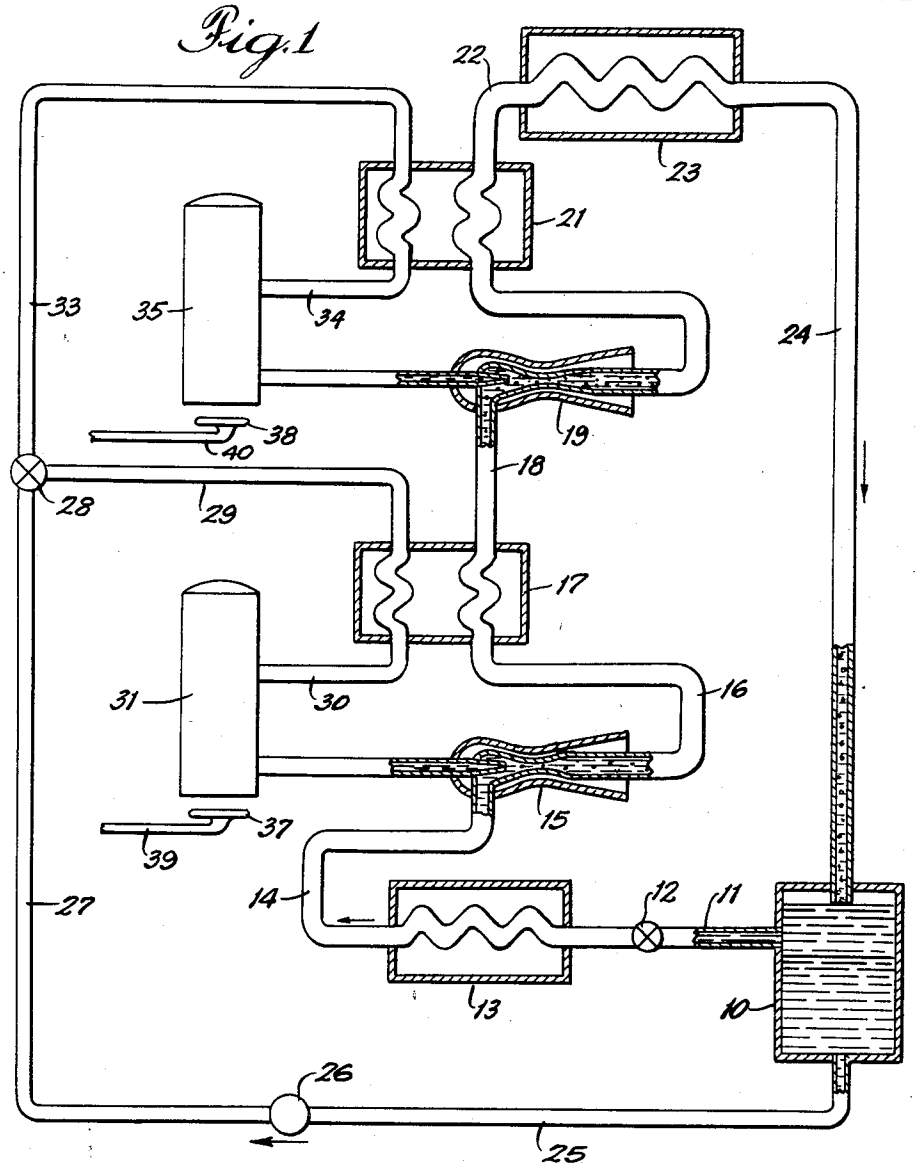
April 5, 1960 M. DUBITZKY 2,931,190

JET REFRIGERATION SYSTEM

Filed May 29, 1957 2 Sheets-Sheet 1

Fig. 1



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Fig. 2

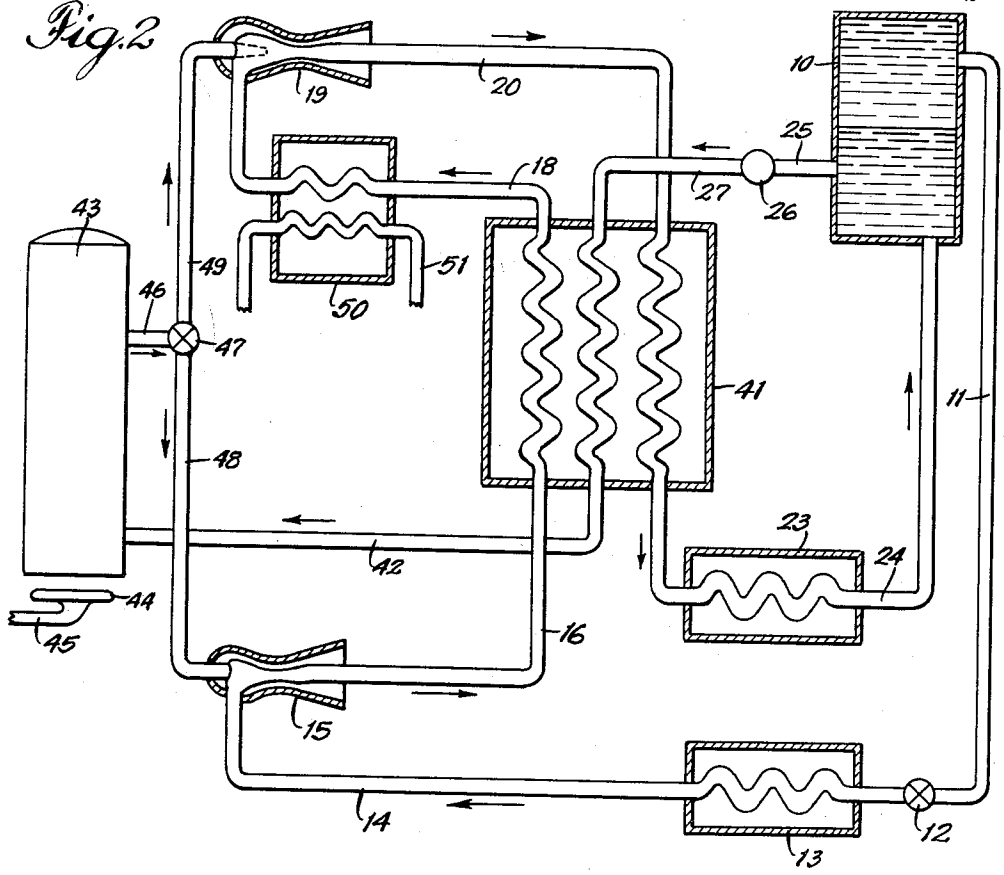
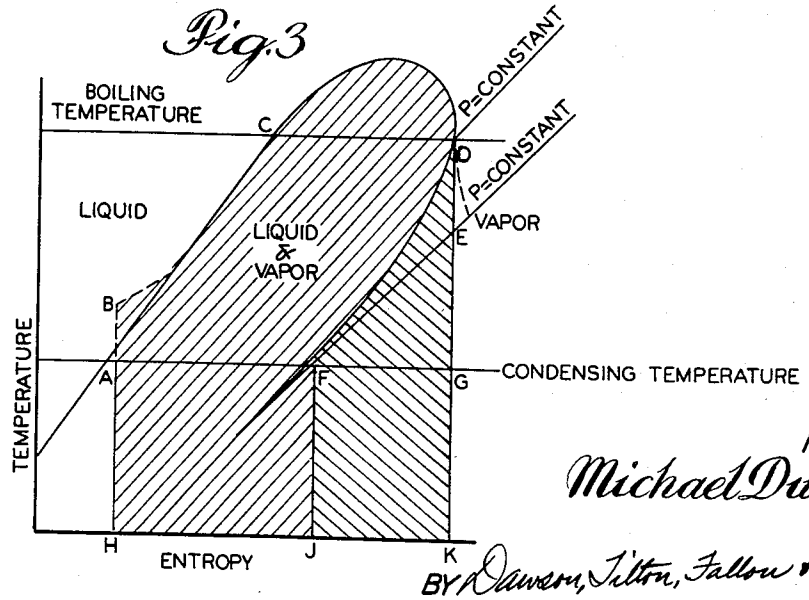


Fig. 3



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2,931,190

JET REFRIGERATION SYSTEM

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Application May 29, 1957, Serial No. 662,360

7 Claims. (Cl. 62—114)

This invention relates to an improvement in refrigeration, and more particularly to an improvement in a fluid jet refrigeration system employing heat as a source of energy.

