

Transcritical Refrigerant Vapor Compression System With Charge Management

Field of the Invention

[0001] This invention relates generally to refrigerant vapor compression systems and, more particularly, to refrigerant charge management in a refrigerant vapor compression system operating in a transcritical cycle.

Background of the Invention

[0002] Refrigerant vapor compression systems are well known in the art and commonly used for conditioning air to be supplied to a climate controlled comfort zone within a residence, office building, hospital, school, restaurant or other facility. Refrigerant vapor compression systems are also commonly used in refrigerating air supplied to display cases, merchandisers, freezer cabinets, cold rooms or other perishable/frozen product storage area in commercial establishments.

[0003] Refrigerant vapor compression systems are also commonly used in transport refrigeration systems for refrigerating air supplied to a temperature controlled cargo space of a truck, trailer, container or the like for transporting perishable/frozen items by truck, rail, ship or intermodally. Refrigerant vapor compression systems used in connection with transport refrigeration systems are generally subject to more stringent operating conditions due to the wide range of operating load conditions and the wide range of outdoor ambient conditions over which the refrigerant vapor compression system must operate to maintain product within the cargo space at a desired temperature. The desired temperature at which the cargo needs to be controlled can also vary over a wide range depending on the nature of cargo to be preserved. The refrigerant vapor compression system must not only have sufficient capacity and refrigerant charge to rapidly pull down the temperature of product loaded into the cargo space at ambient temperature, but also operate efficiently at low load with excess refrigerant charge when maintaining a stable product temperature during transport. Additionally, transport refrigerant vapor compression systems are subject to vibration and movements not experienced by stationary refrigerant vapor compression systems. Thus, the use of a conventional

refrigerant accumulator in the suction line upstream of the compressor suction inlet to store excess refrigerant liquid would be subject to sloshing during movement that could result in refrigerant liquid being undesirably carried through the suction line into the compressor via the suction inlet thereto.

[0004] Traditionally, most of these refrigerant vapor compression systems operate at subcritical refrigerant pressures and typically include a compressor, a condenser, and an evaporator, and expansion device, commonly an expansion valve, disposed upstream, with respect to refrigerant flow, of the evaporator and downstream of the condenser. These basic refrigerant system components are interconnected by refrigerant lines in a closed refrigerant circuit, arranged in accord with known refrigerant vapor compression cycles, and operated in the subcritical pressure range for the particular refrigerant in use. Refrigerant vapor compression systems operating in the subcritical range are commonly charged with fluorocarbon refrigerants such as, but not limited to, hydrochlorofluorocarbons (HCFCs), such as R22, and more commonly hydrofluorocarbons (HFCs), such as R134a, R410A, R404A and R407C.

[0005] In today's market, greater interest is being shown in "natural" refrigerants, such as carbon dioxide, for use in air conditioning and transport refrigeration systems instead of HFC refrigerants. However, because carbon dioxide has a low critical temperature, most refrigerant vapor compression systems charged with carbon dioxide as the refrigerant are designed for operation in the transcritical pressure regime. In refrigerant vapor compression systems operating in a subcritical cycle, both the condenser and the evaporator heat exchangers operate at refrigerant temperatures and pressures below the refrigerant's critical point. However, in refrigerant vapor compression systems operating in a transcritical cycle, the heat rejection heat exchanger, which is a gas cooler rather than a condenser, operates at a refrigerant temperature and pressure in excess of the refrigerant's critical point, while the evaporator operates at a refrigerant temperature and pressure in the subcritical range. Thus, for a refrigerant vapor compression system operating in a transcritical cycle, the difference between the refrigerant pressure within the gas cooler and refrigerant pressure within the evaporator is characteristically substantially greater than the difference between the refrigerant pressure within the

condenser and the refrigerant pressure within the evaporator for a refrigerant vapor compression system operating in a subcritical cycle.

