MULTIPLE-PHASE EJECTOR REFRIGERATION SYSTEM

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2 Sheets-Sheet 1

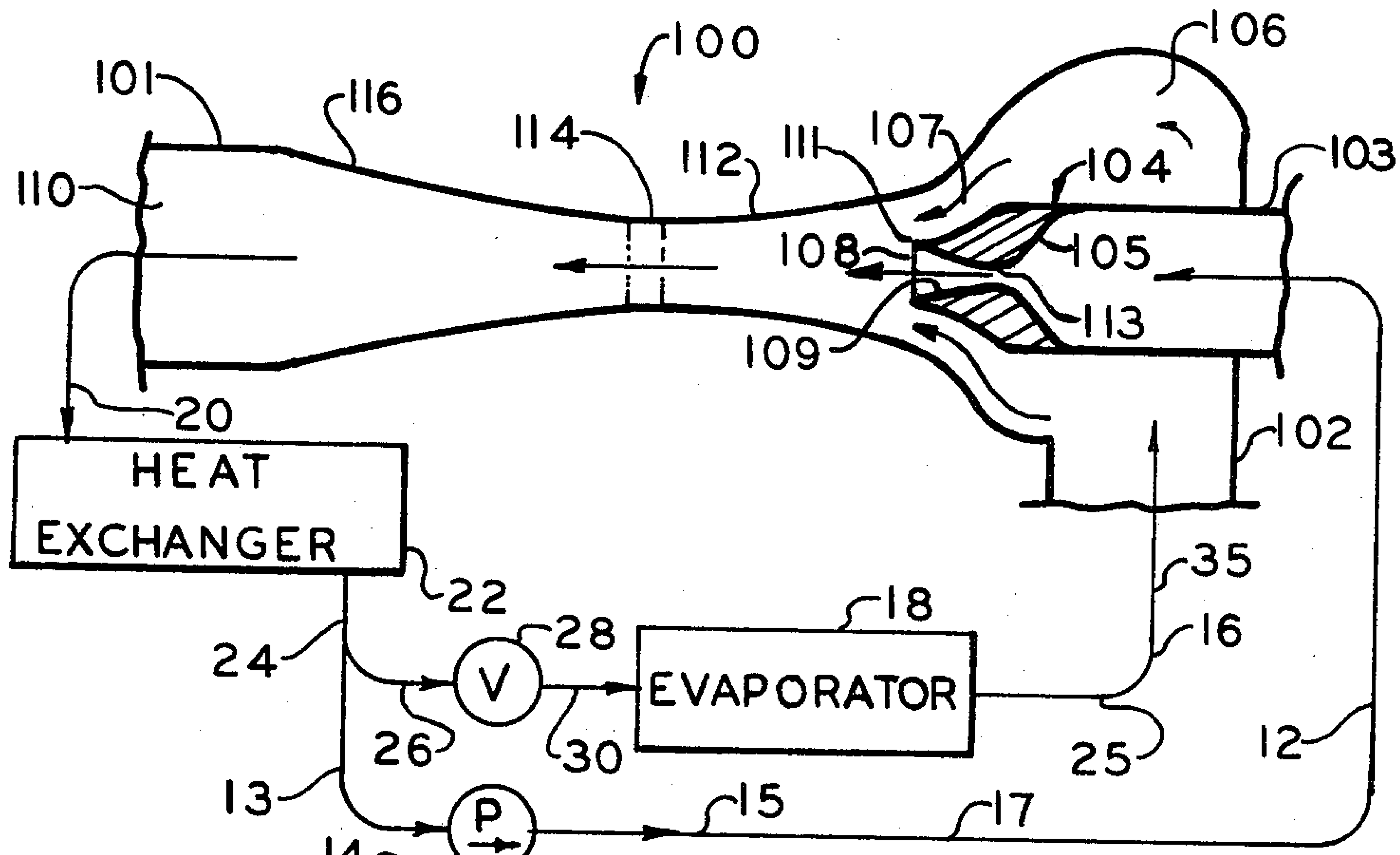

FIGURE 1

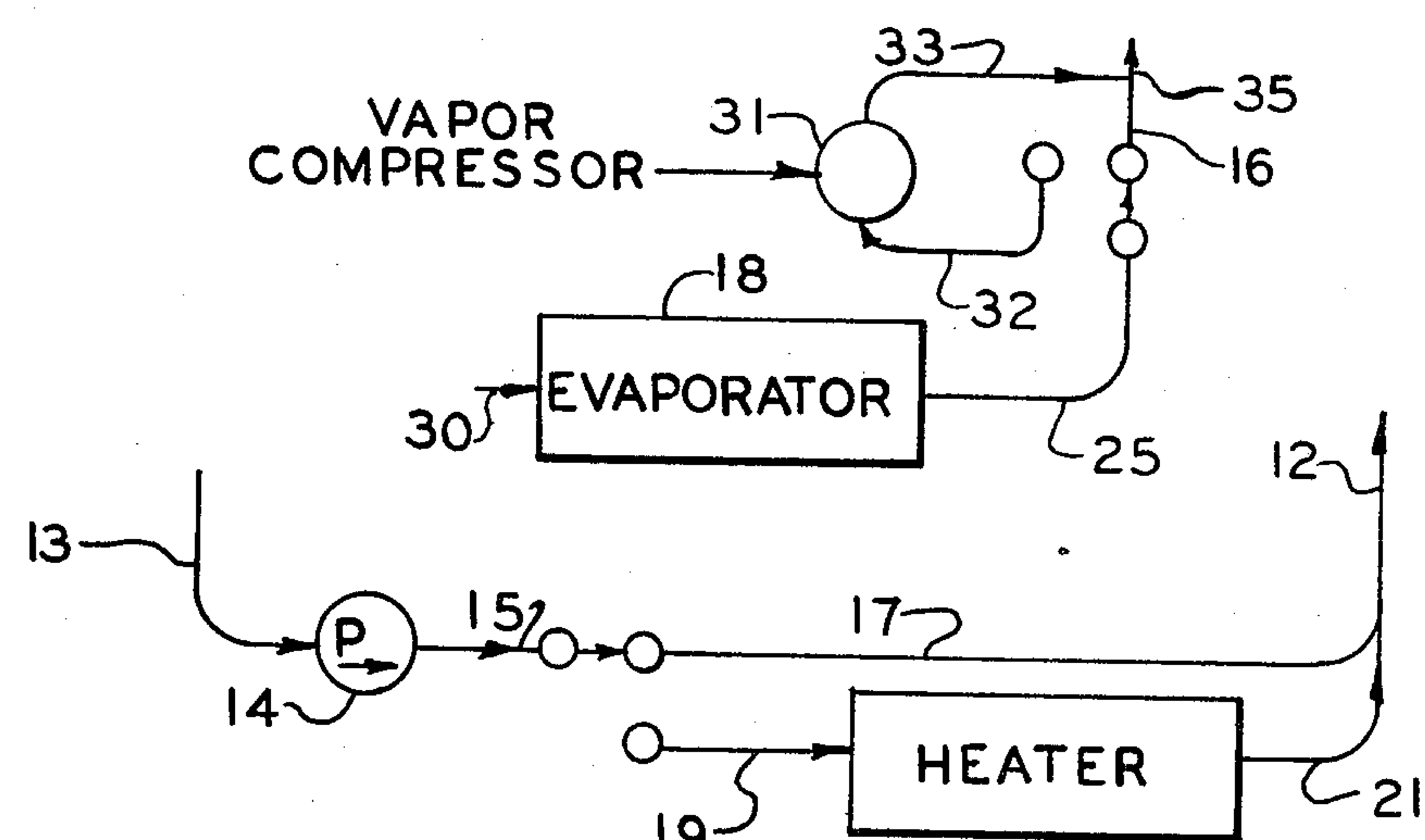

FIGURE 2

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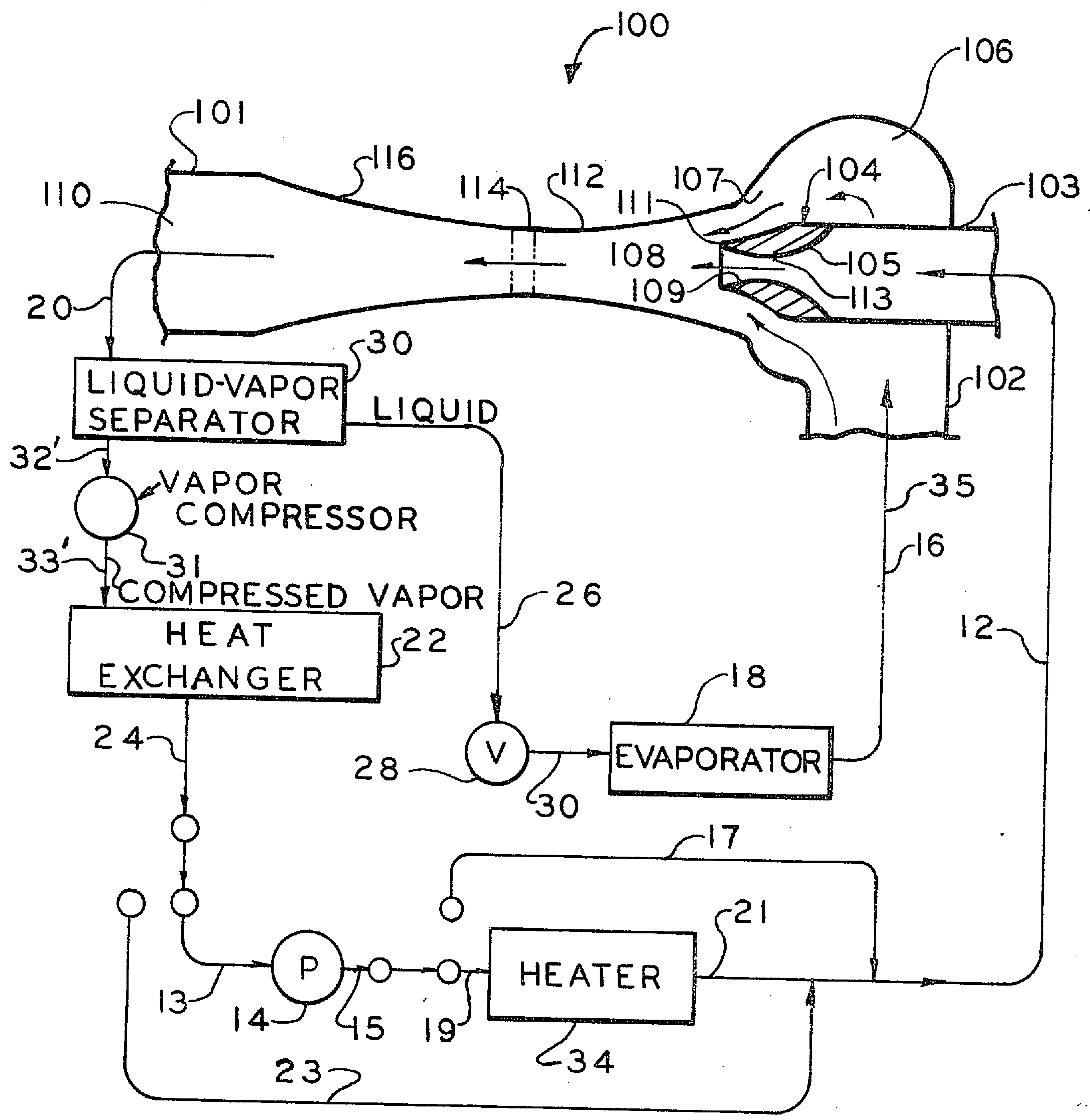

FIGURE 3

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MULTIPLE-PHASE EJECTOR REFRIGERATION SYSTEM

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Continuation of applications Ser. No. 308,907, Sept. 13, 1963, and Ser. No. 489,107, Sept. 22, 1965. This application Dec. 13, 1965, Ser. No. 513,210

33 Claims. (Cl. 62—116)

This is a continuation of of applications, Serial Numbers 308,907, filed September 13, 1963, and 489,107, filed September 22, 1965, both of which are now abandoned.

