A refrigerant unit associated with a product transport container is provided with a dual-path, parallel flow expansion circuit. The expansion circuit includes a primary expansion device disposed in a primary refrigerant flow path and an auxiliary expansion device disposed in a secondary refrigerant flow path. During operation of the refrigeration unit in a stable temperature maintenance mode, refrigerant flow is supplied to the evaporator coil through the primary refrigerant flow path only. During operation of the refrigeration unit in a temperature pull-down mode, to increase the refrigerant mass flow through the evaporator coil, refrigeration flow is supplied to the evaporator coil through the primary refrigerant flow path and the secondary refrigerant flow path of the expansion circuit.
TRANSPORT REFRIGERATION UNIT
CROSS-REFERENCE TO RELATED APPLICATION

[0001] Reference is made to and this application claims priority from and the benefit of U.S. Provisional Application Ser. No. 60/787,244, filed Mar. 30, 2006, and entitled TRANSPORT REFRIGERATION UNIT, which application is incorporated herein in its entirety by reference.

FIELD OF THE INVENTION

[0002] This invention relates generally to transport refrigeration units and, more specifically, to facilitating the pull down of the temperature of product when loaded into a transport container provided with a refrigeration unit.

BACKGROUND OF THE INVENTION

[0003] Refrigerated freight containers require a refrigeration unit for maintaining a desired temperature environment within the interior volume of the container. The refrigeration unit must have sufficient refrigeration capacity to maintain the product stored within the container at the desired temperature over a wide range of outdoor ambient temperatures and load conditions. Refrigerated freight containers are used to transport a wide variety of products, ranging from fresh produce to deep frozen seafood. Product may be loaded into the container unit directly from the field, such as freshly picked fruits and vegetables, or from a warehouse.

[0004] Conventional transport refrigeration units used in connection with cooling refrigerated freight containers include a refrigerant compressor, a condenser coil, a thermostatic expansion valve (TXV), and an evaporator coil connected via appropriate refrigerant lines in a closed refrigerant flow circuit. The refrigeration unit is generally contained in a housing mountable to the container such that the air or gas mixture or other gas within the interior volume of the container may be circulated over the evaporator coil by means of an evaporator fan associated with the evaporator coil. The refrigerant unit may also be equipped with an economizer incorporated into the refrigeration circuit, if desired.

[0005] Generally, products loaded into a container from a warehouse have already been cooled to the desired product storage temperature within a refrigeration facility at the warehouse. Thus, the chilled products may be transferred into a container, without increasing the refrigeration load on the refrigeration unit. In conventional practice, the refrigeration unit is typically designed with a refrigeration capacity sized to provide stable temperature at a low box temperature desired for deep frozen product, which as noted before when loaded into the container has already been pre-cooled to the desired product storage temperature for transport. The TXV, which is located in the refrigerant circuit at the inlet to the evaporator coil, is a mechanical device using a thermal expansion bulb measuring refrigerant temperature leaving the evaporator to meter the refrigerant entering the evaporator, thereby adjusting and controlling the amount of refrigerant flow through the refrigerant circuit. The TXV is sized to be the largest possible yet most stable valve at the deep frozen condition.

[0006] However, when product which has not been pre-cooled, such as for example fresh fruits and vegetables direct from the field, is loaded into the container “hot”, that is at a temperature above the desired product storage temperature, such as for example directly from the field at ambient outdoor temperature, a substantially refrigeration load is imposed upon the transport refrigeration unit in pulling the temperature of the product down from ambient outdoor temperature to the desired product storage temperature. The TXV valve, being sized as noted above for the stable low box temperature condition, typically is undersized when the product is loaded into the container at a temperature above desired product storage temperature, typically referred to as the set point temperature.