[0006] It is also common practice to incorporate an economizer into the refrigerant circuit for increasing the capacity of the refrigerant vapor compression system. For example, in some systems, a refrigerant-to-refrigerant heat exchanger is incorporated into the refrigerant circuit as an economizer. A first portion of the refrigerant leaving the condenser passes through a first pass of the heat exchanger in heat exchange with a second portion of the refrigerant passing through the second pass of the heat exchanger. The second portion of the refrigerant typically constitutes a portion of the refrigerant leaving the condenser that is diverted through an expansion device wherein this portion of the refrigerant is expanded to a lower pressure and a lower temperature vapor or vapor/liquid mixture refrigerant before this second portion of refrigerant is passed through the second pass of the economizer refrigerant-to-refrigerant heat exchanger. Having traversed the second pass of the economizer heat exchanger, the second portion of the refrigerant is thence directed into an intermediate pressure change of the compression process. The refrigerant in the primary refrigerant circuit passes through the first pass of the refrigerant-to-refrigerant economizer heat exchanger and is thus further cooled before it traverses the system's main expansion device prior to entering the evaporator. U.S. Pat. No. 6,058,729 discloses a subcritical refrigerant vapor compression system for a transport refrigeration unit incorporating a refrigerant-to-refrigerant heat exchanger into the refrigerant circuit as an economizer. U.S. Pat. No. 6,694,750 discloses a subcritical refrigeration system that includes a first refrigerant-to-refrigerant heat exchanger economizer and a second refrigerant-to-refrigerant heat exchanger economizer disposed in series in the refrigerant circuit between the condenser and the evaporator.

[0007] In some systems, a flash tank economizer is incorporated into the refrigerant circuit between the condenser and the evaporator. In such case, the refrigerant leaving the condenser is expanded through an expansion device, such as a thermostatic expansion valve or an electronic expansion valve, prior to entering the flash tank wherein the expanded refrigerant separates into a liquid refrigerant component and a vapor refrigerant component. The vapor component of the

refrigerant is thence directed from the flash tank into an intermediate pressure stage of the compression process. The liquid component of the refrigerant is directed from the flash tank through the system's main expansion valve prior to entering the evaporator. U.S. Pat. No. 5,174,123 discloses a subcritical vapor compression system incorporating a flash tank economizer in the refrigerant circuit between the condenser and the evaporator. U. S. Pat. No. 6,385,980 discloses a transcritical refrigerant vapor compression system incorporating a flash tank economizer in the refrigerant circuit between the gas cooler and the evaporator.

Summary of the Invention

[0008] A transcritical refrigerant vapor compression system having improved refrigerant charge management includes a compression device, a refrigerant heat rejection heat exchanger, a refrigerant heat absorption heat exchanger, and a refrigerant-to-refrigerant heat exchanger economizer and a flash tank disposed in a primary refrigerant circuit in series refrigerant flow relationship intermediate a refrigerant heat rejection heat exchanger and a refrigerant heat absorption heat exchanger. A primary expansion valve interdisposed in the refrigerant circuit in operative association with and upstream of the refrigerant heat absorption heat exchanger and a secondary expansion valve interdisposed in the refrigerant circuit in operative association and upstream of the flash tank. A refrigerant vapor bypass line establishes refrigerant vapor flow communication between the flash tank and a suction pressure portion of the primary refrigerant circuit downstream of the refrigerant heat absorption heat exchanger. A bypass flow control valve having an open position and a closed position is interdisposed in the refrigerant vapor bypass line for controlling the flow of refrigerant vapor through the refrigerant vapor bypass line.

[0009] The refrigerant-to-refrigerant heat exchanger has a first refrigerant pass disposed in the primary refrigerant circuit downstream of the refrigerant cooling heat exchanger and upstream of the primary expansion device and a second bypass disposed in an economizer circuit refrigerant line that extends in refrigerant flow communication from the primary refrigerant circuit to an intermediate pressure stage of the compression device. An economizer circuit expansion device is

interdisposed in the economizer circuit refrigerant line upstream with respect to refrigerant flow of the second refrigerant pass of the refrigerant-to-refrigerant heat exchanger economizer. The economizer circuit expansion device may comprise an electronic expansion valve or a thermostatic expansion valve.

