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(54) **HEAT PUMP WATER HEATING SYSTEM USING VARIABLE SPEED COMPRESSOR**

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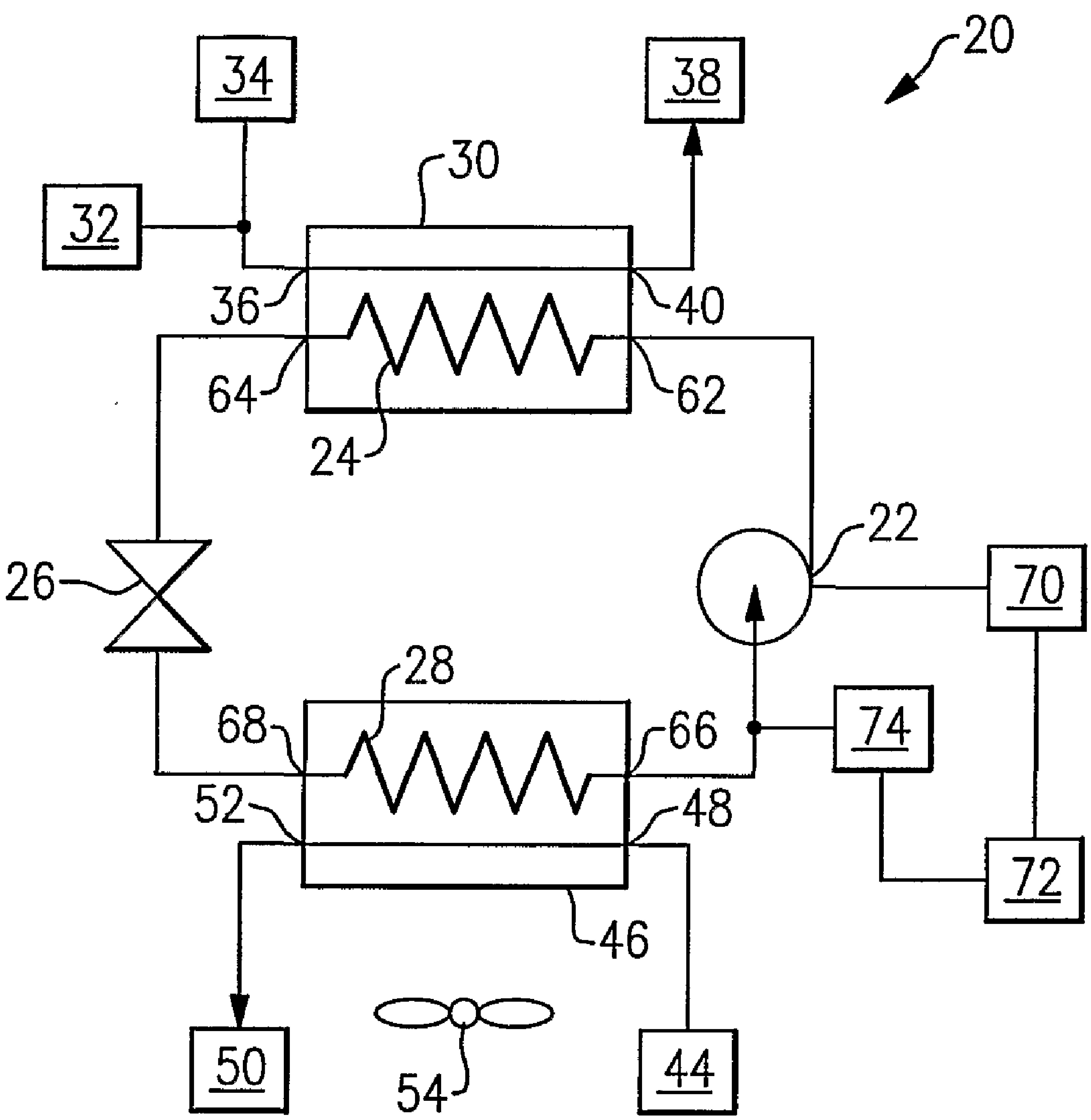
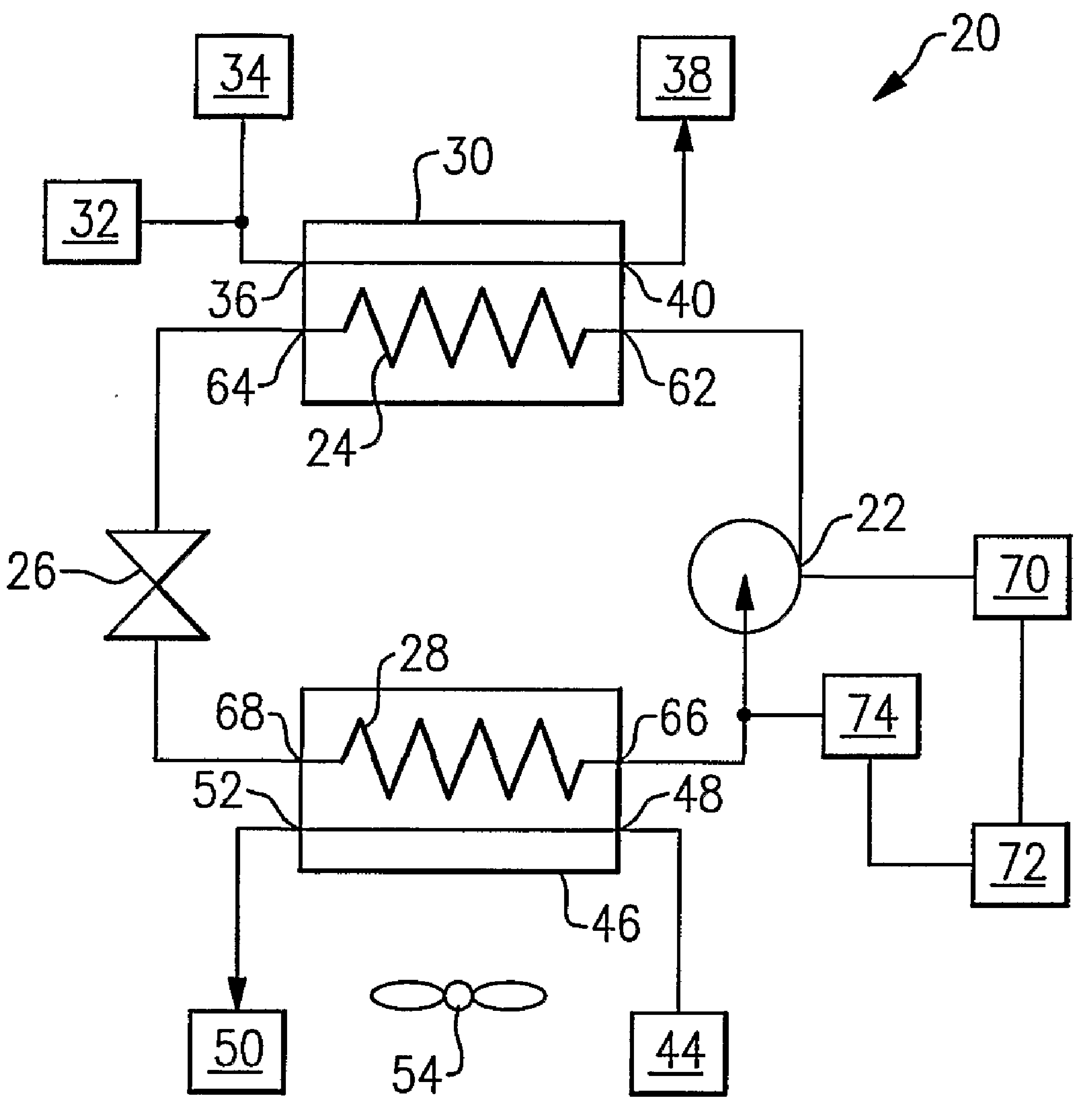
(57) **ABSTRACT**

