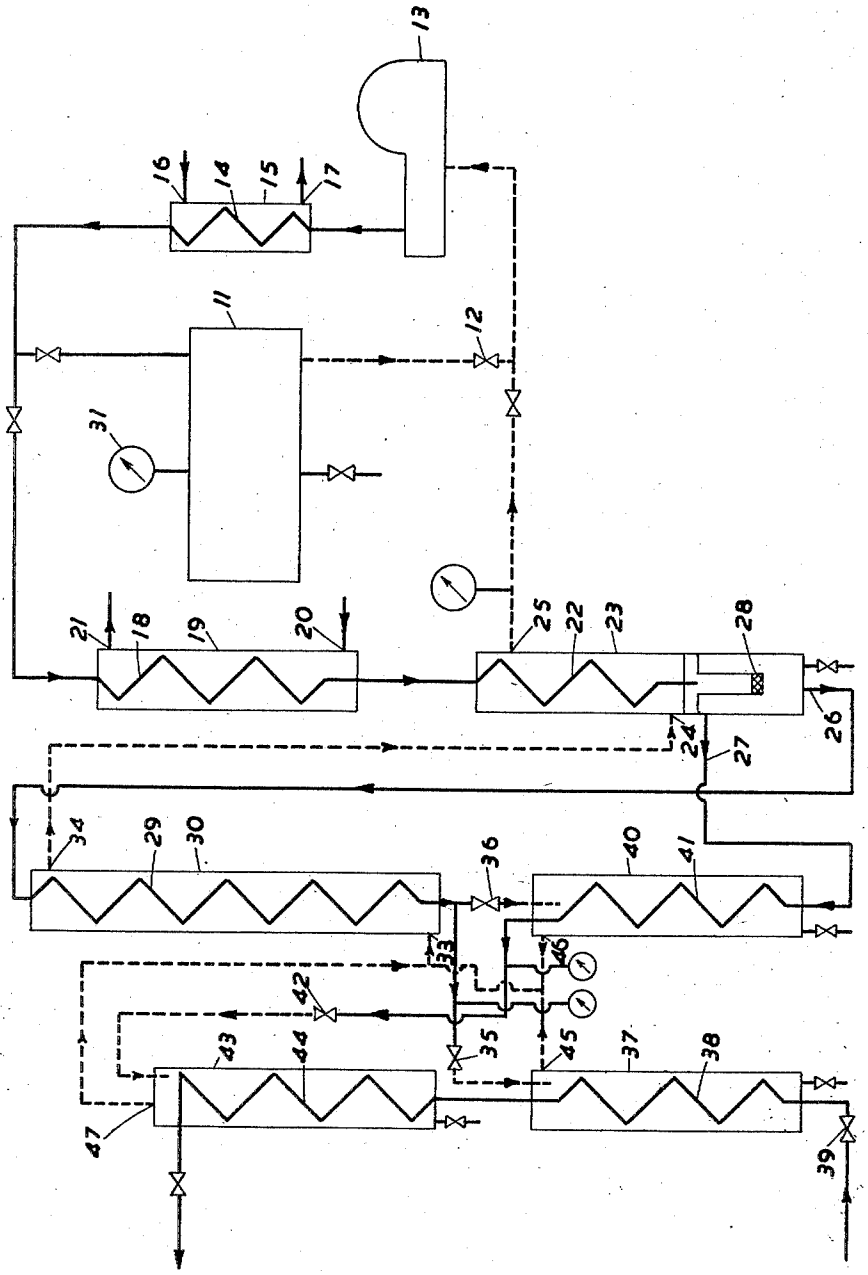
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PLURAL STAGE COOLING MACHINE

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PLURAL STAGE COOLING MACHINE

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This invention relates to cooling processes and machines and more particularly to compression refrigerating processes and machines in which a mixture of two or more refrigerants of different boiling points is used.

It has been proposed to use a two-stage refrigerating cascade in which the first stage is a diffusion-absorption machine and the second stage a compression machine. It has further been proposed to use in the second stage of such a machine a mixture of refrigerants consisting preferably of a mixture of two or more hydrocarbons having different boiling points. This arrangement was shown to have two peculiar advantages in that firstly a lower temperature can generally be reached by the choice of a suitable mixture in the second stage than by the use of a pure refrigerant which can be condensed at the temperature of the first stage and that secondly refrigeration can be effected over a wide temperature interval by using mixed refrigerants, instead of at one low temperature alone, as in the case of a pure refrigerant.