The present invention relates to improved apparatus for and methods of compression of refrigerant and other vapors, being more particularly related to an improved refrigeration system employing novel multiple-phase ejector apparatus.

Refrigeration systems commonly require a vapor compressor in order to condense the vapor from the evaporator at a higher temperature than that of the object or environment being cooled. Vapor compressors are generally characterized by being relatively high in cost, size and in operating noise level. We have now discovered an improved refrigeration apparatus and method that permits the replacement in whole or part of the vapor compressor of conventional refrigeration systems by the employment of a novel multiple-phase ejector system having advantages of simplicity, small size, reliability, and a minimum number of moving parts.

In such vapor compressing systems, vapor which is generated by the evaporation of liquid at some desired temperature and pressure is compressed to higher pressure so that the heat introduced to the system at the temperature of the evaporation process may be rejected from the system at a higher temperature. The vapor in such systems is generally compressed by employing the above-mentioned mechanical vapor compressors, or vapor-driven ejectors, or liquid-driven ejectors. Our noval multiple-phase ejector for compressing vapor, however, does not suffer from the operational limitations of such prior mechanical vapor compressor, and, in addition, is more efficient than vapor-driven and liquid-driven ejectors.

An ejector (sometimes called an injector, jet pump or jet compressor) is a device in which two fluid streams flow in intimate contact at relatively high velocity such that the driving stream transfers momentum to the driven stream, thereby increasing the stagnation pressure of the driven stream. The two fluid streams are accelerated in separate nozzles to approximately the same pressure before being brought together in a mixing section, and the mixed stream is decelerated in a diffuser. The principal sources of inefficiency in such ejectors are momentum transfer through large velocity differences and heat transfer through large temperature differences which exist between the driving and driven streams. In vapor compression systems, such as refrigeration systems and the like, the driven stream is vapor or a high-quality two-phase mixture at a relatively low temperature. If such driving stream is vapor or a high-quality two-phase mixture having approximately the same specific volume as the driven stream when the two streams enter the mixing section, there must be a large velocity difference between the two streams in order for the driving stream to transfer sufficient momentum to the driven stream. If the driving stream is liquid, obtained from the condensation process of the cycle, there will be a large temperature difference between the driving stream and the driven stream providing for inefficient heat transfer between the two streams.

The multiple-phase ejector, however, utilizes low-quality, two-phase, liquid-vapor fluid as the driving stream. Before entering its nozzle and being accelerated, the driving stream may be compressed liquid, saturated liquid, or a low-quality, two-phase, liquid-vapor fluid. When the driving stream is a two-phase fluid at stagnation conditions, the driving stream nozzle may be either a simple convergent nozzle or it may be a convergent-divergent nozzle depending on the operating conditions of the cycle. When the driving stream is liquid at stagnation condiditions, however, the driving stream nozzle must, in accordance with our findings, be a convergent-divergent nozzle in order for the driving stream to be accelerated efficiently, and the driving stream becomes what we term a supersonic velocity stream, in that the square of the local average velocity is greater than the differential change of pressure with density in an isentropic expansion.

Hereinafter, the term "liquid stream" or "liquid refrigerant stream" will be employed to refer to a fluid stream which may be pure liquid or may be a low-quality, two-phase, liquid-vapor fluid being mostly liquid by mass; and the term "vapor stream" or "vapor refrigerant stream" will be employed to refer to a fluid stream which may be pure vapor or may be a high-quality, two-phase, liquid-vapor fluid, mostly vapor by mass.

When a multiple-phase ejector is employed as a vapor compressor in a vapor compression system, such as a refrigeration system, the driving stream is obtained from the ejector exit-stream by some process. The driving stream must have a higher stagnation pressure and a higher density than the ejector exit-stream. Since the ejector exit-stream is, in general, a two-phase, liquid-vapor fluid, there are several processes by which a higher-pressure, higher-density stream may be obtained. The ejector-exit stream may be condensed to form a pure liquid stream, part or all of which is pumped to a higher pressure by a liquid pump; the ejector-exit stream may be separated to form a liquid stream and a vapor stream with part or all of the liquid stream being pumped to a higher pressure by a liquid pump; or the ejector-exit stream may be separated to form a liquid stream and a vapor stream with part or all of the vapor stream being compressed to a higher pressure in a vapor compressor and subsequently being condensed to form a liquid stream. All of the processes above involve adding energy to the system in the form of work and yield a liquid stream which is at a stagnation pressure greater than that of the ejector exit-stream. In some applications, it may be desirable to add additional energy to the system in the form of heat by increasing the temperature of the liquid stream to a value higher than that of the ejector exit-stream, and, if desired, partially to evaporate the stream at the higher temperature to form a low-quality, two-phase driving stream. In the latter case, the quality of the partially evaporated stream should be such that it contains no more than substantially fifty percent vapor by mass.

In an ejector, the driving and driven streams enter the mixing section at approximately the same pressure. In a multiple-phase ejector, the driving stream enters the mixing section as a low-quality, two-phase fluid, and the driven stream enters the mixing section as saturated vapor or as a high-quality two-phase fluid. When the same substance is employed in the two streams, therefore, they will enter the mixing section at approximately the same temperature, and any heat-transfer between the streams or between the liquid and vapor phases of any one stream will occur through small temperature differences, such process being thermodynamically more efficient than heat-transfer through large temperature differences.

Since the driving stream has a greater density than the ejector exit-stream, it will have a greater density, or lower specific volume, than the driven stream. The enthalpy change for a differential pressure change during an isentropic expansion is proportional to the specific volume of the fluid, and the velocity of a stream starting from rest and undergoing an isentropic expansion is proportional to the square-root of the enthalpy change experienced by the stream. Where the driving stream is accelerated from a high stagnation pressure and has a lower specific volume than the driven stream, it has been found possible to design a multiple-phase ejector such that the driving and driven streams enter the mixing section at approximately the same values of velocity. The momentum transfer between the streams or between the liquid and vapor phases of any one stream will thus occur through small velocity differences—a process more efficient than momentum transfer through large velocity differences.

