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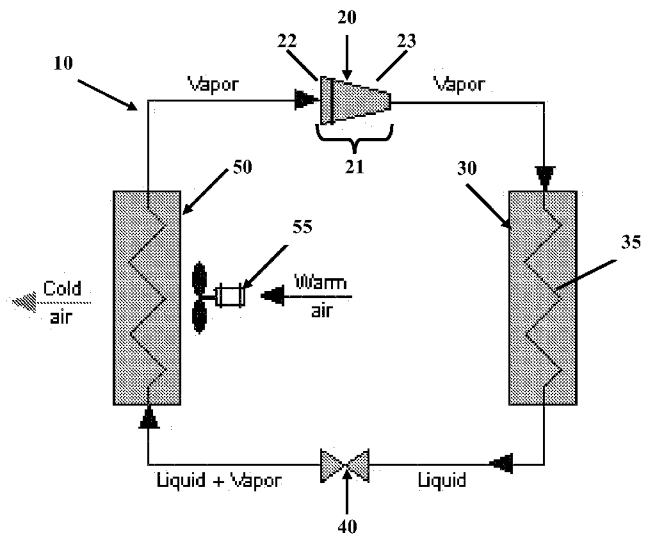
(54) Title: SYSTEM TO PERFORM A VAPOR COMPRESSION REFRIGERATION CYCLE USING WATER AS THE REFRIGERANT

FIG. 1



(57) Abstract: A system to perform a vapor compression refrigeration cycle using water as the refrigerant is provided and includes an evaporator to output water vapor having a water vapor temperature of a first temperature and a water vapor pressure of a first pressure, a condenser to output liquid water at a second temperature, which is higher than the first temperature, and a second pressure, which is higher than the first pressure and a compressor, operably disposed downstream from the evaporator and upstream from the condenser, to compress the water vapor to thereby increase the water vapor temperature from the first temperature and to thereby increase the water vapor pressure from the first pressure by at least a 7:1 ratio.

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SYSTEM TO PERFORM A VAPOR COMPRESSION REFRIGERATION CYCLE USING WATER AS THE REFRIGERANT

BACKGROUND OF THE INVENTION

[0001] The subject matter disclosed herein relates to a system to perform a vapor compression refrigeration cycle using water as the refrigerant.

[0002] Vapor-compression refrigeration is of the many refrigeration cycles available for use. It has been and is the most widely used method for air-conditioning of large public buildings, offices, private residences, hotels, hospitals, theaters, restaurants and automobiles. It is also used in domestic and commercial refrigerators, large-scale warehouses for chilled or frozen storage of foods and meats, refrigerated trucks and railroad cars, and a host of other commercial and industrial services, such as oil refineries, petrochemical and chemical processing plants, and natural gas processing plants.

[0003] Refrigeration may be defined as a lowering of a temperature of an enclosed space by the removal of heat from that space and transferring the heat elsewhere. A typical vapor-compression refrigeration system uses a circulating liquid refrigerant as the medium that absorbs and removes heat from the space to be cooled and subsequently rejects that heat elsewhere. All such systems have four components: a compressor, a condenser, a fluid expansion device (typically a throttling valve but sometimes a work recovery expansion device) and an evaporator. Circulating refrigerant enters the compressor in the thermodynamic state known as a saturated or a slightly superheated vapor and is compressed to a higher pressure, resulting in a higher temperature as well. The hot, compressed vapor is then in the thermodynamic state known as a superheated vapor and it is at a temperature and pressure at which it can be condensed with typically available cooling water or cooling air. That hot vapor is routed through a condenser where it is cooled and condensed into a liquid by flowing through a coil or tubes with cool water or cool air flowing across the coil or tubes. This is where the circulating refrigerant rejects heat from the system and the rejected heat is carried away by either the water or the air (whichever may be the case).