A refrigeration system employing jet pumps in a heat-operated cycle possesses a distinct advantage over conventional refrigeration systems in being able to operate without the need for electrical power. Further, such refrigeration systems operate noiselessly and can be provided through the use of relatively simple equipment and at low cost.

These advantages, particularly the freedom from the need for using electrical power, recommend the fluid jet refrigeration system for use in railway cars, trucks, small craft, and home air conditioning where gaseous or liquid fuel is relatively inexpensive.

The jet, heat-operated refrigeration systems heretofore available have been characterized by an unacceptably low efficiency, or, more precisely, coefficient of performance. The coefficient of performance of a refrigeration system (hereinafter designated COP) is defined as the ratio of effective refrigeration to the total heat energy input. A much investigated fluid jet refrigeration system employed the use of steam as the fluid. The factor of low efficiency referred to above is particularly applicable to steam jet refrigeration which, at normal air conditioning temperatures, has a COP of about 0.25 to about 0.35. Even advances in the design of ejectors (jet pumps) have not contributed significantly to the achievement of higher COP's.

The fact that a good refrigerant does not make the good motive fluid needed in a fluid jet system and that a good motive fluid does not make up a good refrigerant, led workers in this field to suggest that the use of two fluids might improve the performance of a fluid jet refrigeration system. However, no two-fluid system has been advanced that meets the requirements of efficiency of many refrigeration systems, particularly those intended to be used for heat-operated air conditioning devices.

It is a general object of this invention to provide an improved fluid jet refrigeration system that overcomes the disadvantages and problems set forth above. Another object is to provide a heat-operated refrigeration cycle which has an efficiency superior to known heat-operated cycles. Yet another object is to provide a heat-operated refrigeration cycle which is competitive with conventional electrically-operated cycles. Still another object is to provide a heat-operated, fluid jet refrigeration cycle which employs two different fluids. A still further object is to provide a refrigeration system capable of operating on gaseous or liquid fuels. Another object is to provide a heat-operated refrigeration system that is particularly useful in air conditioning applications. Other objects and advantages of my invention can be seen as this specification proceeds.

The binary jet refrigeration cycle employing this invention has two fluids to accomplish the cooling effect by means of heat. The primary or motive fluid acts very much like steam in a power plant: emerges from a boiler as a vapor at high temperature and pressure, expands in an ejector to a lower pressure and temperature, and after it is condensed by external means, it is pumped and fed back to the boiler. The refrigeration or secondary fluid goes through a conventional vapor refrigeration cycle of expansion, evaporation, compression, and condensation—except that it is compressed in the ejector by the expanding motive fluid.

Such a fluid jet refrigeration system employing two fluids operates between three temperatures: the boiler temperature, the condensing temperature, and the refrigerant evaporating temperature. The two latter temperatures are defined by the application. The refrigerant evaporating temperature depends upon the level at which refrigeration is desired. In air conditioning, for example, this level normally is between 35 and 45° F. The condensing temperature depends upon the external cooling means available, and is generally between 80 and 90° F. for water-cooled units, and between 110 and 140° F. for air-cooled units. The boiler temperature is somewhat more flexible, but is subject to the practical limitations of materials used and boiler efficiency desired. A temperature of about 500° F. is usually found reasonable.

My invention will be explained, in an illustrative embodiment, in conjunction with the accompanying drawings, in which—

Figure 1 is a flow diagram showing a fluid jet refrigeration cycle having two boilers and two heat-exchangers; Fig. 2 is a flow diagram showing a fluid jet refrigeration cycle having one boiler and one heat-exchanger; and Fig. 3 is a representation of the thermodynamic cycle for a typical motive fluid of this invention.