An object of the present invention, accordingly, is to provide a new and improved multiple-phase ejector system which is more efficient than ordinary ejectors, because the inefficiencies due to heat-transfer and momentum-transfer are minimized.

Since the multiple-phase ejector is more efficient than ordinary ejectors, refrigeration systems employing such a multiple-phase ejector as the vapor compressor will be more efficient than refrigeration systems employing ordinary ejectors.

A further object of our invention, accordingly, is to provide a new and improved apparatus for and method of compression of refrigerant and other vapors.

Another object of our invention is to provide improved refrigeration systems and methods embodying the vapor compression apparatus and method abovementioned.

Other and further objects will be hereinafter explained and more fully delineated in the appended claims.

The invention will now be described in connection with the accompanying drawing, FIG. 1 of which is a combined partial cross-sectional view of a multiple-phase ejector and a block diagram of a preferred embodiment of a multiple-phase ejector refrigeration system;

FIG. 2 is a modification of portions of the system of FIG. 1, and

FIG. 3 is a combined cross-sectional view of a multiple-phase ejector and a block diagram of another embodiment of a multiple-phase ejector refrigeration system.

Referring to FIG. 1, a multiple-phase ejector of a preferred type is illustrated at **100**, having an input inlet **103** for the introduction of a high-pressure liquid stream communicating with a first nozzle **104** discharging into a mixing chamber **112** having its flow axis substantially aligned with the longitudinal axis of the nozzle **104**. The nozzle **104** is contoured by respective converging-diverging internal flow paths **105** and **109** in which the minimum cross-sectional area at **113** is sufficiently small relative to the outlet area and other dimensions at **108** as to enable the production of a supersonic, high-velocity, two-phase, liquid-vapor stream, as described previously. A second input inlet **102** is provided for the introduction of a low-pressure vapor stream communicating through a chamber **106** with a second nozzle **107** located substantially concentric with the first nozzle **104** for introducing at **111** a high-velocity vapor refrigerant stream into the inlet opening of the mixing chamber **112** so as to be placed in intimate contact with the two-phase stream resulting at **108** from the first nozzle **104**, thereby to combine the streams. The resulting mixed stream continues through the mixing section and a section **114** of substantially constant flow area into a diverging chamber **116**, the function of the latter of which is to decrease the velocity of the combined streams at **110** 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 **107**. The divergent chamber **116** has an outlet at **101** from which the ejector-exit stream is withdrawn. The ejector-exit stream is at a higher pressure and a higher temperature than the vapor stream which was introduced at **102**.

When the liquid stream introduced at **103** is substantially pure liquid, the nozzle **104** must be a convergent-divergent nozzle as shown. When the liquid stream introduced at **103** is a two-phase, liquid-vapor stream, the nozzle **104** may be a convergent-divergent nozzle or may be a simple convergent nozzle.

The nozzle **104** may be and preferably is a single nozzle as shown, or, if desired, a plurality of nozzles may be employed on one or more multiple-phase ejector inlet conduits; or a plurality of nozzles may be placed in any arrangement which permits the rapid and efficient introduction of a liquid stream and a vapor stream from conduits **103** and **102**, respectively, into the inlet opening of the mixing chamber **112**. In the embodiment shown in FIG. 1, the liquid stream is introduced through the central nozzle **104** and the vapor stream is introduced through the concentric annular nozzle **107**. The operation may also be effected by the introduction of the vapor stream through a central nozzle and the introduction of the liquid stream through a concentric annular nozzle.

In the embodiment shown, the multiple-phase ejector **100** has a mixing chamber **112** with an inwardly sloping contour connected to the short section **114** of constant flow area. Mixing sections having geometries different from that shown may also be employed for use in the multiple-phase ejector.

The ejector-exit stream withdrawn at **101** may be and preferably is a two-phase, liquid-vapor fluid or, if desired, may be a completely condensed liquid stream containing only trace amounts of non-condensible gases. The latter condition will find particular utility in rejection of heat from space vehicles where the absence of a gravitational field implies the need of a condensation process other than the conventional one which depends on the existence of a gravitational field for removal of the condensate from the condenser surfaces.

Referring again to FIG. 1, a multiple-phase ejector refrigeration system is illustrated having, in one mode of operation, the multiple-phase ejector **100** of the type described above to which is introduced the high-pressure liquid stream at **103** and the low-pressure vapor stream at **102**, and from which is withdrawn a single two-phase, liquid-vapor refrigerant stream at **101** having a higher pressure and a higher temperature than the vapor stream at **102**. The single stream withdrawn at **101** is applied through conduit **20** to a heat exchanger **22** in which the vapor portion of the stream is condensed, thereby rejecting heat from the system. The liquid stream withdrawn from the heat exchanger **22** through conduit **24** is divided into two portions; the first portion of which is applied through a conduit **26** to a Joule-Thomson valve V or similar structure **28**, whereby the stream is expanded to a lower pressure and is applied through conduit **30** to an evaporator **18**. The liquid is thus evaporated and, in so doing, absorbs heat from the environment-to-be-cooled. The vapor withdrawn from the evaporator **18** through conduit **25** may be applied either directly to the vapor inlet **102** of the multiple-phase ejector **100** through conduits **16** and **35**, as in FIG. 1, or along an alternative path through conduit **32** to a vapor compressor **31**, FIG. 2, whereby its pressure is increased, and thence through conduits **33** and **35** to the vapor inlet **102** of the multiple-phase ejector **100**.