[0010] In an embodiment, the bypass flow control valve may comprise a two-position solenoid valve, a pulse width modulated solenoid valve or an electronic expansion valve. In an embodiment, the primary expansion valve may comprise an electronic expansion valve or a thermostatic expansion valve. In an embodiment, the secondary expansion valve may comprise an electronic expansion valve or a fixed orifice expansion device.

[0011] In an embodiment, the compression device may be single compressor having at least a first compression stage and a second compression stage. In an embodiment, the compression device may be a first compressor and a second compressor disposed in the refrigerant circuit in series refrigerant flow relationship with a discharge outlet of the first compressor in refrigerant flow communication with a suction inlet of the second compressor. In either the single compressor arrangement or the dual compressor arrangement, each compressor may be a scroll compressor, a reciprocating compressor or a screw compressor.

Brief Description of the Drawings

[0012] For a further understanding of the invention, reference will be made to the following detailed description of the invention which is to be read in connection with the accompanying drawing, where:

[0013] FIG. 1 is a schematic diagram illustrating an exemplary embodiment of a refrigerant vapor compression system in accord with the invention;

[0014] FIG. 2 is a graph illustrating the pressure to enthalpy relationship for the exemplary embodiment of the refrigerant vapor compression system of the invention illustrated in FIG. 1 operating in a transcritical cycle;

[0015] FIG. 3 is a graph illustrating the pressure to enthalpy relationship for a prior art refrigerant vapor compression system operating in a transcritical cycle with a single refrigerant-to-refrigerant heat exchanger economizer; and

[0016] FIG. 4 is a graph illustrating the pressure to enthalpy relationship for a prior art refrigerant vapor compression system operating in a transcritical cycle with a single flash tank economizer.

Detailed Description of the Invention

[0017] Referring now to FIG. 1, there is depicted an exemplary embodiment of a transcritical refrigerant vapor compression system 10 suitable for use in a transport refrigeration system for refrigerating air supplied to a temperature controlled cargo space of a truck, trailer, container or the like for transporting perishable and frozen goods. The refrigerant vapor compression system 10 is also suitable for use in conditioning air to be supplied to a climate controlled comfort zone within a residence, office building, hospital, school, restaurant or other facility. The refrigerant vapor compression system could also be employed in refrigerating air supplied to display cases, merchandisers, freezer cabinets, cold rooms or other perishable and frozen product storage areas in commercial establishments.

[0018] The transcritical refrigerant vapor compression system 10 includes a multi-stage compression device 20, a refrigerant heat rejection heat exchanger 40, also referred to herein as a gas cooler, a refrigerant heat absorption heat exchanger 50, also referred to herein as an evaporator, and a primary expansion device 55, such as for example an electronic expansion valve or a thermostatic expansion valve, operatively associated with the evaporator 50, with various refrigerant lines 2, 4 and 6 connecting the aforementioned components in a primary refrigerant circuit.

[0019] The compression device 20 functions to compress the refrigerant and to circulate refrigerant through the primary refrigerant circuit as will be discussed in further detail hereinafter. The compression device 20 may comprise a single, multiple-stage refrigerant compressor, for example a reciprocating compressor, having a first compression stage 20a and a second stage 20b, or a single compressor, for example a scroll compressor or a screw compressor, adapted in a conventional manner for injection of refrigerant, for example via an injection port, into an intermediate pressure point of the compression chamber of the compressor, whereby the first compression stage 20a is upstream of the intermediate pressure point and the second compression stage 20b is downstream of the intermediate pressure point.

The first and second compression stages 20a and 20b are disposed in series refrigerant flow relationship with the refrigerant leaving the first compression stage passing directly to the second compression stage for further compression. The compression device 20 may also comprise a pair of compressors 20a and 20b, connected in series refrigerant flow relationship in the primary refrigerant circuit via a refrigerant line connecting the discharge outlet port of the first compressor 20a in refrigerant flow communication with the suction inlet port of the second compressor 20b. The compressors 20a and 20b may be scroll compressors, screw compressors, reciprocating compressors, rotary compressors or any other type of compressor or a combination of any such compressors.

