Sept. 4, 1934. D. N. CROSTHWAIT, JR 1,972,704

REFRIGERATING APPARATUS AND PROCESS

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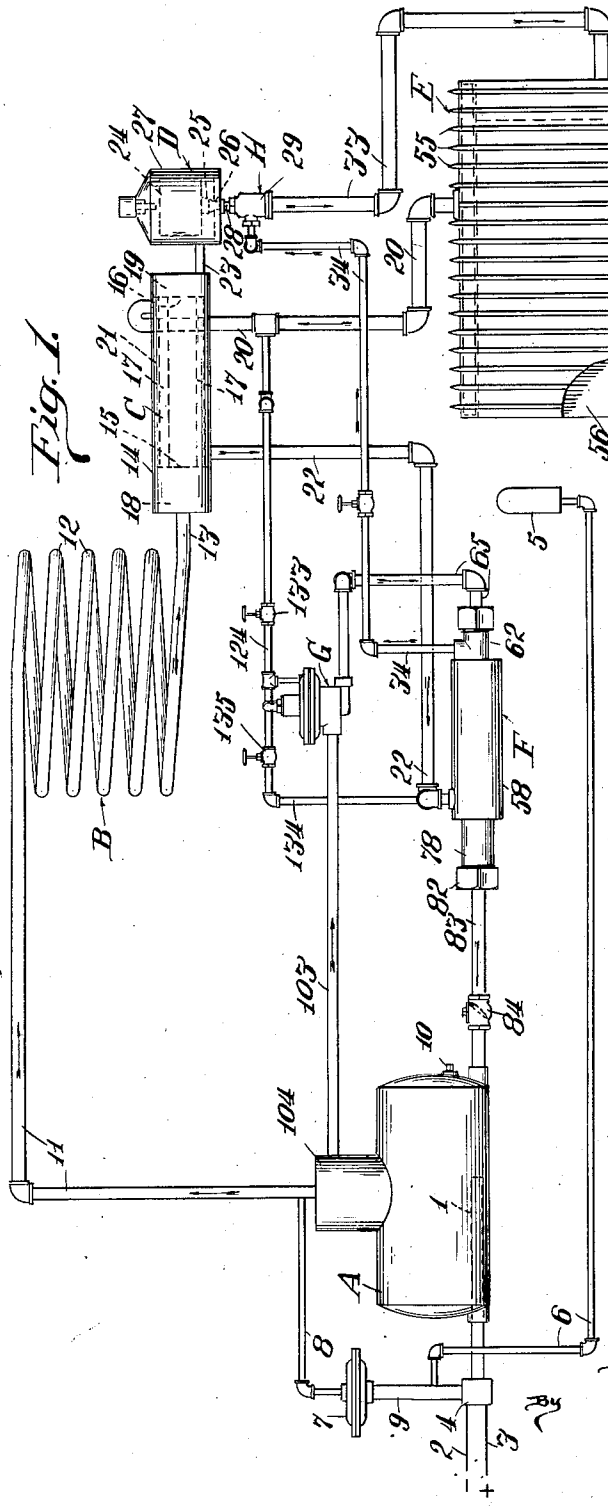


Fig. 1.

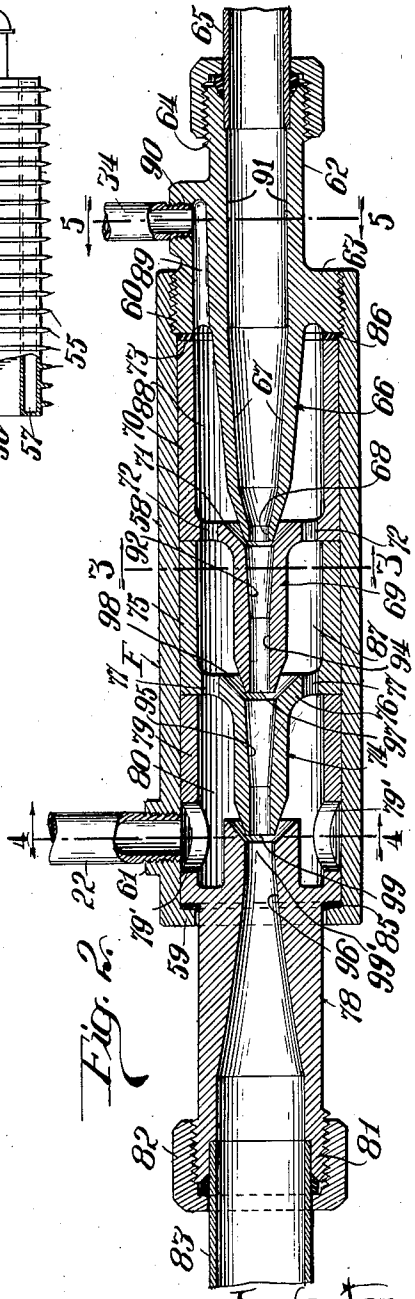


Fig. 2.

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Fig. 3.

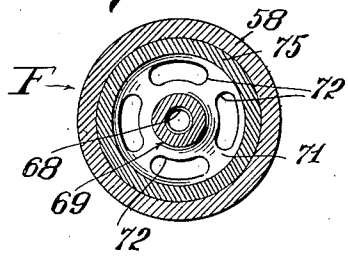


Fig. 6.

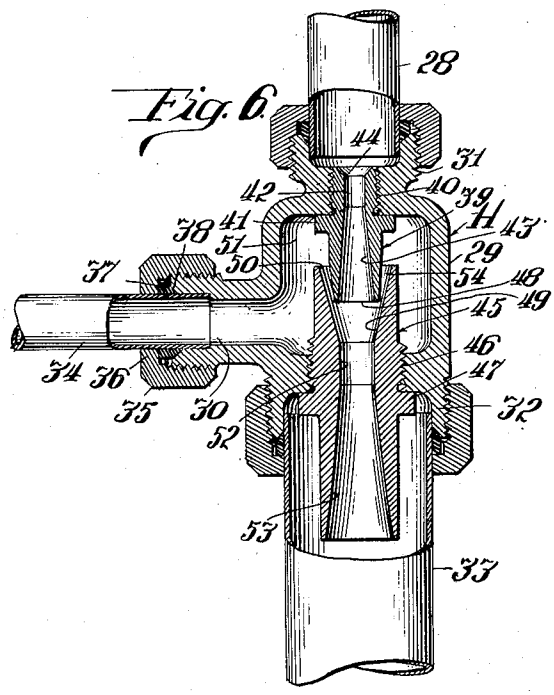


Fig. 4.