[0007] Products applied hot require the refrigeration unit to pull the product temperature down to set point temperature, typically about 2°C (about 36°F) from product temperatures ranging as high as 38°C (100°F) or above. During pull down, the refrigerant unit requires high refrigerant pump input to cool the product down as rapidly as possible. However, the refrigerant mass flow through the refrigerant circuit is limited by the TXV size required for low temperature stability. When product is loaded in the refrigerated container at temperatures higher than the desired product storage temperature, the TXV typically will respond by opening up to maintain a desired superheat. In the event the TXV reaches its maximum capacity the valve is no longer able to provide a stable or adequate superheat. As a result, the refrigeration capacity of the refrigeration unit will decrease and the evaporator superheat will rise above the level required for adequate cooling. Consequently, the time required to pull the product down to the set point temperature will increase. Sizing the TXV for pull down adversely affects the ability of refrigeration unit to provide stable temperature control at low set point temperatures because the TXV is too large for the required system mass flow rates. The orifice size being too large causes flooding of evaporator coil which negatively impacts product temperature control and stability.

[0008] The operating temperature range requirements associated with refrigerated freight containers have increased to the point where the TXV is limiting the performance of the cooling circuit. An electronic expansion valve (EXV) can achieve a larger range of temperature control than a TXV but is more costly and may become a reliability problem by itself and with the system because an EXV is not fail safe in the event power was inadvertently shut off while in operation.

SUMMARY OF THE INVENTION

[0009] Accordingly, it would be desirable to provide for increased refrigerant mass flow during product temperature pull down to increase refrigeration capacity without resorting to replacement of the TXV with an EXV and while maintaining reliability and keeping the system simple.

[0010] To increase the ability of the TXV to control the range from low temperature transport volumes to pull down conditions, a transport refrigerant unit is provided with a dual-path, parallel flow expansion circuit. The expansion circuit is inserted in the refrigerant circuit to increase the refrigerant mass flow during pull down. The expansion circuit includes a primary expansion device disposed in a primary refrigerant flow path and an auxiliary expansion device disposed in a secondary refrigerant flow path. The main refrigerant line from the condenser coil outlet to the evaporator coil forms the primary refrigerant flow path of the expansion circuit and the primary expansion device is the evaporator TXV disposed in this refrigerant line. The secondary refrigerant flow path of the expansion circuit comprises a bypass refrigerant line which connects at its inlet end to the refriger-
a circuit upstream with respect to refrigerant flow of the evaporator TXV and at its outlet end to the refrigerant circuit downstream with respect to refrigerant flow of the evaporator TXV. The auxiliary expansion device and a bypass valve are disposed in the bypass line. The bypass line is shut off during low box temperature operation. The auxiliary expansion device may be a fixed orifice or an additional TXV. A controller opens the bypass valve when it is desired to allow refrigerant flow through the bypass line and closes the bypass valve when it is desired to pass refrigerant flow only through the TXV. In an embodiment, the fixed orifice is located within the bypass valve itself.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] For a further understanding of these and objects 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 drawings, wherein:

[0012] FIG. 1 is a schematic representation of an exemplary embodiment of a transport refrigeration unit with a dual-path, parallel flow expansion circuit depicting operation during a stable product storage temperature maintenance mode;

[0013] FIG. 2 is a schematic representation of the embodiment of the transport refrigeration unit of FIG. 1 depicting operation during a product temperature pull-down mode;

[0014] FIG. 3 is another exemplary embodiment of a transport refrigeration unit with a dual-path, parallel flow expansion circuit;

[0015] FIG. 4 is a further exemplary embodiment of a transport refrigeration unit with a dual-path, parallel flow expansion circuit;

[0016] FIG. 5 is an exemplary embodiment of a transport refrigeration unit with a dual-path, parallel flow expansion circuit and including an economizer circuit; and

[0017] FIG. 6 is a perspective view of an exemplary embodiment of a dual-path, parallel flow expansion circuit.

