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(54) REFRIGERANT SYSTEM WITH CASCADED CIRCUITS AND PERFORMANCE ENHANCEMENT FEATURES

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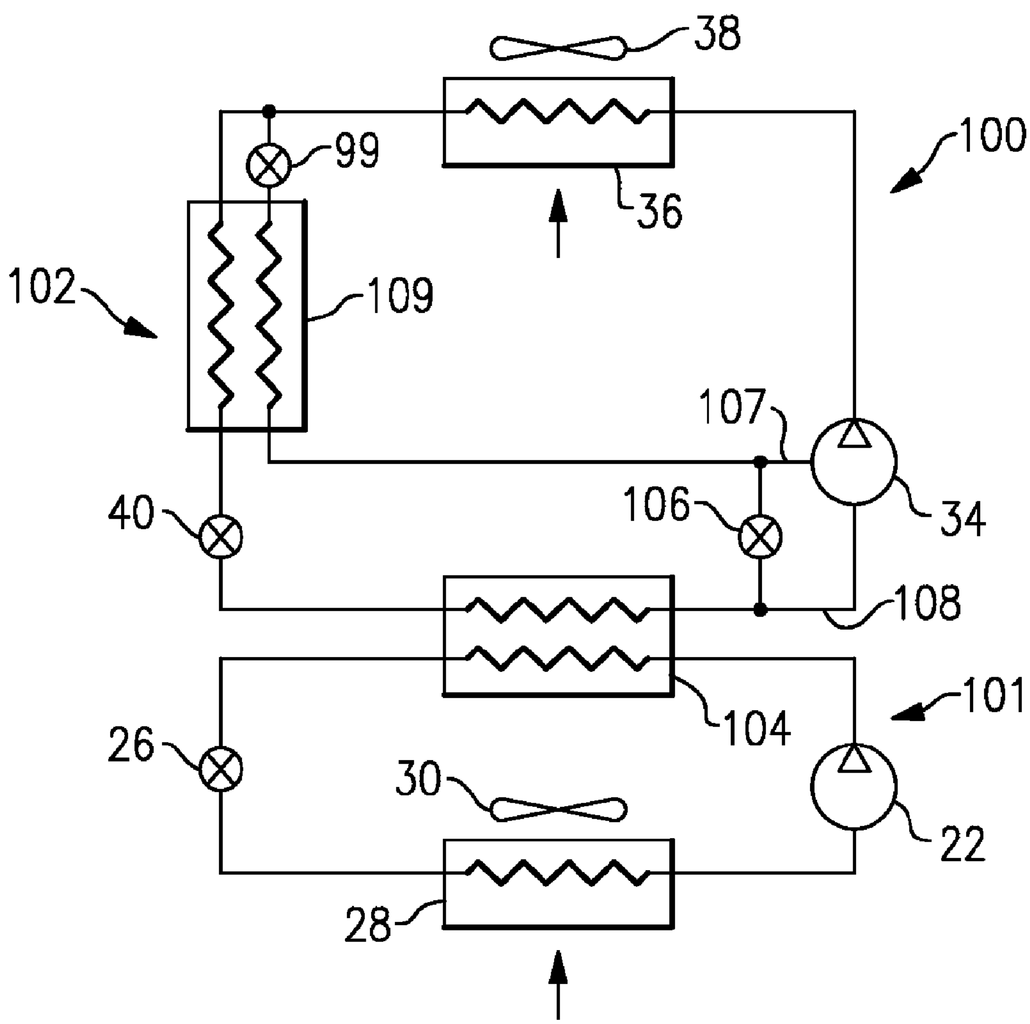
(57) **ABSTRACT**

An improved refrigerant system incorporates at least two circuits arranged in a cascaded relationship. Preferably, the upper circuit utilizes a hydrocarbon refrigerant and preferably the lower circuit utilizes CO_2 refrigerant. Preferably, the CO_2 circuit mainly operates in a subcritical region. To improve the efficiency and capacity control of the cascaded refrigerant system, at least one of the circuits is equipped with performance enhancement features such as, for example, an economized function provided by a flash tank or economizer heat exchanger. Additional enhancement features can also include a liquid-suction heat exchanger and bypass function.