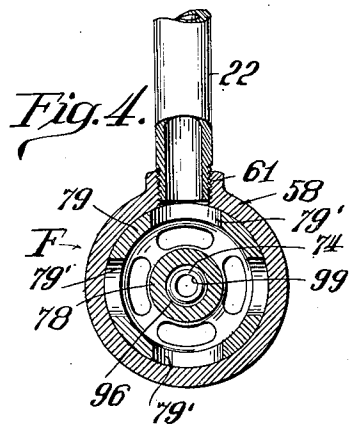


Fig. 5.

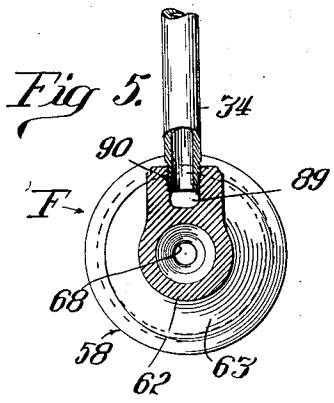
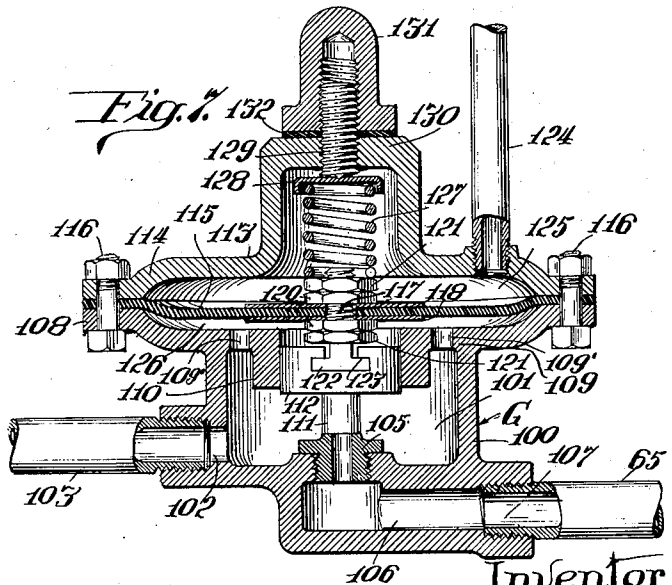


Fig. 7.



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Fig 8.

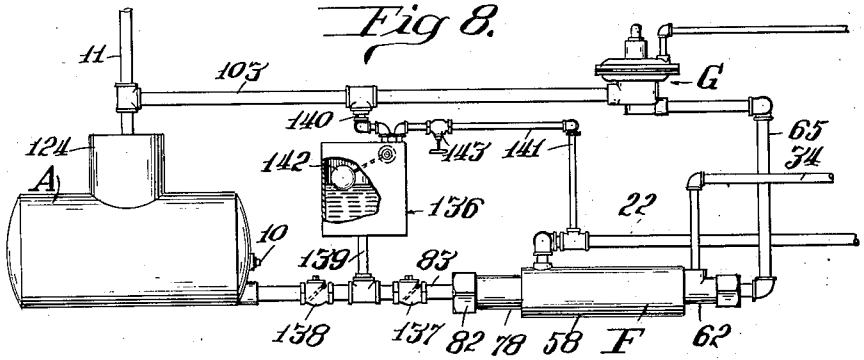


Fig. 9.

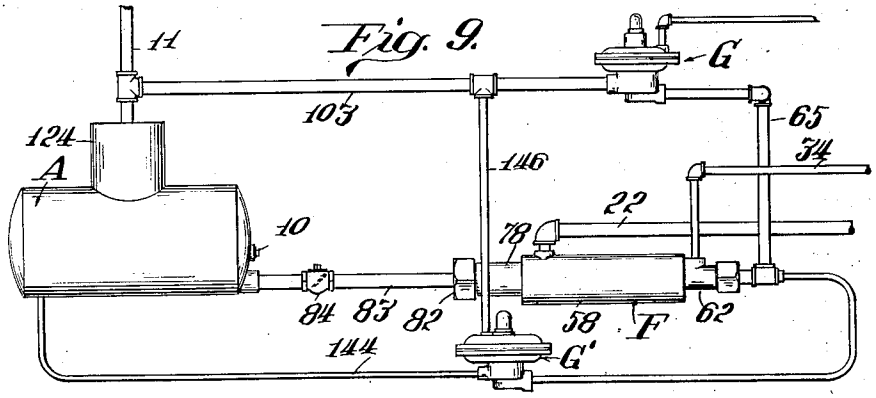
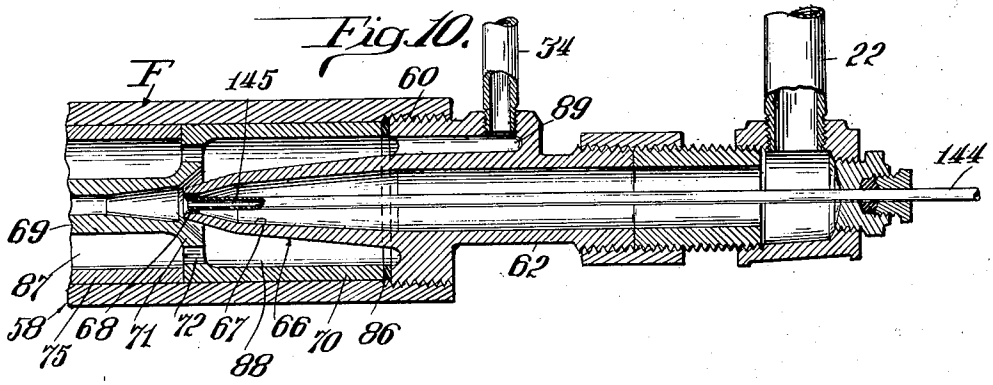


Fig. 10.



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UNITED STATES PATENT OFFICE

1,972,704

REFRIGERATING APPARATUS AND PROCESS

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Application March 31, 1930, Serial No. 440,519

23 Claims. (Cl. 62—115)

This invention relates to a new and improved refrigerating process and apparatus, and more particularly to a closed cycle refrigerating system in which a high velocity jet of vaporized refrigerant from the high pressure side of the system is utilized to condense and return the expanded refrigerant from the low pressure side of the system to the generator or source of the high pressure fluid.