[0020] The refrigerant heat rejecting heat exchanger 40 may comprise a finned tube heat exchanger 42 through which hot, high pressure refrigerant passes in heat exchange relationship with a cooling medium, most commonly ambient air drawn through the heat exchanger 42 by the condenser fan(s) 44. The finned tube heat exchanger 42 may comprise, for example, a fin and round tube heat exchange coil or a fin and flat mini-channel tube heat exchanger.

[0021] Additionally, the refrigerant vapor compression system 10 of the invention includes a refrigerant-to-refrigerant heat exchanger economizer 60 and a flash tank 70 interdisposed in series refrigerant flow relationship in refrigerant line 4 of the primary refrigerant circuit downstream with respect to refrigerant flow of the gas cooler 40 and upstream with respect to refrigerant flow of the evaporator 50. The refrigerant-to-refrigerant heat exchanger economizer 60 is disposed in refrigerant line 4 of the primary refrigerant circuit downstream with respect to refrigerant flow of the gas cooler 40 and upstream with respect to refrigerant flow of the flash tank 70. Additionally, a secondary expansion device 75, such as for example, an electronic expansion valve or a fixed orifice device, is interdisposed in the primary refrigerant circuit intermediate the refrigerant-to-refrigerant heat exchanger economizer 60 and the flash tank 70.

[0022] The refrigerant-to-refrigerant heat exchanger economizer 60 includes a first refrigerant pass 62 and a second refrigerant pass 64 arranged in heat transfer relationship. The first refrigerant pass 62 is interdisposed in refrigerant line 4 and forms part of the primary refrigerant circuit. The second refrigerant pass 64 is

interdisposed in refrigerant line 12 and forms part of an economizer circuit. The economizer circuit refrigerant line 12 connects in refrigerant flow communication with an intermediate pressure stage of the compression process. In the exemplary embodiment depicted in FIG. 1, the economizer circuit refrigerant line 12 connects to refrigerant line 4 of the primary refrigerant circuit either upstream with respect to refrigerant flow of the first pass 62 of the refrigerant-to-refrigerant heat exchanger economizer 60 and establishes refrigerant flow. Alternatively, the economizer circuit refrigerant line may connect to refrigerant line 4 of the primary circuit downstream with respect to refrigerant flow of the first pass 62 of the refrigerant-to-refrigerant heat exchanger economizer 60. The first refrigerant pass 62 and the second refrigerant pass 64 of the refrigerant-to-refrigerant heat exchanger economizer 60 may be arranged in a parallel flow heat exchange relationship or in a counter flow heat exchange relationship, as desired. The refrigerant-to-refrigerant heat exchanger 60 may be a brazed plate heat exchanger, a tube-in-tube heat exchanger, a tube-on-tube heat exchanger or a shell-and-tube heat exchanger.

[0023] An economizer circuit expansion device 65 is disposed in the economizer circuit refrigerant line 12 upstream with respect to refrigerant flow of the second pass 64 of the refrigerant-to-refrigerant heat exchanger economizer 60. The economizer circuit expansion device 65 meters the refrigerant flow that passes through the refrigerant line 12 and the second pass 64 of the refrigerant-to-refrigerant heat exchanger economizer 60 in heat exchange relationship with the refrigerant passing through the first pass of the heat exchanger economizer 60 to maintain a desired level of superheat in the refrigerant vapor leaving the second pass 64 of the heat exchanger economizer 60 to ensure that no liquid is present therein. The expansion valve 65 may be an electronic expansion valve, for example as depicted in FIGs. 1-3, in which case the expansion valve 65 meters refrigerant flow in response to a signal from a controller 100 to maintain a desired refrigerant temperature or pressure in refrigerant line 12. The expansion device 65 may also be a thermostatic expansion valve, in which case the expansion valve 65 meters refrigerant flow in response to a signal indicative of the refrigerant temperature or pressure sensed by the sensing device (not shown) which may be a conventional temperature sensing element, such as a bulb or thermocouple mounted to the