The second portion of the liquid stream at **24**, in FIG. 1, is applied through conduit **13** to a pump **14** which increases its pressure. The high pressure liquid at **15** is applied either directly to the liquid inlet **103** of the multiple-phase ejector **100** through conduits **17** and **12**, as in FIG. 1, or along an alternative path through conduit **19**, FIG. 2, to a heater **34** and thence through conduits **21** and **12** to the liquid inlet **103** of the multiple-phase ejector **100**. When the heater **34** is employed, as in the modification of FIG. 2, the pump **14** serves the purpose of increasing the pressure of the liquid from the heat exchanger **22** so that the liquid may be heated at **34** to a higher temperature, thereby accepting heat energy without evaporation. Once at such higher temperature, if desired, the fluid at **34** may be partially evaporated before introduction to the liquid inlet **103** of the multiple-phase ejector **100**.

Thus, in one embodiment, the total energy-input to operate the system is introduced in the form of work by pump **14**, in which case the vapor at **25** is applied directly through conduits **16** and **35** to the vapor inlet **102** of the multiple-phase ejector **100**, and the high pressure liquid at **15** is applied directly through conduits **17** and **12** to the liquid inlet **103** of the multiple-phase ejector **100**.

In the embodiment of FIG. 2, however, the energy-input to operate the system may be shared between the pump **14** and the heater **34**, in which case the vapor at **25** is applied directly through conduits **16** and **35** to the vapor inlet **102** of the multiple-phase ejector **100** and the liquid at **15** is applied through conduit **19** to the heater **34**, whereby the temperature of the stream is increased, adding energy to the system in the form of heat, and thence through conduits **21** and **12** to the liquid inlet **103** of the multiple-phase ejector. In this mode of operation, the liquid stream introduced at **103** may be pure liquid or may be a low-quality, two-phase, liquid-vapor fluid containing no more than about fifty percent vapor by mass and having a pressure greater than the desired pressure at the exit **101** of the multiple-phase ejector **100**.

In still another embodiment, the energy-input to operate the system may be shared between the pump **14** and a vapor compressor **31**, FIG. 2, in which case the high pressure liquid at **15** is applied directly to the liquid inlet **103** of the multiple-phase ejector **100** through conduits **17** and **12** and the vapor at **25** is applied through conduit **32** to the vapor compressor **31** in which the pressure of the vapor is increased, thereby adding work to the system. The vapor leaving the vapor compressor **31** is applied to the vapor inlet **102** of the multiple-phase ejector **100** through conduits **33** and **35**. In this mode of operation the pressure at the exit **101** of the multiple-phase ejector is greater than the pressure of the vapor at **102** and less than the pressure of the liquid at **103**.

In still another embodiment, the energy-input to operate the system may be shared among the pump **14**, the heater **34** and the vapor compressor **31**, in which case the vapor at **25** is applied through conduit **32** to the vapor compressor **31** in which the pressure of the vapor is increased (thereby adding work to the system), and thence through conduits **33** and **35** to the vapor inlet **102** of the multiple-phase ejector **100**. The liquid at **15** is applied through conduit **19** to the heater **34**, whereby the temperature of the stream is increased (adding energy to the system in the form of heat), and thence through conduits **21** and **12** to the liquid inlet **103** of the multiple-phase ejector. As in the embodiments described above, in this mode of operation the pressure at the exit **101** of the multiple-phase ejector **100** is greater than the pressure of the vapor stream at **102** and less than the pressure of the liquid stream at **103**, and the liquid stream at **103** may contain no more than substantially fifty percent vapor by mass.

Referring to FIG. 3, a multiple-phase ejector refrigeration system is illustrated having a multiple-phase ejector **100** of the same type described previously. The two-phase, liquid-vapor stream at the exit **101** of the multiple-phase ejector **100** is withdrawn through conduit **20** and applied to a liquid-vapor separator **30** whereby the stream is separated into a liquid portion and a vapor portion. The liquid portion is withdrawn from the liquid-vapor separator **30** through conduit **26** and is applied to the Joule-Thomson valve or similar structure **28**, whereby the stream is expanded to a lower pressure and is applied through conduit **30** to an evaporator **18**, thereby evaporating the liquid and in so doing absorbing heat from the environment-to-be-cooled. The vapor withdrawn from the evaporator **18** through conduits **16** and **35** is applied directly to the vapor inlet **102** of the multiple-phase ejector **100**.

The vapor portion is withdrawn from the liquid-vapor separator **30** through conduit **32′** and is applied to a vapor compressor **31**, whereby the pressure of the vapor stream in increased, adding energy to the system in form of work. The resulting high-pressure vapor is applied through conduit **33′** to heat exchanger **22**, in order to desuperheat and condense the vapor and to produce high-pressure liquid at **24**.

The high-pressure liquid at **24** may be applied either to a path which introduces this liquid directly to the liquid inlet **103** of the multiple-phase ejector **100** through conduits **23** and **12**, or it may be applied along an alternative path through conduit **13** to the pump **14** which further increases the pressure of the liquid.

The high-pressure liquid at **15** may be applied directly to the liquid inlet **103** of the multiple-phase ejector **100** through conduits **17** and **12** or it may be applied along an alternative path through conduit **19** to a heater **34**, whereby the temperature of the stream is increased, adding energy to the system in the form of heat, and hence through conduits **21** and **12** to the liquid inlet **103** of the multiple-phase ejector.