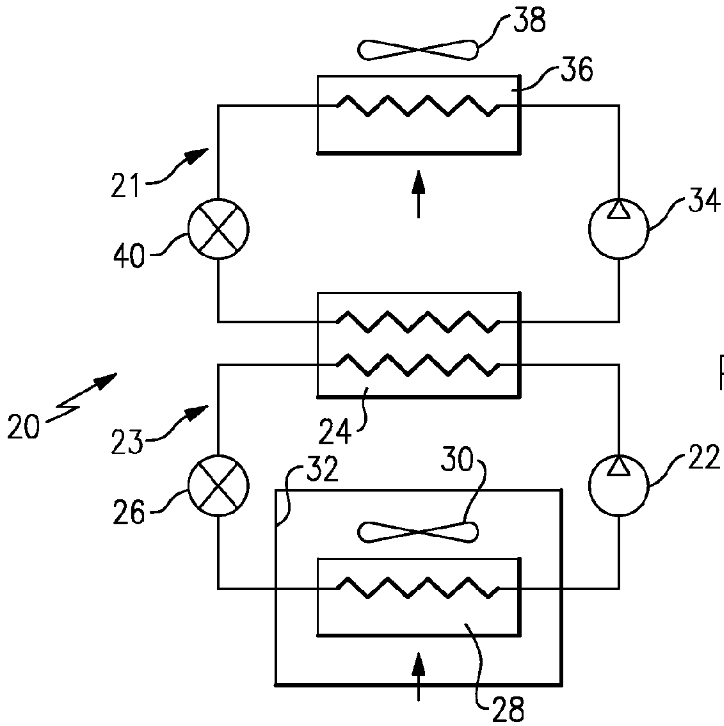


FIG.1
Prior Art

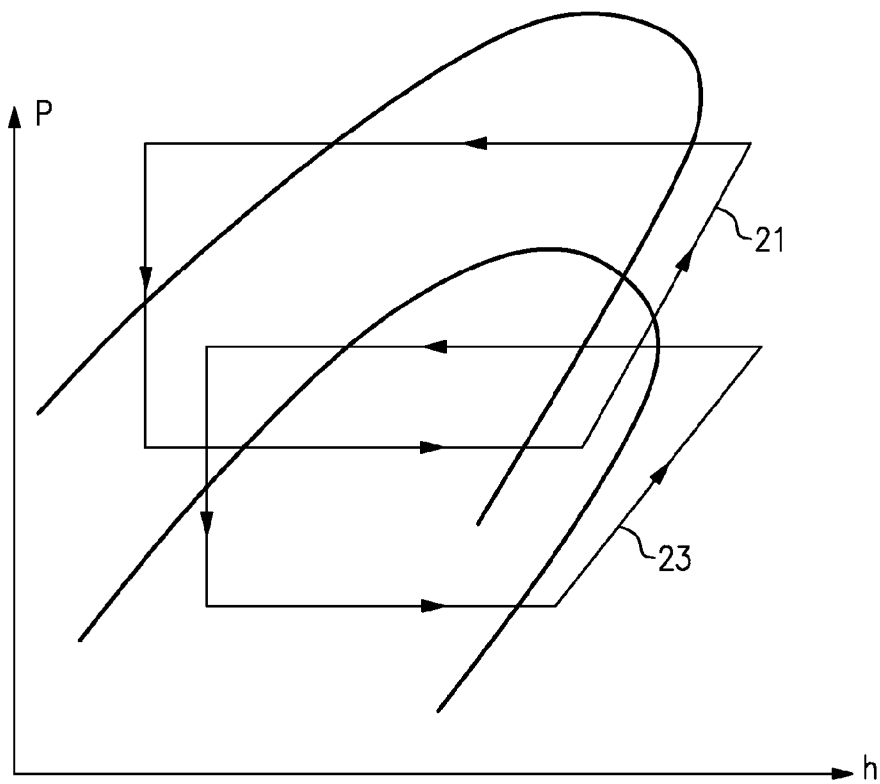


FIG.2

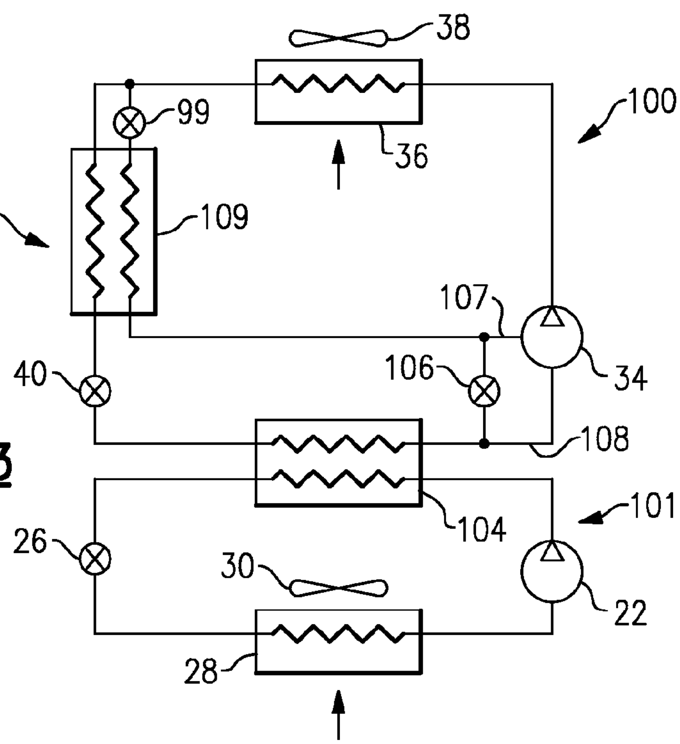
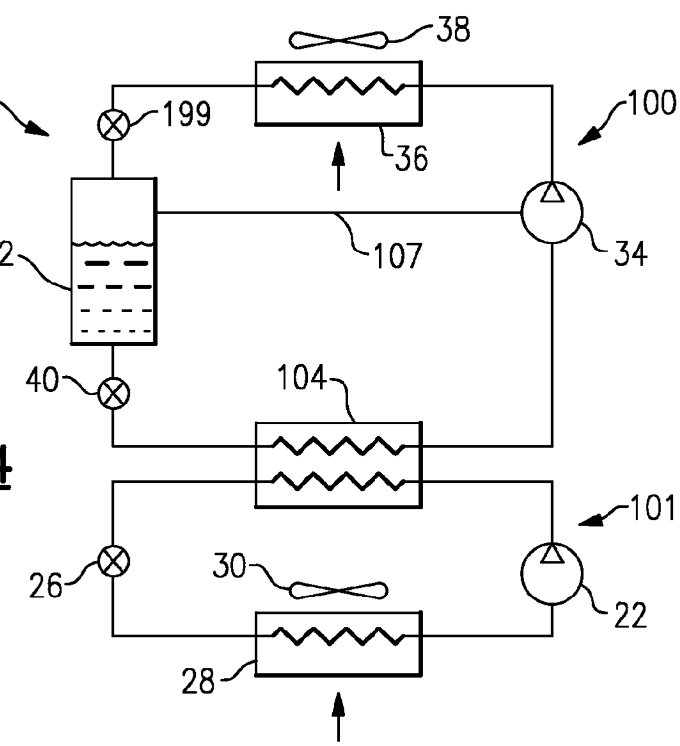