refrigerant line 12 downstream of the second pass of the heat exchanger economizer 60. The refrigerant vapor passing through the economizer circuit refrigerant line 12 is injected into the compression device 20 at an intermediate pressure point of the compression process. For example, if the compression device 20 is a multi-stage reciprocating compressor, refrigerant line 12 directs refrigerant vapor directly into an intermediate pressure stage of the reciprocating compressor between the first compression stage 20a and the second compression stage 20b. If the compression device 20 is a single scroll compressor or a single screw compressor, the refrigerant line 12 directs refrigerant vapor into an injection port of the compression device opening to the compression chamber of the compression device at an intermediate pressure of the compression process. If the compression device 20 is a pair of compressors 20a, 20b, for example a pair of scroll compressors, or screw compressors, or reciprocating compressors, connected in series, or a single reciprocating compressor having a first bank and a second bank of cylinders, the second economizer circuit refrigerant line 12 directs refrigerant vapor into a refrigerant line that connects the discharge outlet port of the first compressor 20a in refrigerant flow communication with the suction inlet port of the second compressor 20b.

[0024] The flash tank 70 is interdisposed in refrigerant line 4 of the primary refrigerant circuit downstream with respect to refrigerant flow of the first pass 62 of the refrigerant-to-refrigerant heat exchanger economizer 60 and upstream with respect to refrigerant flow of the evaporator 50 to receive the refrigerant flowing through refrigerant line 4. A secondary expansion device 75 is interdisposed in refrigerant line 4 of the primary refrigerant circuit downstream with respect to refrigerant flow of the first refrigerant pass 62 of the refrigerant-to-refrigerant heat exchanger economizer 60 and upstream with respect to refrigerant flow of the inlet to the flash tank 70. High pressure refrigerant vapor passing through refrigerant line 4 is expanded as it traverses the secondary expansion device 75 to a subcritical pressure and temperature before the refrigerant passes into the flash tank 70. The secondary expansion device 75 may be an electronic expansion valve, such as illustrated in FIG. 1, in which case the secondary expansion valve 75 meters refrigerant flow in response to a signal from a controller 100 to maintain a desired

refrigerant pressure in refrigerant line 4 upstream with respect to refrigerant flow of the secondary expansion device 75. The secondary expansion device 75 may also simply be a fixed orifice expansion device, in which case the refrigerant pressure in refrigerant line 4 upstream with respect to refrigerant flow of the secondary expansion device 75 will fluctuate depending upon ambient conditions and the refrigerant flow will be inherently metered in accord with the magnitude of the pressure differential across the fixed orifice.

[0025] The flash tank 70 defines a separation chamber 72 into which the expanded refrigerant flows at a subcritical pressure and separates into a liquid refrigerant portion that collects in the lower portion of the flash tank 70 and into a vapor portion that collects in the upper portion of the flash tank 70 above the liquid level within the flash tank 70. Thus, the flash tank 70 functions as a receiver for storing liquid refrigerant whenever the refrigerant vapor compression system is operating at a capacity that does not require the system's full refrigerant charge.

[0026] Additionally, the refrigerant vapor compression system includes a refrigerant line 14 that establishes refrigerant flow communication between the flash tank 70 and refrigerant line 6 of the primary refrigerant circuit at a point downstream with respect to refrigerant flow of the outlet of the evaporator 50 and upstream with respect to refrigerant flow of the suction inlet to the compression device 20. Refrigerant vapor collecting in the portion of the flash tank 70 above the liquid level therein passes from the flash tank 70 through refrigerant line 14 to enter the primary refrigerant circuit to return to the compression device 20. A flow control valve 85 is interdisposed in refrigerant line 14 to restrict the flow of refrigerant vapor through refrigerant line 14 as necessary to maintain the separation chamber 72 of the flash tank 70 at a refrigerant pressure higher than suction pressure. In an embodiment, the flow control valve 85 comprises a solenoid valve having a first open position and a second closed position, such as for example, but not limited to, a pulse width modulated solenoid valve. In an embodiment, the flow control valve 85 may comprise an electronic expansion valve.

