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COMPRESSION SYSTEM****Publication Classification**

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(57) **ABSTRACT**

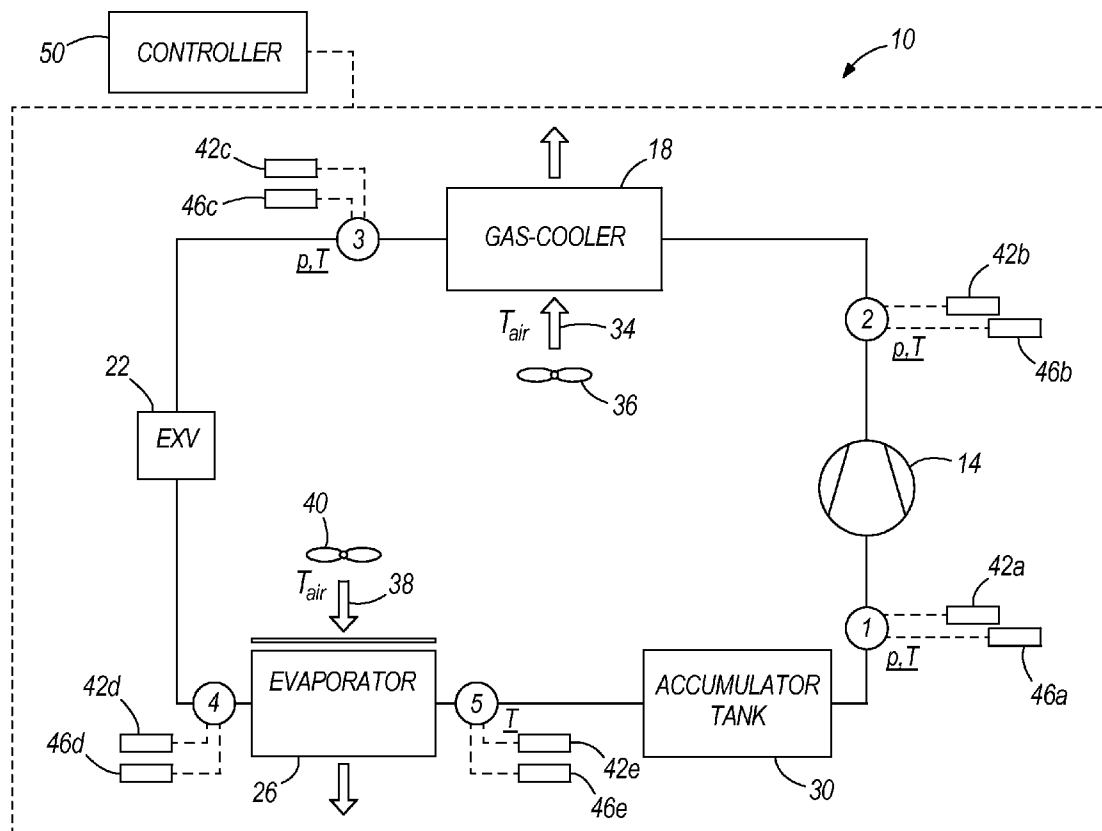
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A transcritical vapor compression system includes a compressor for compressing a refrigerant, a first heat exchanger for cooling the refrigerant, an expansion device for decreasing the pressure of the refrigerant, a second heat exchanger for absorbing heat into the refrigerant, and a controller programmed to calculate a first energy difference across the second heat exchanger and a second energy difference across the compressor, to calculate an energy ratio by dividing the first energy difference by the second energy difference, to compare the energy ratio to a previously calculated energy ratio, and to adjust operating parameters of the system based on the comparison of the energy ratio with respect to the previously calculated energy ratio.



