United States Patent

Newton

[15] **3,670,519**

[45] **June 20, 1972**

[54] **CAPACITY CONTROL FOR MULTIPLE-PHASE EJECTOR REFRIGERATION SYSTEMS**

[72] Inventor: **Alwin B. Newton,** York, Pa.

[73] Assignee: **Borg-Warner Corporation,** Chicago, Ill.

[22] Filed: **Feb. 8, 1971**

[21] Appl. No.: **113,224**

[52] **U.S. Cl.** **62/116,** 62/191, 62/500

[51] **Int. Cl.** **F25b 1/00**

[58] **Field of Search**.....................62/500, 116, 191, 268, 501

[56] **References Cited**

UNITED STATES PATENTS

2,852,922	9/1958	Neumann	62/500
3,276,216	10/1966	Papapanu	62/500
3,496,735	2/1970	Haisma	62/500

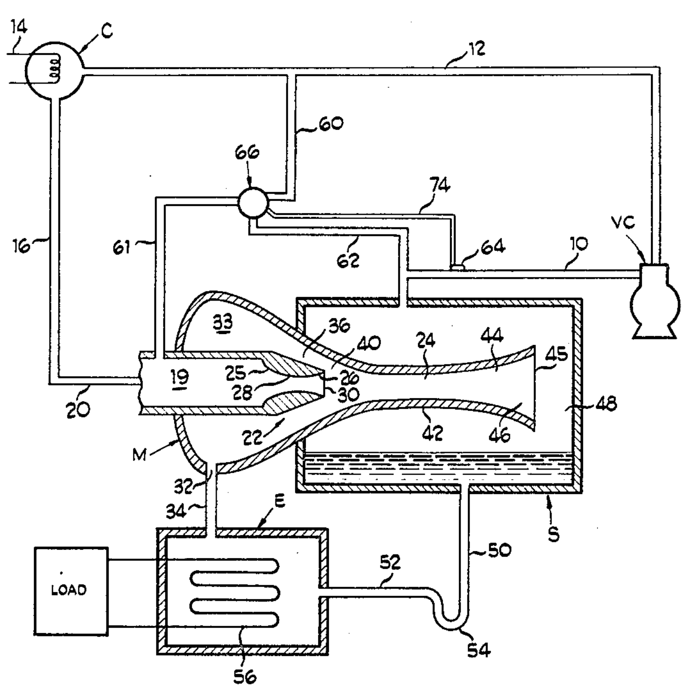
Primary Examiner—Meyer Perlin

Attorney—Donald W. Banner, William S. McCurry and John W. Butcher

[57] **ABSTRACT**

A multiple-phase ejector refrigeration system including a capacity control allowing part-load operation. The capacity is varied by bleeding a stream of hot gas from the discharge side of a vapor compressor and introducing it in a controlled manner into the liquid nozzle of the multiple-phase ejector. This has the effect of first increasing and then reducing the efficiency of the nozzle as the bleed rate increases, thereby affecting the efficiency and flow capacity of the ejector unit.

