

Liquid Vapor Separation in Transcritical Refrigerant Cycle

Field of the Invention

[0001] This invention relates generally to refrigerant vapor compression systems and, more particularly, to improving the separation of a two-phase refrigeration flow into a liquid portion and a vapor portion in a refrigerant vapor compression system having a flash tank economizer and operating in a transcritical cycle.

Background of the Invention

[0002] Refrigerant vapor compression systems are well known in the art and commonly used in transport refrigeration systems for refrigerating air or other gaseous fluid 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 intermodal. Refrigerant vapor compression systems used in connection with transport refrigeration systems are generally subject to 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 stored during transport 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 to rapidly pull down the temperature of product loaded into the cargo space at ambient temperature, but also operate efficiently at low load 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. Transport refrigeration systems are also subject to size restrictions due to limitations on available space not generally associated with stationary refrigerant vapor compression systems, such as air conditioners and heat pumps.

[0003] Traditionally, conventional refrigerant vapor compression systems used in transport refrigeration applications commonly 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.

[0004] 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 and a low liquid phase density to vapor phase density ratio, 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 functions as 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.

[0005] It is also common practice to incorporate an economizer into the refrigerant circuit. So equipped, the refrigerant vapor compression system may be selectively operated in an economized mode to increase the capacity of the refrigerant vapor compression system. In some refrigerant vapor compression systems operating in a transcritical mode, a flash tank economizer is incorporated into the refrigerant circuit between the gas cooler and the evaporator. In such case, the refrigerant vapor leaving the gas cooler 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. 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

[0006] A transport refrigeration refrigerant vapor compression system operating in a transcritical refrigeration cycle includes: a compression device for compressing a refrigerant vapor to a supercritical refrigerant pressure, a gas cooler operating at a supercritical refrigerant pressure, and an evaporator operating at a subcritical refrigerant pressure connected in refrigerant flow communication in a refrigerant circuit; a primary expansion device disposed in the refrigerant circuit between the gas cooler and the evaporator; a secondary expansion device disposed in the refrigerant circuit between the gas cooler and the primary expansion device; and a flash tank disposed in the refrigerant circuit upstream with respect to refrigerant flow of the primary expansion device and downstream with respect to refrigerant flow of the secondary expansion device.

[0007] The flash tank has a shell defining an interior volume having an upper chamber, a lower chamber and a middle chamber; a first fluid passage establishing fluid communication between the middle chamber and the upper

chamber; a second fluid passage establishing fluid communication between the middle chamber and the lower chamber; an inlet port in fluid communication with the middle chamber for receiving the refrigerant flow having traversed the secondary expansion device; a first outlet port in fluid communication with the upper chamber for discharging a gas phase of the refrigerant flow from the flash tank separator; and a second outlet port in fluid communication with the lower chamber for discharging a liquid phase of the refrigerant flow from the flash tank into the refrigerant circuit.

[0008] In an embodiment, the flash tank further includes: a lower plate and an upper plate disposed in spaced relationship within the interior volume defined by the shell, each of which extends across the interior volume thereby sectioning the interior volume into the lower chamber, the middle chamber and the lower chamber; a first opening extending through the upper plate and forming the first fluid passage establishing fluid communication between the middle chamber and the upper chamber; and a second opening extending through the lower plate and forming the second fluid passage establishing fluid communication between the middle chamber and the lower chamber.

[0009] In an embodiment, the flash tank includes: an elongated support tube extending along a central vertical axis of its shell and defining a conduit establishing fluid communication between the lower chamber and the upper chamber; and a helical spiral member extending about the vertical support tube and defining a continuous spiral fluid flow passage. A first portion of the continuous helical passage forms the first fluid passage establishing fluid communication between the middle chamber and the upper chamber. A second portion of the continuous helical passage forms the second fluid passage establishing fluid communication between the middle chamber and the lower chamber. An upper equalization hole passing through the support tube near an upper end thereof may be provided to establish fluid communication between the upper region of the conduit defined by the support tube and the upper chamber, and a lower equalization hole passing through the support tube near a lower end thereof may be provided to establish fluid communication between the lower region of the conduit defined by the support tube and the lower chamber.