DETAILED DESCRIPTION OF THE INVENTION

[0018] Referring now to FIGS. 1 through 5, there are shown schematically, various exemplary embodiments of a transport refrigeration unit 10 designed for regulating and maintaining a desired product storage temperature range within a refrigerated volume wherein a perishable product is stored during transport, such as a refrigerated freight container or the box of a truck or trailer. In each of the depicted embodiments, the refrigeration unit 10 includes a compressor 20, a condenser 30 including a condenser heat exchange coil 32 and associated condenser fan(s) 34, an evaporator heat exchanger 40 including an evaporator heat exchange coil 42 and associated evaporator fan(s) 44, and an evaporator thermal expansion valve (TXV) 50 connected in a conventional manner by refrigerant lines 2, 4 and 6 in a refrigerant flow circuit. Typically, the compressor 20 is a reciprocating compressor or a scroll compressor, single-stage or two-stage; however, the particular type of compressor used is not germane to or limiting of the invention. As will be discussed in greater detail hereinafter, the refrigeration unit 10 depicted in FIG. 5 further includes an economizer 80 operatively associated with a scroll compressor.

[0019] As in conventional practice, refrigerant line 2 connects the discharge outlet of the compressor 20 in refrigerant flow communication with the inlet to the condenser heat exchanger coil 32, refrigerant line 4 connects the outlet of the condenser heat exchanger coil 32 in refrigerant flow communication with the inlet to the evaporator heat exchanger coil 42, and refrigerant line 6 connects the outlet of the evaporator heat exchanger coil 42 in refrigerant flow communication with the suction inlet of the compressor 20, thereby completing the refrigerant flow circuit. As depicted in the exemplary embodiments illustrated in FIGS. 1-4, a refrigerant-to-refrigerant in-line heat exchanger 60 may be included in the refrigerant flow circuit for passing the liquid refrigerant passing through refrigerant line 4 in heat exchange relationship with the vapor refrigerant passing through refrigerant line 6. In addition, a suction modulation valve 12, a suction solenoid valve 13, a quench expansion valve 14, a filter/drier 16, and a receiver 18 with slight glass 15 may be included in the refrigerant circuit in refrigerant line 6 as in conventional practice.

[0020] The refrigeration unit also includes an electronic controller 55 such as, for example, an MicroLink™ controller available from Carrier Corporation of Syracuse, N.Y., USA. The electronic controller 55 is configured to operate the refrigeration unit 10 to maintain a predetermined thermal environment within the enclosed volume, termed a box, wherein the product is stored. The electronic controller 55 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 the suction modulation valve 12. For example, when cooling of the environment within the box is required, the electronic controller 55 provides electrical power to activate the compressor 20, the condenser fan and the evaporator fan. Additionally, the electronic controller 55 adjusts the position of the suction modulation valve 12 to increase or decrease the flow of refrigerant supplied to the compressor 20 as appropriate to control and stabilize the temperature within the box at the set point temperature, which corresponds to the desired product storage temperature for the particular product stored within the box.

[0021] In the exemplary embodiment depicted in FIG. 5, the refrigeration unit 10 incorporates an economizer circuit including an economizer heat exchanger 80 wherein liquid refrigerant passing through refrigerant line 4 passes in heat exchange relationship with refrigerant vapor passing through economizer line 82. Referring to FIG. 5, a portion of the liquid refrigerant having traversed the condenser coil 32 and passing through refrigerant line 4 may be diverted into economizer line 82 upstream of the economizer heat exchanger 80. The diverted refrigerant traverses an expansion device 86, such as for example a thermostatic expansion valve, disposed in economizer line 82 wherein the liquid refrigerant is expanded to a lower pressure and lower temperature vapor refrigerant. The refrigerant vapor continues through refrigerant line 82 to pass through the economizer heat exchanger 80 in heat exchange relationship with the higher pressure, higher temperature refrigerant passing through refrigerant line 4. The refrigerant vapor thereafter continues through the refrigerant line 82 to be injected into an intermediate pressure stage of the compressor 20. In the depicted embodiment, the compressor 20 comprises a scroll compressor, but it is to be understood that any multiple stage compressor or multiple compressors could be used. The liquid refrigerant having passed through the economizer heat exchanger 80 continues through refrigerant line 4 to the evaporator 40. A flow control valve 84, disposed in the economizer line 82 upstream with respect to refrigerant flow of the expansion device 86, is
operative under direction of the system controller 55 to selectively open or close the economizer line 82 to refrigerant flow there through. Additionally, a liquid injection line 88 may be provided to divert a portion of the liquid refrigerant from refrigerant line 4 into the economizer line 82 downstream of the economizer heat exchanger 80 to be injected into an intermediate compression stage of the compressor 20. A flow return valve 85, flow path of the liquid injection line 88, is operative under direction of the system controller 55 to selectively open or close the liquid injection line 82 to refrigerant flow there through.