In one mode of operation of the system shown in FIG. 3, the total energy-input to operate the system is introduced by vapor compressor **31** in the form of work as is typically done in conventional vapor-compression refrigeration systems. In this embodiment, however, an advantageous "bootstrap" type of operation takes place in accordance with which a saturated liquid stream is expanded to a lower pressure and temperature in order to absorb heat from an environment and in which the vapor so produced is introduced to the vapor compressor at a pressure higher than the saturation pressure corresponding to the temperature at which the heat was absorbed. Specifically, in the embodiment whereby the fluid applied to the liquid inlet **103** of the multiple-phase ejector **100** is previously passed through conduit **23**, the saturated liquid leaving the heat exchanger **22** enters the nozzle **104** of the multiple-phase ejector in which its velocity is increased, thereby producing a two-phase, supersonic, liquid-vapor stream at **108**. The vapor produced in the evaporator **18** enters the second nozzle **107** in which its velocity is increased, and the two streams are brought into intimate contact in the mixing chamber **112**. The velocity of the combined stream is decreased in section **116** to provide a two-phase stream at the ejector exit **110** which has a higher pressure than the vapor which left the evaporator through conduit **16** and entered the ejector at **102**. This two-phase stream then enters the liquid-vapor separated **30** from which the liquid is drawn off through conduit **26** and from which the vapor is drawn off and introduced to the vapor compressor **31**, whereby it is compressed to a higher pressure and temperature and returned by conduit **33′** to the heat exchanger **22**. The vapor introduced to the vapor compressor **31** is at a higher pressure than the vapor produced in the evaporator **18**. The liquid which was withdrawn through conduit **26** enters the Joule-Thomson valve **28** and is expanded to a lower pressure and temperature at **30** and enters the evaporator **18** in which it absorbs heat from the environment by evaporation to vapor at **16**. In the typical refrigeration system, the liquid leaving the heat exchanger **22** would be passed immediately through the Joule-Thomson valve **28** into the evaporator **18** and the vapor generated in this evaporator and withdrawn through conduit **16** would be immediately introduced to a vapor compressor whereby it would be compressed to a higher pressure and temperature and re-introduced to heat exchanger **22**. The pressure of the vapor at **16** is lower than that pressure generated by the multiple-phase ejector at **110**. Therefore, the vapor compressor **31**, in this embodiment using the multiple-phase ejector, receives vapor at a higher pressure than does the vapor compressor of a typical refrigeration system operating with the same temperature in the evaporator **18**. Less work, therefore, is required to compress this vapor to the same pressure in the heat exchanger at **22**.

In one embodiment illustrated in FIG. 3, the energy-input to operate the system may be supplemented by additional work-input through the pump **14**, in which case the high-pressure liquid at **24** is applied to the pump **14** through conduit **13** and thence to the liquid inlet **103** of the multiple-phase ejector **100** through conduits **15**, **17** and **12**.

In a further mode of operation of the system of FIG. 3, moreover, the energy-input to operate the system may be further supplemented by the addition of energy in the form of heat, in which case the high-pressure liquid leaving the pump **14** through conduit **15** is applied through conduit **19** to heater **34** and thence to the liquid inlet **103** of the multiple-phase ejector **100** through conduits **21** and **12**.

The refrigerant fluid employed in the refrigeration systems described above may be any low boiling point, high heat capacity, condensable refrigerant fluid such as carbon dioxide, sulfur dioxide, water, ammonia, hydrocarbons, or halohydrocarbons like mono and polychloro and fluoro substituted low molecular weight alkanes such as dichlorodifluoro methanes and trichloromonofluoromethane and the like.

The refrigeration systems described above employ a single stage multiple-phase ejector, but these systems, as before noted, may, if desired, employ more than one multiple-phase ejector arranged in series or in parallel in order to compress the refrigerant vapor obtained from the evaporator **18**.

Further modifications will also occur to those skilled in the art and all such are considered to fall within the spirit and scope of the invention as defined in the appended claims.

What is claimed is:

1. An improved refrigerant process which comprises:
providing a high pressure liquid refrigerant stream at inlet means;
providing a low pressure vapor refrigerant stream at said inlet means;
increasing the velocity of the low pressure vapor refrigerant stream;
increasing the velocity of the high pressure liquid refrigerant stream and forming a supersonic velocity two-phase vapor-liquid refrigerant stream;
mixing the two-phase vapor-liquid refrigerant stream with the increased velocity vapor refrigerant stream to provide a single refrigerant stream;
decreasing the velocity of the said single refrigerant stream to a velocity at which the temperature and pressure of the same are greater than the temperature and pressure of the vapor refrigerant stream before its increase in velocity;
increasing the pressure of a portion of the said single

refrigerant stream to provide the said high pressure liquid refrigerant;
directing the high pressure liquid stream to said inlet means;
expanding the remaining portion of the said single refrigerant stream to a lower temperature and pressure; and
placing the expanded portion in a heat-absorbent relationship with a heat source to provide said vapor refrigerant stream to said inlet means.

2. A process as claimed in claim **1** and in which the said single refrigerant stream is condensed and the condensate divided into the said portion that is increased in pressure and the said remaining portion that is expanded.

3. A process as claimed in claim **1** and in which the said single refrigerant stream is separated into substantially liquid and vapor streams the latter of which comprises the portion that is increased in pressure and the former of which comprises the said remaining portion that is expanded.

4. A refrigeration system comprising, in combination:
inlet means for receiving a high pressure refrigerant liquid stream and a low pressure vapor refrigerant stream;
means for increasing the velocities of the streams including means for forming from the said liquid stream a supersonic velocity two-phase vapor-liquid refrigerant stream;
means for mixing the two-phase vapor-liquid refrigerant stream with the increased velocity vapor refrigerant stream to provide a single refrigerant stream;
means for decreasing the velocity of the said single refrigerant stream to a velocity at which the temperature and pressure of the same are greater than that of the vapor refrigerant stream at the said inlet means;
means for increasing the pressure of a portion of the said single refrigerant stream to provide the said high pressure refrigerant liquid and for directing the same to said inlet means;
means for expanding the remaining portion of the said single refrigerant stream to a lower temperature and pressure; and
means for placing the expanded portion in a heat-absorbent relationship with a heat source to provide the said vapor refrigerant stream to said inlet means.

5. A system as claimed in claim **4** and in which the said single stream is fed to heat exchanger means, the said pressure-increasing means comprises pump means connected to the heat exchanger means and the said expanding means comprises pressure expansion means connected with the heat exchanger means and connected through evaporator means with said inlet means.

6. A system as claimed in claim **5** and in which supplemental heater means is connected between the pump means and the said inlet means.

7. A system as claimed in claim **5** and in which vapor compressor means is connected between said evaporator means and said inlet means.