A transcritical refrigeration system includes a compressor, a gas cooler, an expansion device, and an evaporator. Refrigerant is circulated though the closed circuit system. Preferably, carbon dioxide is used as the refrigerant. A variable speed drive controls the speed of the refrigerant flowing through the compressor. Varying the speed of the refrigerant flowing through the compressor changes the mass flow rate of the refrigerant in the system to optimize the coefficient of performance.

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HEAT PUMP WATER HEATING SYSTEM USING VARIABLE SPEED COMPRESSOR

BACKGROUND OF THE INVENTION

[0001] The present invention relates generally to a heat pump or refrigeration system including a variable speed compressor that changes the speed of refrigerant flowing through the compressor to optimize the Coefficient of Performance (COP) of the system, which is usually defined as a ratio of the heating capacity to the electric power consumption of the compressor and the fan.

[0002] Carbon dioxide is an environmentally friendly refrigerant that is commonly used in a refrigeration system. Carbon dioxide has a low critical point, and most refrigeration systems utilizing carbon dioxide as the refrigerant run transcritically or partially above the critical point. The pressure of a subcritical fluid is a function of temperature under saturated conditions (when both liquid and vapor are present). However, when the temperature of the fluid is higher than the critical temperature or supercritical, the pressure becomes a function of the density of the fluid.

[0003] A heat pump system can operate under a wide range of conditions. The outdoor air temperature can vary from approximately −10° F. in the winter to approximately 120° F. in the summer. Therefore, the refrigerant evaporating temperature can vary from approximately −20° F. in the winter to approximately 100° F. in the summer. As a result, the carbon dioxide density at the compressor suction is eight to ten times greater in the summer than the carbon dioxide density at the compressor suction in the winter. However, the heating load of the refrigeration system does not change much as the outdoor air temperature changes.

[0004] To avoid oversizing the system or the heat exchangers, the heating capacity and the mass flow rate of the refrigerant should be maintained approximately constant. The mass flow rate is a product of the refrigerant density at the compressor suction and the volumetric flow rate. Because the refrigerant suction density is increased in the summer, the volumetric flow rate in the summer should be significantly lower than the volumetric flow rate in the winter.

[0005] Variable speed compressors have been used to regulate the volumetric flow rate to maintain the mass flow rate of the refrigerant under different working conditions. In one system, the compressor speed is related to the outdoor air temperature. The compressor operates at a minimum speed when the outdoor air temperature is close to the highest design temperature, and the compressor operates at a maximum speed when the outdoor air temperature is close to the lowest design temperature. This requires a preset correlation between the compressor speed and the outdoor air temperature to regulate the volumetric flow rate of the refrigerant. In another system, the compressor speed is based on the cooling load of the evaporator. The compressor operates at a minimum speed when the cooling load of the evaporator is the highest, and the compressor operates at the maximum speed when the cooling load is the lowest.

[0006] In both of these systems, the compressor speed is lower in the summer to maintain a nearly constant heating capacity. However, the preset compressor speed for a certain outdoor air temperature may not be the optimal compressor speed to achieve the optimal coefficient of performance. Additionally, the preset compressor speed cannot accommodate any changes in the COP caused by degradation of the system components over time. That is, the preset compressor speed is not adaptive.

[0007] Therefore, there is a need for a heat pump or refrigeration system including a variable speed compressor that is adaptive and able to vary the compression speed to achieve the optimal coefficient of performance under all operating conditions.

SUMMARY OF THE INVENTION

[0008] A heat pump or refrigeration system includes a compressor, a gas cooler, an expansion device, and an evaporator. Refrigerant is circulated though the closed circuit system. Preferably, carbon dioxide is used as the refrigerant. Carbon dioxide has a low critical point, and systems utilizing carbon dioxide as the refrigerant usually run transcritically.

[0009] The refrigerant is compressed in the compressor and then cooled in a gas cooler. The refrigerant in the gas cooler rejects heat to a fluid medium, such as water, heating the water. The refrigerant then passes through the expansion device and is expanded to a low pressure. After expansion, the refrigerant flows through the evaporator and is heated by ambient outdoor air. The refrigerant is then compressed, completing the cycle.

[0010] A variable speed drive controls the speed of the refrigerant flowing through the compressor. Varying the speed of the refrigerant flowing through the compressor changes the mass flow rate of the refrigerant in the system and affects the performance of the gas cooler and the evaporator. Decreasing the refrigerant mass flow rate causes the refrigerant to flow through the heat exchangers more slowly, increasing the energy exchanger per unit flow rate of the refrigerant and improving the performance of the heat exchangers. However, as the mass flow rate is reduced, the fan power per unit flow rate increases in the evaporator coil. As the power of the fan per unit flow rate increases, the coefficient of performance decreases. For any environmental condition, there is an optimal operating speed for the compressor that achieves the optimal coefficient of performance. In general, the higher the outdoor temperature, the lower the optimal speed of the compressor to obtain the optimal coefficient of performance.