38
99
100
36
102
109
107
34
40
106
108
104
101
26
30
22
28

FIG.3


38
102
199
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36
107
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112
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104
101
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FIG.4

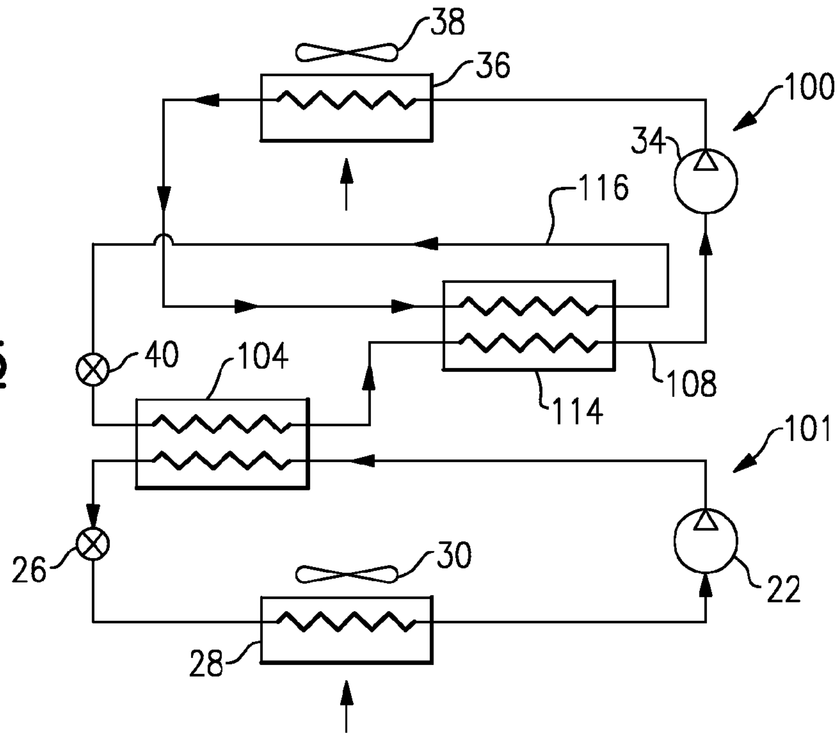
38
36
100
34
116
40
104
108
114
101
26
30
22
28