28 Claims, 5 Drawing Figures



PATENTED JUN 20 1972

3,670,519

SHEET 1 OF 2

Fig 1

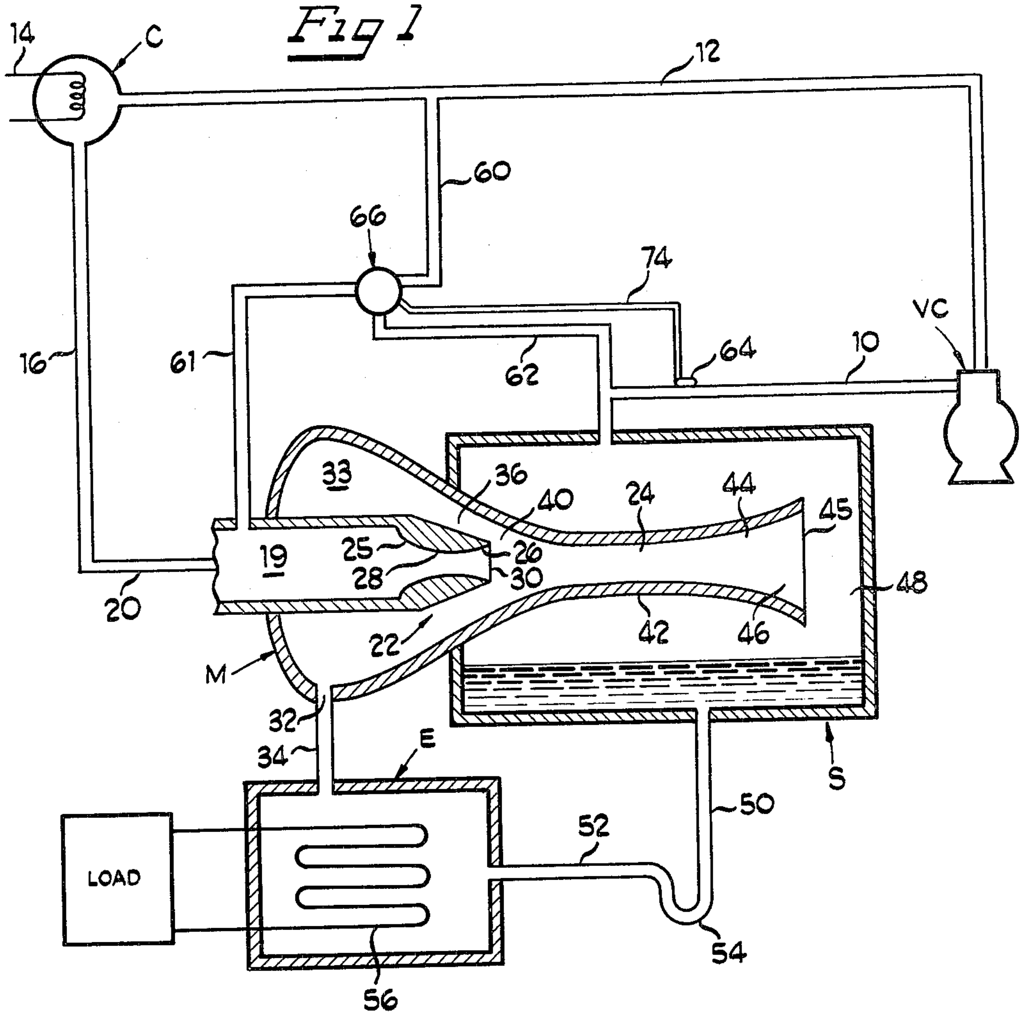
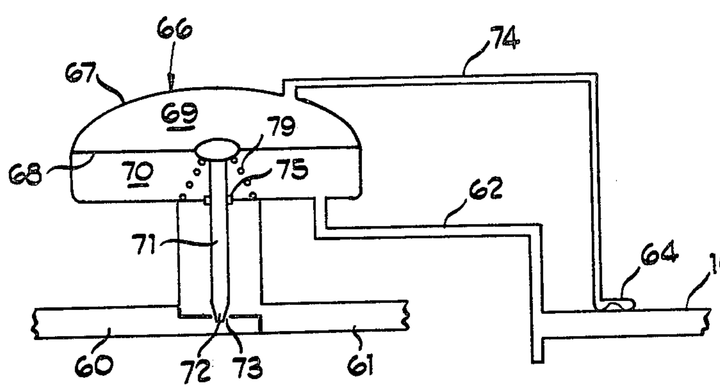