The general object of the invention is to provide a simple and automatically operating refrigerating machine which may be operated under a variety of conditions, that is free from moving parts, and in which a wide variety of refrigerants may be used such as liquids, liquid solutions of a refrigerant in a solvent, or solids such as salts from which vapors may be driven off. The circulation in the system is obtained entirely from pressure and temperature differences in different parts of the system. Briefly described, a body of the liquid refrigerant is heated in a closed generating space whereby this refrigerant is vaporized under relatively high pressure, and while still under this high pressure heat is withdrawn in a condensing coil so as to liquefy the refrigerant. By means of an expansion valve of improved type, the liquefied refrigerant is admitted in limited quantities into the evaporator wherein it expands and vaporizes and absorbs heat so as to carry out the desired refrigerating process. A jet or stream of vaporized refrigerant from the generator, under relatively high pressure and high velocity, is utilized to entrain a portion of the expanded refrigerant from the vaporizer, whereby the mixture of refrigerants will be condensed and returned to the high pressure source in liquid form or as a liquid vapor mixture. More specifically, this invention contemplates precooling the jet-forming fluid so as to increase the efficiency of the process and to reduce a larger portion of the actuating vapor and entrained low pressure vapor to liquid form before it is returned to the high pressure source. In previous forms of kinetic exhausters or jet compressors, the resulting temperature of the mixture of the actuating vapor and the vapor being compressed was at a higher temperature than the initial temperature of the vapor that is compressed. The actuating jet was cooled to some value which resulted from the expansion and the cooling effect of the gases or vapors being compressed by the jet as a result of the mixing of the two but no previous attempt has been made, so far as known to me, to secure a cooling of the actuating jet by the vapors to be compressed prior to the admixture of the vapor or gas to be compressed with the actuating jet. According to my improved process, the fluid forming the actuating jet is surrounded prior to the formation of the jet by a jacket of the cooled and expanded vapor that is to be compressed and returned to the generator. In this manner, the temperature of the jet-forming fluid is lowered.

Another object of the invention is to provide an improved form of compressor especially adapted to carry out the process briefly outlined hereinabove and explained more in detail in the specifications which follow.

Another object is to provide improved means for circulating the vapor from the evaporator through the jet compressor whereby to precool the actuating jet fluid.

Another object is to provide improved means for automatically controlling the flow of actuating fluid to the jet so that the compressor will only be operated after a predetermined minimum pressure differential has been established and maintained between the pressure of the actuating fluid and the pressure of the vapor to be compressed.

Another object is to provide automatic means for controlling the generator in accordance with temperature and pressure conditions existing in the evaporator and generator, so that the heat cycle may be automatically repeated and so as to maintain the desired temperature in the space to be refrigerated.

Another object is to provide an improved means whereby the liquefied refrigerant from the compressor need not be discharged against the entire pressure existing in the generator, but may be temporarily discharged into an intermediate receiver in which a pressure lower than generator pressure is maintained, and subsequently automatically permitted to gravitate into the generator.

Another object is to provide improved means whereby an absorption cycle can be combined with the compression cycle so as to return an additional quantity of expanded refrigerant into the generator.

Other objects and advantages of this invention will be more apparent from the following detailed description of certain forms of apparatus capable of carrying out the principles of this invention.

In the accompanying drawings:

Fig. 1 is a diagrammatic layout of the assembled refrigerating apparatus, shown in elevation.

Fig. 2 is a central longitudinal section through the jet compressor.

Fig. 3 is a transverse vertical section taken substantially on the line 3—3 of Fig. 2.

Fig. 4 is a transverse vertical section taken substantially on the line 4—4 of Fig. 2.

Fig. 5 is a transverse vertical section taken substantially on the line 5—5 of Fig. 2.

Fig. 6 is a central vertical section through the recirculator.

Fig. 7 is a central vertical section through the differential control valve.

Fig. 8 is a partial elevation, similar to Fig. 1, showing a modified form of system utilizing an intermediate receiver for boosting up the pressure of the condensed refrigerant.

Fig. 9 is a partial elevation, similar to Fig. 1, illustrating the addition of an absorption jet.

Fig. 10 is a vertical central section through the right hand end of the jet compressor shown in Fig. 9.

It is to be understood that many of the devices shown in the drawings, especially such parts as are heretofore well known in the art, are merely indicated diagrammatically and might take a variety of suitable forms.

Referring first to Fig. 1, the principal elements of the refrigerating apparatus are the generator A, the condenser B, the heat-exchanger C, the expansion valve D, the evaporator E, and the jet-compressor F for returning the refrigerant to the generator A. The differential control valve G governs the flow of actuating high pressure vapor to the compressor F, and the re-circulator indicated at H maintains a flow of cooling low-pressure vapor into and through the compressor F. Other auxiliary devices will be subsequently described. It might be here noted that the parts A to F hereinabove identified constitute a closed system through which the same body of refrigerant or refrigerating fluid is continuously circulated. The relatively high pressure side of the system exists in the generator A, condenser B and expansion valve D. The low pressure side of the system extends through the evaporator E and the outer casing of compressor F. In this compressor the refrigerant is liquefied and returned into the high pressure generator A. In general, the fluids flow through the various pipings in the directions indicated by the small arrows, and the high pressure side of the system may be considered to exist from the generator A to and through the expansion valve D and the low pressure side of the system to prevail from expansion valve D back to the generator A.

The several constituent parts of the apparatus will now be described in somewhat more detail, after which the cycle of operations will be described. The generator A is in the form of a closed tank or receptacle containing a body of liquid refrigerant. In the lower portion of generator A is a heating element 1, here shown in the form of an electric heater deriving its power from the mains 2 and 3 through an automatic control switch indicated at 4. A thermostat 5, positioned adjacent the evaporator E, or so as to register the temperature in the space to be refrigerated, controls the automatic switch 4 through connections 6 so that the heater 1 will be energized when the temperature at 5 rises above a desired maximum, and the supply of power to heater 1 will be cut off when the temperature has been lowered at 5 to the desired minimum. 7 is a pressure controller subject through pipe 8 to the pressure existing in generator A, and adapted through connections 9 to open the switch 4 when a predetermined maximum pressure is reached in the generator A and the high-pressure side of the system. The generator A is provided with a filling plug indicated at 10. It will be apparent that when the heater 1 is energized, the refrigerant in the generator will be vaporized and its temperature and pressure is considerably increased. The maximum pressure of the vaporized refrigerant is established by the controller 7 which automatically cuts off the flow of power to heater 1 when a predetermined maximum pressure is reached. It will be understood that gas or other forms of heating means could be used for raising the temperature of the refrigerant in generator A, the electric means herein briefly described being merely shown by way of example although particularly suited for this purpose.