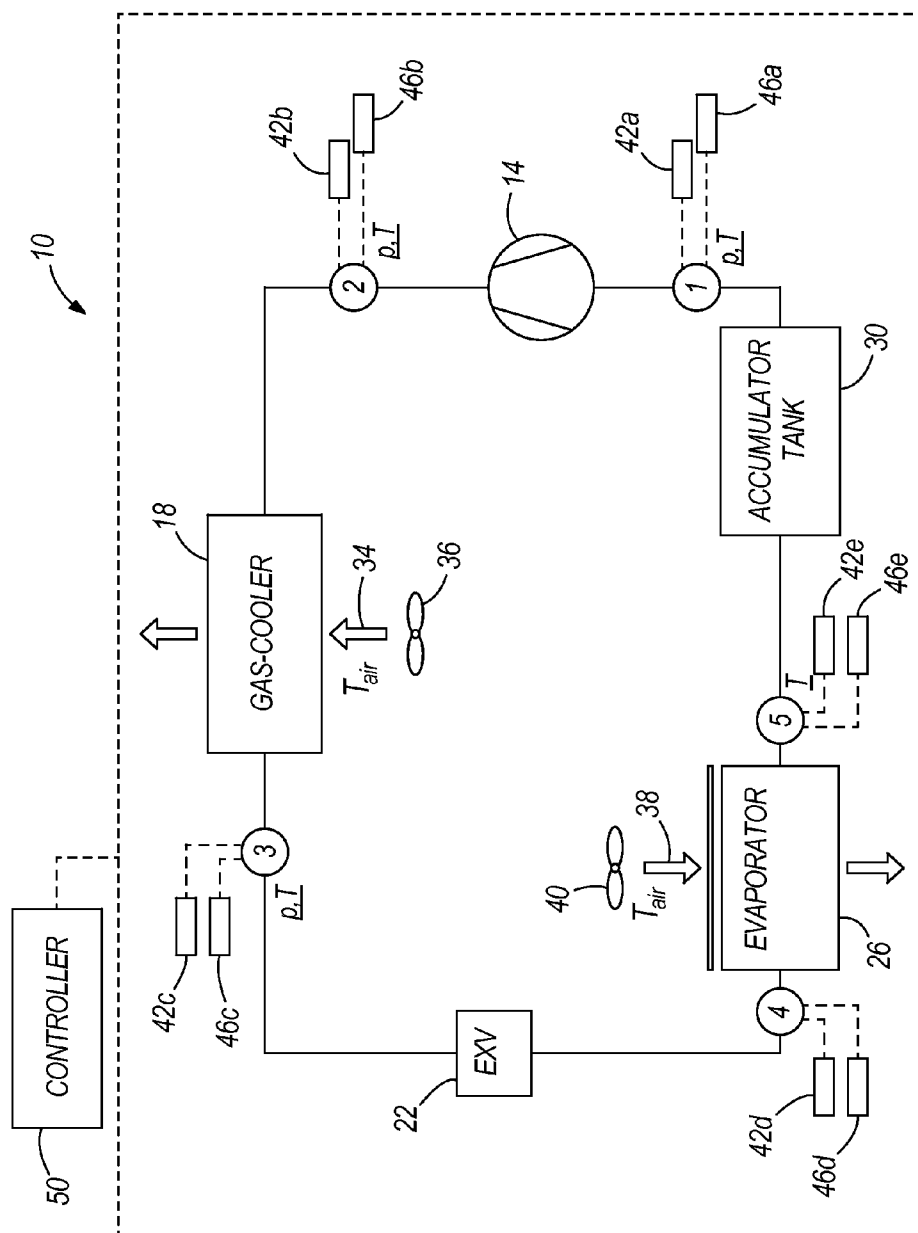


FIG. 1

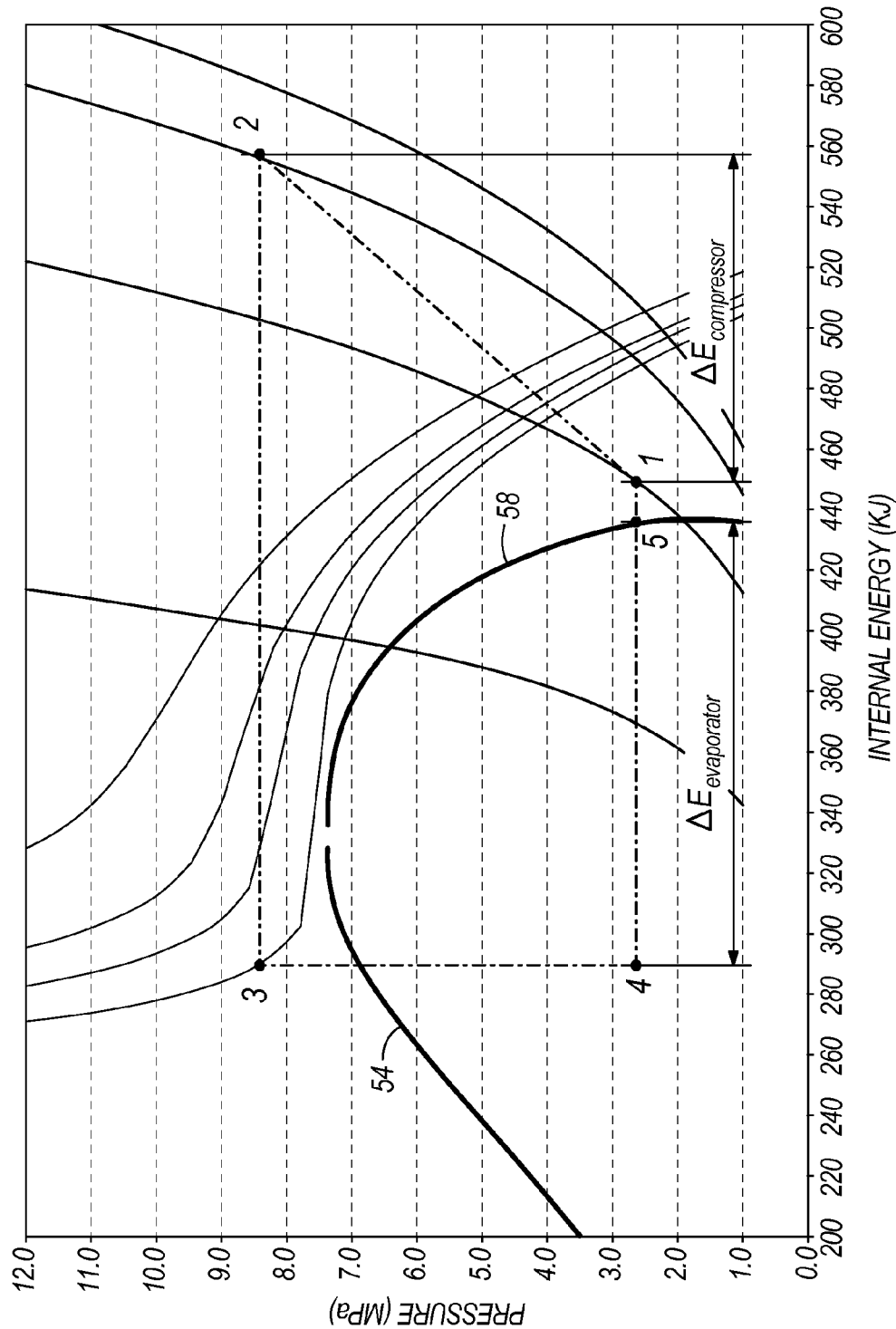


FIG. 2

CONTROL OF A TRANSCRITICAL VAPOR COMPRESSION SYSTEM

BACKGROUND

[0001] The present invention relates to control of a transcritical vapor compression system.

[0002] Typically, a transcritical vapor compression system is controlled to optimize the coefficient of performance (COP). Known control methods include measuring various parameters and comparing the measured parameter to a stored value representative of an efficient system. For example, if the measured parameter is significantly higher than the stored value, then the system is operating inefficiently and operating parameters are adjusted accordingly.

SUMMARY

[0003] In one aspect, the invention provides a transcritical vapor compression system. The transcritical vapor compression system includes a compressor for compressing a refrigerant, a first heat exchanger for cooling the refrigerant, an expansion device for decreasing the pressure of the refrigerant, a second heat exchanger for absorbing heat into the refrigerant, and a controller programmed to calculate a first energy difference across the second heat exchanger and a second energy difference across the compressor, to calculate an energy ratio by dividing the first energy difference by the second energy difference, to compare the energy ratio to a previously calculated energy ratio, and to adjust operating parameters of the system based on the comparison of the energy ratio with respect to the previously calculated energy ratio.