Fig 2



INVENTOR
ALWIN B. NEWTON

BY Thomas B. Hunter
ATTORNEY

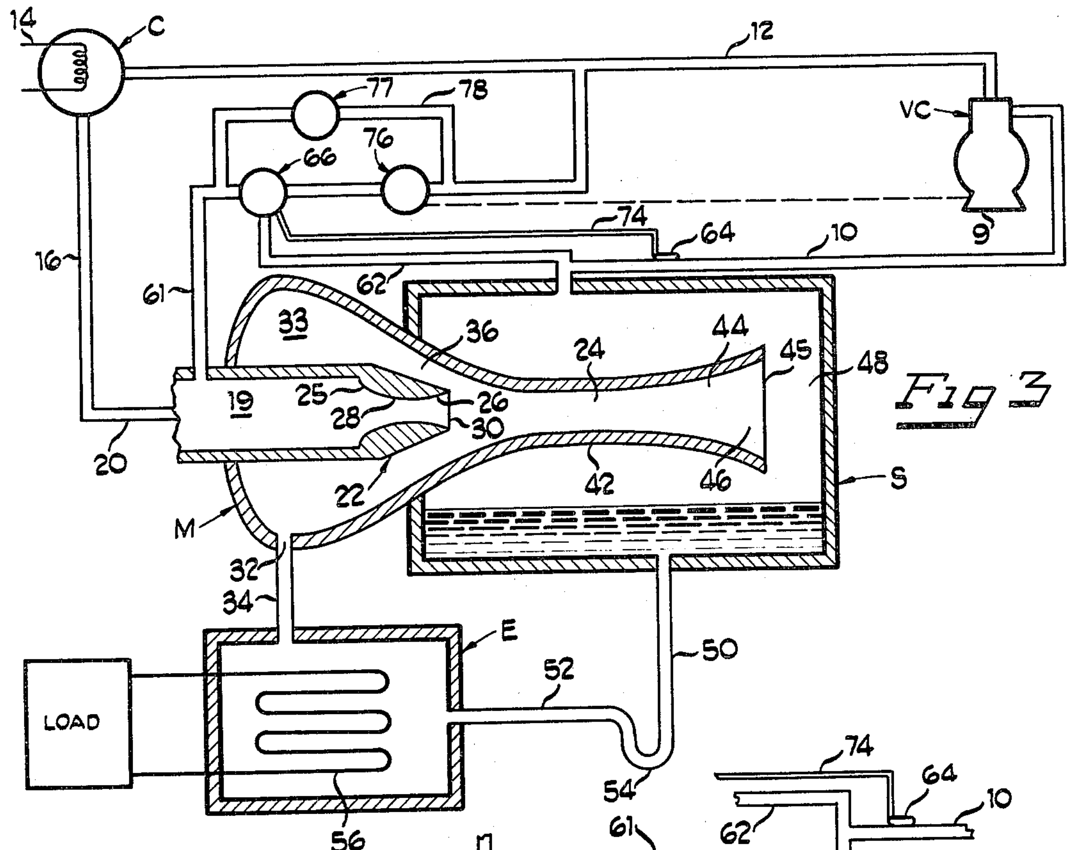


Fig 3

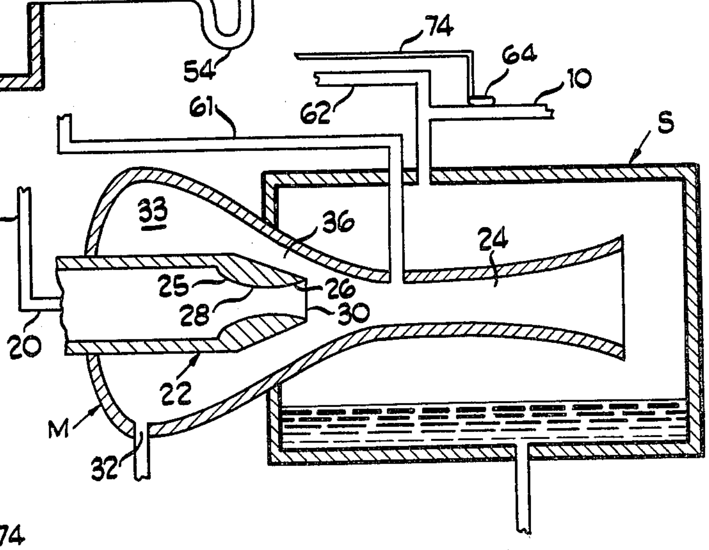


Fig 4

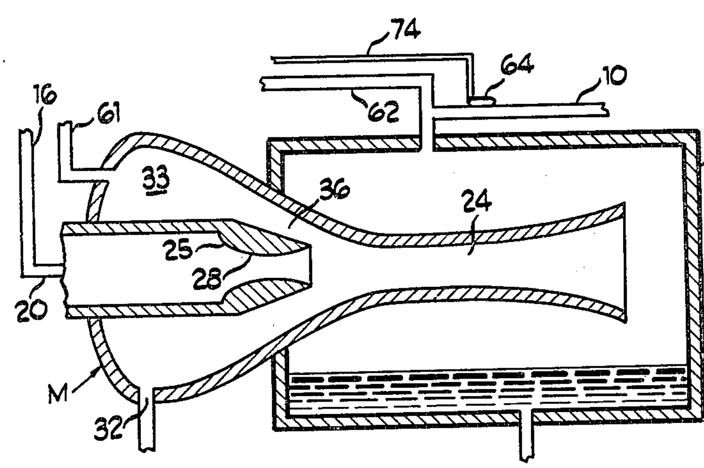


Fig 5

INVENTOR
ALWIN B. NEWTON

BY Thomas B. Hunter
ATTORNEY

CAPACITY CONTROL FOR MULTIPLE-PHASE EJECTOR REFRIGERATION SYSTEMS

BACKGROUND AND SUMMARY OF THE INVENTION

This invention relates to improved refrigeration systems and more particularly to a capacity control for refrigeration systems utilizing a multiple-phase ejector apparatus as one of the primary components in said refrigeration system.