The vaporized refrigerant under relatively high pressure flows through pipe 11 to the condenser B which is in the form of a pipe coil 12 or similar form of conduit having a large condensing surface. This condenser may be cooled either by air or by water or other liquids depending upon the range of pressures it is desired to operate the apparatus between. Ordinarily atmospheric air will be sufficient to extract the desired quantity of heat from the fluid and condense the refrigerant. The liquefied or partially liquefied refrigerant (still under high pressure) flows through pipe 13 into the heat-exchanger C. This device is provided to secure increased condensing effect by passing the fluid from condenser B through a jacket containing cooled expansion gases from the evaporator E, whereby additional heat is withdrawn from the condensed fluid. In the form here shown, this heat exchanger C comprises a tubular casing 14 closed at its ends and provided with interior transverse partitions 15 and 16 adjacent its respective ends, these partitions being connected by a plurality of tubes 17 opening into the spaces 18 and 19 at the respective ends of the container. The refrigerant from condenser B flows through pipe 13 into the chamber 18 and thence through pipes 17 to the chamber 19 at the other end of the casing. A pipe 20 serves to conduct the cooled and expanded refrigerant under low pressure from the evaporator E into the space or jacket 21 surrounding the pipes 17, this vapor flowing out through pipe 22 to the compressor F, as hereinafter described. The high pressure refrigerant flowing through tubes 17 will be further cooled by the surrounding jacket 21 of lower pressure refrigerant so as to more completely condense the same before it flows in liquid form through pipe 23 into the expansion valve D. While the use of the heat-exchanger C is preferred, this device might be omitted and the liquefied refrigerant conducted directly from the condenser B through pipe 13 into the expansion valve D. In this case the pipes 20 and 22 would be consolidated to conduct the low pressure refrigerant direct from evaporator E to the compressor F.

The expansion valve D is here shown as being of the float type, although it could be either of the fixed adjustment type or a spring loaded diaphragm operated type both of which are familiar to those skilled in the refrigerating art or, if desired both the float type of expansion valve and the spring loaded diaphragm type may be used in conjunction. The float 24 carries a valve member 25 cooperating with a fixed valve seat 26. When the liquid level rises in the casing 27, the float 24 will be lifted to raise the valve 25 and permit a limited quantity of liquid to flow out through

pipe 28, but as the liquid level falls within the casing 27, the float 24 will again reseat the valve 25 to cut off the further flow of liquid refrigerant through the outlet 28. In this manner limited quantities of refrigerant are permitted to flow out into the lower pressure existing in the evaporator E and the return side of the system.

Before passing to the evaporator E, the refrigerant released from expansion valve D passes through the recirculator H, shown in section in Fig. 6. The function of this recirculator is to insure a circulation of the low pressure cooling vapor through the compressor F, as hereinafter described. Referring to Fig. 6, the casing 29 of the recirculator is provided with an upper externally threaded inlet 31, a similar side inlet 30 and a lower outlet 32. The pipe 28 leading from expansion valve D is connected with inlet 31, and the pipe 33 leading to the evaporator E connects with outlet 32. A small pipe 34 leading from the compressor F connects with the suction inlet 30 at the side of casing 29. Preferably all of these connections will be made by what is termed a "solderless connection", the pipe end extending into the exteriorly threaded nipple such as 30, and the coupling nut 35 which is threaded onto the nipple having an inwardly extending end shoulder 36 adapted to force a gasket 37 against the interiorly beveled end portion 38 of the nipple so as to compress the gasket (which may be of copper or a suitable composition) into fluid-tight engagement with the pipe end. While this form of pipe connection is preferred, other suitable types of pipe joints might be used. The discharge nozzle 39 is threaded at 40 into the upper inlet passage of casing 29, the nozzle having an annular shoulder 41 to engage the upper interior wall of the casing and properly position the nozzle and insure a tight joint at this point. Preferably this nozzle is provided with a relatively small cylindrical throat portion 42 and a flared discharge passage 43. A short converging inlet passage 44 leads to the throat 42. A delivery tube 45 is similarly threaded at 46 into the lower outlet passage of casing 29, and is provided with an annular limiting shoulder 47. The discharge end 48 of nozzle 39 terminates within the converging inlet passage 49 of the delivery tube 45. The inlet end 50 of the delivery tube terminates within the suction chamber 51 of casing 29. The passage within the delivery tube comprises the converging inlet portion 49, an intermediate cylindrical portion 52 and a diverging portion 53 from which the fluids are discharged into the pipe 33. The liquid discharged from the expansion valve D through pipe 28 starts to vaporize as it passes through the recirculator H, and the contour of the passages through nozzle 39 and delivery tube 45 cause this jet of actuating fluid to be projected with some velocity through the recirculator, whereby the low pressure vapor introduced through pipe 34 into the suction chamber 51 will be partially entrained in the annular inlet passage 54 and carried along through the delivery tube, wherein the mixed gases are again compressed in the expanded portion 53 of the passage and discharged into the pipe 33 through which they are delivered through the evaporator E. It is only necessary that a relatively small suction effect be exerted in chamber 51 sufficient to induce a flow of fluid through pipe 34 from the compressor F.

The evaporator E is in the form of a hollow shell provided exteriorly with a plurality of ribs 55 adapted to provide additional contacting surface with the air in the space to be cooled. It is to be understood that the evaporator E (as well as the thermostat 5) is inclosed in the chamber or space that is to be refrigerated. The space 56 within the hollow shell of the evaporator may serve as a receptacle for articles to be frozen, such as ice cubes. The liquid refrigerant flows in through pipe 33 into the hollow space 57 within the evaporator shell and there expands and vaporizes, thus absorbing heat through the walls of the evaporator shell from the space to be cooled or the articles placed therein.

The expanded refrigerant, now at a low pressure and still at a relatively low temperature, flows out from the evaporator E through pipe 20 to and through the heat exchanger C wherein it absorbs additional heat from the condensed high pressure refrigerant, as hereinabove described. The still relatively cool low pressure refrigerant then flows through pipe 22 to the compressor F.