[0004] The condensed liquid refrigerant, which is now in the thermodynamic state known as a saturated or a slightly sub-cooled liquid, is next routed through an expansion device where it undergoes an abrupt reduction in pressure. That pressure reduction results in the adiabatic flash evaporation of a part of the liquid refrigerant. The auto-refrigeration effect of the adiabatic flash evaporation lowers the temperature of the liquid and vapor refrigerant mixture to where it is colder than the temperature of the enclosed space to be refrigerated. The cold mixture is then routed through the coil or tubes in the evaporator. A fan circulates the warm air in the enclosed space across the coil or tubes carrying the cold refrigerant liquid and vapor mixture. That warm air evaporates the liquid part of the cold refrigerant mixture. At the same time, the circulating air is cooled and, thus, lowers the temperature of the enclosed space to the desired temperature. The evaporator is where the circulating refrigerant absorbs and removes heat from the enclosed space, which is subsequently rejected in the condenser and transferred elsewhere by the water or air used in the condenser. To complete the refrigeration cycle, the refrigerant vapor from the evaporator is again a saturated or slightly superheated vapor and is routed back into the compressor.

[0005] The types of refrigerants that have been used up until now are varied and include fluorocarbons and more particularly, chlorofluorocarbons. As high global warming potential (GWP) refrigerants are phased out and banned, however, other types of refrigerants are being investigated. Recently, this has led to water becoming an attractive alternative as water offers zero GWP, high efficiency, high heat of vaporization, low cost, and makes possible the use of direct contact heat exchangers. On the other hand, water requires a high volumetric flow rate and a high compression ratio, which cannot be achieved efficiently by conventional centrifugal or axial compressors.

BRIEF DESCRIPTION OF THE INVENTION

[0006] According to one aspect of the invention, a system to perform a vapor compression refrigeration cycle using water as the refrigerant is provided and includes an evaporator to output water vapor having a water vapor temperature of a first temperature and a water vapor pressure of a first pressure, a condenser to output liquid water at a second temperature, which is higher than the first temperature, and a second pressure, which is higher than the first pressure and a compressor, operably disposed downstream from the evaporator and upstream from the condenser, to compress the water vapor to thereby increase the water vapor temperature from the first temperature and to thereby increase the water vapor pressure from the first pressure by at least a 7:1 ratio.

[0007] According to another aspect of the invention, a system to perform a vapor compression refrigeration cycle using water as the refrigerant is provided and includes an evaporator to output water vapor having a water vapor temperature of a first temperature and a water vapor pressure of a first pressure, a condenser to output liquid water at a second temperature, which is higher than the first temperature, and a second pressure, which is higher than the first pressure and a supersonic compressor, operably disposed downstream from the evaporator and upstream from the condenser, to supersonically compress the water vapor to thereby increase the water vapor temperature from the first temperature and to thereby increase the water vapor pressure from the first pressure by at least a 7:1 ratio.

[0008] According to yet another aspect of the invention, a system to perform a vapor compression refrigeration cycle using water as the refrigerant is provided and include an evaporator to vaporize liquid water to produce water vapor and to output the water vapor having a water vapor temperature of a first temperature and a water vapor pressure of a first pressure, a condenser to output liquid water at a second temperature, which is higher than the first temperature, and a second pressure, which is higher than the first pressure and a supersonic compressor assembly having a first stage centrifugal compressor and a second stage supersonic compressor, operably disposed downstream from the evaporator and upstream from the condenser, to supersonically compress the water vapor to thereby increase the water vapor temperature from the first temperature and to thereby increase the water vapor pressure from the first pressure by at least a 7:1 ratio.

[0009] These and other advantages and features will become more apparent from the following description taken in conjunction with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The subject matter which is regarded as the invention is particularly pointed out and distinctly claimed in the claims at the conclusion of the specification. The foregoing and other features, and advantages of the invention are apparent from the following detailed description taken in conjunction with the accompanying drawings in which:

[0011] FIG. 1 illustrates a system to perform a refrigeration cycle; and

[0012] FIG. 2 is a flow diagram illustrating a method of operating the system of FIG. 1.

[0013] The detailed description explains embodiments of the invention, together with advantages and features, by way of example with reference to the drawings.

DETAILED DESCRIPTION OF THE INVENTION

[0014] The proposed invention adapts the operating principles of the supersonic aircraft inlet to a rotary supersonic compressor to enable the use of water or other low density refrigerants in vapor-compression refrigeration.