U. S. Pat. No. 3,277,660 issued to Clarence A. Kemper et al. on Oct. 11, 1966, describes several novel refrigeration systems in which multiple-phase ejectors are employed in place of, or in combination with, a vapor compressor used in the conventional vapor cycle refrigeration system. In each of the systems described in the Kemper et al. patent, a stream of high pressure liquid refrigerant is introduced into the inlet side of a nozzle which is adapted to accelerate the liquid refrigerant stream to form a supersonic velocity, two-phase, vapor-liquid refrigerant stream. This two-phase stream is then mixed with a low-pressure vapor refrigerant stream to provide a single refrigerant stream. Next, the velocity of the single refrigerant stream is decreased by expansion through a nozzle until the temperature and the pressure are greater than the temperature and pressure of the vapor stream before it is increased in velocity.

One of the advantages of the refrigeration system described in the Kemper et al. patent, particularly the work input system illustrated in FIG. 3, is that it is extremely flexible and can be easily designed to meet specific requirements, such as condensing and evaporating temperatures, compressor capacity, etc. One of the reasons for this flexibility is that the system, contrary to the conventional refrigeration system, works at three different pressures: The high side pressure on the discharge side of the vapor compressor; and intermediate pressure, as measured on the suction side of the vapor compressor; and a low evaporating pressure, as measured in the evaporator or at the inlet side of the ejector. In effect, the ejector has the capability of significantly boosting the pressure on the suction side of the vapor compressor. This reduces the pressure difference against which the compressor has to work, so that a smaller compressor can be used to produce a given capacity, or alternatively, the same size compressor can be used with increased capacity.

The present invention may be considered generally as a refrigeration system which utilizes to the best advantage the unique features of the Kemper et al. multiple-phase ejector. The Kemper et al. system does not disclose any mechanism by which the capacity may be conveniently controlled. The present invention proposes to utilize a stream of hot gas from the discharge side of a vapor compressor to be introduced in controlled quantities into the high pressure liquid nozzle to change the character and efficiency of the flow of said liquid during its acceleration to a supersonic velocity, two-phase, vapor-liquid stream.

Accordingly, a principal object of the invention is to provide an improved capacity control for a multiple-phase ejector refrigeration system.

Another object of the invention is to provide an improved capacity control for a multiple-phase ejector refrigeration system in which the capacity and effectiveness of the liquid nozzle of the ejector is varied by feeding hot gas from a compressor to the nozzle.

Additional objects and advantages will be apparent from the following detailed description taken in conjunction with the drawings.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic or diagrammatic view of a refrigeration system embodying my improved control including a thermostatically-operated valve;

FIG. 2 is a detailed cross-sectional view of the valve;

FIG. 3 is a schematic or diagrammatic view of a modification of the refrigeration system shown in FIGS. 1 and 2;

FIG. 4 is a modification of portions of the refrigeration systems shown in FIGS. 1 and 3; and