This improved jet compressor F is best shown in Fig. 2. This improved jet compressor is designed so as to secure an increased heat exchange, and consequently a greater pressure difference and a greater compression effect upon the gaseous refrigerant from the evaporator, for the purpose of returning this gaseous refrigerant to the generator. This compressor F comprises a rather long tubular casing 58 provided with an inwardly extending annular flange or collar 59 at one end, and an internally threaded portion 60 at the other end. The conduit 22 for the low pressure refrigerant is threaded into an inlet nozzle 61 adjacent the discharge end of the casing. The inlet nozzle member 62 for the actuating fluid is provided with a large central collar member 63 exteriorly threaded to engage within the internally threaded end portion 60 of the casing 58, and with an exteriorly threaded outer inlet nipple 64 which is connected (preferably by a solderless connection of the type hereinabove described) with the pipe 65 through which vaporized refrigerant under relatively high pressure from the generator A is conducted into the compressor. The inlet nozzle member 62 is provided with a discharge nozzle 66 having a converging passage 67 leading to the discharge opening 68 which is located slightly beyond the minimum diameter of the passage, that is the discharge end of the nozzle preferably flares outwardly slightly. A second nozzle member comprises a nozzle portion 69, a cylindrical shell 70 adapted to fit within the outer casing 58, and a connecting annular wall or web 71 provided with a circular series of openings or passageways 72. One end 73 of the hollow cylindrical shell 70 is adapted to abut against the inner side of collar 63 on the first nozzle member 62. Similarly, a third nozzle member comprises a nozzle portion 74, a hollow cylindrical shell 75, and a connecting wall 76 provided with a circular series of openings 77. As will be hereinafter apparent, a greater number of nozzle members such as 69 and 74 could be used if desired in order to accomplish the desired compression and heat exchange effects. The delivery tube 78 comprises a cylindrical shell portion 79 adapted to be clamped between the flange 59 at one end of casing 58 and the inner end of cylindrical shell 75 of the next adjacent nozzle member 74. The shell portion 79 is provided with a plurality of openings 79', one of which is adapted to be brought into register with the inlet pipe 22 so as to establish communication with the chamber 80 inclosed within the shell portion 79. The outlet end 81 of delivery tube 78 is connected by means of a solderless con-

nection 82 with the pipe section 83 leading back to the generator A. A one-way valve 84 in pipe 83 is adapted to open against the higher pressure existing in the generator. It will be apparent that the delivery tube 78 and the several interior nozzle members may all be inserted into the outer casing 58 from the right hand end (as shown in Fig. 4) and then securely clamped in place by screwing in the inlet nozzle member 62. Suitable gasket members 85 and 86 may be inserted between the flange 59 and the end of delivery tube 78, and between the first and second nozzle members, in order to insure fluid tight connections.

The cooled low pressure refrigerant from the evaporator flows in through pipe 22 to the chamber 80 surrounding nozzle member 74, thence through passages 77 to the chamber 87 surrounding nozzle member 69, thence through passages 72 to the chamber 88 surrounding the inlet nozzle 66. A relatively small outlet passage 89 is formed in the outer portion of inlet nozzle member 62, leading from the chamber 88 to an outlet opening 90 into which is threaded the end of pipe 34 leading to the recirculator H. The outlet passage 89 is of considerably smaller capacity than the inlet pipe 22, since only a portion of the low pressure gas is to be recirculated sufficient to insure a flow of this vapor through all of the chambers 80, 87 and 88, the greater portion of this vapor being entrained with the actuating fluid and returned to the generator A.

Upon the initial starting of the actuating jet, a lower pressure will exist in the chambers 80, 87 and 88 than in the inlet passage 91, because the differential valve G (hereinafter described) will prevent the actuating jet being started until this predetermined pressure difference shall have been obtained. Normally the pressure in the chambers 80, 87 and 88 will be substantially the low pressure existing in the evaporator E, whereas the pressure of the actuating fluid in inlet passage 91 will be substantially that existing in the generator A. The low pressure vapor in chamber 88 will also be at a much lower temperature than the actuating fluid entering through passage 91 so that a heat exchange will occur between the actuating vapor and the low pressure refrigerant through the wall of the nozzle 66. The converging passage 67 in nozzle 66 will be shaped to converge in proportion to the change in specific volume resulting from this heat exchange. The actuating fluid passing through the nozzle 66 will be subject to a drop in pressure and an increase in velocity so that when passing through the outlet orifice 68 which may or may not be diverging, it will expand adiabatically and its kinetic energy will increase so that a portion of the difference in the heat content at the two pressures will become available as kinetic energy. At the outlet 68 the pressure will have dropped to a critical value such that the velocity will enable a portion of the low pressure vapor in chamber 88 to be entrained in the annular passage 92 and carried along with the actuating fluid into the second nozzle 69. A partial condensing action will also take place at this point. The second nozzle 69 comprises a converging passage 92 leading into a diverging passage 94 which discharges into the converging passage 95 in the third nozzle 74, which in turn discharges into the diverging passage 96 in the delivery tube 78. As the fluids pass through the second nozzle 69 more heat will be abstracted by the jacket of cooler refrigerant in chamber 87, and the pressure will be further decreased, so that at the discharge end 97 the velocity and pressure will have such a value due to the proportioning of the passage that more gas may be entrained from chamber 87 through the annular passage 98 and compressed and carried into the third nozzle 74. A further condensing action will occur here resulting in a decrease in the volume of the vapor-liquid mixture, and owing to the high velocity obtained here a portion of the energy may be utilized to start a further compressing action. At the discharge outlet 99 of the third nozzle more of the low temperature and low pressure refrigerant may be entrained, and a further condensing action is secured, and the fluids are discharged into the delivery tube 78. The diverging passage 96 in the delivery tube will decelerate the velocity of the fluid mixture so as to cause compression, and the refrigerant now mostly liquefied, will be raised to a pressure sufficient to permit its discharge through pipe 83 into the generator A. The energy of the jet stream will be concentrated on a small area at the inlet 99' of the delivery tube so as to enable it to overcome the generator pressure and force the liquids past one-way valve 84 and thence into the generator. It should be noted that the passages provided for the introduction of gas into the actuating stream are at a very gradual angle so that there will be a minimum of energy lost at these points.

It is to be noted that a countercurrent flow occurs in this jet exhauster, that is the vapor to be compressed flows in a direction opposite to that followed by the actuating jet fluid. This tends to give a uniform temperature difference between the gas entering from the evaporator and the actuating jet and whatever mixture may have been drawn into the actuating stream. As the cooled low pressure vapor flows through the chambers 80, 87 and 88 its temperature will be gradually raised, so that the cooler vapor will exist in the chamber 80, and the relatively warmer vapor in the chamber 88. It will also be apparent that the actuating fluid in the jet will be initially at a much higher temperature as it enters from the generator, than when it leaves the compressor with the entrained and compressed fluids. In this manner a substantially uniform temperature difference is maintained between the actuating fluids passing through the several jet nozzles and the cooling fluid in the surrounding chambers.