Brief Description of the Drawings

[0010] 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:

[0011] FIG. 1 is a schematic diagram illustrating a first exemplary embodiment of a refrigerant vapor compression system operating in a transcritical cycle;

[0012] FIG. 2 is a schematic diagram illustrating a second exemplary embodiment of a refrigerant vapor compression system operating in a transcritical cycle;

[0013] FIG. 3 is a sectioned perspective view of a first exemplary embodiment of the flash tank of the refrigerant vapor compression system shown in FIG. 1; and

[0014] FIG. 4 is a sectioned perspective view of a first exemplary embodiment of the flash tank of the refrigerant vapor compression system shown in FIG. 2.

Detailed Description of the Invention

[0015] Referring now to FIGs. 1 and 2, there are depicted therein exemplary embodiments of a refrigerant vapor compression system 100 suitable for use in a transport refrigeration system for refrigerating the air or other gaseous atmosphere within the temperature controlled cargo space 200 of a truck, trailer, container or the like for transporting perishable/frozen goods. The refrigerant vapor compression system 100 is particularly adapted for operation in a transcritical cycle with a low critical temperature refrigerant, such as for example, but not limited to, carbon dioxide. The refrigerant vapor compression system 100 includes a multi-step compression device 20, a refrigerant heat rejecting heat exchanger 40 and a refrigerant heat absorbing heat exchanger 50, also referred to herein as an evaporator, with refrigerant lines 2, 4 and 6 connecting the aforementioned components in refrigerant flow communication in a refrigerant circuit. A primary expansion device 55, such as for example an electronic expansion valve, operatively associated with the evaporator 50 is disposed in the refrigerant circuit in refrigerant

line 4 between the refrigerant heat rejection heat exchanger 40 and the evaporator 50. A secondary expansion device 65, such as for example an electronic expansion valve, is disposed in the refrigerant circuit in refrigerant line 4 between the refrigerant heat rejecting heat exchanger 40 and the primary expansion device 55. Additionally, a flash tank 10A, 10B is disposed in refrigerant line 4 of the primary refrigerant circuit downstream with respect to refrigerant flow of the secondary expansion device 65 and upstream of the primary expansion device 55. Thus, the flash tank 10A, 10B is position in the refrigerant circuit downstream with respect to refrigerant flow of the refrigerant heat rejecting heat exchanger 40 and upstream with respect to refrigerant flow of the evaporator 50.

[0016] In a refrigerant vapor compression system operating in a transcritical cycle, the refrigerant heat rejecting heat exchanger 40 operates at a pressure above the critical point of the refrigerant and therefore functions to cool supercritical refrigerant vapor passing therethrough in heat exchange relationship with a cooling medium, such as for example, but not limited to ambient air or water, and may be also be referred to herein as a gas cooler. In the depicted embodiments, the refrigerant heat rejecting heat exchanger 40 includes a finned tube heat exchanger 42, such as for example a fin and round tube heat exchange coil or a fin and mini-channel flat tube heat exchanger, through which the refrigerant passes in heat exchange relationship with ambient air being drawn through the finned tube heat exchanger 42 by the fan(s) 44 associated with the gas cooler 40.

[0017] The refrigerant heat absorbing heat exchanger 50 serves an evaporator wherein refrigerant liquid is passed in heat exchange relationship with a fluid to be cooled, most commonly air or an air and inerting gas mixture, drawn from and to be returned to a temperature controlled environment 200, such as the cargo box of a refrigerated transport truck, trailer or container. In the depicted embodiments, the refrigerant heat absorbing heat exchanger 50 comprises a finned tube heat exchanger 52 through which refrigerant passes in heat exchange relationship with air drawn from and returned to the refrigerated cargo box 200 by the evaporator fan(s) 54 associated with the evaporator 50. The finned tube heat exchanger 52 may comprise, for example, a fin and round tube heat exchange coil or a fin and mini-channel flat tube heat exchanger.

[0018] The compression device 20 functions to compress the refrigerant to a supercritical pressure 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, such as for example a scroll compressor, a screw compressor or a reciprocating compressor, disposed in the primary refrigerant circuit and having a first compression stage 20a and a second compression stage 20b, such as illustrated in FIG. 1. The first and second compression stages 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. Alternatively, the compression device 20 may comprise a pair of independent compressors 20a and 20b, connected in series refrigerant flow relationship in the primary refrigerant circuit via a refrigerant line 8 connecting the discharge outlet port of the first compressor 20a in refrigerant flow communication with the suction inlet port of the second compressor 20b, such as illustrated in FIG. 2. In the independent compressor embodiment, 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.