[0027] Liquid refrigerant collecting in the lower portion of the flash tank economizer 70 passes therefrom through refrigerant line 4 and traverses the primary refrigerant circuit expansion valve 55, which may be an electronic expansion valve

or a conventional thermostatic expansion valve, disposed in refrigerant line 4 upstream with respect to refrigerant flow of the evaporator 50. As this liquid refrigerant traverses the first expansion device 55, it expands to a lower pressure and temperature before entering the evaporator 50. As the liquid refrigerant passes through the evaporator 50, the liquid refrigerant passes in heat exchange relationship with a heating medium whereby the liquid refrigerant is vaporized and typically superheated and the heating medium is cooled. In an embodiment, the evaporator 50 constitutes a finned tube coil heat exchanger 52, such as a fin and round tube heat exchanger or a fin and flat, mini-channel tube heat exchanger. The heating fluid passed in heat exchange relationship with the refrigerant in the evaporator 50 may be air drawn by an associated fan(s) 54 from a climate controlled environment, such as a perishable/frozen cargo storage zone associated with a transport refrigeration unit, or a food display or storage area of a commercial establishment, or a building comfort zone associated with an air conditioning system, to be cooled, and generally also dehumidified, and thence returned to a climate controlled environment. The low pressure refrigerant vapor leaving the evaporator 50 returns through refrigerant line 6 to the suction inlet of the compression device 20.

[0028] As in conventional practice, the primary expansion valve 55 meters the refrigerant flow through the refrigerant line 4 to maintain a desired level of superheat in the refrigerant vapor leaving the evaporator 50 and passing through refrigerant line 6 to ensure that no liquid is present in the refrigerant leaving the evaporator. As noted before, the primary expansion valve 55 may be an electronic expansion valve, in which case the expansion valve 55 meters refrigerant flow in response to a signal from a controller 100 to maintain a desired suction temperature or suction pressure in refrigerant line 6 on the suction side of the compression device 20. The primary expansion device 55 may also be a thermostatic expansion valve in which case the expansion valve 55 meters refrigerant flow in response to a signal indicative of the refrigerant temperature or pressure sensed by the sensing device, which may be a conventional temperature sensing element, such as a bulb or thermocouple mounted to the refrigerant line 6 in the vicinity of the evaporator outlet.

[0029] In the exemplary embodiment of the refrigerant vapor compression system 10 depicted in FIG. 1, operation of the refrigerant vapor compression system is controlled by a control system that includes a controller 100 operatively associated with the flow control valve 85 interdisposed in refrigerant line 14 and the economizer circuit expansion device 65 interdisposed in refrigerant line 12. The controller 100 also may control operation of the electronic expansion valves 55 and 65, the compression device 20, and the fans 44 and 54. As in conventional practice, in addition to monitoring ambient conditions, the controller 100 may also monitors various operating parameters by means of various sensors operatively associated with the controller 100 and disposed at selected locations throughout the system. For example, in the exemplary embodiments depicted in FIG. 1, a pressure sensor 102 may be disposed in operative association with the flash tank 70 to sense the pressure within the flash tank 70, a temperature sensor 103 and a pressure sensor 104 may be provided to sense the refrigerant suction temperature and pressure, respectively, and a temperature sensor 105 and a pressure sensor 106 may be provided to sense refrigerant discharge temperature and pressure, respectively. The pressure sensors 102, 104, 106 may be conventional pressure sensors, such as for example, pressure transducers, and the temperature sensors 103 and 105 may be conventional temperature sensors, such as for example, thermocouples or thermistors.

[0030] The refrigerant vapor compression system of the invention is particularly adapted for operation in a transcritical cycle with a lower critical point refrigerant such as carbon dioxide, but may also be operated in a subcritical cycle with a conventional higher critical point refrigerant. When the refrigerant vapor compression system 10 is operating in an economized mode, the controller 100 controls the economizer circuit expansion device 65 to meter the flow of refrigerant vapor from refrigerant line 4 through the economizer circuit refrigerant line 12 in response to system operating conditions and capacity requirements. When the system is operating in a non-economized mode, the controller 100 closes the economizer circuit expansion valve 65 so that all of the refrigerant passing from the gas cooler 40 through refrigerant line 4 passes through the secondary expansion device 75 and thence into the flash tank 70. In either the economized or non-

economized modes, the controller 100 controls the primary expansion valve 55 to meter the correct amount of refrigerant liquid out of the flash tank 70 in response to the sensed system operating parameters, for example compressor discharge temperature, to match the refrigerant charge demand of the system.