The differential control valve G (best shown in Fig. 7) will now be explained. The main casing 100 houses the main chamber 101 having the inlet port 102 with which inlet pipe 103 communicates, this pipe leading from the dome or separating chamber 104 of the generator A. The valve seat 105 is removably secured in the entrance to outlet passage 106 leading to outlet port 107 in which pipe 65 leading to the compressor F is secured. The lower half of a diaphragm chamber is formed integrally with the casing 100, this portion of the casing comprising an outwardly extending flange 108, an inwardly extending flange 109, and a centrally and downwardly projecting cylindrical portion 110. The valve member 111 which cooperates with valve seat 105 to close the passage through the valve, projects downwardly from a piston or guide member 112 which slides vertically in this cylindrical passage in member 110. The upper casing member or cover 113 comprises an outwardly extending and downwardly dished flange portion 114 which mates with the corresponding

flange portion 108 of the lower casing, and the peripheral portion of a flexible diaphragm 115 is clamped between the two flange members 108 and 114 by means of a circular row of bolts 116. A threaded stem member 117 projects through a central aperture in diaphragm 115, and also through a pair of diaphragm plates 118 positioned at the two sides of the diaphragm, and is clamped in sealing engagement with these members by nuts 120 and lock nuts 121. A head 122 on the lower end of stem 117 engages in a transverse T-shaped slot 123 in the upper side of valve member 112 so as to lock these parts together for simultaneous vertical movement. A pressure control pipe 124 leading from some portion of the low pressure side of the system, for example from the pipe 20 leading from evaporator E, communicates with the pressure chamber 125 above diaphragm 115. The relatively high pressure existing in chamber 101 will be communicated through piston 112 to the chamber 126 beneath the diaphragm 115. A compression spring 127 is confined between the upper nut 121 and a spring cup 128 bearing against the lower end of adjusting screw 129 threaded through the cap portion 130 of casing 113. A cap 131 may be interiorly threaded to engage the upper end of screw 129, and a gasket 132 interposed between the cap members 131 and 130 will effectively seal the opening through the upper side of the casing. It will now be apparent that the force of spring 127 together with the low pressure communicated through control pipe 124 are exerted on the upper side of diaphragm 115, while the relatively high pressure of the actuating fluid taken from the generator A through pipe 103 is exerted on the under side of diaphragm 115, since chamber 101 communicates with diaphragm chamber 126 through passages 109'. The adjustable force exerted by spring 127 will determine the pressure differential that must exist between the high and low pressure fluids before the valve 111 will open to permit the actuating fluid to pass through pipe 65 to the compressor F. In other words, until this maximum pressure differential has been reached, there can be no flow of actuating pressure fluid to the jet compressor F, so that a predetermined pressure differential must exist between the low pressure refrigerant that is to be compressed, and the high pressure refrigerant used for actuating fluid before the operation of the compressor is automatically started.

An ordinary pressure control valve might be used in this system instead of the differential pressure control valve, although the differential valve is preferred.

A cut-off valve 133 is positioned in the control pipe 124, and this control pipe has a branch 134, provided with a cut-off valve 135, and leading into the pipe 22 adjacent its connection with the jet compressor F. By properly opening one of the valves 133 or 135 and closing the other, the low pressure connection to differential control valve G can be established either with the pipe 20 leading from evaporator E, or with the pipe 22 leading into the jet compressor F. In this way the minimum pressure used for control purposes may be changed as conditions may indicate advisable.

In the general operation of the system as thus far described, assuming that the thermostat 5 calls for heat to be abstracted from the space that is being cooled by the evaporator, and assuming that the maximum pressure has not been established in the generator A, the switch 4 will be closed and the heater 1 will be operative to raise the temperature of the refrigerant in the generator, and thus vaporize a portion of this refrigerant and raise its pressure and temperature. It is necessary to raise the temperature of the refrigerant to the point where heat may be abstracted from it in the condenser B. This vaporized refrigerant under relatively high pressure will flow to and through the condenser B where heat is withdrawn and the refrigerant is liquefied, and from the condenser it flows through the heat exchanger C where more heat is abstracted before the completely liquefied refrigerant flows into the expansion valve D. This valve feeds the refrigerant in limited quantities through the recirculator H to the evaporator E, where the refrigerant again vaporizes at a low pressure so as to extract considerable quantities of heat from the space to be refrigerated. The cooled low pressure refrigerant flows back through heat exchanger C, wherein it extracts some further heat from the incoming high pressure refrigerant, and then flows through pipe 22 to the jet compressor F. The jet compressor will remain out of operation until a sufficient predetermined pressure difference has been established between the high and low pressure sides of the system, and when this pressure difference is obtained, the differential valve will open and admit actuating vapor at high pressure to flow from generator A through pipe 103, valve G and pipe 65 to the jet compressor F. This jet compressor will operate as already described to return the actuating high pressure refrigerant, together with an entrained portion of the low pressure refrigerant, both in a liquid condition, back through pipe 83 and one-way valve 84 to the generator A. A portion of the low pressure refrigerant flowing into the compressor F sufficient to maintain a constant flow of the cooling low pressure refrigerant through the compressor, flows back through pipe 34 to the recirculator H and thence passes again through the low pressure side of the system. It will be evident that this cycle of operations will continue to be repeated as long as the generator pressure does not exceed a predetermined maximum, or the temperature in the space being cooled by the evaporator does not decrease below a predetermined minimum. If the pressure in the generator exceeds the predetermined maximum, the pressure switch will shut off the current supply to heater 1, and the heat supply will also be shut off in the same manner in case the temperature in the space being refrigerated falls below the desired minimum. Whenever the generator pressure again falls below this critical pressure, and the temperature in the refrigerated space again rises above the established minimum, the heater 1 will again be thrown into operation by the automatic closing of switch 4.

The heat exchanger C might be omitted entirely, as might also be the recirculator H, although this latter is beneficial in insuring initial cooling of the suction space of the jet compressor F so as to insure the desired heat conditions and pressure conditions for efficiently and reliably operating the jet compressor.

If desired or found necessary, one-way valves may be inserted in pipes 22 and 34, or either of them, to insure the flow of fluids in only the desired direction.

A modified form of the apparatus is shown in Fig. 8, the parts that are the same as those al-

ready described in connection with Fig. 1 being indicated by the same reference characters, and it being understood that features not shown in Fig. 8 are the same as those used in the first described modification. An alternating receiver, or intermediate receiving tank for the liquefied refrigerant, is indicated at 136, this tank being positioned at a higher level than the generator A. The discharge conduit 83 leading from jet compressor F to generator A is provided with two one-way valves 137 and 138, both opening toward the generator, and a branch discharge pipe 139 leads up from between these valves into the receiver 136. A pressure control pipe 140 leads from the high pressure pipe 103, and a pressure control pipe 141 leads from the low pressure pipe 22, and the valves alternatively establishing communication between these control pipes and the interior of receiver 136 are automatically controlled by a float 142 in the manner well known in apparatus of this type so as to alternatively establish the high or low pressures in the receiver 136 in accordance with the liquid level therein. The float 142 has a lost motion connection with the valve operating mechanism so that when a predetermined quantity of liquid refrigerant has been forced into the receiver 136, the valves will be manipulated to establish communication with control pipe 140 and cut off communication with control pipe 141 thus establishing generator pressure in the receiver 136. When the tank has been emptied, or a predetermined quantity of liquid has been withdrawn therefrom, the high pressure connection will be cut off and the low pressure will be reestablished in the receiver 136. A valve 143 is positioned in control pipe 141, this valve being of a type that opens at a predetermined maximum pressure. This valve will be so adjusted that a pressure somewhat higher than that existing in the low pressure side of the system must be established in the receiving tank 136 before this valve will open to prevent a further raising of the pressure in the receiver.