FIG.5

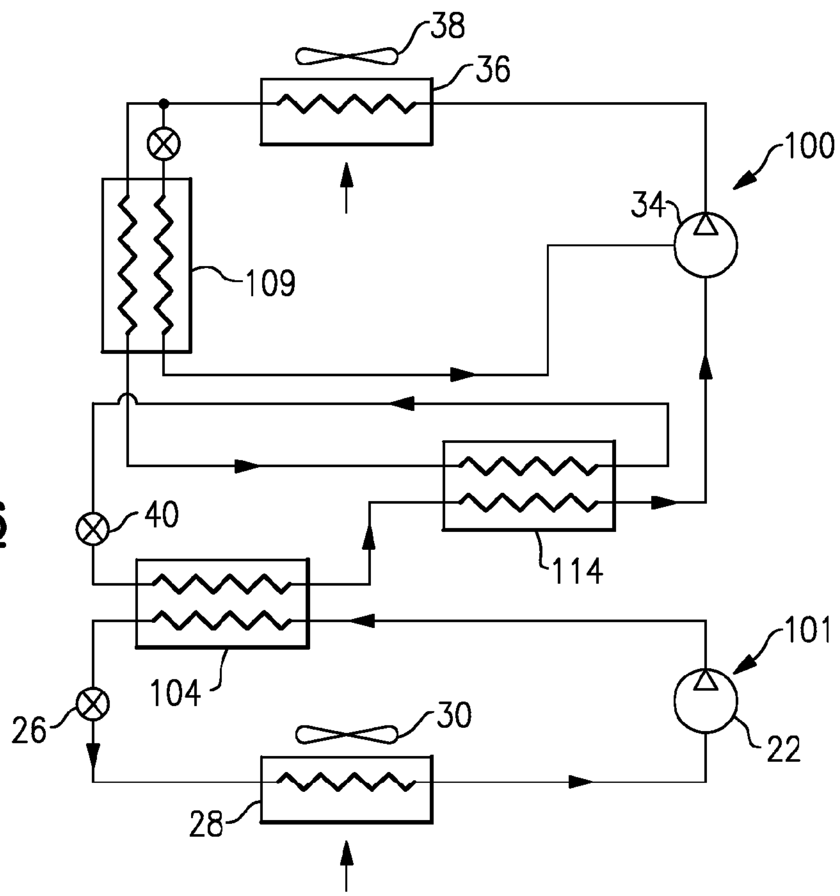
38
36
100
34
109
40
114
104
101
26
30
22
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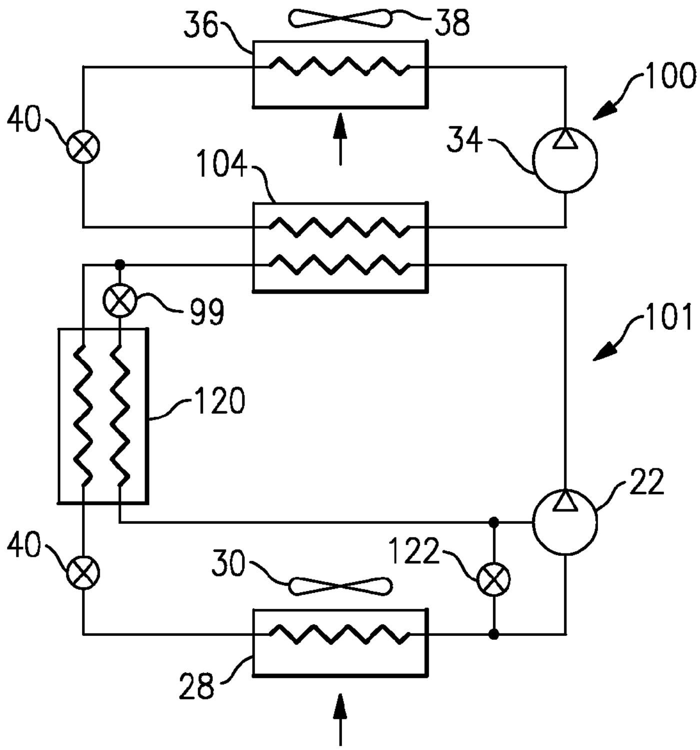
FIG.6



36
38
100
40
34
104
99
101
120
22
40
122
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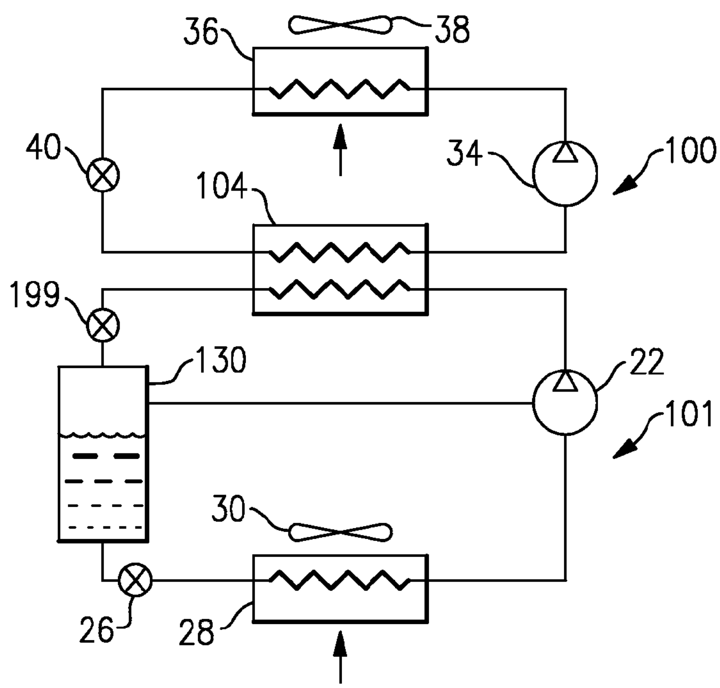
28