[0019] In operation, high temperature, supercritical pressure refrigerant vapor discharged from the second compression stage or second compressor 20b of the compression device is cooled to a lower temperature as it traverses the heat exchanger 42 of the gas cooler 40 before traversing the secondary expansion device 65. In traversing the secondary expansion device 65, the supercritical pressure refrigerant vapor is expanded to a lower subcritical pressure sufficient to establish a two-phase mixture of refrigerant vapor and refrigerant liquid prior to entering the flash tank 10.

[0020] Referring now to Figs. 3 and 4 in particular, flash tank 10A, 10B has a shell 120 that encloses an interior volume having an upper chamber 122, a middle chamber 124 and a lower chamber 126. The two-phase refrigerant flow having traversed the secondary expansion device 65 passes into the central chamber 124 through an inlet 125 opening in fluid communication with the middle chamber 124. The two-phase refrigerant flow received within the middle chamber 124 separates

into a vapor phase which migrates upwardly into the upper chamber 122 and a liquid phase which migrates downwardly into the lower chamber 126 of the shell 120 of the flash tank 10A, 10B. The flash tank 10A, 10B also includes a first outlet 127 in fluid communication with the lower chamber 126 and a second outlet 129 in fluid communication with the upper chamber 122.

[0021] The liquid phase refrigerant, which is typically saturated liquid, passes from the lower chamber 126 of the flash tank 10A, 10B through a first outlet 127 in fluid communication with the lower chamber 126 into refrigerant line 4 of the refrigerant circuit. In one mode of operation, all of the liquid phase refrigerant passing from the lower chamber 126 of the flash tank 10A, 10B traverses the primary refrigerant circuit expansion device 55 interdisposed in refrigerant line 4 upstream with respect to refrigerant flow of the evaporator 50. As this liquid refrigerant traverses the primary expansion device 55, it expands to a lower pressure and temperature before entering the evaporator 50. The evaporator 50 constitutes a refrigerant evaporating heat exchanger through which expanded refrigerant passes in heat exchange relationship with the air to be cooled, whereby the refrigerant is vaporized and typically superheated. As in conventional practice, the primary expansion device 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 to ensure that no liquid is present in the refrigerant leaving the evaporator. The low pressure refrigerant vapor leaving the evaporator 50 returns through refrigerant line 6 to the suction port of the first compression stage or first compressor 20a of the compression device 20.

[0022] In an embodiment, a refrigerant bypass line 5 may be provided to permit bypass of all or a portion of the liquid phase refrigerant passing through refrigerant line 4 from the lower chamber 126 of the flash tank around the primary expansion device 55. The refrigerant bypass line 5 taps into refrigerant line 4 at a first location upstream with respect to refrigerant flow of the primary expansion device 55 and downstream with respect to refrigerant flow of the flash tank 10A, 10B and at a second location downstream with respect to refrigerant flow of the primary expansion device 55 and upstream with respect to refrigerant flow of the evaporator 50. A flow control device 57, such as for example a solenoid valve

having an open position and a closed position, may be interdisposed in the refrigerant bypass line 5 for selectively opening and closing the bypass flow passage to refrigerant flow therethrough.

[0023] The refrigerant vapor compression system 100 also includes a refrigerant vapor injection line 14 that establishes refrigerant flow communication between the upper chamber 122 of the interior volume defined within the shell 120 of the flash tank 10A, 10B via the second outlet 129 of the flash tank 10A, 10B and an intermediate stage of the compression process. The refrigerant vapor compression system 100 may also include a refrigerant liquid injection line 18 that establishes refrigerant flow communication the lower chamber 126 of the interior volume defined within the shell 120 of the flash tank 10A, 10B, typically via tapping refrigerant line 4 at a location downstream with respect to refrigerant flow of the flash tank 10A, 10B and upstream with respect to refrigerant flow of the primary expansion valve 55, and between an intermediate stage of the compression process. In the exemplary embodiment of the refrigerant vapor compression system 100 depicted in FIG. 1, injection of refrigerant vapor or refrigeration liquid into the intermediate pressure stage of the compression process would be accomplished by injection of the refrigerant vapor or refrigerant liquid into the refrigerant passing from the first compression stage 20a into the second compression stage 20b of a single compressor. In the exemplary embodiment of the refrigerant vapor compression system 100 depicted in FIG. 2, injection of refrigerant vapor or refrigeration liquid into the intermediate pressure stage of the compression process would be accomplished by injection of the refrigerant vapor or refrigerant liquid into the refrigerant passing through refrigerant line 8 from the discharge outlet of the first compressor 20a to the suction inlet of the second compressor 20b.