[0011] These and other features of the present invention will be best understood from the following specification and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The various features and advantages of the invention will become apparent to those skilled in the art from the following detailed description of the currently preferred embodiment. The drawings that accompany the detailed description can be briefly described as follows:

[0013] FIG. **1** schematically illustrates a diagram of a refrigeration system employing a variable speed compressor.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0014] FIG. **1** illustrates a transcritical refrigeration system **20** including a compressor **22**, a gas cooler **24**, an expansion device **26**, and an evaporator **28**. Refrigerant circulates through the closed circuit system **20**. Preferably, carbon dioxide is used as the refrigerant. Although carbon dioxide is described, other refrigerants may be used. Carbon dioxide has a low critical point, and systems utilizing carbon dioxide as the refrigerant usually run transcritically.

[0015] When operating in a water heating mode, the refrigerant exits the compressor **22** at a high pressure and a high enthalpy. The refrigerant flows through the gas cooler **24** and loses heat, exiting the gas cooler **24** at a low enthalpy and a high pressure. A fluid medium, such as water, flows through a heat sink **30** of the gas cooler **24** and exchanges heat with the refrigerant. A water pump **32** flows the fluid medium through the heat sink **30**. The cold fluid **34** enters the heat sink **30** at the heat sink inlet or return **36** and flows in a direction opposite to the direction of flow of the refrigerant. After accepting heat from the refrigerant, the heated water **38** exits at the heat sink outlet or supply **40**. The refrigerant enters the gas cooler **24** at a refrigerant inlet **62** and exits at a refrigerant outlet **64**.

[0016] The refrigerant is expanded to a low pressure in the expansion device **26**. The expansion device **26** can be an electronic expansion valve (EXV) or other type of expansion device. The refrigerant exits the expansion device at a low pressure and a low enthalpy.

[0017] After expansion, the refrigerant flows through the evaporator **28** and accepts heat from the outdoor air. Outdoor air **44** flows through a heat sink **46** and rejects heat to the refrigerant passing through the evaporator **28**. The outdoor air enters the heat sink **46** through the heat sink inlet or return **48** and flows in a direction opposite to the direction of flow of the refrigerant. A fan **54** moves the ambient air across the evaporator **28** and controls the speed of the air that moves across the evaporator **28**. After exchanging heat with the refrigerant, the cooled outdoor air **50** exits the heat sink **46** through the heat sink outlet or supply **52**. The refrigerant enters the evaporator **28** at a refrigerant inlet **68** and exits at a refrigerant outlet **66**. The refrigerant exits the evaporator **28** at a high enthalpy and a low pressure.

[0018] The speed of the compressor **22** is adjusted to achieve the optimal coefficient of performance for any outdoor air **44** temperature. Coefficient of performance is defined as the heating capacity of the system **20** divided by the power input of the system **20**. The heating capacity of the system **20** is the amount of heat transfer in the gas cooler **24**, and the power input of the system **20** is the work of the compressor **22** plus the work of the fan **54** that blows air over the evaporator **28**.

[0019] A variable speed drive **70** controls the speed of the refrigerant flowing through the compressor **22**. Varying the speed of the refrigerant flowing through the compressor **22** changes the mass flow rate of the refrigerant in the system **20** and affects the heat transfer performance of the gas cooler **24** and the evaporator **28**.

[0020] Decreasing the mass flow rate causes the refrigerant to flow through the gas cooler **24** and the evaporator **28** more slowly, increasing the energy exchanger per unit flow rate of the refrigerant and improving the performance of the gas cooler **24** and the evaporator **28**. However, as the mass flow rate is reduced, the power of the fan **54** per unit flow rate increases. Therefore, as the power of the fan **54** per unit flow rate increases, the coefficient of performance decreases. In general, the higher the outdoor temperature **44**, the lower the optimal speed of the compressor **22**.