8. A system as claimed in claim **4** and in which the said single stream is fed to liquid-vapor separator means the resulting vapor portion of which is fed to the said pressure-increasing means and the liquid portion of which is connected with the said expanding means.

9. A system as claimed in claim **8** and in which the pressure-increasing means comprises vapor compressor means connected with heat exchanger means to the said inlet means.

10. A system as claimed in claim **9** and in which pump means is connected with or without supplemental heater means between the heat exchanger means and the said inlet means.

11. A system as claimed in claim **8** and in which the said expanding means comprises pressure expansion means connected through evaporator means to said inlet means.

12. A vapor compressing apparatus which comprises, in combination:

means for introducing a high-pressure liquid stream;
means for increasing the velocity of the high-pressure liquid stream and producing a high-velocity supersonic two-phase liquid-vapor stream;
means for introducing a low-pressure vapor stream;
means for increasing the velocity of the low-pressure vapor stream;
means for combining said high-velocity, supersonic two-phase liquid-vapor stream and said low-pressure vapor stream, thereby to form a combined stream which is a two-phase stream and whose density is greater than the density of the low-pressure vapor stream and less than the density of the supersonic two-phase liquid-vapor stream; and
means for decreasing the velocity of said combined stream to a velocity at which the temperature and pressure of the combined stream is greater than the temperature and pressure which the low-pressure vapor stream had before its velocity was increased.

13. An apparatus as set forth in claim 12 wherein the means to increase the velocity of the high-pressure liquid stream is a convergent-divergent nozzle.

14. Refrigeration system which comprises, in combination:

an input for a liquid refrigerant stream of relatively high pressure;
an ejector comprising an elongated tube having a contoured internal fluid flow path including a mixing chamber with an inlet opening;
means for increasing the velocity of the relatively high pressure liquid refrigerant stream and producing a supersonic velocity two-phase liquid-vapor stream, said means comprising a first nozzle discharging into the inlet opening of said ejector and having a flow axis aligned with the longitudinal axis of the flow of said ejector;
means to introduce the liquid refrigerant stream from the input to the first nozzle;
a second nozzle located concentrically with the first nozzle for introducing a high velocity vapor refrigerant stream into the inlet opening of the mixing chamber and placing stream into intimate contact with the two-phase stream formed by the first nozzle, thereby to combine the streams;
means for decreasing the velocity of the combined streams in the said chamber to a velocity at which the temperature and pressure of the combined streams is greater than the temperature and pressure of the vapor refrigerant stream prior to passage through said second nozzle, the last-mentioned means comprising a divergent chamber of said ejector tube leading from said mixing chamber;
liquid-vapor separator means connected to receive the output from the divergent chamber and to separate the same into liquid and vapor portions;
vapor compressor means connected to receive the separated vapor portion and to compress the same to a high pressure and temperature;
a heat exchanger to form a condensed refrigerant stream;
means to introduce the compressed vapor from the vapor compressor into the heat exchanger;
means to withdraw the condensed refrigerant stream from the heat exchanger and to introduce the same to the said input as the said liquid refrigerant stream of relatively high pressure;
an evaporator to form a vapor refrigerant stream;
means for receiving the said separated liquid portion of the liquid-vapor separator means to expand the same to a lower pressure and temperature;
means to introduce the lower pressure and temperature stream into the evaporator; and
means to introduce the vapor refrigerant stream from the evaporator into the second nozzle.

15. The refrigeration system of claim 14 wherein pressure-increasing means is interposed in the path between the heat exchanger and the said input.

16. The refrigeration system of claim 15 and in which further energy-supply means is interposed in the said path to increase the energy of the liquid refrigerant at the said input.

17. An apparatus for compressing a refrigereant vapor which apparatus comprises, in combination:

a pump to increase the pressure of a liquid refrigerant stream to a relatively high pressure;
an ejector comprising an elongated tube having a contoured internal fluid flow path including a mixing chamber with an inlet opening;
means for increasing the velocity of the relatively high pressure liquid refrigerant stream and producing a supersonic velocity two-phase liquid-vapor stream, said means comprising a first nozzle discharging into the inlet opening of said ejector and having a flow axis aligned with the longitudinal axis of the flow path of said ejector;
means to introduce the liquid refrigerant stream from the pump to the first nozzle;
a second nozzle located concentrically with the first nozzle for introducing a high velocity vapor refrigerant stream into the inlet opening of the mixing chamber and placing this stream into intimate contact with the two-phase stream formed by the first nozzle, thereby to combine the streams; and
means for decreasing the velocity of the combined streams in the said chamber to a velocity at which the temperature of the combined streams is greater than the temperature of the vapor refrigerant stream prior to passage through the second nozzle, the last-mentioned means comprising a divergent chamber of said ejector tube leading from said mixing chamber.

18. The apparatus of claim 17, wherein the first nozzle is characterized by a contoured convergent-divergent internal flow path in which the convergence is sufficiently sharp and the minimum cross-section area sufficiently small to produce said supersonic stream.

19. The apparatus of claim 17, wherein the ejector tube has an internal section of substantially constant cross-section between the mixing chamber and the divergent chamber.

20. A refrigerant system which comprises in combination:

a pump to increase the pressure of a liquid refrigerant stream to a relatively high pressure;
an ejector comprising an elongated tube having a contoured internal fluid flow path including a mixing chamber with an inlet opening;
means for increasing the velocity of the relatively high pressure liquid refrigerant stream and producing a supersonic velocity two-phase liquid-vapor stream, said means comprising a first nozzle discharging into the inlet opening of said ejector and having a flow axis aligned with the longitudinal axis of the flow path of said ejector;
means to introduce the liquid refrigerant stream from the pump to the first nozzle;
a second nozzle located concentrically with the first nozzle for introducing a high velocity vapor refrigerant stream into the inlet opening of the mixing chamber and placing this stream into intimate contact with the two-phase stream formed by the first nozzle, thereby to combine the streams;
means for decreasing the velocity of the combined streams in the said chamber to a velocity at which the temperature of the combined streams is greater

than the temperature of the vapor refrigerant stream prior to passage through said second nozzle, the last-mentioned means comprising a divergent chamber of said ejector tube leading from said mixing chamber;
a heat exchanger to form a condensed refrigerant stream;
means to introduce the refrigerant stream from the divergent chamber into the heat exchanger;
means to withdraw a first portion of the condensed refrigerant stream from the heat exchanger and to introduce that portion to the pump;
an evaporator to form a vapor refrigerant stream;
means to withdraw a second portion of the condensed refrigerant stream from the heat exchanger and to expand that portion to a lower pressure and temperature;
means to introduce the lower pressure and temperature stream into the evaporator; and
means to introduce the vapor refrigerant stream from the evaporator into the second nozzle.