[0024] The refrigerant vapor compression system 100 may also include a compressor unload refrigerant line 16 that establishes refrigerant flow communication between an intermediate pressure stage of the compression device and the suction pressure portion of the refrigerant circuit, i.e. refrigerant line 6 extending between the outlet of the evaporator 50 and the suction inlet of the first stage 20a of the compression device 20, as depicted in the FIG. 1 embodiment, or the suction inlet of the first compressor 20a, as depicted in the FIG. 2 embodiment.

Each of the refrigerant vapor injection line 14 and the refrigerant liquid injection line 18 may open in refrigerant flow communication with the compressor unload refrigerant line 16, whereby the compressor unload refrigerant line 16 forms a downstream portion of both the refrigerant vapor injection line 14 and the refrigerant liquid injection line 18. In this manner, refrigerant vapor may pass through the refrigerant vapor injection line 14 to be selectively injected either into an intermediate stage of the compression process or into the suction pressure portion of the refrigerant circuit. Similarly, refrigerant liquid may pass through the refrigerant liquid injection line 18 to be selectively injected either into an intermediate stage of the compression process or into the suction pressure portion of the refrigerant circuit. Additionally, to unload the compression device, all or a portion of the refrigerant discharging from the first stage 20a or the first compressor 20a may be passed through the compressor unload refrigerant line 16 to the suction pressure portion of the refrigerant circuit.

[0025] The refrigerant vapor compression system 100 may further include a control system including a controller 70. In an embodiment, the controller 70 may comprise a microprocessor controller such as, by way of example, but not limitation, a MicroLink™ controller available from Carrier Corporation of Syracuse, N.Y., USA. The controller 70 is configured to operate the refrigeration unit to maintain a predetermined thermal environment within the enclosed interior volume 200, i.e. the cargo box, wherein the product being transported is stored. The controller 70 maintains the predetermined environment by selectively controlling the operation of the compressor 20, the condenser fan(s) 34 associated with the condenser heat exchanger coil 32, the evaporator fan(s) 44 associated with the evaporator heat exchanger coil 42, and a plurality of refrigerant flow control devices operatively associated with the control 70. The plurality of flow control devices operatively associated with the controller 70 may include a flow control device 53 interdisposed in refrigerant line 18 for controlling the flow of liquid refrigerant passing therethrough from the lower chamber 126 of the flash tank 10A, 10B, and a flow control device 73 interdisposed in refrigerant line 14 for controlling the flow of vapor phase refrigerant therethrough from the upper chamber 122 of the flask tank 10A, 10B. The plurality of flow control devices operatively associated with the

controller 70 may also include a flow control device 93 interdisposed in the refrigerant line 16 for controlling the flow of refrigerant therethrough to a suction portion of the refrigerant circuit. Each of the aforementioned flow control devices 53, 73, 93 may comprise a flow control valve selectively positionable between an open position wherein refrigerant flow may pass through the refrigerant line in which the flow control valve is interdisposed and a closed position wherein refrigerant flow is blocked through the refrigerant line in which the flow control valve is interdisposed. In an embodiment, each of the flow control valves 53, 73, 93 may comprise a two-position solenoid valve of the type selectively positionable between a first open position and a second closed position. The plurality of flow control devices operatively associated with the controller 70 may also include the primary expansion valve 55, the secondary expansion valve 65, and the flow control device 57. In operation, the controller 70 may selectively open and close various of these flow control devices operatively associated therewith for selectively directing refrigerant flow through the primary refrigerant circuit, as well as refrigerant lines 5, 14, 16 and 18, as desired.