In the operation of this modified form of the system, the high generator pressure will exist from generator A back to the one-way valve 138, but the jet compressor F is not compelled to discharge the liquefied refrigerant against this high pressure, the refrigerant being forced through pipe 83, one-way valve 137 and branch pipe 139 into the receiving tank 136 in which a pressure exists intermediate that in the generator A and the low pressure in pipe 22. When a sufficient quantity of the liquid refrigerant has been forced into the receiver 136, the float controlled valves will be automatically operated to establish generator pressure in the tank 136, whereupon this body of refrigerant will gravitate through pipe 139, one-way valve 138 and pipe 83 into the generator A. As the receiver 136 is emptied, the float control valves will again be automatically manipulated to reestablish the intermediate pressure in the receiving tank 136. It will be noted that by the use of this auxiliary mechanism, the pressure is reduced against which the jet compressor F must operate.

In the systems as thus far described, it has been assumed that an undiluted refrigerant was used. If a gas dissolved in a liquid is used, such as ammonia dissolved in water, the apparatus may be modified as indicated in Figs. 9 and 10. In this modification, a small pipe 144 leads from the lower portion of generator A into the inlet end of the compressor F and terminates in a discharge nozzle 145 centered within the first discharge nozzle 66 of the compressor as already described. This pipe line 144 serves to conduct a stream of weak water-ammonia mixture from the lower part of the generator, but under high pressure, into the compressor where it is discharged as a central liquid jet within the high pressure vapor jet as already described. Preferably a pressure control or differential control valve G' is included in the pipe line 144, this valve operating similarly to the control valve G and being under the control of generator pressure through control pipe 146. If desired a single control valve G could be designed to control both the liquid jet and the vapor jet. Since the amount of ammonia which will be absorbed by water increases as the temperature decreases, gas from the evaporator will be absorbed by the liquid discharged from nozzle 145, so that this weak mixture will be converted into a strong mixture which returns to the generator along with the condensed gases. The advantages of a compression and an adsorption system are thus combined.

It may be noted that refrigerating systems such as disclosed hereinabove are particularly applicable in the field of small domestic refrigerators, since the system is entirely closed, there are no moving parts and the flow areas are relatively small. The operation of the system is entirely automatic, and the system may be adjusted to maintain any desired temperature, within certain limits, in the space to be refrigerated.

I claim:

1. The method of refrigerating consisting in heating the refrigerant in a closed generating space to vaporize it under relatively high pressure, condensing this refrigerant by extracting heat therefrom, expanding and vaporizing this refrigerant at a lower pressure, compressing and returning the low pressure vaporized refrigerant to the original closed space by means of a jet of the high pressure vaporized refrigerant from the closed space and simultaneously condensing the intermingled fluids by enveloping the jet with the low temperature vaporized refrigerant.

2. The method of refrigerating consisting in heating the refrigerant in a closed generating space to vaporize it under relatively high pressure, condensing this refrigerant by extracting heat therefrom, expanding and vaporizing this refrigerant at a lower pressure, and utilizing a jet of high pressure vaporized refrigerant from the closed space to return the low pressure vaporized refrigerant to the generating space and simultaneously utilizing an envelope of the low pressure refrigerant to condense the mixture of returned refrigerants.

3. The method of refrigerating consisting in heating the refrigerant in a closed generating space to vaporize it under relatively high pressure, condensing this refrigerant by extracting heat therefrom, expanding and vaporizing this refrigerant at a lower pressure, withdrawing high pressure vaporized refrigerant from the closed space to form a jet, precooling this fluid, and utilizing the precooled jet to return the low pressure vaporized refrigerant along with the jet fluid to the generating space, and to simultaneously liquefy this mixture of vaporized refrigerants.

4. The method of refrigerating consisting in heating the refrigerant in a closed generating space to vaporize it under relatively high pressure, condensing this refrigerant by extracting heat therefrom, expanding and vaporizing this refrigerant at a lower pressure, withdrawing high

pressure vaporized refrigerant from the closed space to form a jet, surrounding this jet-forming fluid with low pressure refrigerant to precool the jet, and utilizing the jet to return a mixture of condensed jet fluid and the low pressure refrigerant to the generating space.

5. The method of refrigerating consisting in heating the refrigerant in a closed generating space to vaporize it under relatively high pressure, condensing this refrigerant by extracting heat therefrom, expanding and vaporizing this refrigerant at a lower pressure, withdrawing high pressure vaporized refrigerant from the generating space to form a jet and utilizing this jet to liquefy a temperature-controlled mixture of the jet fluid and low pressure vaporized refrigerant and to force this mixture into an intermediate receiving space positioned at a higher level and normally under a lower pressure than the generating space, and equalizing the pressures in the generating space and receiving space when a predetermined volume of liquefied refrigerant has accumulated in the receiving space whereby the liquefied refrigerant will gravitate into the generator.

6. The method of refrigerating consisting in heating the refrigerant in a closed generating space to vaporize it under relatively high pressure, condensing this refrigerant by extracting heat therefrom, expanding and vaporizing this refrigerant at a lower pressure, and utilizing a jet of high pressure vaporized refrigerant from the closed space to return the low pressure vaporized refrigerant to the generating space and simultaneously condense the mixture of returned refrigerants, and simultaneously utilizing a jet of liquefied refrigerant from the generating space to absorb a portion of the vaporized low pressure refrigerant and return same to the generating space.

7. The method of refrigerating consisting in heating the refrigerant in a closed generating space to vaporize it under relatively high pressure, condensing this refrigerant by extracting heat therefrom, expanding and vaporizing this refrigerant at a lower pressure, withdrawing high pressure vaporized refrigerant from the closed space to form a jet, surrounding this jet-forming fluid with low pressure refrigerant to precool the jet, and utilizing the jet to return a mixture of condensed jet fluid and the low pressure refrigerant to the generating space, and simultaneously utilizing a jet of liquefied refrigerant from the generating space to absorb a portion of the vaporized low pressure refrigerant and return same to the generating space.

8. In a method of refrigerating, the step of condensing and returning low pressure vaporized refrigerant to a body of liquid refrigerant in a generator under higher pressure by utilizing a jet of the higher pressure refrigerant from the generator, entraining in the jet a portion of the low pressure refrigerant and cooling the mingled fluids by surrounding the jet with a jacket of the low pressure refrigerant.