21. The refrigeration system of claim **20**, wherein the means to introduce the vapor refrigerant stream from the evaporator to the second nozzle includes a vapor compressor.

22. The refrigeration system of claim **20**, wherein the first nozzle is characterized by a contoured convergent-divergent internal fluid flow path in which the convergence is sufficiently sharp and the minimum cross-section area sufficiently small to produce said supersonic stream.

23. A process for compressing a vapor stream which process comprises:
increasing the pressure of a liquid refrigerant stream to a relatively high pressure;
increasing the velocity of a vapor refrigerant stream;
increasing the velocity of the pressurized liquid-refrigerant stream and forming a supersonic velocity two-phase vapor-liquid refrigerant stream therefrom;
mixing the two-phase vapor-liquid refrigerant stream with the increased velocity vapor refrigerant stream; and
decreasing the velocity of the mixed streams to a velocity at which the temperature of the mixed streams is greater than the temperature of the vapor refrigerant stream before its increase in velocity.

24. An improved refrigeration process which comprises:
increasing the pressure of a liquid refrigerant stream to a relatively high pressure;
increasing the velocity of a vapor refrigerant stream;
increasing the velocity of the pressurized liquid refrigerant stream and forming a supersonic velocity two-phase vapor-liquid refrigerant stream therefrom;
mixing the two-phase vapor-liquid refrigerant stream with the increased velocity refrigerant stream;
decreasing the velocity of the mixed streams to a velocity at which the temperature of the mixed streams is greater than the temperature of the vapor refrigerant stream before its increase in velocity;
condensing the mixed refrigerant streams;
recycling a first portion of the condensed streams as a liquid refrigerant stream;
expanding a second portion of the condensed streams to a lower temperature and pressure; and
placing the expanded second portion in a heat absorbing relationship with a heat source to provide a first vapor refrigerant stream.

25. The process of claim **24**, which includes compressing the vapor refrigerant stream prior to its increase in velocity.

26. The process of claim **24**, wherein the vapor refrigerant stream is increased in velocity to form a two-phase vapor-liquid stream and both two-phase streams have substantially the same temperature and pressure immediately prior to mixing.

27. An apparatus for compressing a refrigerant vapor which apparatus comprises, in combination:
means for producing a liquid refrigerant stream of a relatively high pressure;
an ejector comprising an elongated tube having a contoured internal fluid flow path including a mixing chamber with an inlet opening;
means for increasing the velocity of the relatively high pressure liquid refrigerant stream and producing a supersonic velocity two-phase liquid-vapor stream, said means comprising a first nozzle discharging into the inlet opening of said ejector and having a flow axis aligned with the longitudinal axis of the flow path of said ejector;
means to introduce the liquid refrigerant stream to the first nozzle;
a second nozzle located concentrically with the first nozzle for introducing a high velocity vapor refrigerant stream into the inlet opening of the mixing chamber and placing this stream into intimate contact with the two-phase stream formed by the first nozzle, thereby to combine the streams; and
means for decreasing the velocity of the combined streams in the said chamber to a velocity at which the temperature and pressure of the combined streams is greater than the temperature and pressure of the vapor refrigerant stream prior to passage through the second nozzle, the last-mentioned means comprising a divergent chamber of said ejector tube leading from said mixing chamber.

28. The apparatus of claim **27**, wherein the first nozzle is characterized by a contoured convergent-divergent internal flow path in which the convergence is sufficiently sharp and the minimum cross-section area sufficiently small to produce said supersonic stream.

29. The apparatus of claim **27**, wherein the ejector tube has an internal section of substantially constant cross-section between the mixing chamber and the divergent chamber.

30. The apparatus of claim **27**, wherein there is further provided:
a heat exchanger to form a condensed refrigerant stream;
means to introduce the refrigerant stream from the divergent chamber into the heat exchanger;
means to withdraw a first portion of the condensed refrigerant stream from the heat exchanger and to introduce that portion to the said first nozzle;
an evaporator to form a vapor refrigerant stream;
means to withdraw a second portion of the condensed refrigerant stream from the heat exchanger and to expand that portion to a lower pressure and temperature;
means to introduce the lower pressure and temperature stream into the evaporator; and
means to introduce the vapor refrigerant stream from the evaporator into the said second nozzle.

31. The refrigeration system of claim **30**, wherein the means to introduce the vapor refrigerant stream from the evaporator to the second nozzle includes a vapor compressor.

32. A process for compressing a vapor stream which process comprises:
producing a liquid refrigerant stream of a relatively high pressure;
increasing the velocity of a vapor refrigerant stream;
increasing the velocity of the pressurized liquid refrigerant stream and forming a supersonic velocity two-phase vapor-liquid refrigerant stream therefrom;
mixing the two-phase vapor-liquid refrigerant stream with the increased velocity vapor refrigerant stream; and
decreasing the velocity of the mixed streams to a velocity at which the temperature of the mixed streams is

greater than the temperature of the vapor refrigerant stream before its increase in velocity.

33. A process as claimed in claim 32 and in which the following further steps are performed:
condensing the mixed refrigerant streams;
recycling a first portion of the condensed streams as a liquid refrigerant stream;
expanding a second portion of the condensed streams to a lower temperature and pressure; and
placing the expanded second portion in a heat absorbing relationship with a heat source to provide a first vapor refrigerant stream.

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