The cycles illustrated in Figs. 1 and 2 are typical of cycles which may be used to embody the process of this invention. Figs. 1 and 2 differ in the number of boilers and heat exchangers used. Fig. 1 shows a boiler and a heat exchanger for each jet pump, while Fig. 2 shows one boiler and one heat exchanger serving both jet pumps.

In Fig. 1 there is provided a separator **10** in which the motive fluid and refrigerant are physically separated by gravity or other means as indicated hereinafter. From this separator **10**, each of the fluids is drawn off to enter its own part of the cycle. The following description will trace first the refrigerant and then the motive fluid, for the sake of simplicity. The refrigerant is taken from separator **10** by means of conduit **11** which contains expansion valve **12** into the evaporator **13**, and out of the evaporator by means of conduit **14** to the jet pump **15**. The motive fluid moving into the jet pump **15** draws the refrigerant into the jet pump where it is compressed and mixed with the motive fluid at an elevated temperature. By means of conduit **16** the refrigerant and motive fluid are led into heat exchanger **17**, where the sensible heat of the motive fluid is transferred by out-of-contact heat exchange means to the compressed motive fluid just prior to the latter's entering boiler **31**. From heat exchanger **17** the mixtures of refrigerant and motive fluid is led out by line **18** to be drawn into jet pump **19**. In jet pump **19**, additional compression is achieved and additional heat transfer takes place between the motive fluid and refrigerant both in the fluid mixture and in heat exchanger **21** which is comparable to heat exchanger **17**. Conduit **22** leads the fluid mixture into condenser **23** where the fluids are liquefied and subsequently returned by means of line **24** to separator **10**.

From separator **10** the motive fluid is drawn off by line **25** to pump **26** where it is compressed and simultaneously heated. By means of conduit **27** the compressed and heated motive fluid is passed through distributor valve **28** which directs a portion of the motive fluid into

line 29 which carries it into heat exchanger 17 where it gives up its sensible heat to the fluid mixture from jet pump 15. From heat exchanger 17 the motive fluid is led by conduit 30 to boiler 31 where it is vaporized by heat furnished it to the boiler from burner 37 fed by fuel line 39, and passed by means of line 32 to jet pump 15. The remaining portion of the compressed motive fluid is directed by distributor valve 28 through line 33 to heat exchanger 21, and then by line 34 to boiler 35 (where it is vaporized by heat from burner 38 fed by fuel line 40), and conduit 36 to jet pump 19. Thus, the second portion of motive fluid is subjected to treatment duplicating that through which the first portion passes. In jet pump 19 the remaining motive fluid enters the fluid mixture stream.

Fig. 2 illustrates one possible scheme in which one boiler and one heat exchanger may be used to serve the two jet pumps. As in the case of the cycle shown in Fig. 1, and described above, the motive fluid and refrigerant going to jet pump 15 in the same manner. Likewise, the vaporized motive fluid enters jet pump 15, and with the refrigerant is compressed, led out by line 16 and passed through heat exchanger 41 where it gives up part of its sensible heat to the motive fluid before the latter enters boiler 43. After leaving heat exchanger 41, the mixture of motive fluid and refrigerant passes to the second jet pump 19 by way of line 18. An auxiliary cooler 50 may be placed in line 18 to cool the mixture before it enters jet pump 19 to reduce the work of compression. Cooling fluid, such as water, may be introduced into auxiliary cooler 50 by means of line 51. The compressed fluid mixture from jet pump 19 leaves by line 20, passes through heat exchanger 41, and then enters condenser 23 as in Fig. 1.

The motive fluid leaving heat exchanger 41 is led by line 42 into boiler 43. Heat is supplied to boiler 43 by means of burner 44 fed by fuel line 45. After being vaporized in boiler 43, the motive fluid goes by line 46 to a distributing valve 47 where the stream is split, half going by line 48 into jet pump 15, and half going by line 49 to jet pump 19.

Although Figs. 1 and 2 illustrate the separation of the motive fluid and refrigerant by gravitational means, other ways of physically separating them may be used, such as centrifuging, etc. Preferably, the two fluids should possess different densities for ease of separation.

The jet pumps 15 and 19 are of any suitable type known in the art. Pump 26 may be a conventional positive-displacement type, or may be a liquid jet injector type.