[0004] In another aspect, the invention provides a method of controlling a transcritical vapor compression system. The method includes providing a compressor for compressing a refrigerant, providing a first heat exchanger for cooling the refrigerant, providing an expansion device for decreasing the pressure of the refrigerant, providing a second heat exchanger for absorbing heat into the refrigerant, calculating a first energy difference across the second heat exchanger, calculating a second energy difference across the compressor, calculating an energy ratio by dividing the first energy difference by the second energy difference, comparing the energy ratio to a previously calculated energy ratio, and adjusting operating parameters of the system based on the comparison of the energy ratio with respect to the previously calculated energy ratio.

[0005] In another aspect, the invention provides a transcritical vapor compression system. The transcritical vapor compression system includes a compressor for compressing a refrigerant, a first heat exchanger for cooling the refrigerant, an expansion device for decreasing the pressure of the refrigerant, a second heat exchanger for absorbing heat into the refrigerant, a first blower for directing a first fluid over the first heat exchanger, a second blower for directing a second fluid over the second heat exchanger, a first temperature sensor and a first pressure sensor positioned proximate an inlet to the compressor for measuring temperature and pressure, respectively, a second temperature sensor and a second pressure sensor positioned proximate an outlet of the compressor for measuring temperature and pressure, respectively, a third temperature sensor positioned proximate an inlet to the second heat exchanger for measuring temperature, a fourth temperature sensor positioned proximate an outlet of the second

heat exchanger for measuring temperature, a third pressure sensor positioned proximate one of the inlet and the outlet to the second heat exchanger for measuring pressure, and a controller. The controller is programmed to calculate the internal energy of the refrigerant proximate the inlet to the compressor, the outlet of the compressor, the inlet of the second heat exchanger and the outlet of the second heat exchanger based on the measurements of temperature and pressure, to calculate a first energy difference by subtracting the internal energy of refrigerant proximate the inlet to the second heat exchanger from the internal energy of refrigerant proximate the outlet of the second heat exchanger, to calculate a second energy difference by subtracting the internal energy of refrigerant proximate the inlet to the compressor from the internal energy of the refrigerant proximate the outlet of the compressor, to calculate an energy ratio by dividing the first energy difference by the second energy difference, to compare the energy ratio to a previously calculated energy ratio, and to adjust at least one of speed of the first blower, speed of the second blower, speed of the compressor and opening of the expansion device based on the comparison of the energy ratio with respect to the previously calculated energy ratio.

[0006] Other aspects of the invention will become apparent by consideration of the detailed description and accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. 1 is a schematic diagram of a transcritical vapor compression system in accordance with the invention.
[0008] FIG. 2 is a diagram of internal energy and pressure of the transcritical vapor compression system shown in FIG. 1.

DETAILED DESCRIPTION

[0009] Before any embodiments of the invention are explained in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of components set forth in the following description or illustrated in the following drawings. The invention is capable of other embodiments and of being practiced or of being carried out in various ways.

[0010] FIG. 1 illustrates a transcritical vapor compression system 10. The transcritical vapor compression system 10 is a closed circuit single stage vapor compression cycle preferably utilizing carbon dioxide (CO₂) as a refrigerant, although other refrigerants suitable for a transcritical vapor compressor system may be employed, as are known in the art. The system 10 includes a compressor 14, a gas cooler 18, an expansion valve 22, an evaporator 26 and an accumulator tank 30 connected in series. Temperature sensors 42a-42e and pressure sensors 46a-46e are located at the compressor inlet 1, the compressor outlet 2, the gas cooler outlet 3, the evaporator inlet 4 and the evaporator outlet 5, respectively.