[0015] With reference to FIG. 1, a system 10 to perform a vapor compression refrigeration cycle using water as the refrigerant is provided. The system 10 includes a compressor 20, a condenser 30, a fluid expansion device 40 (typically a throttling valve but sometimes a work recovery expansion device) and an evaporator 50. In an operation of the system 10 and, in accordance with embodiments, circulating water vapor enters the compressor 20 in the thermodynamic state known as a saturated or a slightly superheated vapor and is compressed from a first temperature and a first pressure to a second, higher pressure and a second, higher temperature. The hot, compressed water vapor is then in the thermodynamic state known as a superheated vapor and it is at a greater temperature and pressure relative to, for example, ambient conditions, such that it can be condensed with typically available cooling water or cooling air. That hot water vapor is routed through the condenser 30 where it is cooled and condensed into a liquid by flowing through a coil or tubes with cool water or cool air flowing across the coil or tubes. This occurs as a heat exchanger 35, which is coupled to or disposed downstream from the condenser 30, and which represents a location where the circulating water rejects heat from the system 10.

[0016] The condensed liquid water, which is now in the thermodynamic state known as a saturated or a slightly sub-cooled liquid, is next routed through the expansion device 40, which is operably disposed downstream from the condenser 30 and upstream from the evaporator 50, where it undergoes an abrupt reduction in pressure. That pressure reduction results in the adiabatic flash evaporation of a part of the water. The auto-refrigeration effect of the adiabatic flash evaporation lowers the temperature of the liquid water to where it is colder than the temperature of the enclosed space to be refrigerated.

[0017] The cold water is then routed through the coil or tubes in the evaporator 50. A fan 55 circulates the warm air in the enclosed space to be cooled across the coil or tubes carrying the cold water. That warm air evaporates the liquid water and, at the same time, the circulating air is cooled. Thus, the temperature of the enclosed space is lowered to the desired temperature. The evaporator 50 is representative of a location where the circulating water absorbs and removes heat from the enclosed space. To complete the refrigeration cycle, the water vapor from the evaporator 50 is again a saturated or a slightly superheated vapor and is routed back into the compressor 20.

[0018] With water being used as the refrigerant, the compressor 20 may have only a single supersonic compression stage or, as an alternative, may include a supersonic compressor assembly 21 having a first stage centrifugal compressor 22 and a second stage supersonic compressor 23, where the two stages may be counter rotating. As shown in FIG. 1, the supersonic compressor assembly 21 is operably disposed downstream from the evaporator 50 and upstream from the condenser 30. In this configuration, the system 10 may have an isentropic compression efficiency of about 90% with a reduced number of stages as compared to conventional compressors. The supersonic compressor assembly 21 supersonically compresses the water vapor to thereby increase the water vapor temperature from the first temperature and to thereby increase the water vapor pressure from the first pressure by at least a 7:1 ratio or, in some cases, at least an 8:1 ratio and, in still further cases, at least a 10:1 ratio.

[0019] Thus, in accordance with embodiments, the first temperature may be about 45 degrees Fahrenheit and the first pressure may be about 0.09 pounds per square inch on the low side to 0.1-0.2 pounds per square inch on the high side. Here, the water vapor temperature is increased from the first temperature to about 100 degrees Fahrenheit and the water vapor pressure is increased from the first pressure to about 0.1-0.2 pounds per square inch on the low side and 1-2 pounds per square inch on the high side. In accordance with further embodiments, the first temperature may be about 45 degrees Fahrenheit and the first pressure may be about 0.15 pounds per square inch. Here, the water vapor temperature is increased from the first temperature to about 100 degrees Fahrenheit or somewhat higher and the water vapor pressure is increased from the first pressure to about 1.0 - 1.5 pounds per square inch.

[0020] As a result of the use of supersonic compression, the system 10 can accommodate a relatively high volumetric flow rate and a high compression ratio as compared to conventional refrigeration system compressors. In particular, for an exemplary system having a given system size that uses a typical refrigerant, such as R134a, a compressor inlet specific volume may be 0.953 ft^3/lbm. By contrast, the same sized system using water as a refrigerant and supersonic compression may have a compressor inlet specific volume of about 2,400-2,500 ft^3/lbm or approximately 2,444 ft^3/lbm.