FIG.7



36
38
40
34
100
104
199
130
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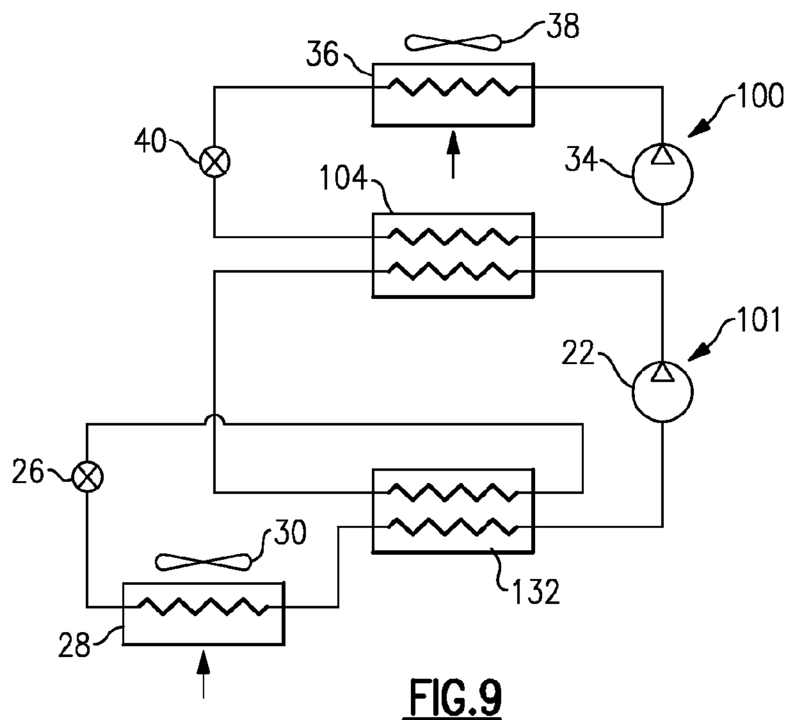
101
30
26
28

FIG.8


38
36
100
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34
104
101
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26
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132
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FIG.9

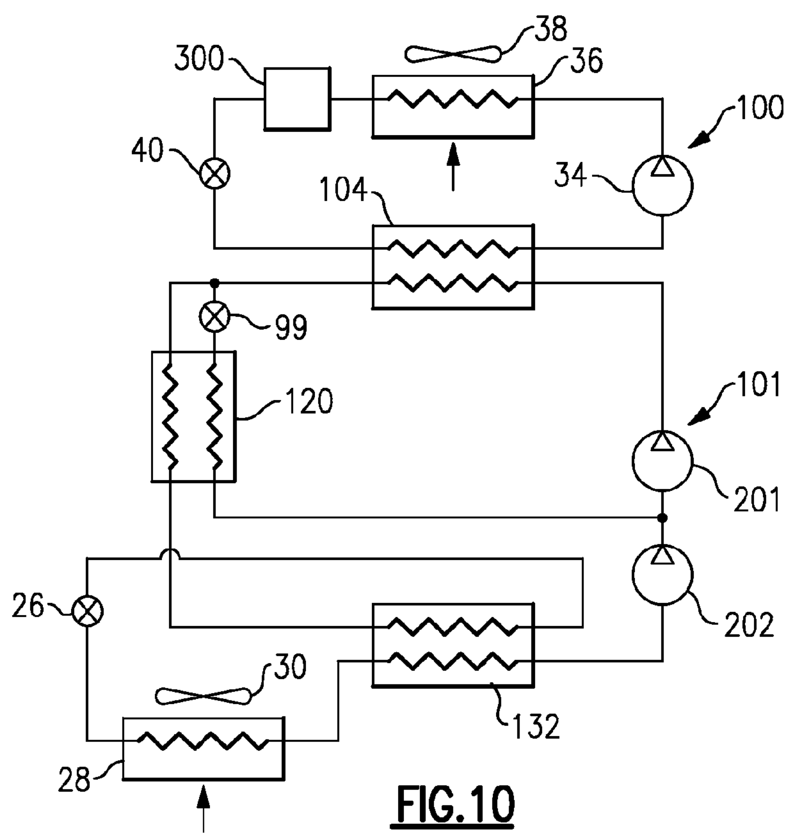
38
300
36
100
40
34
104
99
120
101
201
26
202
30
132
28

FIG.10

REFRIGERANT SYSTEM WITH CASCADED CIRCUITS AND PERFORMANCE ENHANCEMENT FEATURES

BACKGROUND OF THE INVENTION

[0001] This application relates to refrigerant systems with at least two cascaded circuits, and more particularly, to cascade refrigerant systems with performance enhancement features.

[0002] For instance, two distinct refrigerants can be utilized in each of the two circuits, with a hydrocarbon refrigerant utilized only in the upper stage circuit and another refrigerant utilized in the lower stage circuit. The hydrocarbon type of refrigerant can be, for example, propane or isobutene refrigerant. Since the upper stage circuit can be located outside of the enclosed conditioned compartment, it would offer an advantage of locating the flammable refrigerant also outside of the enclosed space, which would mitigate flammability concerns of these refrigerants. By utilizing the two cascaded circuits, the amount of charge in the upper stage circuit would be substantially reduced as compared to a single circuit refrigerant system. Since the amount of charge in the upper circuit is minimized, the concerns for the flammability of the refrigerant in this circuit are also reduced.

[0003] Historically, conventional HFC and HCFC refrigerants such as R22, R123, R407C, R134a, R410A and R404A, have been utilized in air conditioning and refrigeration applications. However, recent, concerns about global warming and, in some cases, ozone depletion promoted usage of natural refrigerants such as R744 (CO_2), R718 (water) and R717 (ammonia). In particular, CO_2 is a promising natural refrigerant that has zero ozone depletion potential and extremely low global warming potential of one. Thus, CO_2 is becoming more widely used as a replacement refrigerant for conventional HFC refrigerants. However, there are challenges for a refrigerant system designer with regard to utilizing CO_2. Due to its low critical point, CO_2 often operates in a transcritical cycle (rejects heat above the two-phase dome or above the critical point) that has certain inefficiencies associated with this heat rejection process. Therefore, refrigerant systems utilizing CO_2 as a refrigerant do not always operate at the efficiency levels of traditional refrigerant systems.