[0011] In the illustrated construction, CO₂ refrigerant exits the evaporator coil 26 as a heated gas and is drawn into a suction port of the compressor 14, such as a variable speed compressor. The temperature and pressure of the CO₂ refrigerant are measured at the compressor inlet 1 by the temperature and pressure sensors 42a, 46a, respectively. The compressor 14 pressurizes and discharges heated CO₂ refrigerant gas into the gas cooler 18. The temperature and pressure of the heated CO₂ refrigerant are measured at the compressor outlet

2 by the temperature and pressure sensors 42b, 46b, respectively. In the gas cooler 18, or heat exchanger, the heated CO₂ refrigerant is cooled to a lower temperature gas as a result of a forced flow of air 34 flowing over the gas cooler 18 and generated by blowers 36, such as variable speed blowers. The gas cooler 18 can include one or more heat exchanger coils having any suitable construction, as is known in the art. The temperature and pressure of the cooled CO₂ refrigerant are measured at the gas cooler outlet 3 by the temperature and pressure sensors 42c, 46c, respectively. Then, the cooled CO₂ is throttled through the expansion valve 22, such as an electronic expansion valve, and directed toward the evaporator coil 26 at a decreased pressure as a liquid-vapor mixture. The temperature and pressure of the cooled CO₂ refrigerant are measured at the evaporator inlet 4 by the temperature and pressure sensors 42d, 46d, respectively. In the evaporator coil 26, or heat exchanger, the cooled CO₂ refrigerant is heated to a higher temperature gas as a result of a forced flow of air 38 generated by blowers 40, such as variable speed blowers. In other words, the CO₂ passing through the evaporator coil 26 absorbs the heat from the flow of air 38 such that the flow of air 38 is cooled. The evaporator coil 26 can include one or more heat exchanger coils having any suitable construction, as is known in the art. The temperature of the heated CO₂ refrigerant is measured at the evaporator outlet 5 by the temperature sensor 42e and, optionally, the pressure is measured by the pressure sensor 46e. As the pressures at the inlet 4 and outlet 5 of the evaporator 26 are substantially the same, only one of the pressure sensors 46d, 46e are necessary.

[0012] In the illustrated construction, CO₂ refrigerant does not change phase to a liquid in the transcritical CO₂ refrigeration cycle. In other words, the CO₂ refrigerant behaves as a single-phase refrigerant in a transcritical CO₂ refrigeration cycle, as opposed to the two-phase behavior of refrigerant in a reverse-Rankine refrigeration cycle. To obtain desirable refrigeration characteristics from the CO₂ refrigerant, or other refrigerant used, the transcritical refrigeration cycle requires higher operating pressures compared to a reverse-Rankine refrigeration cycle. The pressure of the refrigerant in the gas cooler 18 is in the supercritical region of the refrigerant, i.e., at or above the critical temperature and critical pressure of the refrigerant. For example, the critical point of CO₂ occurs at approximately 7.38 MPa (1070 psia) and approximately 31.1 degrees Celsius (88 degrees Fahrenheit). In the illustrated construction, the pressure of refrigerant in the gas cooler 18 is approximately 8.5 MPa (1233 psia). The pressure of refrigerant in the evaporator 26 is also higher than pressures seen in a reverse-Rankine refrigeration cycle. In the illustrated construction, the pressure of refrigerant in the evaporator 26 is approximately 2.7 MPa (392 psia). As a result, the gas cooler 18 and evaporator coil 26 employ a heavy-duty construction to withstand the higher pressures. In the illustrated construction, the gas cooler 18 is built to withstand pressures of at least 7.38 MPa (1070 psia) and the evaporator 26 is built to withstand pressures of at least 2.7 MPa (392 psia).

[0013] As shown schematically in FIG. 1, the transcritical vapor compression system 10 is controlled by a controller 50. The controller 50 controls the opening of the expansion valve 22, the speed of the blowers 36, 40 and the speed of the compressor 14, and receives input signals from the temperature sensors 42a-42e and the pressure sensors 46a-46e, as will be described in greater detail below.