[0031] Additionally, the controller 100 controls positioning of the flow control valve 85 interdisposed in refrigerant line 14 to restrict the flow of refrigerant vapor from the flash tank 70 in response to the sensed pressure within the separation chamber flash tank 70 so as to maintain a desired subcritical flash tank pressure. As the ratio of refrigerant liquid to refrigerant vapor present in the flash tank will depend upon the subcritical pressure level within the separation chamber, the flash tank pressure may be controlled through positioning of the flow control valve 85 so as to produce a selected refrigerant quality upon expansion. If the flow control valve 85 is continuously closed, the pressure within the flash tank will rise to an upper limit of the gas cooler pressure. If the flow control valve 85 is continuously open, the pressure within the flash tank 70 will fall to a lower pressure, but above the suction pressure. The actual pressure differential between the pressure within flash tank and suction pressure when the flow control valve is fully open will be governed by the size of the orifice in the particular flow control valve used. The controlled discharge of refrigerant vapor from the flash tank 70 through refrigerant line 14 to suction pressure is essential for maintaining a low pressure within the flash tank. Therefore, the controller 100 may also continuously cycle the flow control valve 85 between its open and closed positions to selectively control the flash tank pressure. This manipulation of the primary expansion valve 55 and the flow control valve 85 provides the controller 100 with the ability to effectively manage refrigerant charge over a wide range of operating conditions even when the refrigerant vapor compression system 10 is operating in a transcritical mode. Additionally, separating the refrigerant into its liquid and vapor phases in the flash tank 70 and sending only the liquid refrigerant through the evaporator, while diverting the vapor refrigerant to a point downstream of the evaporator, improves the effectiveness of heat exchange in the evaporator.

[0032] A comparison of the pressure to enthalpy relationship presented in FIG. 2, which represents a characteristic pressure to enthalpy relationship for the refrigerant vapor compression system 10 of FIG. 1, to either of the pressure to enthalpy relationships representative of conventional refrigerant vapor compression systems presented in FIG. 3 or FIG. 4, illustrates the capacity improvement associated with the refrigerant vapor compression system of the invention. FIG. 3 presents a characteristic pressure to enthalpy relationship for a conventional prior art transcritical refrigerant vapor compression having a single refrigerant-to-refrigerant heat exchanger economizer. FIG. 4 presents a characteristic pressure to enthalpy relationship for a conventional prior art transcritical refrigerant vapor compression having a single flash tank economizer. In each of FIGs. 2-4, AB represents the gas heat rejection process within gas cooler 40 and DE represents the gas heat absorption process within the evaporator 50. In FIG. 2, KG represents the process within the refrigerant-to-refrigerant heat exchanger economizer circuit and MN represents the process within the flash tank-to-suction evaporator bypass circuit. In FIG. 3, KG represents the process within the refrigerant-to-refrigerant heat exchanger economizer circuit. In FIG. 4, JL represents the process within a flash tank economizer circuit. The evaporator line DE in FIG. 1 is longer than the respective evaporator lines associated with either of the prior art single economizer systems, indicating the increased evaporator effectiveness associated with the refrigerant vapor compression system of the invention.

[0033] Those skilled in the art will recognize that many variations may be made to the particular exemplary embodiments described herein. While the present invention has been particularly shown and described with reference to the exemplary embodiment as illustrated in the drawings, it will be understood by one skilled in the art that various changes in detail may be effected therein without departing from the spirit and scope of the invention as defined by the claims.