[0026] To facilitate control of the refrigeration system 100, the controller 70 also monitors operating parameters at various points in the refrigeration system through a plurality of sensors disposed at selected locations throughout the system 100. Among the sensors that may be provided include, among others not specifically shown: an ambient air temperature sensor 90 which inputs into the controller 70 a variable resistance value indicative of the ambient air temperature in front of the condenser 30; a return air temperature sensor 92 which inputs into the controller 70 a variable resistance value indicative of the temperature of the air leaving the evaporator 50 to return to the cargo box 200; a box air temperature sensor 94 which inputs into the controller 70 a variable resistance value indicative of the temperature of the air within the cargo box 200, i.e. the product storage temperature; a flash tank temperature sensor 101 which inputs into the controller 70 a variable resistance value indicative of the refrigerant temperature entering the flash tank 10A, 10B; a flash tank pressure sensor 102 which inputs a variable voltage indicative of the refrigerant pressure entering the flash tank 10A, 10B; a compressor suction temperature sensor 103 which inputs into the controller 70 a variable

resistance value indicative of the refrigerant suction temperature; a compressor suction pressure sensor 104 which inputs into the controller 70 a variable voltage indicative of the refrigerant suction pressure; a compressor discharge temperature sensor 105 which inputs into the controller 70 a variable resistance value indicative of the compressor discharge refrigerant temperature; a compressor discharge pressure sensor 106 which inputs into the controller 70 a variable voltage indicative of the compressor discharge refrigerant pressure; a gas cooler temperature sensor 107 which inputs into the controller 70 a variable resistance value indicative of the refrigerant temperature having traversed the gas cooler 40; a gas cooler pressure sensor 108 which inputs a variable voltage indicative of the refrigerant pressure having traversed the gas cooler 40. The pressure sensors 102, 104, 106, 108 may be conventional pressure sensors, such as for example, pressure transducers, and the temperature sensors 90, 92, 94, 101, 103, 105, 107 may be conventional temperature sensors, such as for example, thermocouples or thermistors. The aforementioned sensors are merely examples of some of the various sensors that may be associated with the system 100, and are not meant to limit the type of sensors or transducers that may be provided.

[0027] The refrigerant vapor compression system 100 may be operated in selected operating modes depending upon load requirements and ambient conditions, such as for example, but not limited to, a box temperature pull down mode, a deep frozen box temperature maintenance mode, and a refrigerated product box temperature maintenance mode. The controller 100 determines the desired mode of operation based upon ambient conditions, box conditions, and various sensed system controls and then positions the various flow control valves accordingly.

[0028] As noted previously, a flash tank 10A, 10B is disposed in refrigerant line 4 of the refrigerant circuit upstream with respect to refrigerant flow of the primary expansion device 55 and downstream with respect to refrigerant flow of the secondary expansion device 65. Referring now to FIGs. 3 and 4 in particular, as noted hereinbefore, the flash tank 10A, 10A includes a shell 120 defining an interior volume having an upper chamber 124, a lower chamber 126 and a middle chamber 122. The shell 120 has a generally cylindrical central portion 120-1 extending

between an upper end cap 120-2 and a lower end cap 120-3. The upper and lower end caps 120-2, 120-3 are attached in such a manner, for example by welding or brazing or the like, as to form a sealed enclosure defining the interior volume of the flash tank.

[0029] The flash tank 10A, 10B further includes an inlet port 125, a first outlet port 127 and a second outlet port 129. The inlet port 125 is in fluid communication with the middle chamber 124 for receiving the refrigerant flow having traversed the secondary expansion device. The inlet port 125 may be defined by the outlet opening of a tube 160 that penetrates through the shell 120 and is in fluid communication at its inlet end with refrigerant line 4 on the upstream side (with respect to refrigerant flow) of the flash tank. The second outlet port 129 is in fluid communication with the upper chamber 122 for discharging a gas phase of the refrigerant flow from the flash tank 10A, 10B. The second outlet port 129 may be defined by the inlet opening of a tube 162 that penetrates through the shell 120 and is in fluid flow communication at its outlet end with refrigerant line 14. The first outlet port 127 is in fluid communication with the lower chamber 126 for discharging a liquid phase of the refrigerant flow from the flash tank 10A, 10B into the refrigerant circuit. The first outlet port 127 may be defined by the inlet opening of a tube 164 that penetrates through the shell 120 and is in fluid flow communication at its outlet end with refrigerant line 4 on the downstream side (with respect to refrigerant flow) of the flash tank.