[0014] FIG. 2 is a diagram illustrating the saturated liquid line 54 for CO₂, the saturated vapor line 58 for CO₂, and the relationship between internal energy and pressure of the CO₂ refrigerant throughout the cycle of the transcritical vapor compression system 10. The controller 50 is programmed to calculate the internal energy of the refrigerant at each of the compressor inlet 1, the compressor outlet 2, the gas cooler outlet 3, the evaporator inlet 4 and the evaporator outlet 5 from the respective temperature and pressure measurements from the respective temperature and pressure sensors 42a-42e, 46a-46e, in a manner well understood in the art. Further, the controller 50 is programmed to calculate the change in energy ($\Delta E_{\text{evaporator}}$) across the evaporator 26 and the change in energy ($\Delta E_{\text{compressor}}$) across the compressor 14, as shown in FIG. 2. The change in energy ($\Delta E_{\text{evaporator}}$) across the evaporator 26 is calculated as the difference between the internal energy calculated at the evaporator outlet 5 and the internal energy calculated at the evaporator inlet 4. The change in energy ($\Delta E_{\text{compressor}}$) across the compressor 14 is calculated as the difference between the internal energy calculated at the compressor outlet 2 and the internal energy calculated at the compressor inlet 1. Further, the controller 50 is programmed to calculate an energy ratio across the evaporator 26 and compressor 14 by dividing the energy change across the evaporator ($\Delta E_{\text{evaporator}}$) by the energy change across the compressor ($\Delta E_{\text{compressor}}$).

[0015] Further, the controller 50 is programmed to compare the energy ratio to a previous energy ratio, more specifically, to the immediately previous energy ratio calculated. Then, the controller is programmed to adjust operating parameters, such as the opening of the expansion valve 22, the compressor speed of the compressor 14 and the blower speed of the blowers 36, 40, based on the energy ratio and, more specifically, based on the comparison between the current and previous energy ratios. Specifically, the controller 50 is programmed to adjust the operating parameters to optimize the energy balance, i.e., reach a desired efficiency of the transcritical vapor compression system 10. The controller 50 is programmed to repeat the above steps to continuously adjust the operating parameters based on the difference between the current and previous energy ratios, as described above, in order to maintain the efficiency of the system 10.

[0016] Thus, the invention provides, among other things, a transcritical vapor compression system and a controller therefor programmed to adjust the operating parameters of the system based on the energy ratio across the evaporator and compressor. Various features and advantages of the invention are set forth in the following claims.

What is claimed is:

1. A transcritical vapor compression system, comprising:
 - a compressor for compressing a refrigerant;
 - a first heat exchanger for cooling the refrigerant;
 - an expansion device for decreasing the pressure of the refrigerant;
 - a second heat exchanger for absorbing heat into the refrigerant; and
 - a controller programmed to calculate a first energy difference across the second heat exchanger and a second energy difference across the compressor, to calculate an energy ratio by dividing the first energy difference by the second energy difference, to compare the energy ratio to a previously calculated energy ratio, and to adjust oper-

ating parameters of the system based on the comparison of the energy ratio with respect to the previously calculated energy ratio.

2. The transcritical vapor compression system of claim 1, further comprising:

a first blower for directing a first fluid over the first heat exchanger; and

a second blower for directing a second fluid over the second heat exchanger;

wherein the controller is programmed to adjust at least one of speed of the first blower, speed of the second blower, speed of the compressor and opening of the expansion device based on the comparison of the energy ratio with respect to the previously calculated energy ratio.

3. The transcritical vapor compression system of claim 1, further comprising:

a first temperature sensor and a first pressure sensor positioned proximate an inlet to the compressor for measuring temperature and pressure, respectively;

a second temperature sensor and a second pressure sensor positioned proximate an outlet of the compressor for measuring temperature and pressure, respectively;

a third temperature sensor positioned proximate an inlet to the second heat exchanger for measuring temperature;

a fourth temperature sensor positioned proximate an outlet of the second heat exchanger for measuring temperature; and

a third pressure sensor positioned proximate one of the inlet and the outlet to the second heat exchanger for measuring pressure.

4. The transcritical vapor compression system of claim 3, wherein the controller is programmed to calculate the internal energy of the refrigerant proximate the inlet to the compressor, the outlet of the compressor, the inlet of the second heat exchanger and the outlet of the second heat exchanger based on the measurements of temperature and pressure.