[0021] In accordance with still further embodiments of the invention, water may be substituted for with other similarly low density refrigerants that have no or limited global warming impact.

[0022] In accordance with further aspects of the invention and, with reference to FIG. 2, a method of operating a system to perform a vapor compression refrigeration cycle using water as the refrigerant is provided. As shown in FIG. 2, the method includes operably disposing the compressor 20 downstream from the evaporator 50 and upstream from the condenser 30 (200), providing water vapor output from the evaporator 50 to the compressor 20, the water vapor having a water vapor temperature of a first temperature and a water vapor pressure of a first pressure (201), compressing the water vapor at the compressor 20 to thereby increase the water vapor temperature from the first temperature and to thereby increase the water vapor pressure from the first pressure by at least a 7:1 ratio (202) and providing the water vapor from the compressor 20 to the condenser 30 (203).

[0023] In accordance with embodiments, the compressor 20 may be provided as a supersonic compressor assembly 21 that includes a first stage centrifugal compressor 22 and a second stage supersonic compressor 23. In this case, the compressing is achieved by the supersonic compressor assembly 21 supersonically compressing the water vapor. Here, as mentioned above, a specific volume of the water vapor at an inlet of the supersonic compressor assembly 21 is about 2,400-2,500 ft^3/lbm and the water vapor pressure may be increased by at least a 7:1 ratio, an 8:1 ratio or a 10:1 ratio.

[0024] While the invention has been described in detail in connection with only a limited number of embodiments, it should be readily understood that the invention is not limited to such disclosed embodiments. Rather, the invention can be modified to incorporate any number of variations, alterations, substitutions or equivalent arrangements not heretofore described, but which are commensurate with the spirit and scope of the invention. Additionally, while various embodiments of the invention have been described, it is to be understood that aspects of the invention may include only some of the described embodiments. Accordingly, the invention is not to be seen as limited by the foregoing description, but is only limited by the scope of the appended claims.

CLAIMS:

1. A system to perform a vapor compression refrigeration cycle using water as the refrigerant, the system comprising:

an evaporator to output water vapor having a water vapor temperature of a first temperature and a water vapor pressure of a first pressure;

a condenser to output liquid water at a second temperature, which is higher than the first temperature, and a second pressure, which is higher than the first pressure; and

a compressor, operably disposed downstream from the evaporator and upstream from the condenser, to compress the water vapor to thereby increase the water vapor temperature from the first temperature and to thereby increase the water vapor pressure from the first pressure by at least a 7:1 ratio.

2. The system according to claim 1, wherein a specific volume of the water vapor at an inlet of the compressor is about 2,400-2,500 ft^3/lbm.

3. The system according to claim 1, wherein the water vapor pressure is increased by at least an 8:1 ratio.

4. The system according to claim 1, wherein the water vapor pressure is increased by at least a 10:1 ratio.

5. The system according to claim 1, further comprising a heat exchanger coupled to or disposed downstream from the condenser.

6. The system according to claim 1, further comprising a fluid expansion device operably disposed downstream from the condenser and upstream from the evaporator to expand the liquid water to thereby decrease a fluid pressure thereof.

7. A system to perform a vapor compression refrigeration cycle using water as the refrigerant, the system comprising:

an evaporator to output water vapor having a water vapor temperature of a first temperature and a water vapor pressure of a first pressure;

a condenser to output liquid water at a second temperature, which is higher than the first temperature, and a second pressure, which is higher than the first pressure; and

a supersonic compressor, operably disposed downstream from the evaporator and upstream from the condenser, to supersonically compress the water vapor to thereby increase the water vapor temperature from the first temperature and to thereby increase the water vapor pressure from the first pressure by at least a 7:1 ratio.

8. The system according to claim 7, wherein a specific volume of the water vapor at an inlet of the supersonic compressor is about 2,400-2,500 ft^3/lbm.