[0030] Referring now to FIG. 3, in the exemplary embodiment depicted therein, the flash tank 10A includes a lower plate 130 and an upper plate 140 disposed in spaced relationship within the interior volume defined by the shell 120. Each of the plates 130, 140 extends across the interior volume and sealingly abuts the inner wall of the generally cylindrical central portion 120-1 of the shell 120 thereby sectioning the interior volume of the shell 120 into three separate chambers: the middle chamber 124 between the two spaced apart plates 130, 140; the upper chamber 122 between the upper plate 140 and the upper end cap 120-2; and the lower chamber 126 between the lower plate 130 and the lower end cap 120-3. In this embodiment, a first fluid passage 142 is provided in and extends through the upper plate 140 thereby establishing fluid communication between the middle

chamber 124 and the upper chamber 122, and a second fluid passage 132 is provided in and extends through the lower plate 130 thereby establishing fluid communication between the middle chamber 124 and the lower chamber 126.

[0031] In operation, the two-phase refrigerant flow passing into the flash tank 10A through the inlet tube 160 into the middle chamber 124 through the inlet port 125. Within the middle chamber 124, the two-phase flow separates due the density differential existing between the liquid phase and the vapor phase. The vapor phase refrigerant passes upwardly through the first fluid passage 142 to enter the upper chamber 122. The liquid phase refrigerant passes downwardly through the second fluid passage 132 to enter the lower chamber 126. The outlet portion of the inlet tube 160 may be fluted whereby the two phase refrigerant flow passing through the inlet port 125 decelerates as it enters the middle chamber 124. The resulting deceleration enhances separation of the vapor and liquid phases thereby reducing carryover of liquid refrigerant in the vapor phase refrigerant flow passing upwardly through the first passage 142 and the carry under of vapor phase refrigerant in the liquid phase refrigerant flow passing downwardly through the second fluid flow passage 132. Additionally, the first fluid passage 142 and the second fluid passage 132 may be located diametrically opposite each other to further reduce the potential for carryover. Also, the outlet end of the inlet tube 160 may extend into the middle chamber 122 sufficiently that the inlet port 125 is juxtaposed opposite the upper surface of the lower plate 130 and the first fluid passage 142 in the upper plate 140 may be located vertically above the fluted portion of the inlet tube 160 as illustrated in FIG. 3. So located, a portion of the vapor phase refrigeration would tend to flow upwardly along the fluted contour of the outlet end of the inlet tube 160 to pass through the first fluid passage 142, while almost all of the liquid phase of the incoming refrigerant flow would spread out horizontally along the upper surface of the lower plate 130. In this arrangement, the second fluid passage 132 in the second plate 130 would be located diametrically opposite the first fluid passage 142 and thus away from the turbulent zone beneath the inlet port 125.

[0032] Referring now to FIG. 4, in the exemplary embodiment depicted therein, the flash tank 10B includes a helical spiral member 150 that extends about a vertical support tube 152 disposed along the central axis of the shell 120. The

radially outward edge of the helical spiral member 150 sealingly abuts the inner wall of the generally cylindrical central portion 120-1 of the shell 120. The helical spiral member 150 thereby defines a continuous spiral passage from extending between the lower chamber 126 and the upper chamber 122. The inlet tube 160 opens into the continuous spiral passage at a location between the upper chamber 124 and the lower chamber 126, which is referred to in this embodiment as the middle chamber 124. In an embodiment, the inlet tube 160 may be arranged such that the two-phase refrigerant flow passing into the middle chamber 124 through the inlet 125 enters tangentially along the inner wall of the generally cylindrical central member 120-1 of the shell 120. Due to the density differential between the vapor phase and the liquid phase, the vapor phase refrigerant in the entering two-phase flow will tend to flow generally upwardly through the continuous spiral passage defined by the helical spiral member 150, while the liquid phase of the two-phase flow will tend to flow generally downwardly through the continuous spiral passage defined by the helical spiral member 150. The central support tube 152 that supports the helical spiral member 150 also defines an elongated conduit 155 that extends along the central vertical axis of the shell 120 thereby establishing fluid communication between the upper chamber 122 and the lower chamber 126.