FIG. 5 is another modification of portions of the refrigeration system shown in FIGS. 1 and 3.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to FIG. 1, the refrigeration system of the present invention includes a vapor compressor VC, a condenser C, an evaporator E, a multiple-phase ejector M and a vapor-liquid separator S. Refrigerant vapor of any suitable type, such as R–12 for example, is supplied to the suction side of compressor VC through conduit **10**, compressed, and forwarded through conduit **12** to the condenser C. Heat is removed from the hot refrigerant vapor by the condenser heat exchanger **14** through which a coolant is circulated (usually water, but, in some cases, air). The hot vapor is caused to liquefy in the condenser and is delivered through conduit **16** to the multiple-phase ejector M which has means defining a liquid chamber **19**, in the form of a tube, having an inlet **20** for the introduction of the high-pressure liquid stream, said liquid chamber **19** communicating with a first nozzle **22** provided at one end of the tube, discharging into a mixing chamber **24** having its flow axis substantially aligned with the longitudinal axis of the nozzle **22**. The nozzle **22** is contoured by respective converging-diverging internal flow paths **25** and **26** in which the minimum cross-sectional area at **28** is sufficiently small, relative to the outlet area and other dimensions at **30**, as to enable the production of a high-velocity, two-phase, liquid-vapor stream, which may be supersonic. A second input inlet **32** is provided for the introduction of a low-pressure vapor stream communicating through means defining a vapor chamber **33** with a second nozzle **36** located substantially concentric with the first nozzle **22** for introducing at **40** a high-velocity vapor refrigerant stream into the inlet opening of the mixing chamber **24** so as to be placed in intimate contact with the two-phase stream resulting at **30** from the first nozzle **22**, thereby to combine the streams. The resulting mixed stream continues through the mixing section, and a section **42** of substantially constant flow area, into a diverging chamber **44**, the function of the latter being to decrease the velocity of the combined streams at **46** to a velocity at which the temperature and the pressure of the combined stream is greater than the temperature and the pressure of the vapor refrigerant stream prior to passage through the second nozzle **36**. The divergent chamber **44** has an outlet at **45** from which the ejector-exit stream is withdrawn and delivered into the vapor-liquid separator S. The latter comprises means defining a chamber **48** surrounding and in communication with the outlet portion of the ejector nozzle. Liquid refrigerant collects in the lower portion of chamber **48** and is supplied to the evaporator E through conduits **50** and **52**. For a more detailed disclosure and explanation of the above described refrigeration system including particularly the multiple-phase ejector M and its operation, reference is made to U. S. Pat. No. 3,277,660.

Conduits **50** and **52** are connected by means **54** for maintaining the pressure differential achieved at various loads between the diffuser outlet **45** and conduit **34**. The pressure at **45** is essentially the same pressure existing at the suction side of the vapor compressor VC, while the pressure at **34** is essentially the pressure within the evaporator E. Means **54** may take the form of a float valve or orifice, but is preferably a liquid dropleg designed to accommodate a suitable pressure differential, say 5–10 p.s.i. at full load for refrigerants such as R–22. The main function of liquid dropleg **54** is to provide an interface between liquid returning to the evaporator through conduit **52**, and vapor residing in chamber **48** and entering the evaporator E through conduit **50**. No vapor should enter conduit **52** and no liquid should enter conduit **10**. The pressure loss in this action should not exceed the pressure rise between conduit **34** and chamber **48**. Liquid, fed to the evaporator E, evaporates and the vapor is forwarded to the second nozzle **36** in the multiple-phase ejector M through conduit **34**. In vaporizing, the refrigerant absorbs heat so that, in the conventional system, a second cooling coil is provided in the evaporator, such as in a conventional liquid chiller wherein water is circulated through a closed circuit including a tube bundle **56** (in the evaporator) and the load.

As pointed out in the preliminary remarks, the principal feature of the invention comprises a capacity control which affects the efficiency of the multiple-phase ejector unit M. In a preferred embodiment, ejector efficiency is controlled by bleeding off a portion of the vapor from hot vapor conduit **12** through conduit **60** to the inlet nozzle **22** receiving the liquid from the condenser. The vapor, as it mixes with the liquid stream, disrupts the flow through the nozzle so that the efficiency of the nozzle flow may be conveniently and accurately controlled.

Control of the flow of hot gas is preferably in response to the absolute superheat of the gas being delivered to the inlet side of vapor compressor VC. Accordingly, a pressure tap **62** and a thermal-sensing bulb **64** are respectively responsive to the pressure and temperature of the gas in the suction conduit **10** and which are operable to control a valve **66** in the bleed conduit between the hot gas conduit and the inlet nozzle **22.** More particularly and referring to FIG. **2**, valve **66** comprises a hollow casing **67** provided with a flexible diaphragm **68** dividing the casing into an upper compartment **69** and a lower compartment **70** and supporting a vertically-movable valve member **71** having its lower cone-shaped end **72** disposed adjacent a circular opening **73** of the valve seat located between and connecting conduits **60** and **61** so that movement of the valve member will control the quantity of gas flowing from conduit **12** to the conduit **67** and the inlet nozzle **22.** The compartment **69** is connected to the refrigerant filled, pressure-responsive thermal-sensing bulb **64** by a conduit **74** so that movement of the diaphragm **68** will occur upon expansion and contraction of the vapor in compartment **69** in response to variations in temperature of the refrigerant in the bulb sensing the temperature of the gas in conduit **10.** The vapor compartment **70** is sealed from communication with the gas flowing in conduits **60** and **67** by a seal **75** connected to the casing **67** and in sealing engagement with valve member **71**, which is biased open by spring **79.** As vapor compartment **70** is connected by conduit **62** to the conduit **10**, any variations in the pressure of the gas in conduit **10** will cause the diaphragm to be moved in response thereto.