In the arrangements hitherto described for the use of mixed refrigerants, whether in a single-stage compression machine or as the second stage of a two-stage machine, the lowest temperature obtainable is the boiling point, at the lowest obtaining pressure, of the mixture of refrigerants having the composition at which it enters the machine. Moreover this composition, and hence the lowest temperature obtainable, cannot be varied beyond a certain limit in view of the necessity in the known arrangements of liquefying the whole of the mixture with atmospheric air or cooling water or in the first stage of the machine.

In order to obtain still lower temperatures it is necessary, according to existing proposals, to add a third stage to the machine, thus making the arrangement more complicated and costly.

It is an object of the present invention to provide a process and machine free of the above disadvantages, that is to say, a process which enables lower temperatures to be reached in a compression stage using mixed refrigerants, both in the case of a single-stage process and in the case of cascade refrigeration, and a machine operating by the above process. In other words or further an object of the invention is to produce with

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a compression refrigerating machine using mixed refrigerants lower temperatures than could otherwise be obtained with the same refrigerant mixture between the same pressure limits while at the same time retaining the characteristic advantage of refrigeration with mixed refrigerants, namely, the absorption of heat or the production of cold over a wide interval of low temperatures.

In the compression refrigeration process of the invention which operates with a mixture of gaseous refrigerants of different boiling points, the condensation of the gaseous mixture after compression takes place in at least two steps and the liquid portion and the gaseous portion resulting from the first partial condensation step are physically separated from each other (i. e. are passed into separate conduits), the gaseous portion being condensed in one or more subsequent condensation steps.

The cooling required for the first partial condensation step may be effected by means of atmospheric air or of cooling water when the process is carried out in a single stage machine. On the other hand, if the process forms a second or later stage of a cascade refrigeration system the cooling for the first partial condensation step may be effected by the refrigerant of the first or preceding stage of the cascade system.

The partial condensation step forming part of the process of the invention and referred to above and hereinafter may be carried out in one or more cooling units and comprises the whole step from its commencement down to the point at which physical separation of the liquid and gaseous portions takes place.

The compression refrigeration process of the invention may be operated with two refrigerants, for example, ethylene and propane for a single stage process or ethylene and methane when it forms the second stage of a cascade refrigeration system. In such case, the gaseous portion left after the first partial condensation step is generally completely condensed whilst under pressure in a second condensation step by cooling in thermal contact with at least part of the liquid portion evaporating at a lower pressure. The last condensed portion is then evaporated at a lower pressure to produce cold over a range of temperature and thus performs the refrigerating duty required.

The condensation of the gaseous portion may be effected by the evaporation of the whole of the liquid portion or only part thereof. The proportion of the gaseous mixture condensed in the first condensation step is adjusted to meet either of these requirements. In the case where the evaporation of only a part of the liquid portion is used to condense the gaseous portion, the evaporation of the remaining part of the liquid portion may be used to perform part of the refrigerating duty of the process.

The invention also consists of a compression refrigeration machine for operation with a mixture of gaseous refrigerants of different boiling points which comprises a compressor, cooling means for partially condensing the gaseous mixture after compression, a condenser-evaporator having a coil passing therethrough, a conduit for leading the condensate from the cooling means through an expansion valve to the exterior of the said coil and a second conduit for leading the gaseous portion from the cooling means to the interior of the said coil.

By the utilisation of the compression refrigeration process of the invention, the lowest temperature obtainable is no longer fixed by the boiling point at the lowest obtaining pressure of the mixed refrigerants of initial composition. Thus with a mixture of two refrigerants which is separated at the first partial condensation step into a liquid portion richer in the less volatile component and a gaseous portion richer in the more volatile component than the initial mixture, the lowest temperature obtainable is the boiling point, at the lowest obtaining pressure, of this new gaseous portion which will be lower than that of the initial mixture.

Moreover, since in the process of the invention the whole of the gaseous mixture of refrigerants is not liquefied in one step, greater scope is provided in choosing the composition of the mixed refrigerants. More especially it enables a mixture of refrigerants to be used containing a higher percentage of more volatile components than would otherwise be the case.

In one method of carrying out the process of the invention, a mixture of gaseous refrigerants of suitable composition is compressed to a pressure at which a certain portion of it can be condensed in heat exchange with atmospheric air or cooling water or, if the mixed refrigerant is used in the second stage of a cascade, by the refrigerant of the first stage of the machine. The liquefied portion of the mixed refrigerant, which will be richer in the less volatile components, and the gaseous portion, which will be richer in the more volatile components, are then separated and fed into separate conduits, i. e. are physically separated from each other.

