the container. In this system, which works with incomplete evaporation, the quality of the mixture at the beginning of the evaporator is always $x_1=0$. At the end of the evaporator the quality of the mixture is about $x_2=0.1 \ldots 0.2$.

It is known that the heat transfer coefficient for a two phase flow of liquid/vapour mixtures with change of phase (evaporation) is, beside other factors, a function of the intensity of heat flux, the refrigerant mass flow rate and the quality of the refrigerant liquid/vapour mixture (the quality of mixture represents the ratio of the vapour mass flow rate to the total refrigerant mass flow rate). By the term heat flux, I mean the heat to be exchanged through the functioning of the refrigeration cycle. For an evaporator tube where the refrigerant enters with a low quality and is almost completely evaporated at the end of the evaporator, depending upon the heat flux intensity and the mass flow rate, there exist two regions along the evaporator tube in which the heat transfer coefficient is governed by different laws. At the beginning of the evaporator (low qualities and consequently low velocities) the heat transfer coefficient depends primarily upon the heat flux (nucleate boiling). The mass flow rate does not play an important part in this region. The flow velocity increases with the increase in the quality of the mixture.

After a particular point along the evaporator tube the heat transfer coefficient is governed by the laws of *convective* heat transfer. In this region the heat transfer coefficient is independent of the heat flux intensity and is a strong function of the mass flow rate and the quality of the mixture. The heat transfer coefficient has a maximum value at about $x=0.8$. The two phase flow goes over to a single phase flow (vapour only) with further evaporation thus lowering the heat transfer coefficient considerably. The above description shows that the heat transfer coefficient has a very good value at some particular qualities.

For refrigeration units with dry expansion (complete evaporation), nucleate boiling region is present in the greater part of the evaporator because of the relatively low mass flow rates. The average heat transfer coefficient for such evaporators is very low. All the known systems of the second type work with relatively low qualities of the mixturre ($x=0 \ldots 0.25$). The heat transfer coefficient is also here relatively low (mostly nucleate boiling). An attempt has been made to increase the value of the refrigerant side heat transfer coefficient by achieveing an almost complete wetting of the internal surface of the tube. For this purpose, it has been proposed to bore holes at particular intervals along the tube and to suck away the vapour generated in between. Thus the quality of the mixture was kept intentionally low.

The purpose of the invention is to increase the refrigerant side heat transfer coefficient remarkably and to create a refrigerant cycle which allows to adjust an optimum value for the refrigerant side heat transfer coefficient.

The real core of the invention is that means and circuits are provided, which allow to adjust the quality of the mixture at the beginning of the evaporator tube and the mass flow rate (or the quality of the mixture at the end of the evaporator) in order to achieve a remarkably high value of the refrigerant side heat transfer coefficient. After having recognized the main idea of the invention, one would find a number of possibilities and ways to realize it. A preferable system employs two circuits between the low pressure space at the end of the evaporator and the beginning of the evaporator. One circuit is meant for liquid refrigerant and the other for the refrigerant vapour. The equipment for the adjustment of the mixture quality at the beginning and the end of the evapo-

rator consists of a liquid pump in the liquid circuit and a vapour blower in the vapour circuit as well as a mixing chamber at the beginning of the evaporator. These circuits and equipment allow to adjust the desired quality of the mixture at the beginning and the end of the evaporator. Taking into consideration the pressure drop in the evaporator tubes, one would preferably choose a value for the quality of the mixture at the beginning of the evaporator, which lies below or near that x which gives a maximum for the heat transfer coefficient for the respective mass flow rate. The quality of the mixture increases in the evaporator because further evaporation takes place. The quality of the mixture at the end of the evaporator is slightly higher than at the beginning of the evaporator and may have a value near about x which gives the maximum for the heat transfer coefficient.