5. The transcritical vapor compression system of claim 4, wherein the controller is programmed to calculate the first energy difference by subtracting the internal energy of refrigerant proximate the inlet to the second heat exchanger from the internal energy of refrigerant proximate the outlet of the second heat exchanger, and wherein the controller is programmed to calculate the second energy difference by subtracting the internal energy of refrigerant proximate the inlet to the compressor from the internal energy of the refrigerant proximate the outlet of the compressor.

6. (canceled)

7. A method of controlling a transcritical vapor compression system, the method comprising:

providing a compressor for compressing a refrigerant;

providing a first heat exchanger for cooling the refrigerant; providing an expansion device for decreasing the pressure of the refrigerant;

providing a second heat exchanger for absorbing heat into the refrigerant;

calculating a first energy difference across the second heat exchanger;

calculating a second energy difference across the compressor;

calculating an energy ratio by dividing the first energy difference by the second energy difference;

comparing the energy ratio to a previously calculated energy ratio; and

adjusting operating parameters of the system based on the comparison of the energy ratio with respect to the previously calculated energy ratio.

8. The method of claim 7, further comprising:

providing a first blower for directing a first fluid over the first heat exchanger;

providing a second blower for directing a second fluid over the second heat exchanger;

adjusting at least one of speed of the first blower, speed of the second blower, speed of the compressor and opening of the expansion device based on the comparison of the energy ratio with respect to the previously calculated energy ratio.

9. The method of claim 7, further comprising:

measuring temperature and pressure proximate an inlet to the compressor;

measuring temperature and pressure proximate an outlet of the compressor;

measuring temperature proximate an inlet to the second heat exchanger;

measuring temperature proximate an outlet of the second heat exchanger; and

measuring pressure proximate one of the inlet and the outlet to the second heat exchanger.

10. The method of claim 9, further comprising calculating the internal energy of the refrigerant proximate the inlet to the compressor, the outlet of the compressor, the inlet of the second heat exchanger and the outlet of the second heat exchanger based on the measurements of temperature and pressure.

11. The method of claim 10, further comprising calculating the first energy difference by subtracting the internal energy of refrigerant proximate the inlet to the evaporator from the internal energy of refrigerant proximate the outlet of the evaporator, and calculating the second energy difference by subtracting the internal energy of refrigerant proximate the inlet to the compressor from the internal energy of the refrigerant proximate the outlet of the compressor.

12. (canceled)

13. A transcritical vapor compression system, comprising:

a compressor for compressing a refrigerant;

a first heat exchanger for cooling the refrigerant;

an expansion device for decreasing the pressure of the refrigerant;

a second heat exchanger for absorbing heat into the refrigerant;

a first blower for directing a first fluid over the first heat exchanger;

a second blower for directing a second fluid over the second heat exchanger;

a first temperature sensor and a first pressure sensor positioned proximate an inlet to the compressor for measuring temperature and pressure, respectively;

a second temperature sensor and a second pressure sensor positioned proximate an outlet of the compressor for measuring temperature and pressure, respectively;

a third temperature sensor positioned proximate an inlet to the second heat exchanger for measuring temperature;

a fourth temperature sensor positioned proximate an outlet of the second heat exchanger for measuring temperature;

a third pressure sensor positioned proximate one of the inlet and the outlet to the second heat exchanger for measuring pressure; and

a controller programmed to calculate the internal energy of the refrigerant proximate the inlet to the compressor, the outlet of the compressor, the inlet of the second heat exchanger and the outlet of the second heat exchanger based on the measurements of temperature and pressure, to calculate a first energy difference by subtracting the internal energy of refrigerant proximate the inlet to the second heat exchanger from the internal energy of refrigerant proximate the outlet of the second heat exchanger, to calculate a second energy difference by subtracting the internal energy of refrigerant proximate the inlet to the compressor from the internal energy of

the refrigerant proximate the outlet of the compressor, to calculate an energy ratio by dividing the first energy difference by the second energy difference, to compare the energy ratio to a previously calculated energy ratio, and to adjust at least one of speed of the first blower, speed of the second blower, speed of the compressor and opening of the expansion device based on the comparison of the energy ratio with respect to the previously calculated energy ratio.

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