9. The system according to claim 7, wherein the water vapor pressure is increased by at least an 8:1 ratio.

10. The system according to claim 7, wherein the water vapor pressure is increased by at least a 10:1 ratio.

11. The system according to claim 7, further comprising a heat exchanger coupled to or disposed downstream from the condenser.

12. The system according to claim 7, further comprising a fluid expansion device operably disposed downstream from the condenser and upstream from the evaporator to expand the liquid water to thereby decrease a fluid pressure thereof.

13. A system to perform a vapor compression refrigeration cycle using water as the refrigerant, the system comprising:

an evaporator to vaporize liquid water to produce water vapor and to output the water vapor having a water vapor temperature of a first temperature and a water vapor pressure of a first pressure;

a condenser to output liquid water at a second temperature, which is higher than the first temperature, and a second pressure, which is higher than the first pressure; and

a supersonic compressor assembly having a first stage centrifugal compressor and a second stage supersonic compressor, operably disposed downstream from the evaporator and upstream from the condenser, to supersonically compress the water vapor to thereby increase the water vapor temperature from the first temperature and to thereby increase the water vapor pressure from the first pressure by at least a 7:1 ratio.

14. The system according to claim 13, wherein a specific volume of the water vapor at an inlet of the supersonic compressor assembly is about 2,400-2,500 ft^3/lbm.

15. The system according to claim 13, wherein the water vapor pressure is increased by at least an 8:1 ratio.

16. The system according to claim 13, wherein the water vapor pressure is increased by at least a 10:1 ratio.

17. The system according to claim 13, wherein the first temperature is about 45 degrees Fahrenheit and the first pressure is about 0.1-0.2 pounds per square inch, and

wherein the water vapor temperature is increased from the first temperature to about 100 degrees Fahrenheit and the water vapor pressure is increased from the first pressure to about 1-2 pounds per square inch.

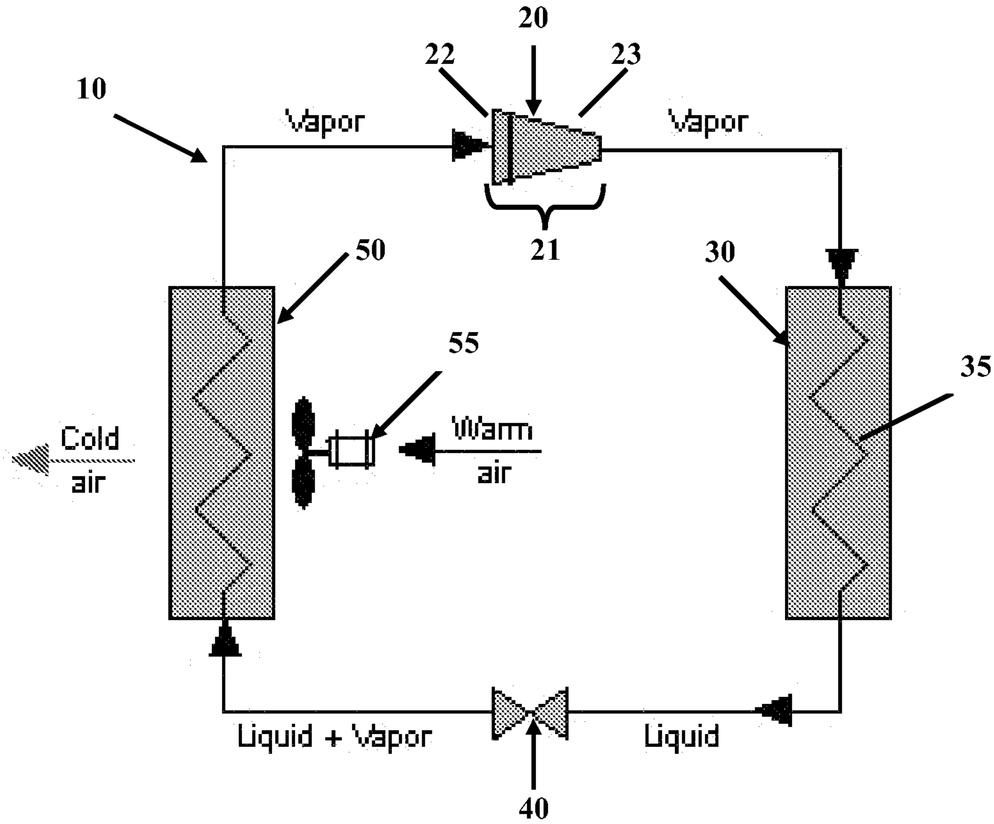
18. The system according to claim 13, wherein the first temperature is about 45 degrees Fahrenheit and the first pressure is about 0.15 pounds per square inch, and