A second possible system consists of a liquid and a vapour circuit between the low pressure space at the end of the evaporator and the beginning of the evaporator. The means (equipment) to adjust the mixture quality at the beginning and the end of the evaporator include a liquid pump in the liquid circuit and an injector which sucks the vapour over the vapour circuit as well as a mixing chamber at the beginning of the evaporator. Either the injector is adjustable or a regulating valve is provided in the vapour circuit in order to adjust the desired vapour flow rate. These two means can also be combined. By this way it is also possible to adjust an optimum quality of the mixture at the beginning and the end of the evaporator as desired according to the working conditions.

Another system employs also a liquid and a vapour circuit between the low pressure space at the end of the evaporator and the beginning of the evaporator. The equipment to adjust the desired quality of the mixture at the beginning and the end of the evaporator consists of a vapour blower in the vapour circuit and an injector which sucks the liquid over the liquid circuit as well as a mixing chamber at the beginning of the evaporator. In order to regulate the liquid mass flow rate either the injector is adjustable or a regulating valve is provided in the liquid circuit. These two means can be combined here, too.

Another economically interesting system provides a liquid circuit between the end and the beginning of the evaporator and a vapour circuit between the compressor (pressure side) and the beginning of the evaporator. The means to adjust the mixture quality at the beginning and the end of the evaporator consist of an injector (with high pressure vapour as driving medium) which sucks the liquid over the liquid circuit and a mixing chamber at the beginning of the evaporator. A regulating valve is provided in the vapour circuit and the injector is adjustable and/or another regulating valve is provided in the liquid circuit in order to adjust the desired liquid and vapour mass flow rates.

The idea of the invention which includes in general the adjustment of the optimum value of the refrigerant side heat transfer coefficient by providing a refrigerant cycle for refrigeration units is shown in the diagrams attached herewith. These diagrams show the main interesting systems. Other systems are also conceivable but they do not possess any major advantages as compared to the systems shown here, and may work with greater losses and require more equipment and energy investments.

The figures show:

FIG. 1 refrigerant cycle with two additional circuits for vapour and liquid as driving mediums,

FIG. 2 refrigerant cycle with two additional circuits—liquid as the driving medium,

FIG. 3 refrigerant cycle with two additional circuits—vapour as the driving medium,

FIG. 4 another possible system.

Compressor **1** draws the refrigerant vapour from the low pressure space **5** and compresses it to a higher pressure. The compressed vapour is liquified in the condenser **2** and flows after throttling in the expansion valve **3** to the mixing chamber **8**. The mixing chamber is located at the beginning of the evaporator tubes. Refrigerant vapour and liquid are drawn from the low pressure space **5** and are fed into the mixing chamber **8** with the help of a liquid pump **6** and the vapour blower **7**. The desired refrigerant mass flow rate and the quality of the refrigerant liquid/vapour mixture at the beginning and the end of the evaporator can be adjusted by suitable regulation of the liquid pump **6** and the vapour blower **7** for given working conditions (heating intensity and temperature difference between the evaporation temperature and the temperature of the medium to be cooled). The size of the compressor **1** does not change in this system. The main refrigeration cycle is numbered **13**, the liquid circuit **14** and the vapour circuit **15** or **16** in all the figures.

FIG. 2 shows another possible system with the liquid as the driving medium, whereby it is possible to eliminate the need for the vapour blower **7** of FIG. 1. Compressor **1** draws the refrigerant vapour from the low pressure space **5** and compresses it to a higher pressure. It is liquified in the condenser **2** and flows after throttling in the expansion valve **3** to the mixing chamber **8**. The liquid refrigerant is led from the low pressure space **5** to the injector **9** by a liquid pump **6**. Vapour is sucked by the injector **9** from the low pressure space **5** and the mixture is fed into the mixing chamber **8**. An adjustable injector is provided in order to regulate the vapour flow rate over the vapour circuit **15**. A regulating valve **11** is provided in the vapour circuit **15** in addition to or instead of the *adjustable* injector.