We Claim:

1. A refrigerant vapor compression system comprising:

a primary refrigerant circuit including a refrigerant compression device, a refrigerant cooling heat exchanger for passing refrigerant received from said compression device at a high pressure in heat exchange relationship with a cooling medium, a refrigerant heating heat exchanger for passing refrigerant at a low pressure refrigerant in heat exchange relationship with a heating medium, and a primary expansion device interdisposed in the primary refrigerant circuit downstream of said refrigerant cooling heat exchanger and upstream of said refrigerant heating heat exchanger;

a refrigerant-to-refrigerant heat exchanger economizer having a first refrigerant pass disposed in the primary refrigerant circuit downstream of said refrigerant cooling heat exchanger and upstream of said primary expansion device and a second bypass disposed in an economizer circuit refrigerant line;

a flash tank disposed in the primary refrigerant circuit downstream of the first refrigerant pass of said refrigerant —to-refrigerant exchanger and upstream of said primary expansion device, said flash tank defining a separation chamber wherein refrigerant in a liquid state collects in a lower portion of said separation chamber and refrigerant in a vapor state in a portion of said separation chamber above the liquid refrigerant;

a secondary expansion device disposed in the primary refrigerant circuit in operative association with and upstream with of said flash tank;

a refrigerant vapor bypass line establishing refrigerant flow communication between an upper portion of said separation chamber of said flash tank and a suction pressure portion of said primary refrigerant circuit downstream of said refrigerant heating heat exchanger; and

a bypass flow control valve interdisposed in said evaporator bypass line, said bypass flow control valve having a first open position whereat refrigerant vapor may pass through said evaporator bypass line and a second closed position whereat refrigerant vapor is blocked from passing through said evaporator bypass line.

2. A refrigerant vapor compression system as recited in claim 1 wherein said flow control valve comprises a solenoid valve having a first open position and a second closed position.
3. A refrigerant vapor compression system as recited in claim 1 wherein said flow control valve comprises a pulse width modulated solenoid valve.
4. A refrigerant vapor compression system as recited in claim 1 wherein said flow control valve comprises an electronic expansion valve.
5. A refrigerant vapor compression system as recited in claim 1 wherein said primary expansion device comprises an electronic expansion valve.
6. A refrigerant vapor compression system as recited in claim 1 wherein said primary expansion device comprises a thermostatic expansion valve.
7. A refrigerant vapor compression system as recited in claim 1 wherein said secondary expansion device comprises an electronic expansion valve.
8. A refrigerant vapor compression system as recited in claim 1 wherein said secondary expansion device comprises a fixed orifice expansion device.
9. A refrigerant vapor compression system as recited in claim 1 wherein said economizer circuit refrigerant line extends in refrigerant flow communication from said primary refrigerant circuit to an intermediate pressure stage of said compression device.
10. A refrigerant vapor compression system as recited in claim 9 further comprising an economizer circuit expansion device interdisposed in said economizer circuit refrigerant line upstream with respect to refrigerant flow of the second refrigerant pass of said refrigerant-to-refrigerant heat exchanger economizer.

11. A refrigerant vapor compression system as recited in claim 10 wherein said economizer circuit expansion device comprises an electronic expansion valve.

12. A refrigerant vapor compression system as recited in claim 10 wherein said economizer circuit expansion device comprises a thermostatic expansion valve.

13. A refrigerant vapor compression system as recited in claim 1 wherein said compression device comprises a single compressor having at least two compression stages.

14. A refrigerant vapor compression system as recited in claim 1 wherein said compression device comprises at least two compressors disposed in the refrigerant circuit in a series relationship with respect to refrigerant flow.

15. A refrigerant vapor compression system as recited in claim 1 wherein said compression device comprises a scroll compressor.

16. A refrigerant vapor compression system as recited in claim 1 wherein said compression device comprises a reciprocating compressor.

17. A refrigerant vapor compression system as recited in claim 1 wherein said compression device comprises a screw compressor.

18. A refrigerant vapor compression system as recited in claim 1 wherein said system is incorporated in a transport refrigeration system for conditioning a temperature controlled cargo storage region.

19. A refrigerant vapor compression system as recited in claim 18 wherein said system operates in a transcritical cycle.

20. A refrigerant vapor compression system as recited in claim 19 wherein the refrigerant comprises carbon dioxide.