[0004] One of the approaches to overcome the deficiencies of the CO_2 refrigerant is to utilize a cascaded design of the refrigerant system. For example, each of the two cascaded circuits can be charged with the CO_2 refrigerant. In this case, the system can be designed in such a way that each circuit would have a lower pressure differential across the circuit, than if only a single circuit refrigerant system was utilized. By reducing the pressure differential for each cascaded circuit the reliability and efficiency of the compressors can be increased. In another approach, the lower stage circuit is charged with the CO_2 refrigerant. Since only the lower stage circuit is charged with CO_2, this circuit would operate at much lower pressure as compared to a single circuit refrigerant system (not cascaded) charged with CO2 refrigerant. Propane or a like refrigerant would be utilized in the upper circuit. However, even after splitting a single circuit into two independent cascaded circuits, the refrigerant system designer is still faced with many challenges dealing with further improvements of the system efficiency and capacity control.

[0005] Various enhancement features are known to increase the functionality and performance of refrigerant systems. As one example, an economizer cycle may be incorporated into a refrigerant system for its performance boost. An economizer cycle operates to subcool a main refrigerant flow, and does so, in one variation, by tapping a portion of refrigerant from the main refrigerant flow and expanding this tapped refrigerant to some intermediate pressure. This expanded refrigerant is at a cooler temperature, and passes in a heat exchange relationship with the main refrigerant flow in an economizer heat exchanger. In a variation of the economizer cycle, a flash tank replaces the heat exchanger, where vapor and liquid refrigerant phases are separated, with the liquid flow continuing through the main circuit and the vapor flow injected into the compression process at some intermediate pressure. In either variation, a vapor refrigerant is returned to the compressor.

[0006] Another enhancement feature is a refrigerant bypass function. In a bypass function, at least a portion of partially compressed refrigerant is returned to a refrigerant suction line, allowing for unloading of the refrigerant system.

[0007] Still another enhancement feature is a liquid-suction heat exchanger. In a liquid-suction heat exchanger, refrigerant downstream of an evaporator passes in heat exchange relationship with a refrigerant downstream of the condenser, allowing for additional subcooling and capacity increase of the refrigerant system. In the past, these enhancement features were associated with a standard circuit, where the circuit had an evaporator and gas cooler (or condenser).

[0008] However, none of the above-referenced enhancement features has been incorporated into a cascaded refrigerant system. In cascaded refrigerant systems, each of the cascaded circuits does not operate with an evaporator and gas cooler. Instead, the lower stage circuit has an evaporator and shares the common refrigerant-to-refrigerant heat exchanger with the upper stage circuit. The upper circuit has the gas cooler and shares the same common refrigerant-to-refrigerant heat exchanger with the lower circuit. In other words, there is no evaporator associated with the upper circuit and there is no gas cooler associated with the lower circuit.

[0009] This invention provides additional design features enhancing the cascaded system performance and functionality to become comparable to the traditional refrigerant systems for a wide spectrum of operating and environmental conditions as described in the main body of this application.

SUMMARY OF THE INVENTION

[0010] In this invention, cascaded refrigerant circuits are incorporated into a refrigerant system design. As one particular application, an upper stage circuit includes a hydrocarbon refrigerant, such as for example propane or isobutene, which can be located outdoors. The upper stage circuit is positioned in a cascaded relationship with a lower stage circuit, which would normally utilize the CO_2 refrigerant. The upper stage circuit is mainly located in the outdoor environment, while the lower stage circuit is normally located in the indoor environment. However, other locations would also fall within the scope of this invention. As one of the features of this invention, the lower stage inside CO_2 circuit operates in a subcritical region while the upper stage outside cascaded circuit would operate in a transcritical region if it was charged with the same CO_2 refrigerant. The combination of the two circuits provides performance enhancements for the supercritical region operation of the CO_2 circuit. To enhance the operation of the cascaded refrigerant system at least one of the circuits can be equipped with the economized cycle, utilizing either economizer heat exchanger or flash tank arrangements. Additionally, or as a stand alone feature, at least one of the circuits can be equipped with a liquid suction heat exchanger. Further, an unloading feature can be provided for one or both cascaded refrigerant circuits.

[0011] These and other features of the present invention can be best understood from the following specification and drawings, the following of which is a brief description.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] FIG. **1** shows a schematic of prior art system

[0013] FIG. **2** generally illustrates a feature of this prior art.

[0014] FIG. **3** shows a first embodiment of the present invention.

[0015] FIG. **4** shows a second embodiment of the present invention.

[0016] FIG. **5** shows a third embodiment of the present invention.

[0017] FIG. **6** shows a fourth embodiment of the present invention.

[0018] FIG. **7** shows a fifth embodiment of the present invention.

[0019] FIG. **8** shows a sixth embodiment of the present invention.