The operation of the control mechanism may be described as follows: (1) a rise in the absolute superheat of gas entering the vapor compressor would indicate an increase in the load requiring additional capacity. The joint action of the pressure tap and the bulb would thus tend to close valve **66** to throttle any flow of gas into the nozzle and thereby increase the efficiency of the same; (2) a drop in the absolute superheat would indicate that a reduction in capacity is required; the bulb and the pressure tap would cooperate to open the valve to bleed additional gas into the nozzle, thus reducing the efficiency of the fluid flow into the multiple-phase ejector M and producing a corresponding reduction in capacity for the entire system.

Accordingly, the control of the present invention causes the capacity of the refrigeration system to be varied by bleeding a stream of hot gas from the discharge side of the vapor compressor and introducing it in a controlled manner into the liquid nozzle of the ejector. Introduction of a small amount of vapor into the nozzle inlet stream improves the efficiency of the nozzle but normally reduces the total flow rate through the nozzle. Introduction of an increased amount of vapor into the nozzle inlet stream may reduce the efficiency of the nozzle, but more importantly always reduces the total mass flow rate. The introduction of the high pressure gas bleed controls the amount of refrigerant passing through the nozzle and causes the nozzle to meter the flow, similarly to the operation of a thermostatic expansion valve in a conventional refrigeration system.

A secondary effect occurs by the action of the vapor flow into the inlet region of the nozzle. More particularly the hot uncondensed gas has a higher enthalpy than the liquid which could enter through conduit **16.** Accordingly, when the temperature of the vapor in conduit **10**, sensed by bulb **64**, reduces with no change in pressure of the vapor in conduit **62**, there is provided an indication of reduction in superheat and a need to reduce the total supply of refrigerant to the evaporator circuit. In this invention, reduction of the total supply of refrigerant to the evaporator conduit occurs by valve **66** opening more widely, allowing a higher flow rate of vapor and consequent reduction in the total mass flow through the nozzle **22.** Thus, liquid entering through conduit **16** is reduced similarly to the operation of a conventional expansion valve located in conduit **16** if the valve was somewhat closed in response to the reduction in superheat. Another effect of the entrance of hot gas is the equivalent of the hot gas bypass in conventional systems, but with the added advantage that the hot gas assists in compressing the vapor from evaporator **34** and thus both the vapor and hot gas flow itself enters the compressor at a higher pressure than would otherwise be the case.

The embodiment of the invention illustrated in FIG. **3** is an improvement of the refrigeration system of FIG. **1** and **2**, like parts being similarly identified numerically or alphabetically in the several views. As in FIGS. **1** and **2**, FIG. **3** also discloses a refrigeration system having a multiple-phase ejector M, a vapor compressor VC, a condenser C, an evaporator E, and vapor-liquid separator S, connected together and arranged in a refrigerant flow pattern. In addition, as in FIG. **1**, valve **66** connects the hot vapor conduit **60** to the liquid chamber **19** and senses the pressure and temperature of the vapor in the suction conduit **10** to the compressor to open the valve **66** and thereby reduce capacity requirements of the refrigeration system when the superheated vapor drops below a normal level. One improvement disclosed in FIG. **3** is the provision of a valve **76** between and connecting conduit **60** and valve **66** and closable to override valve **66** by discontinuing vapor flow to the inlet nozzle **22** when valve **66** is open. Valve **76** may be connected, as shown by dotted lines, to a controlling timer on a float (not shown) in compressor crankcase **9** to cause liquid flood-back and, therefore, oil return at periodic intervals. Another improvement is valve **77** in conduit **78** between and directly connecting conduit **60** and conduit **61** and, thereby, bypassing valves **66** and **76.** Accordingly, valve **77** can override the effect of valve **66** and **76** by feeding vapor to the inlet nozzle **22** to reduce capacity even though valves **66** and **76** are closed. Valve **77** can be connected to a safety control such as a high or low pressure sensor, or low water temperature sensor. It will be apparent that valves **66, 76** and **77** control the flow of hot refrigerant vapor or gas from the compressor VC to the liquid chamber **19** and thereby to the inlet nozzle **22** of the ejector M. By thus introducing the gas into the nozzle **22,** these valves reduce the capacity of the ejector M and thereby of the refrigeration system.