Optimum results have been achieved when systems of the character shown in Figs. 1 and 2 have been employed using water as the refrigerant fluid and a cyclic fluorocarbon ether having the formula $C_8F_{16}O$ as the motive fluid. This compound is described in U.S. Patent No. 2,644,823 issued July 7, 1953, and is commercially available under the trade name "Fluorochemical 0–75" from the Minnesota Mining & Manufacturing Company, of St. Paul, Minnesota. An example of the operation of a fluid jet refrigeration system using this binary mixture is set forth below.

Example

The motive fluid, as indicated above, had the empirical formula $C_8F_{16}O$ and at room temperature was a colorless liquid. Its boiling-point was 101° C., its density at 25° C. was 1.760 grams per cubic centimeter. The specific heat ratio of this compound

$$\left(k=\frac{c_p}{c_v}\right)$$

was slightly over 1.0, i.e., below 1.1.

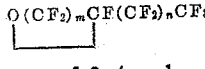
The refrigerant fluid, being water, had a lesser density than the motive fluid and formed the top layer in separator 10. Water, drawn from separator 10 at about 100° F. and 1.0 p.s.i.a., was expanded in valve 12 to 40° F. and 0.12 p.s.i.a. The motive fluid was simultaneously drawn off the bottom portion of separator 10, raised to 150 p.s.i.a. by pump 26, and directed into boilers 31 and 35 by way of heat exchangers 17 and 21. As vaporized motive fluid passed into and through jet pumps 15 and 19, it drew water vapor from conduit 14 and water vapor—$C_8F_{16}O$ mixture from conduit 18—into the stream of the jet pumps. The fluid mixtures were compressed in the jet pumps.

For example, the fluid mixture had a temperature of 100° F. and a pressure of 0.3 p.s.i.a. in conduit 18. The mixture then passed through condenser 23 and, after leaving condenser 23, was a liquid mixture having a temperature of 100° F. and 1.0 p.s.i.a. Thereafter, the mixture returned to a separator at essentially the same temperature and pressure. The coefficient of performance in the example given was about 0.7, which compares favorably with an average of about 0.3 for steam jet pump refrigeration systems.

I have found that an important contribution to the successful operation of a fluid jet refrigeration system is made by the thermodynamic characteristics of the motive fluid $C_8F_{16}O$. Of particular importance in this connection is the above mentioned ratio of specific heats which results in appreciable sensible heat in the vapor as well as in the liquid phase. In the case of most fluids, the sensible heat is negligible compared to the latent heat. The sensible heat, in the example given, is the product of the specific heat taken at constant pressure and the temperature difference existing between the boiler temperature and the condenser temperature. However, thtis is not the case for the motive fluid described above. Because of the relatively high molecular weight of this motive fluid, the latent heat per unit of weight is relatively low. On the other hand, the sensible heat is high and affords recoverable heat for heating the motive fluid entering the boiler. Thus, where the amount of heat thus recovered is appreciable, a very significant improvement in COP can be obtained with little or no increase in heat transfer surface. The heat required to be put into the boiler is decreased by the use of heat exchange surface, thereby improving the COP.

The effect of the considerable amount of sensible heat displaced by this motive fluid is shown in Fig. 3. In Fig. 3, there is illustrated a thermodynamic chart of a typical motive fluid of this invention, such a cyclic fluoroether of the formula $C_8F_{16}O$. In Fig. 3, the area ABCDEF represents the output of the cycle, while the area HABCDEGK represents the energy input to the cycle. When the saturated vapor is expanded isentropically, there is created a highly superheated vapor having an appreciable amount of sensible heat represented by area JFDGK in Fig. 3.

The motive fluid employed additionally possessed the desirable characteristics of being nontoxic, noninflammable, and noncorrosive to metallic equipment. Other motive fluids possessing analogous characteristics can be employed satisfactorily, such as compounds related to the particular motive fluid employed here. Such compounds may have the empirical formula



where m is an integer of 3–4 and n is an integer such that the total number of carbon atoms is in the range 6–10.