[0033] An upper equalization hole 154 and a lower equalization hole 156 opening through the wall of the tube 152 near the upper and lower ends, respectively, of the tube 152. The upper equalization hole 154 provides fluid communication between the upper chamber 122 and the conduit 155, while the lower equalization hole 156 provides fluid communication between the lower chamber 126 and the conduit 155. The fluid path established between the upper equalization hole 154 and the lower equalization hole 156 via the conduit 155 permits the fluid level in the conduit 155 defined within the support tube 152 to be equal to the fluid level within the continuous helical passage defined between the outer wall of the central support tube 152 and the inner wall of the central portion 120-1 of the shell 120. This fluid path also provides for a relatively stagnant refrigerant flow within the conduit 155 which enhances the opportunity for improved phase separation.

[0034] Unlike flash tanks used in stationary refrigeration systems, in transport refrigeration applications, the refrigerant vapor compression system is subject to vibration and movement due to the travel along roads, rail and sea. Consequently, refrigerant in the flash tank 10A, 10B would be subject to sloshing, which tends to increase intermixing of the vapor and liquid phases of the refrigerant within the flash tank. The presence of the plates 130, 140 or the helical spiral member 150 serve to lessen the degree of sloshing resulting from vibration and movement of the transport refrigeration system. Additionally, the flash tanks 10A, 10B include internal components that substantially improve separation of the liquid phase and the vapor phase introduced into the flash tank, thereby maximizing the enthalpy difference of the refrigerant across the evaporator which allows for limiting the size of system components while optimizing the coefficient of performance, COP, and energy efficiency rating, EER, of the system. Additionally, the improved quality of the refrigerant vapor withdrawn from the upper chamber of the flash tank 10A, 10B and injected into the intermediate-stage of the compression process, results in increased capacity of the refrigeration system. It is to be understood that either embodiment of the flash tanks 10A, 10B may be used in either the Figure 1 embodiment or the Figure 2 embodiment of the refrigerant vapor compression system 100.

[0035] Those skilled in the art will recognize that many variations may be made to the particular exemplary embodiments described herein. For example, the refrigerant vapor compression system may also be operated in a subcritical cycle, rather than in a transcritical cycle as described hereinbefore. While the present invention has been particularly shown and described with reference to the exemplary embodiments 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 transport refrigeration refrigerant vapor compression system operating in a transcritical refrigeration cycle comprising:
 - a compression device for compressing a refrigerant vapor to a supercritical refrigerant pressure, a gas cooler operating at a supercritical refrigerant pressure, and an evaporator operating at a subcritical refrigerant pressure, said compression device, said gas cooler and said evaporator connected in refrigerant flow communication in a refrigerant circuit;
 - a primary expansion device disposed in said refrigerant circuit between said gas cooler and said evaporator;
 - a secondary expansion device disposed in said refrigerant circuit between said gas cooler and said primary expansion device;
 - a flash tank disposed in the refrigerant circuit upstream with respect to refrigerant flow of said primary expansion device and downstream with respect to refrigerant flow of said secondary expansion device, said flash tank having:
 - a shell defining an interior volume, said interior volume divided into an upper chamber, a lower chamber and a middle chamber;
 - a first fluid passage establishing fluid communication between the middle chamber and the upper chamber;
 - a second fluid passage establishing fluid communication between the middle chamber and the lower chamber;
 - an inlet port in fluid communication with the middle chamber for receiving the refrigerant flow having traversed the secondary expansion device;
 - a first outlet port in fluid communication with the upper chamber for discharging a vapor phase of the refrigerant flow from said flash tank separator; and
 - a second outlet port in fluid communication with the lower chamber for discharging a liquid phase of the refrigerant flow from said flash tank into the refrigerant circuit.

2. The transport refrigeration refrigerant vapor compression system as recited in claim 1 further comprising: a refrigerant vapor injection line establishing refrigerant flow communication between the first outlet port in fluid communication with the upper chamber of said flash tank and an intermediate pressure stage of said compression device.

3. The transport refrigeration refrigerant vapor compression system as recited in claim 1 further comprising: a refrigerant liquid injection line establishing refrigerant flow communication between the second outlet port in fluid communication with the lower chamber of said flash tank and an intermediate pressure stage of said compression device.

4. The transport refrigerant vapor compression system as recited in claim 1 wherein said flash tank further comprises:

a lower plate and an upper plate disposed in spaced relationship within the interior volume defined by said shell, each of said lower plate and said upper plate extending across the interior volume thereby sectioning the interior volume into the lower chamber, the middle chamber and the lower chamber;

a first opening extending through said upper plate and forming the first fluid passage establishing fluid communication between said middle chamber and said upper chamber; and

a second opening extending through said lower plate and forming the second fluid passage establishing fluid communication between said middle chamber and said lower chamber.