[0022] In each of the embodiments depicted in FIGS. 1-5, the refrigerant circuit of the refrigeration unit 10 includes a dual-path, parallel-flow expansion circuit 70 in operative association with the evaporator 40. In the embodiment depicted in FIGS. 1-4, the expansion circuit is incorporated into the refrigerant circuit in line 4 downstream of the refrigerant-to-refrigerant heat exchanger 60 and upstream of the inlet to the evaporator heat exchanger coil 42. In the embodiment depicted in FIG. 5, the expansion circuit 70 is incorporated into the refrigerant circuit in line 4 downstream with respect to refrigerant flow of the economizer heat exchanger coil 80 and upstream with respect to refrigerant flow of the inlet to the evaporator heat exchanger coil 42.

[0023] Referring now also to FIG. 6, the expansion circuit 70 includes a primary expansion device disposed in a primary refrigerant flow path and an auxiliary expansion device disposed in a secondary refrigerant flow path. In the depicted exemplary embodiments, the refrigerant line 4 forms the primary refrigerant flow path of the expansion circuit and the primary expansion device comprises the evaporator TXV 50 disposed in refrigerant line 4 with section 4A of refrigerant line 4 upstream of the TXV 50 and with section 4B of refrigerant line 4 downstream with respect to refrigerant flow of the TXV. The secondary refrigerant flow path of the expansion circuit 70 comprises a bypass refrigerant line 8 which connects at its inlet end to section 4A of refrigerant line 4 of the refrigerant circuit upstream with respect to refrigerant flow of the evaporator TXV 50 and at its outlet end to section 4B of refrigerant line 4 of the refrigerant circuit downstream with respect to refrigerant flow of the evaporator TXV. The auxiliary expansion device 72 and a bypass valve 74 are disposed in the bypass line 70. The auxiliary expansion device 72 may be positioned downstream or upstream with respect to refrigerant flow of the bypass valve 74.

[0024] In the embodiment depicted schematically in FIGS. 1 and 2, the auxiliary expansion device 72 comprises a fixed orifice device disposed in refrigerant line 8 downstream with respect to refrigerant flow of the bypass valve 74. In the embodiment depicted in FIG. 5, the auxiliary expansion valve 72 comprises a fixed orifice device disposed in refrigerant line 8 upstream with respect to refrigerant flow of the bypass valve 74. The auxiliary expansion device 72 could also be a fixed-bore device such as a capillary tube. In the embodiment depicted in FIG. 4, the auxiliary expansion device 72 comprises a fixed orifice embodied within the bypass valve 74.

[0025] In the embodiment depicted schematically in FIG. 3, the auxiliary expansion device 72 comprises a thermostatic expansion valve disposed in refrigerant line 8 downstream with respect to refrigerant flow of the bypass valve 74. In the depicted embodiments, the bypass valve 74 comprises a solenoid valve having an open position in which refrigerant may pass from section 4A of refrigerant line 4 through refrigerant line 8 and into section 4B of refrigerant line 4 and having a closed position in which refrigerant flow through refrigerant line 8 is blocked. The solenoid valve 72 is in electrical communication with the controller 55 which controls the positioning of the solenoid valve 74 is either its open or closed position.