9. In a method of refrigerating, the step of condensing and returning low pressure vaporized refrigerant to a body of liquid refrigerant in a generator under higher pressure by utilizing a jet of the higher pressure refrigerant from the generator, precooling the jet-forming fluid by surrounding it with the low pressure refrigerant, and then entraining in the jet a portion of the low pressure refrigerant.

10. In a method of refrigerating, the step of condensing and returning low pressure vaporized refrigerant to a body of liquid refrigerant in a generator under higher pressure by utilizing a jet of the higher pressure refrigerant from the generator, precooling the jet-forming fluid, and then entraining in the jet a portion of the low pressure refrigerant.

11. In a method of refrigerating, the step of condensing and returning low pressure vaporized refrigerant to a body of liquid refrigerant in a generator under higher pressure by utilizing the momentum of a stream of the refrigerant at high velocity to entrain and compress a mass of the gas at a lower pressure and simultaneously cooling the intermingled fluids by surrounding the stream with a counter-flowing stream of the low pressure refrigerant.

12. In a method of refrigerating, the step of condensing and returning low pressure vaporized refrigerant to a body of liquid refrigerant in a generator under higher pressure by utilizing a jet of the higher pressure refrigerant from the generator and entraining in the jet and condensing a portion of the low pressure refrigerant, the condensed mixture being first forced into an intermediate space positioned at a higher level and in which a pressure lower than generator pressure prevails, and establishing generator pressure in this intermediate space wherever a predetermined volume of liquefied refrigerant has accumulated therein so that the liquefied refrigerant may gravitate into the generator.

13. A closed cycle refrigerating apparatus comprising a generator, a condenser, an expansion valve, an evaporator, and a jet compressor, the compressor including means for utilizing a stream of high pressure refrigerant from the generator to compress low pressure refrigerant from the evaporator and return the mixed fluids to the generator the mixed fluids being simultaneously condensed by means of a counter-flowing envelope of the low pressure refrigerant.

14. A closed cycle refrigerating apparatus comprising a generator, a condenser, an expansion valve, an evaporator, and a jet compressor, the compressor including nozzles through which a jet of high pressure fluid from the generator is projected, and a cooling jacket surrounding the nozzles through which the low pressure vapor from the evaporator is circulated before a portion of this low pressure vapor is entrained and condensed by the jet and returned to the generator.

15. A closed cycle refrigerating apparatus comprising a generator, a condenser, an expansion valve, an evaporator, and a jet compressor, the compressor including nozzles through which a jet of high pressure fluid from the generator is projected, and a cooling jacket surrounding the nozzles through which the low pressure vapor from the evaporator is circulated before a portion of this low pressure vapor is entrained and condensed by the jet and returned to the generator, and a recirculator for maintaining a flow of the cooling refrigerant through the jacket, this recirculator comprising a jet exhauster actuated by the flow of refrigerant between the expansion valve and the evaporator.

16. A closed cycle refrigerating apparatus comprising a generator, a condenser, an expansion valve, an evaporator, and a jet compressor, the compressor including means for utilizing a stream of high pressure fluid from the generator to compress and condense low pressure refrigerant from the evaporator and return the mixed fluids to the generator, and a differential valve

subject to the high pressure in the generator and the low pressure of the evaporator, for permitting a flow of actuating fluid to the compressor only when a predetermined pressure differential has been established between the high and low pressure fluids.

17. A closed cycle refrigerating apparatus comprising a generator, a condenser, an expansion valve, an evaporator, and a jet compressor, the compressor including means for utilizing a stream of high pressure fluid from the generator to compress and condense low pressure refrigerant from the evaporator and return the mixed fluids to the generator, and pressure actuated means to automatically control the starting and stopping of the jet.

18. A closed cycle refrigerating apparatus comprising a generator, a condenser, an expansion valve, an evaporator, and a jet compressor, the compressor including means for utilizing a stream of high pressure fluid from the generator to compress and condense low pressure refrigerant from the evaporator, a receiving tank into which the condensed mixed fluids are discharged from the compressor, said tank being positioned at a higher level than the generator, a discharge connection between the tank and generator provided with a one-way valve opening toward the generator, and float-actuated means connected with the high and low pressure sides of the system for placing the contents of the tank under generator pressure when a predetermined liquid level has been reached in the tank whereby the contents of the tank may gravitate into the generator.

19. In a refrigerating apparatus, in combination with a generator for supplying vaporized refrigerant under relatively high pressure and temperature, and an evaporator from which the refrigerant is returned at a lower pressure and temperature, a compressor for condensing and returning refrigerant to the generator comprising a casing, a plurality of jet-projecting nozzles arranged in tandem within the casing whereby one nozzle projects its jet into the next succeeding nozzle of the series, there being a plurality of connected chambers in the casing surrounding the nozzles, said chambers being in open communication with the jets, connections for discharging high pressure refrigerant from the generator through the nozzles, and connections for maintaining a flow of low pressure refrigerant into and through the chambers, the flow of low pressure refrigerant through the chambers being in the opposite direction to the flow of high pressure refrigerant through the nozzles.

20. A closed cycle refrigerating apparatus comprising a generator, a condenser, an expansion valve, a recirculator, an evaporator, a jet compressor and a return connection from the compressor to the generator, these elements all being connected in a closed series in the order named, pipe connections for delivering high pressure refrigerant from the generator directly to the compressor through which it is projected as an actuating fluid and returned to the generator, a differential-pressure control valve in this pipe connection for permitting a flow therethrough only when a predetermined pressure differential exists between the high and low pressure sides of the system, and a pipe connection from the compressor to the recirculator for maintaining a partial flow of low pressure refrigerant from the compressor back to the evaporator.

21. In a compression system of refrigeration, the step of controlling the compressing operation in response to changes in the pressure differential between the high and low pressure sides of the system, the compression operation starting when the differential rises above a predetermined minimum and continuing as long and only as long as the differential remains above this minimum.

22. In a compression system of refrigeration comprising a high pressure side including a generator, and a low pressure side including an evaporator, a compressor, and means for controlling the compressor in response to changes in the pressure difference between the high and low pressure sides of the system.

23. In a compression system of refrigeration comprising a high pressure side including a generator, and a low pressure side including an evaporator, a jet compressor for compressing and returning low pressure refrigerant to the generator, said compressor being operated by high pressure refrigerant from the generator, and a differential-pressure valve for controlling the flow of this high pressure refrigerant to the compressor so that the compressor will operate when and only when the pressure difference between the high and low pressure sides of the system is above a predetermined minimum.

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