[0020] FIG. **9** shows a seventh embodiment of the present invention.

[0021] FIG. **10** shows an eighth embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0022] FIG. **1** shows a prior art refrigerant system **20** incorporating two cascaded circuits **21** and **23**. A lower stage circuit **23** includes a compressor **22** delivering a compressed refrigerant into a refrigerant-to-refrigerant heat exchanger **24**. Heat exchanger **24** is preferably positioned outside of an environment **32** to be conditioned. Refrigerant passes from the heat exchanger **24** through an expansion device **26**, and to an indoor heat exchanger **28**. As known, a fan **30** blows air over external surfaces of the indoor heat exchanger **28** and delivers that conditioned air into the environment **32**. The lower stage circuit **23** would normally be charged with a refrigerant that would operate in a subcritical region. One such refrigerant that can be used for this circuit would be CO_2 refrigerant that, while in the lower cascaded circuit, would still be in the subcritical region. If this same CO_2 refrigerant would have been used in the upper cascaded circuit, it is likely to operate at transcritical regime.

[0023] In the upper stage circuit **21**, a compressor **34** compresses a refrigerant and delivers it to a second outdoor heat exchanger **36**. A fan **38** blows air over the heat exchanger **36**. Refrigerant passes from the heat exchanger **36** downstream to an expansion device **40**, and then back through the refrigerant-to-refrigerant heat exchanger **24** to the compressor **22**.

[0024] FIG. **2** shows a P-h chart for the refrigerant system **20**.

[0025] The upper stage circuit **21** can be charged with a hydrocarbon refrigerant, and in particular, this refrigerant is disclosed as one of propane or isobutene. It is known that propane and isobutene have great thermo-physical properties as refrigerants, however, they are both potentially explosive, and there are safety concerns to use them, especially in confined environments. By limiting hydrocarbon refrigerant applications to the outdoor heat exchangers, the problem of explosiveness is significantly reduced. Further, by charging only the upper stage cascaded circuit **21** with the hydrocarbon refrigerant, the refrigerant system designer reduces the total amount of the hydrocarbon refrigerant used within the refrigerant system **20**, consequently decreasing the flammability risk from using hydrocarbon refrigerants. Moreover, by positioning the fans **38** in an optimum orientation with respect to heat exchanger **36**, any leakage or accidental discharge of the hydrocarbon refrigerant into the conditioned space can be directed toward the outdoor environment, thus further minimizing risks of explosion.

[0026] The lower stage cascaded circuit **23** preferably operates in a subcritical region. Further, while it is disclosed that the upper stage cascaded circuit **21** operates with a hydrocarbon refrigerant, the circuit **21** can operate with other suitable refrigerants.

[0027] In disclosed embodiments, additional enhancement features are provided to allow the cascaded circuits to perform more efficiently.

[0028] As shown in FIG. **3**, the upper stage cascaded circuit **100** is equipped with an economizer function **102** that would increase the capacity and amount of subcooling to the main refrigerant flow for this upper stage cascaded economized circuit **100**. Consequently, the performance of the lower stage cascaded circuit **101** is also enhanced, since the performance of the refrigerant-to-refrigerant heat exchanger **104**, that provides heat transfer interaction means between the upper stage cascaded circuit **100** and the lower stage cascaded circuit **101** and serves as a condenser for the lower stage cascaded circuit **101**, is increased. An economizer heat exchanger **109** and an economizer expansion device **99** are shown. Therefore, the capacity and efficiency of the overall cascaded refrigerant system shown in FIG. **3** is augmented. As an additional enhancement feature, a bypass valve **106** can be installed to connect an intermediate pressure side **107** of the upper stage cascaded circuit **100** to the suction pressure side **108** of this circuit. Selective opening of the bypass valve **106** provides the compressor unloading and capacity control means for the upper stage cascaded circuit **100**, and therefore for the entire refrigerant system.

[0029] The economizer function **102** provided for the upper stage cascaded circuit **100** by the economizer heat exchanger **109** in the FIG. **3** embodiment can be also provided by a flash tank **112**, as shown in FIG. **4**, and an expansion device **199**.

[0030] In general, the use of economized circuits improves the system efficiency, but also provides capacity control by selectively engaging these circuits. As known, there are many variations of the economizer cycle schematics, all of which can benefit and are within the scope of the invention. Also, selectively opening and closing the bypass valve would provide additional flexibility for the capacity control for the cascaded refrigerant system.

[0031] The upper stage cascaded circuit **100** can also be equipped with a liquid-suction heat exchanger (LSHE) **114**, as shown in FIG. **5**, once again for the purpose of improving the capacity and amount of subcooling achieved in this upper stage cascaded circuit **100**, by transferring heat from the hot refrigerant in a refrigerant line **116** to the suction refrigerant vapor in a refrigerant line **108**.

[0032] Furthermore, FIG. **6** shows another embodiment where the economizer heat exchanger **109** and the liquid-suction heat exchanger **114** features are combined to achieve even further capacity and efficiency improvements for the upper stage cascaded circuit **100**, and thus for the entire cascaded refrigerant system.