As shown in FIGS. **4** and **5**, conduit **61** may be alternately connected to the diffuser section (FIG. **4**), or to the eductor section (FIG. **5**) of the ejector and similar results achieved with varying flow levels in conduit **61.**

While this invention has been described in connection with specific embodiments thereof, it is to be understood that this is by way of illustration and not by way of limitation; and the scope of the appended claims should be construed as broadly as the prior art will permit.

What is claimed is:

1. A refrigeration system comprising an evaporator; a vapor compressor adapted to compress a refrigerant; a condenser receiving hot refrigerant vapor from said compressor, said condenser operating to liquefy said refrigerant; a multiple-phase ejector comprising means defining a liquid chamber having a liquid inlet, means defining a vapor chamber having a vapor inlet, and an outlet discharging a two-phase vapor-liquid refrigerant stream; means for supplying high pressure liquid from the condenser to said liquid inlet; a vapor-liquid separator receiving the two-phase refrigerant stream and adapted to separate said phases; means for transferring the liquid phase from said separator to said evaporator; means for connecting said evaporator to said vapor inlet; means connecting said separator to said compressor to deliver refrigerant vapor to the suction side of said compressor; and means for supplying a portion of the hot vapor, flowing from said compressor to said condenser, to one of said ejector chambers.

2. A system as defined in claim **1** in which said hot vapor-supplying means supplies said hot vapor portion to said ejector liquid chamber.

3. A system as defined in claim **2** in which said hot vapor-supplying means is operative to supply said hot vapor portion to said ejector liquid chamber at a controlled rate in response to the capacity requirements of said system.

4. A system as defined in claim **2** in which said hot vapor-supplying means includes a conduit conducting said hot vapor portion to said liquid chamber, means controlling vapor flow in said conduit and including a valve, and means for operating said valve.

5. A system as defined in claim **4** in which said valve-operating means includes means for sensing the absolute superheat of vapor delivered to the suction side of said vapor compressor.

6. A system as defined in claim **4** in which said valve-operating means includes means responsive to variations in pressure of the vapor delivered to the suction side of said compressor.

7. A system as defined in claim **4** in which said valve-operating means includes means responsive to variations in pressure and temperature of the vapor delivered to the suction side of said compressor.

8. A system as defined in claim **4** in which said valve includes a movable valve member operative to control the flow of vapor through said conduit; and said valve-operating means includes a casing, a flexible diaphragm in said casing and defining a compartment, said diaphragm being connected to said valve member, a thermal-sensing member responsive to variations in the temperature of the refrigerant vapor delivered to the suction side of said compressor and connected to said compartment to effect movement of said diaphragm and thereby move said valve member.

9. A system as defined in claim **4** in which said valve includes a movable valve member operative to control the flow of vapor through said conduit; and said valve-operating means includes a casing, a flexible diaphragm in said casing and defining a vapor compartment, said diaphragm being connected to said valve member, passage means connected to said separator-and compressor-connecting means and to said vapor compartment for providing refrigerant vapor to said vapor compartment to effect movement of said diaphragm, in response to variations in the pressure of the refrigerant vapor, to move said valve member.

10. A system as defined in claim **4** in which said valve includes a movable valve member operative to control the flow of vapor through said conduit; and said valve-operating means includes a casing having a flexible diaphragm in said casing and dividing said casing to provide spaced first and second compartments, said diaphragm being connected to said valve member, a thermal-sensing bulb responsive to variations in the temperature of the refrigerant vapor delivered to the suction side of said compressor and connected to said first compartment to effect movement of said diaphragm and thereby move said valve member, said valve-operating means further including passage means connecting said second compartment and said separator-and compressor-connecting means for providing refrigerant vapor to said vapor compartment to effect movement of said diaphragm, in response to variations of the pressure of the refrigerant vapor, to move said valve member in cooperation with movement of said valve member by the variations in pressure in said first compartment controlled by said bulb.

11. A system as defined in claim **3** in which said hot vapor-supplying means includes a first conduit conducting said hot vapor portion to said liquid chamber; a first valve in said first conduit; means for operating said first valve to supply said hot vapor portion to said liquid chamber at a controlled rate in response to the capacity requirement of said system, and a second conduit in parallel with said first conduit and bypassing said first valve to conduct said hot vapor portion to said liquid chamber, and a second valve in said second conduit.