[0021] A sensor **74** detects the coefficient of performance of the system **20** and sends this value to a control **72**. The control **72** is programmed to determine if the detected coefficient of performance is the optimal coefficient of performance. The control **74** varies the speed of the compressor **22** accordingly to provide the optimal coefficient of performance.

[0022] By varying the speed of the refrigerant flowing through the compressor **22**, the system **20** can be dynamically adapted to different environmental conditions and system degradations to achieve the optimal coefficient of performance at all times. There is an optimal operating speed for the compressor **22** for every environmental condition that achieves the optimal coefficient of performance.

[0023] This system **20** can be used in a stand alone way or jointly with other system operating methods.

[0024] The foregoing description is only exemplary of the principles of the invention. Many modifications and variations of the present invention are possible in light of the above teachings. The preferred embodiments of this invention have been disclosed, however, so that one of ordinary skill in the art would recognize that certain modifications would come within the scope of this invention. It is, therefore, to be understood that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described. For that reason the following claims should be studied to determine the true scope and content of this invention.

1-15. (canceled)

16. A transcritical refrigeration system comprising:

a compression device to compress a refrigerant to a high pressure;

a variable speed device that moves said refrigerant through said compression device at a variable speed to optimize a coefficient of performance of the system;

a sensor that monitors the coefficient of performance of the system; and

a control that controls the variable speed device, wherein the control adjusts a mass flow rate of the refrigerant using the variable speed device when the control determines that the coefficient of performance detected by the sensor is not an optimal coefficient of performance.

17. The system as recited in claim **16** wherein the refrigerant is carbon dioxide.

18. The system as recited in claim **27** further including a fan that blows a fluid over said heat accepting heat exchanger.

19. The system as recited in claim **18** wherein the coefficient of performance is relative to a heating capacity of the system and an amount of work of the compression device plus an amount of work of the fan, wherein the heating capacity of the system is an amount of heat transfer in the heat rejecting heat exchanger.

20. The system as recited in claim **27** further including a fan that blows the airflow, wherein decreasing the mass flow rate of the refrigerant increases a power of the fan per unit mass flow of the refrigerant.

21. A transcritical refrigeration system comprising:

a compression device to compress a refrigerant to a high pressure;

a heat rejecting heat exchanger for cooling said refrigerant;

an expansion device for reducing said refrigerant to a low pressure;

a heat accepting heat exchanger for evaporating said refrigerant, wherein a fluid exchanges heat with said refrigerant in said heat accepting heat exchanger;

a fan that blows the fluid over said heat accepting heat exchanger;

a variable speed device that moves said refrigerant through said compressor at a variable speed to optimize a coefficient of performance of the system;

a sensor that monitors the coefficient of performance of the system; and

a control that controls the variable speed device, wherein the control adjusts the mass flow rate of the refrigerant using the variable speed device when the control determines that the coefficient of performance is not an optimal coefficient of performance.

22. The system as recited in claim **21** wherein the coefficient of performance is relative to a heating capacity of the system and an amount of work of the compression device plus an amount of work of the fan, wherein the heating capacity of the system is an amount of heat transfer in the heat rejecting heat exchanger.

23. A method of optimizing a coefficient of performance of a transcritical refrigeration system comprising the steps of:

compressing a refrigerant to a high pressure;

sensing a coefficient of performance of the system;

determining whether the coefficient of performance of the system is optimal: and

adjusting a speed of the refrigerant flowing through the compression device if the step of determining determines that the coefficient of performance is not optimal to optimize the coefficient of performance of the system.

24. The system as recited in claim **16** wherein the system runs transcritically.

25. The system as recited in claim **16** further comprising a heat rejecting heat exchanger for cooling said refrigerant.

26. The system as recited in claim **16** further comprising an expansion device for reducing said refrigerant to a low pressure.

27. The system as recited in claim **16** further comprising a heat accepting heat exchanger for evaporating said refrigerant, wherein an airflow exchanges heat with said refrigerant in said heat accepting heat exchanger.

28. The method as recited in claim **23** further comprising the step of cooling the refrigerant.

29. The method as recited in claim **23** further comprising the step of expanding the refrigerant to a low pressure.

30. The method as recited in claim **23** further comprising the step of evaporating the refrigerant.

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