5. The transport refrigerant vapor compression system as recited in claim 1 wherein said flash tank further comprises:

an elongated support tube extending along a central vertical axis of said shell, said support tube defining a conduit establishing fluid communication between said lower chamber and said upper chamber; and

a helical spiral member extending about said vertical support tube and defining a continuous spiral fluid flow passage, a first portion of said continuous

helical passage forming the first fluid passage establishing fluid communication between the middle chamber and the upper chamber and a second portion of said continuous helical passage forming the second fluid passage establishing fluid communication between the middle chamber and the lower chamber.

6. A refrigerant vapor compression system as recited in claim 1 wherein the refrigerant comprises carbon dioxide.

7. A refrigerant vapor compression system as recited in claim 1 wherein said compression device comprises a single compressor having at least a first relatively lower pressure compression stage and a second relatively higher pressure compression stage.

8. A refrigerant vapor compression system as recited in claim 1 wherein said compression device comprises a first compressor and a second compressor disposed in said refrigerant circuit in series refrigerant flow relationship with a discharge outlet of said first compressor in refrigerant flow communication with a suction inlet of said second compressor.

9. A refrigerant vapor compression system as recited in claim 5 further comprising:

an upper equalization hole passing through said support tube and located near an upper end of said support tube, said upper equalization hole establishing fluid communication between an upper region of said conduit and an upper region of said continuous helical passage; and

a lower equalization hole passing through said support tube and located near a lower end of said support tube, said lower equalization hole establishing fluid communication between a lower region of said conduit and a lower region of said continuous helical passage.

10. A flash tank separator comprising:
a shell defining an interior volume;
a lower plate and an upper plate disposed in spaced relationship within the interior volume defined by said shell, each of said lower plate and said upper plate extending across the interior volume thereby sectioning the interior volume into the lower chamber, the middle chamber and the lower chamber;
a first opening extending through said upper plate and establishing fluid communication between said middle chamber and said upper chamber;
a second opening extending through said lower plate and establishing fluid communication between said middle chamber and said lower chamber;
an inlet port in fluid communication with the middle chamber for receiving a flow of a mixed liquid phase and vapor phase fluid;
a first outlet port in fluid communication with the upper chamber for discharging a vapor phase of the refrigerant flow from the upper chamber; and
a second outlet port in fluid communication with the lower chamber for discharging a liquid phase from the lower chamber.

11. The flash tank separator as recited in claim 10 wherein the first opening in said upper plate and the second opening in said lower plate are disposed remotely from each other.

12. The flash tank separator as recited in claim 10 further comprising an inlet tube penetrating said shell and having a fluted outlet defining said inlet port.

13. A flash tank separator comprising:
a shell defining an interior volume having an upper chamber, a middle chamber and a lower chamber;
an elongated support tube extending along a central vertical axis of said shell between the lower chamber and the upper chamber;
a helical spiral member extending about said vertical support tube and defining a continuous spiral fluid flow passage, a first portion of said continuous helical passage establishing fluid communication between the middle chamber and

the upper chamber and a second portion of said continuous helical passage establishing fluid communication between the middle chamber and the lower chamber;

an upper equalization hole passing through said support tube and located near an upper end of said support tube, said upper equalization hole establishing fluid communication between an upper region of said conduit and an upper region of said continuous helical passage;

a lower equalization hole passing through said support tube and located near a lower end of said support tube, said lower equalization hole establishing fluid communication between a lower region of said conduit and a lower region of said continuous helical passage;

an inlet port in fluid communication with the middle chamber for receiving the refrigerant flow having traversed the secondary expansion device;

a first outlet port in fluid communication with the upper chamber for discharging a gas phase of the refrigerant flow from said flash tank separator; and

a second outlet port in fluid communication with the lower chamber for discharging a liquid phase of the refrigerant flow from said flash tank into the refrigerant circuit.

14. The flash tank separator as recited in claim 13 further comprising an inlet tube penetrating said shell and having a outlet defining said inlet port for directing an incoming flow of a mixed liquid phase and vapor phase fluid to pass circumferentially along an inner wall of said shell.