[0033] FIG. **7** represents another cascaded schematic, where an economizer heat exchanger **120** is incorporated into the lower stage cascaded circuit **101**. As an illustration of the additional optional feature, this lower stage cascaded circuit **101** can also be equipped with an unloader valve **122**, which would allow for bypass of a portion of refrigerant from an intermediate pressure side to suction pressure side.

[0034] FIG. **8** shows yet another cascaded schematic where a flash tank **130** is incorporated into the lower stage cascaded circuit **101**.

[0035] FIG. **9** shows still another cascaded schematic where a liquid-suction heat exchanger **132** is incorporated into the lower stage cascaded circuit **101**.

[0036] FIG. **10** yet shows another yet another cascaded schematic where both functions of the liquid-suction heat exchanger **132** and economizer heat exchanger **120** are incorporated into the lower stage cascaded circuit **101**. These enhancement features can be used independently or in combination with each other. This embodiment shows a lower stage compressor **202** and an upper stage compressor **201**.

[0037] FIG. **10** also schematically shows a "black box" **300**, which illustrates a performance enhancement feature such as disclosed in any of the above embodiments. That is, both circuits can be provided with such a feature.

[0038] It should be noted that the performance enhancement features described above could be incorporated and operated independently or in combination with each other for each of the cascaded circuits within the refrigerant system. Also, it has to be understood that there could be more than two cascaded circuits operating within a refrigerant system. Obviously, in many cases, it would make more sense to apply performance enhancement features listed above to the cascaded circuits charged with the refrigerants that don't operate well in the basic refrigerant cycle.

[0039] It should be pointed out that many different compressor types could be used in this invention. For example, scroll, screw, rotary, or reciprocating compressors can be employed.

[0040] The refrigerant systems that utilize this invention can be used in many different applications, including, but not limited to, air conditioning systems, heat pump systems, marine container units, refrigeration truck-trailer units, and supermarket refrigeration systems.

[0041] Although embodiments of this invention have been disclosed, a worker of ordinary skill in the art would recognize that certain modifications would come within the scope of this invention. For that reason, the following claims should be studied to determine the true scope and content of this invention.

1. A refrigerant system comprising:

at least one pair of circuits operated in a cascade fashion, with a first circuit including a first compressor compressing a refrigerant and delivering the refrigerant to a heat rejection heat exchanger, refrigerant passing from said heat rejection heat exchanger through an expansion device, and then to a refrigerant-to-refrigerant heat exchanger, refrigerant from said refrigerant-to-refrigerant heat exchanger being returned to said first compressor;

a second circuit, said second circuit including a second compressor, said second compressor delivering refrigerant to said refrigerant-to-refrigerant heat exchanger, refrigerant from said refrigerant-to-refrigerant heat exchanger passing through an expansion device, and then through said heat accepting heat exchanger;

said refrigerant-to-refrigerant heat exchanger providing heat transfer communication between said first circuit and said second circuit;

said first circuit utilizing a first refrigerant, and said second circuit utilizing a second refrigerant; and

at least one additional performance enhancement feature incorporated in at least one of said first circuit or said second circuit.

2. The refrigerant system as set forth in claim **1**, wherein said additional performance enhancement feature is an economizer.

3. The refrigerant system as set forth in claim **2**, wherein the economizer function is provided by an economizer heat exchanger.

4. The refrigerant system as set forth in claim **2**, wherein said economizer function is provided by a flash tank.

5. The refrigerant system as set forth in claim **2**, wherein a bypass function is also incorporated into the refrigerant system.

6. The refrigerant system as set forth in claim **5**, wherein the economizer and the bypass function are both included in the first circuit.

7. The refrigerant system as set forth in claim **5**, wherein the economizer and the bypass function are both included in the second circuit.

8. The refrigerant system as set forth in claim **2**, wherein the economizer is included in the first circuit.

9. The refrigerant system as set forth in claim **2**, wherein the economizer is included in the second circuit.

10. The refrigerant system as set forth in claim **1**, wherein the additional performance enhancement feature is a liquid-suction heat exchanger.

11. The refrigerant system as set forth in claim **10**, wherein an economizer is also included in the refrigerant system.

12. The refrigerant system as set forth in claim **11**, wherein the liquid-suction heat exchanger and the economizer are both included in the first circuit.

13. The refrigerant system as set forth in claim **11**, wherein the liquid-suction heat exchanger and the economizer are both included in a second circuit.

14. The refrigerant system as set forth in claim **10**, wherein the liquid-suction heat exchanger is included in the first circuit.

15. The refrigerant system as set forth in claim **10**, wherein the liquid-suction heat exchanger is included in the second circuit.

16. The refrigerant system as set forth in claim **1**, wherein said first refrigerant is hydrocarbon.

17. The refrigerant system as set forth in claim **1**, wherein said second refrigerant is CO2.

18. The refrigerant system as set forth in claim **1**, wherein said first refrigerant and said second refrigerant are the same refrigerants.

19. The refrigerant system as set forth in claim **1**, wherein said first refrigerant and said second refrigerant are different refrigerants.

20. The refrigerant system as set forth in claim **1**, wherein at least one circuit from said pair of circuits itself is represented by a pair of circuits.

21.-**42**. (canceled)

* * * * *