The gaseous portion of the mixed refrigerant, with or without suitable pre-cooling, is partially or completely liquefied in thermal contact with the liquid portion evaporating at a lower pressure. Thereupon the liquid resulting from this second condensation step is itself expanded to a lower pressure, preferably atmospheric pressure, thereby reaching a very low temperature. This cold liquid can be evaporated over a wide interval of low temperatures, thereby serving to liquefy a condensable gas from a gaseous mixture or to perform any other suitable refrigerating duty.

The two portions into which the mixed refrigerant has been separated are again allowed to mix, whereupon the cycle can be repeated.

One form of refrigerating apparatus constructed and operating in accordance with the invention is illustrated diagrammatically in the accompanying drawing and together with the method of operation, will be described below.

Referring to the drawing, the mixed gaseous refrigerants which may be ethylene and propane in equimolecular proportions, are stored in tank 11 from which they are drawn through the valve 12 into the compressor 13 and then pumped at a pressure, which may be 20 atmospheres, into the refrigerating system. The amount of gases pumped into the plant is estimated by means of the gauge 31 and when sufficient has been transferred the valve 12 is closed and the storage tank is then isolated from the system. The gases leaving the compressor 13 first pass up through the coil 14 of after-cooler 15 in which they are cooled by water entering at 16 and leaving at 17. They then pass down through the coil 18 of water cooler 19 in which they are further cooled and partially condensed by water entering at 20 and leaving at 21. The extent of the condensation is determined by the initial composition of the gaseous mixture, the working pressure and the temperature of the cooling water. The droplets of liquid formed in coil 18 are swept on by the remaining gases downwardly through the coil 22 of the vessel 23 where further cooling, and hence further condensation, is effected by cold gases returning from a later part of the system to the compressor 13 and entering at 24 and leaving at 25. The liquid and gaseous portions resulting from the partial condensation step carried out in vessels 19 and 23 are physically separated at the lower end of vessel 23 by leading off the liquid portion through pipe 26 at the bottom and leading off the gaseous portion through pipe 27 at the side.

In order to minimise entrainment of the fine liquid droplets by the gaseous stream, the two portions may be passed through an agglomerator 28 which causes the droplets to coalesce as they pass into the lower end of the vessel 23, but the use of an agglomerator is not essential. When used, the agglomerator 28 is a vertical cylindrical ring fitted with a tightly wound vertical helix of thin metallic ribbon having a closely spaced fine corrugation. The liquid portion leaving through the pipe 26 then passes down through the coil 29 of the sub-cooler 30 in which it is cooled below its boiling point at the working pressure by returning cold gases which pass upwardly through cooler 30, entering at 33 and leaving at 34 as shown by the dotted line. The cooled liquid then divides into two streams, one passing through expansion valve 35 and the other through expansion valve 36 expanding in each case to a lower pressure which may be atmospheric pressure. The liquid which has passed through valve 35 is then led into the condenser-evaporator 37 in which it flows downwardly over the coil 38 and evaporates at the lower pressure, cooling the load which is led into the bottom of the coil 38 through valve 39. The liquid passing through valve 36 similarly evaporates at the lower pressure in condenser-evaporator 40 where it cools the gaseous portion coming from vessel 23 and passing upwardly through the coil 41. This gaseous portion is condensed in passing through condenser-evaporator 40 and the liquid is passed through the expansion valve 42, expanding to a lower pressure, and at this lower pressure, which may be atmospheric pressure, into the condenser-evaporator 43 where it flows downwardly over the coil 44 and evaporates to further cool the load.

which passes from the coil 38 upwardly through the coil 44 of condenser-evaporator 43. The evaporating liquids pass downwardly over the coils in each of the condenser-evaporators 37, 40 and 43, and the gases formed also pass downwardly and then pass upwardly through the core of the condenser-evaporator in each case to leave at the top of each condenser-evaporator. The cold gases leaving the condenser-evaporators 37, 40 and 43 at points 45, 46 and 47 respectively are passed together into sub-cooler 30 at point 33 and pass upwardly through the sub-cooler 30 and thence through vessel 23 to the compressor 13, as indicated by the dotted line and arrows. The dotted line indicates the flow of refrigerants at the lower pressure.