[0026] When the refrigeration unit 10 is operating under normal load, that is operating to maintain a stable box temperature at a temperature set point equal to a desired product storage temperature for the particular product within the box with which the refrigeration unit is associated, the controller 55 maintains the bypass valve 74 in its normal closed position. Referring now to FIG. 1, with the bypass valve 74 in its closed position, no refrigerant flows through refrigerant line 8 of the expansion circuit 70. Rather, all refrigerant flow through refrigerant line 4 passes through the evaporator TXV 50. Thus, the amount of flow passing through the evaporator heat exchanger coil 42 is adjusted and controlled by the evaporator TXV 50 in a conventional manner.

[0027] However, when the temperature of the product within the box is above a predetermined temperature, for example when the product has been loaded into the box in a “hot” condition, the load will be considered to be in a pull down condition. When the refrigeration unit 10 is required to pull down the temperature of, the controller 55 will energize the solenoid valve 74 to position the solenoid valve 74 in its open position, thereby permitting refrigerant to flow from section 4A of refrigerant line 4 through refrigerant line 8 into section 4B of refrigerant line 4 to pass through the evaporator heat exchanger coil 42 while bypass the TXV 50. Referring now to FIGS. 2, 3, 4 and 5, with the bypass valve 74 in its open position, refrigerant flows through both paths of the dual-path, parallel flow expansion circuit 70. A first flow of liquid refrigerant passes through refrigerant line 4 traversing the primary expansion device, TXV 50, wherein it is expanded to a vapor state, and thence passes to the evaporator heat exchanger coil 42. A second flow of liquid refrigerant passes from section 4A of the refrigerant line 4 through refrigerant line 8 traversing the auxiliary expansion device 72, wherein it is expanded to a vapor state, and thence passes to and through section 4B of refrigerant line 4 to the evaporator heat exchanger coil 42. In this manner, the amount of refrigerant flowing through the evaporator heat exchanger coil 42 is significantly increased, thereby increasing the refrigeration capacity of the evaporator 40.

[0028] The controller 55 may be configured to open and close the bypass solenoid valve 74 in response to evaporator or compressor suction superheat in addition to a fixed return air temperature range. A fixed temperature range can be used knowing the existing limitations of the current valve and system. At temperatures below this transition point, the controller 55 will de-energize the solenoid valve 74 thereby causing the solenoid valve 74 to move to its closed position, thereby closing refrigerant line 8. With the solenoid valve 74 closed, the mechanical evaporator TXV 50 will assume control of the amount of refrigerant flowing through the evaporator heat exchanger coil 42 as in conventional practice.