Refrigerant vapour is the driving medium in FIG. 3 and the liquid is sucked by the injector **9** in order to achieve the desired mixture quality. The injector **9** is also adjustable in this system in order to regulate the liquid flow rate. In addition to that a regulating value **10** may be provided in the liquid circuit **14**.

FIG. 4 shows a system avoiding the use of both the liquid pump **6** and vapour blower **7** of the first three modifications. The system is provided with a bigger compressor **1** than that in previous figures. Compressor **1** draws the refrigerant vapour from the low pressure space **5** and compresses it to a higher pressure. A part of the superheated high pressure vapour flows to the condenser **2** and is liquified. The liquid refrigerant flows after throttling in the expansion valve to the mixing chamber **8**. A part of the superheated high pressure refrigerant vapour flows from the compressor **1** to the injector **9** over the vapour circuit **16**. Refrigerant vapour is the driving medium here. The liquid is sucked by the injector **9** from the low pressure space **5** over the liquid circuit **14**. The mixture flows now into the mixing chamber **8**. In order to regulate the vapour flow rate and to adjust the quality of the mixture at the beginning and the end of the evaporator **4**, a regulating valve **12** is provided in the vapour circuit **16**. The injector **9** is adjustable as before. In addition to that another regulating valve **10** may be prvoided in the liquid circuit **14**.

Other systems with slight changes may also be applied. For example, the refrigerant can be led to the low pressure space **5** instead of leading it to the mixing chamber **8** after throttling in the expansion valve **3** (FIG. 2). In any event, it should be clear to those skilled in the art that while the means I have conceived for the purpose of controlling a refrigerant cycle are extremely important, my basic contribution to the art resides in the concept of controlling the vapour/liquid content of the refrigerant moving through the evaporator.

I claim:

1. In a refrigerant cycle for a refrigeration unit, an evaporator having a high pressure beginning and a relatively low pressure end, a chamber in communication with

said low pressure end for receiving fluid and vapour from the low pressure end of the evaporator, a compressor, a passage leading from the vapour containing portion of said chamber to said compressor, a condenser for receiving refrigerant from the compressor, means for transmitting fluid from the condenser to the high pressure beginning of the evaporator, a liquid circuit functionally in by-pass relation to said compressor leading from the liquid containing portion of said chamber and extending also to the beginning of the evaporator, a vapour circuit also functionally in by-pass relation to said compressor leading from the vapour containing portion of said chamber to the said beginning of the evaporator, and means for withdrawing measured amounts of liquid from said chamber and also measured amounts of vapour from said chamber through said liquid and vapour circuits respectively whereby to predetermine the quality of the refrigerant mixture and the total refrigerant mass flow rate in said refrigeration unit in order to achieve a high value for the refrigerant side heat transfer coefficient.

A method for controlling the quality of the refrigerant and the total refrigerant mass flow rate cycle of a refrigeration cycle utilizing an evaporator having a low pressure end and a high pressure beginning, that comprises utilizing a compressor for receiving vapour from the low pressure end of the evaporator and transmitting refrigerant formed by the compression of said vapour to the high

pressure beginning of the evaporator through the intermediary of a condenser, and controlling the ratio of vapour to the total refrigerant at both the high pressure beginning of the evaporator where the refrigerant is introduced from the condenser and also at the low pressure end from which vapour is withdrawn to the compressor, by withdrawing measured amounts of refrigerant vapour from the said low pressure end of the evaporator additional to that withdrawn to the compressor, and also measured amounts of refrigerant liquid from another part of the low pressure end of the evaporator, and introducing both said vapour and liquid refrigerant thus withdrawn into the high pressure beginning of the evaporator functionally in bypass relation to said compressor and condenser.

References Cited

UNITED STATES PATENTS

1,958,087	5/1934	Hoffman	62—512X
1,978,382	10/1934	Jones	62—512
2,267,152	12/1941	Gygax	62—512

MEYER PERLIN, Primary Examiner

U.S. Cl. X.R.

62—196, 512