A significant contribution toward the achievement of the excellent results discussed above was made by the refrigerant fluid, which, in the example given, was water. Water is considered desirable as a refrigerant fluid, since it is nonreactive and immiscible with the motive fluid and possesses a substantially different density to make the separation therebetween expeditious. I have found it further desirable that the two fluids have approximately identical boiling pressures at the condensing (ambient)

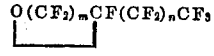
temperature, and that they both may be vaporized at temperatures and pressures within the range of conditions readily permissible in present-day equipment. Water and other low molecular weight, low-boiling liquids such as methanol, ethanol, and ammonia, are considered highly desirable for use as refrigerant fluids. Use of a low molecular weight refrigerant fluid such as water aids in obtaining of the high and desirable COP's characteristic of the system of my invention.

I also have found that the achievement of excellent results is brought about by having the saturation pressure of the motive fluid at evaporating temperature much lower than the saturation pressure of the refrigerant fluid. This is achieved where the motive fluid possesses a high rate of change of vapor pressure with temperature.

While, in the foregoing specification, I have described at considerable length and in considerable detail certain specific embodiments of my invention, it will be understood that these embodiments are illustrative only and that many variations therein may be made by persons skilled in the art without departing from the spirit of my invention.

I claim:

1. A method of furnishing refrigeration, comprising separating a liquified refrigerant and a liquified motive fluid, the motive fluid being a cyclic fluorocarbon ether having the formula



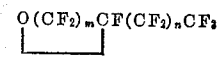
wherein *m* is an integer of from about 3 to 4, and *n* is an integer such that the total number of carbon atoms is from 6 to 10, evaporating said refrigerant to provide refrigeration, reuniting said refrigerant and said motive fluid in a jet pump, previous to said reunion passing said motive fluid through heat exchange means and boiler means, passing said united refrigerant and motive fluid through said heat exchange means and through condenser means, and returning said united refrigerant and motive fluid to means for separating the same.

2. A method according to claim 1, in which the said motive fluid is a cyclic fluoroether of the formula $C_8F_{16}O$.

3. A method of furnishing refrigeration from a binary jet fluid system employing water as the refrigerant and a cyclic fluoroether of the formula $C_8F_{16}O$ as the motive fluid, comprising compressing the said water in a jet pump in conjunction with the expansion of said cyclic fluoroether, condensing the mixture of said water and said fluoroether, separating the said mixture, evaporating the said water at sub-atmospheric pressure to provide refrigeration, heating the said cyclic ether, and reuniting said cyclic ether and said evaporated water for the compressing of said water.

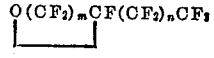
4. A method according to claim 3, in which the temperature during condensing is less than about 140° F., and the temperature during the step of evaporating is in the range of about 35–45° F.

5. A method of furnishing refrigeration from a binary jet fluid system employing a cyclic fluorocarbon ether having the formula



wherein *m* is an integer of from about 3 to 4, and *n* is an integer such that the total number of carbon atoms is from 6 to 10, as the motive fluid and water as the refrigerant fluid, comprising compressing the refrigerant fluid in a jet pump in conjunction with the expansion of said cyclic fluorocarbon ether, condensing the mixture of said refrigerant fluid and said fluorocarbon ether, separating the said mixture, evaporating the said refrigerant fluid at sub-atmospheric pressure to provide refrigeration, heating the said cyclic fluorocarbon ether, and reuniting said cyclic fluorocarbon ether and said evaporated refrigerant fluid for compressing the said refrigerant fluid.

6. In a method of furnishing refrigeration employing a jet pump, the steps of flowing a motive fluid into heat exchange relation with a source of heat, said motive fluid being a cyclic fluorocarbon ether having the formula



wherein *m* is an integer of from 3 to 4, and *n* is an integer such that the total number of carbon atoms is from 6 to 10, flowing said motive fluid from said source to a jet pump, combining a refrigerant fluid with said motive fluid in said jet pump, and passing said combined fluids in heat exchange relation with said motive fluid prior to the flowing thereof into heat exchange relation with said source of heat.

7. A method according to claim 6 wherein the motive fluid is $C_8F_{16}O$.

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