wherein the water vapor temperature is increased from the first temperature to about 100 degrees Fahrenheit and the water vapor pressure is increased from the first pressure to about 1.5 pounds per square inch.

19. The system according to claim 13, further comprising a heat exchanger coupled to or disposed downstream from the condenser.

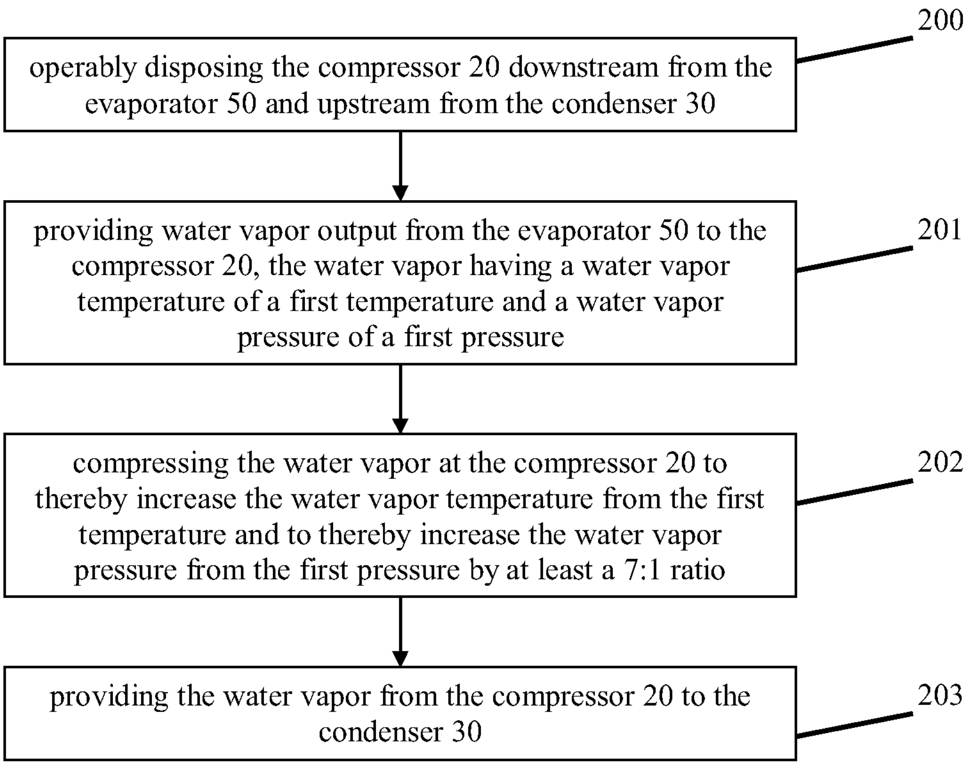
20. The system according to claim 13, further comprising a fluid expansion device operably disposed downstream from the condenser and upstream from the evaporator to expand the liquid water to thereby decrease a fluid pressure thereof.

FIG. 1



10
20
22
23
21
Vapor
Vapor
50
30
55
35
Cold
air
Warm
air
Liquid + Vapor
Liquid
40

FIG. 2


operably disposing the compressor 20 downstream from the evaporator 50 and upstream from the condenser 30
200
providing water vapor output from the evaporator 50 to the compressor 20, the water vapor having a water vapor temperature of a first temperature and a water vapor pressure of a first pressure
201
compressing the water vapor at the compressor 20 to thereby increase the water vapor temperature from the first temperature and to thereby increase the water vapor pressure from the first pressure by at least a 7:1 ratio
202
providing the water vapor from the compressor 20 to the condenser 30
203