Operating the apparatus described above as a single stage refrigeration machine with a mixture of ethylene and propane in equimolecular proportions and with a working pressure of 20 atmospheres absolute and a return pressure of 1 atmosphere absolute, cooling water being supplied at 10° C., the following results were obtained:

	° C.
Inlet temperature of cooling medium in vessel	43—92
Outlet temperature of cooling medium in vessel	43—70
Inlet temperature of cooling medium in vessel	37—70
Outlet temperature of cooling medium in vessel	37—55

Thus cold was supplied to the load passing through vessels 37 and 43 over a temperature interval of −92° C. to −55° C. The cold produced was found to be 55.2 gals per kg. of mixed refrigerants passing through the compressor.

The gradient over which cold is supplied may be broken into several stages so that if the load is a mixed gaseous one the liquid fractions formed at various temperatures can be led off whilst the remaining gaseous part is allowed to pass further along the exchanger to be taken off at some lower temperature.

In the apparatus described and illustrated, the liquid portion having passed through coil 29 of sub-cooler 30 is divided into two streams, but the working conditions may be so chosen that the amount of refrigerants condensed in coolers 19 and 23 is such that the evaporation of the whole of this condensate at the lower pressure is required to condense the gaseous portion passing through the coil 41. In this case, the condenser-evaporator 37 may be omitted and the whole of the refrigerating duty is performed in condenser-evaporator 43. The apparatus described and illustrated is a single stage compression refrigeration machine but the process of the invention can obviously be used to advantage in a two stage cascade refrigeration system. In the latter case the apparatus illustrated may comprise the second stage of the cascade refrigeration system, the water cooler 19 being replaced by a condenser-evaporator into which a refrigerant which has been compressed and liquefied by cooling in the first stage is fed through an expansion valve and evaporated, the gas resulting from this evaporation being returned to the compressor of the first stage.

It is also possible with the process of the invention to use a mixture of three gaseous refrigerants, for example, propane, ethylene, and methane. The working pressure may then be arranged so that in the initial partial condensation step a smaller portion of the refrigerant mixture is condensed. The gaseous and liquid portions thus formed are physically separated and about half of the gaseous portion is condensed by cooling in thermal contact with at least part of the liquid portion evaporating at a lower pressure. The gaseous and liquid portions resulting from the second condensation step are also physically separated and the gaseous portion is completely liquefied by cooling in thermal contact with at least part of the condensate from the second condensation step evaporating at a lower pressure. The final condensate is then expanded to a lower pressure and evaporated to produce cold over a range of temperature. Any condensate resulting from the first condensation step and not evaporated in the second condensation step is evaporated at a lower pressure to perform part of the refrigerating duty of the process. Similarly any condensate resulting from the second condensation step and not evaporated in the final condensation step is evaporated at a lower pressure to perform a further part of the refrigerating duty of the process.

Such a system would enable another exchanger to be added which would cool the load from say −90° C. to −120° C. and hence one single refrigerating unit can handle a fairly complex mixture of gases.

I claim:

1. A compression refrigeration machine for operation with a mixture of gaseous refrigerants of different boiling points, which comprises a compressor, cooling means for partially condensing the gaseous mixture after compression, a condenser-evaporator having a coil passing therethrough, a conduit for leading the condensate from the cooling means through an expansion valve to the exterior of the said coil and a second conduit for leading the gaseous portion from the cooling means to the interior of the said coil.

2. A closed-circuit compression refrigeration system for supplying the cooling requirements of a system outside said closed-circuit system, and operating with a mixture of normally-gaseous refrigerants of different boiling points, which comprises in combination a compressor having a suction side and a pressure side for compressing said gaseous refrigerants, heat-exchanging means for cooling the compressed gaseous mixture thereby partially liquefying said mixture, means for separating the resulting liquid fraction from the gaseous fraction, means for further cooling the separated liquid fraction, an expansion valve, means for conducting at least part of the sub-cooled liquid fraction through said expansion valve and then in indirect thermal contact with the separated gaseous fraction thereby causing the latter to condense, a second expansion valve, means for passing the resulting condensate through said second expansion valve and then in heat exchanging relationship with said outside system to supply the cooling requirements thereof and conduit means for returning the vapors derived from said condensate back to the suction side of said compressor.

3. The system of claim 2 wherein said means for further cooling the separated liquid fraction is a heat exchanger in which said liquid fraction is brought into indirect thermal contact with the vapors returning to the suction side of the compressor.

4. The system of claim 2 wherein only part of the liquid fraction is passed through said first

named expansion valve and used to condense the separated gaseous fraction, means being provided to pass the remainder of the liquid fraction through another expansion valve and then in heat exchanging relationship with said outside system to supply cooling thereto over a temperature range above that supplied by the condensed gaseous fraction.

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