[0029] While the present invention has been particularly shown and described with reference to the preferred mode as illustrated in the drawing, 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 refrigeration unit comprising:
a refrigerant flow circuit including a refrigerant compressor, a condenser coil, and an evaporator coil connected by refrigerant lines in refrigerant flow communication; and
a dual-path, parallel flow expansion circuit having a primary expansion device disposed in a primary refrigerant flow path and an auxiliary expansion device disposed in a secondary refrigerant flow path, said expansion circuit inserted in said refrigerant circuit downstream with respect to refrigerant flow of said condenser coil and upstream with respect to said evaporator coil.
2. A refrigeration unit as recited in claim 1 wherein said primary expansion device comprises a thermostatic expansion valve.
3. A refrigeration unit as recited in claim 2 wherein said auxiliary expansion device comprises a fixed orifice.
4. A refrigeration unit as recited in claim 2 wherein said auxiliary expansion device comprises a thermostatic expansion valve.
5. A refrigeration unit as recited in claim 2 wherein said auxiliary expansion device comprises a capillary tube.
6. A refrigeration unit as recited in claim 1 wherein said auxiliary expansion device comprises a fixed orifice.
7. A refrigeration unit as recited in claim 1 wherein said auxiliary expansion device comprises a capillary tube.
8. A refrigeration unit as recited in claim 1 wherein said auxiliary expansion device comprises a bypass line having an inlet in refrigerant flow communication with said refrigerant flow circuit at a point upstream with respect to refrigerant flow of said primary expansion device and an outlet in refrigerant flow communication with said refrigerant flow circuit at a point downstream with respect to refrigerant flow of said primary expansion device.
9. A refrigeration unit as recited in claim 9 further comprising a bypass valve disposed in said bypass line, said bypass valve operative to selectively open and close said bypass line to refrigerant flow there through.
10. A refrigeration unit as recited in claim 9 wherein said auxiliary expansion device is disposed in said bypass line upstream with respect to refrigerant flow of said bypass valve.
11. A refrigeration unit as recited in claim 10 wherein said auxiliary expansion device is disposed in said bypass line downstream with respect to refrigerant flow of said bypass valve.
12. A refrigeration unit as recited in claim 10 wherein said auxiliary expansion device is disposed in said bypass line downstream with respect to refrigerant flow of said bypass valve.
13. A refrigeration unit as recited in claim 1 wherein said refrigerant flow circuit further includes an economizer circuit.
14. A refrigeration unit as recited in claim 13 wherein said compressor comprises a scroll compressor.
15. A method of operating a refrigeration unit for providing a temperature controlled environment within a container having a product disposed therein to be maintained at a product storage temperature, the refrigeration unit having a refrigerant flow circuit including a refrigerant compressor, a condenser coil, and an evaporator coil connected by refrigerant lines in refrigerant flow communication, said method comprising the steps of:
   providing a dual-path, parallel flow expansion circuit having a primary expansion device disposed in a primary refrigerant flow path and an auxiliary expansion device disposed in a secondary refrigerant flow path;
   passing refrigerant flow to the evaporator coil through the primary refrigerant flow path only when the refrigeration unit is operating in a stable temperature maintenance mode; and
   passing refrigerant flow to the evaporator coil through both the primary refrigerant flow path and the secondary refrigerant flow path when the refrigeration unit is operating in a temperature pull-down mode.
16. A method of operating a refrigeration unit as recited in claim 15 wherein the step of passing refrigerant flow to the evaporator coil through the primary refrigerant flow path only when the refrigeration unit is operating in a stable temperature maintenance mode includes the step of passing the refrigerant flow through a thermostatic expansion valve disposed in the primary refrigerant flow path.
17. A method of operating a refrigeration unit as recited in claim 16 wherein the step of passing refrigerant flow to the evaporator coil through both the primary refrigerant flow path and the secondary refrigerant flow path when the refrigeration unit is operating in a temperature pull-down mode includes the step of passing refrigerant flow to the evaporator coil through a thermostatic expansion valve disposed in the primary refrigerant flow path and through a fixed orifice disposed in the secondary refrigerant flow path.
18. A method of operating a refrigeration unit as recited in claim 16 wherein the step of passing refrigerant flow to the evaporator coil through both the primary refrigerant flow path and the secondary refrigerant flow path when the refrigeration unit is operating in a temperature pull-down mode includes the step of passing refrigerant flow to the evaporator coil through a thermostatic expansion valve disposed in the primary refrigerant flow path and through a thermostatic expansion device disposed in the secondary refrigerant flow path.
19. A method of operating a refrigeration unit as recited in claim 16 wherein the step of passing refrigerant flow to the evaporator coil through both the primary refrigerant flow path and the secondary refrigerant flow path when the refrigeration unit is operating in a temperature pull-down mode includes the step of passing refrigerant flow to the evaporator coil through a thermostatic expansion valve disposed in the primary refrigerant flow path and through a capillary tube disposed in the secondary refrigerant flow path.