12. A system as defined in claim **11** in which said first valve-operating means includes means for sensing the absolute superheat of vapor delivered to the suction side of said vapor compressor.

13. A system as defined in claim **11** in which said first valve-operating means includes means for sensing variations in the pressure of the vapor delivered to the suction side of said vapor compressor.

14. A system as defined in claim **11** in which said first valve-operating means includes means for sensing variations in pressure and temperature of the vapor delivered to the suction side of said vapor compressor.

15. A system as defined in claim **3** in which said hot vapor-supplying means includes a conduit conducting said hot vapor portion to said liquid chamber; a first valve in said conduit; means for operating said first valve to supply said hot vapor portion to said liquid chamber at a controlled rate in response to the capacity requirements of said system, and a second valve in series with said first valve in said conduit.

16. A system as defined in claim **3** in which said hot vapor-supplying means includes a conduit conducting said hot vapor portion to said liquid chamber; a first valve in said conduit; means for operating said first valve to supply said hot vapor portion to said liquid chamber at a controlled rate in response to the capacity requirements of said system, and a second valve in series with said first valve in said conduit and controlling the supply of said hot vapor portion to said first valve.

17. A system as defined in claim **15** in which said first valve-operating means includes means for sensing the absolute superheat of vapor delivered to the suction side of said vapor compressor.

18. A system as defined in claim **15** in which said first valve-operating means includes means for sensing variations in the pressure of the vapor delivered to the suction side of said vapor compressor.

19. A system as defined in claim **15** in which said first valve-operating means includes means for sensing variations in pressure and temperature of the vapor delivered to the suction side of said vapor compressor.

20. A system as defined in claim **3** in which said hot vapor-supplying means includes a first conduit conducting said hot vapor portion to said liquid chamber; a first valve in said first conduit; means for operating said first valve to supply said hot vapor portion to said liquid chamber at a controlled rate in response to the capacity requirements of said system, and a second valve disposed in said first conduit and in series with said first valve, a second conduit disposed in parallel with said first conduit and bypassing said first valve and said second valve to conduct said hot vapor portion to said liquid chamber, and a third valve in said second conduit.

21. A system as defined in claim **20** in which said first valve-operating means includes means for sensing the absolute superheat of vapor delivered to the suction side of said vapor compressor.

22. A system as defined in claim **20** in which said first valve-operating means includes means for sensing variations in the pressure of the vapor delivered to the suction side of said vapor compressor.

23. A system as defined in claim **20** in which said first valve-operating means includes means for sensing variations in pressure and temperature of the vapor delivered to the suction side of said vapor compressor.

24. A system as defined in claim **1** in which said vapor chamber of said ejector comprises an educator section and a diffuser section, and said hot vapor supply means is connected to, and provides said hot vapor portion to, one of said eductor and diffuser sections.

25. A system as defined in claim **24** in which said hot vapor supply means provides said hot vapor portion to said eductor section.

26. A system as defined in claim **24** in which said hot vapor supply means provides said hot vapor portion to said diffuser section.

27. A method of controlling the capacity of a multiple-phase ejector comprising the steps of delivering high-pressure liquid into said multiple-phase ejector to produce a supersonic, mixed-phase refrigerant stream; introducing vapor into the inlet side of a nozzle during acceleration of said stream to reduce the efficiency of said nozzle; and controlling the admission of said vapor in response to the capacity requirements of said system, such that increased vapor is supplied during reduced capacity demand.

28. In a vapor cycle refrigerant system including a compressor, a condenser and an evaporator connected to provide a closed refrigeration circuit; a multiple-phase ejector connected in said circuit to boost the suction pressure of vapor supplied to said compressor, said ejector being driven by high-pressure liquid refrigerant; means for separating the two-phase stream leaving said ejector and returning the vapor phase to said compressor and delivering a liquid phase to said evaporator, the improvement comprising means for disrupting the efficiency of the pressure boosting capacity of said ejector by admitting vapor to the substantially liquid driving stream from said condenser.

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,670,519 Dated June 20, 1972

Inventor(s) Alwin B. Newton

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 6, line 69, "educator" should read -- eductor -- .

Signed and sealed this 19th day of December 1972.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents

FORM PO-1050 (10-69)

USCOMM-DC 60376-P69
☆ U.S. GOVERNMENT PRINTING OFFICE : 1969 O—366-334.