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(54) **MULTI-STAGE COMPRESSOR UNIT FOR REFRIGERATION SYSTEM**

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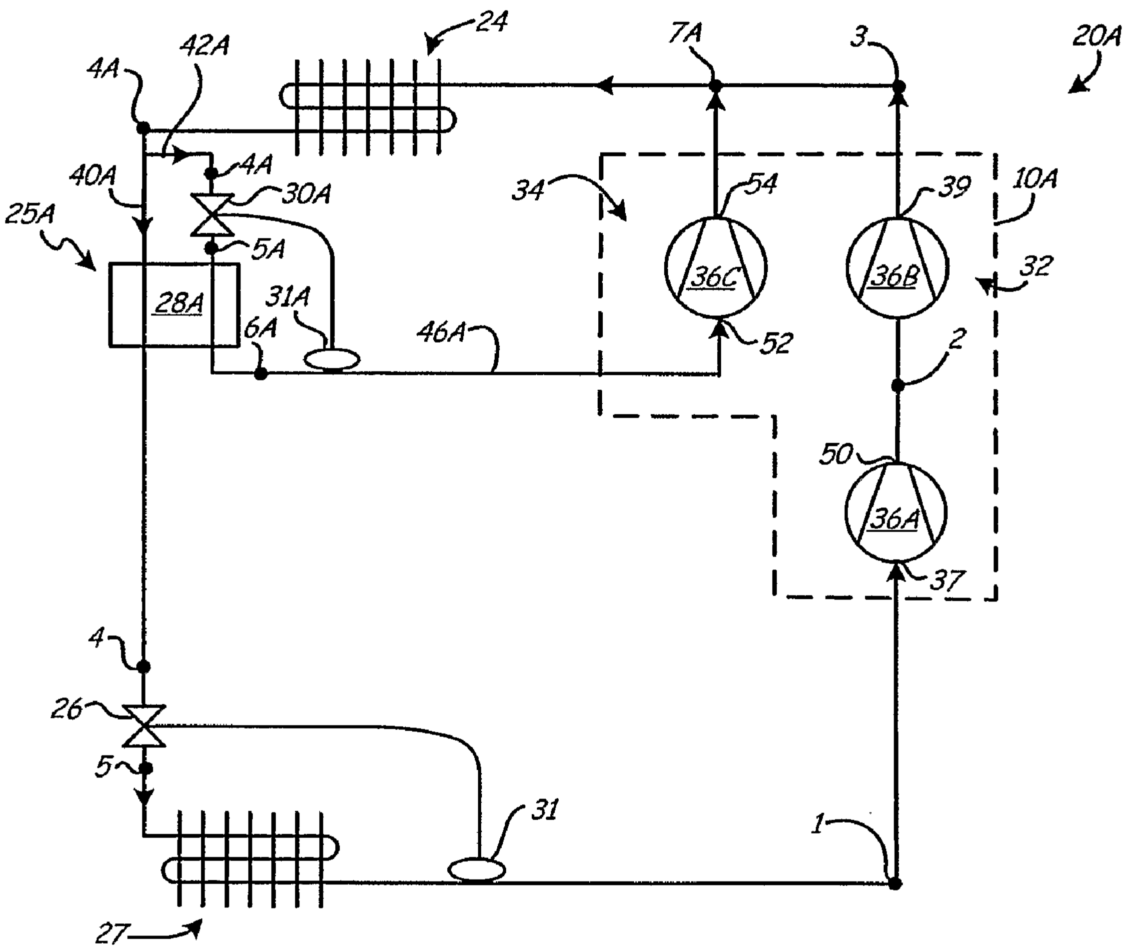
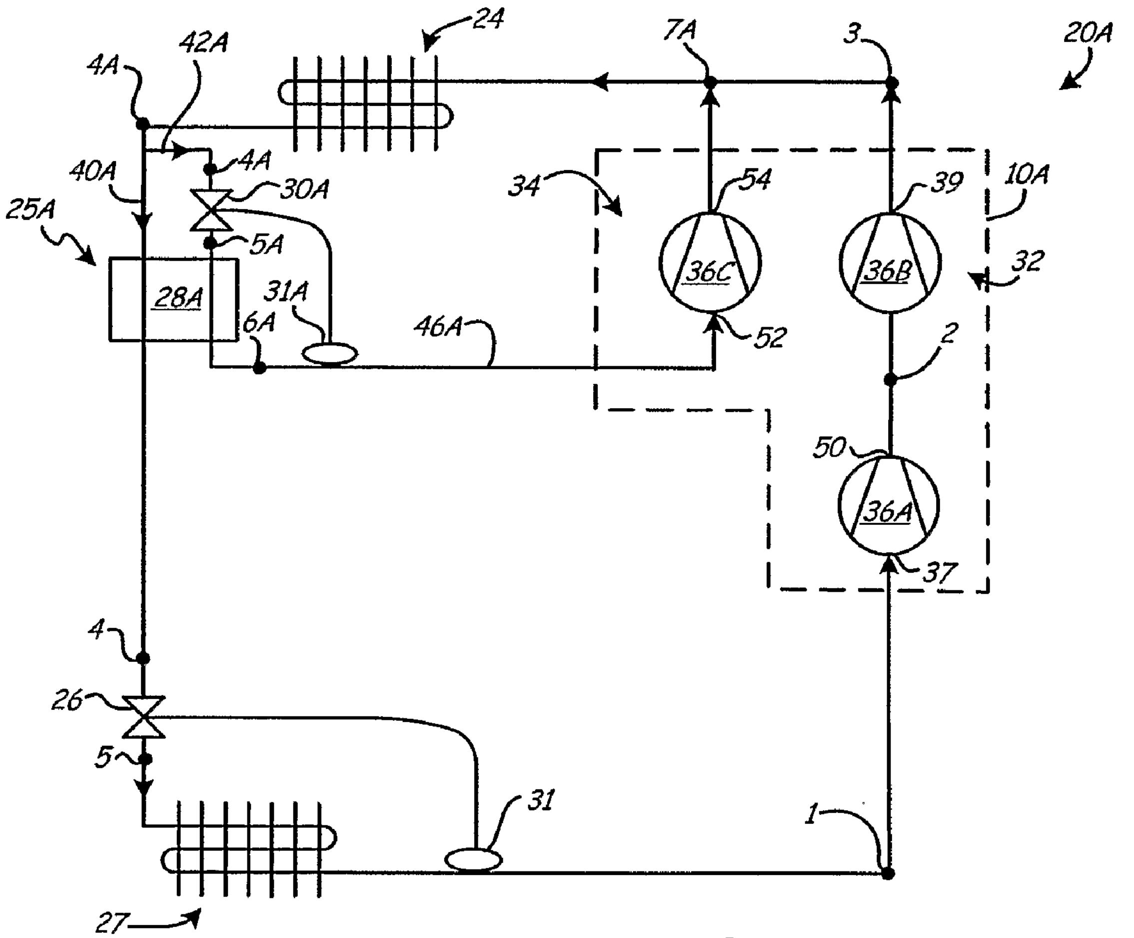
(57) **ABSTRACT**

A multi-stage compressor unit for a refrigeration system configured to circulate a refrigerant comprises a first compressor sub-unit having a first stage and a second stage, and a second compressor sub-unit in parallel with the first compressor sub-unit and having a first stage. The first and second stages of the first compressor sub-unit each have a suction port and a discharge port. The first compressor sub-unit is configured to receive and compress a first portion of the refrigerant from an evaporator. The first stage of the second compressor sub-unit is configured to compress a second portion of the refrigerant.

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7A
3
20A
4A
42A
4A
30A
40A
25A
5A
34
54
39
10A
36C
36B
32
28A
31A
6A
46A
52
2
50
36A
37
4
26
5
31
1
27

Fig. 1A

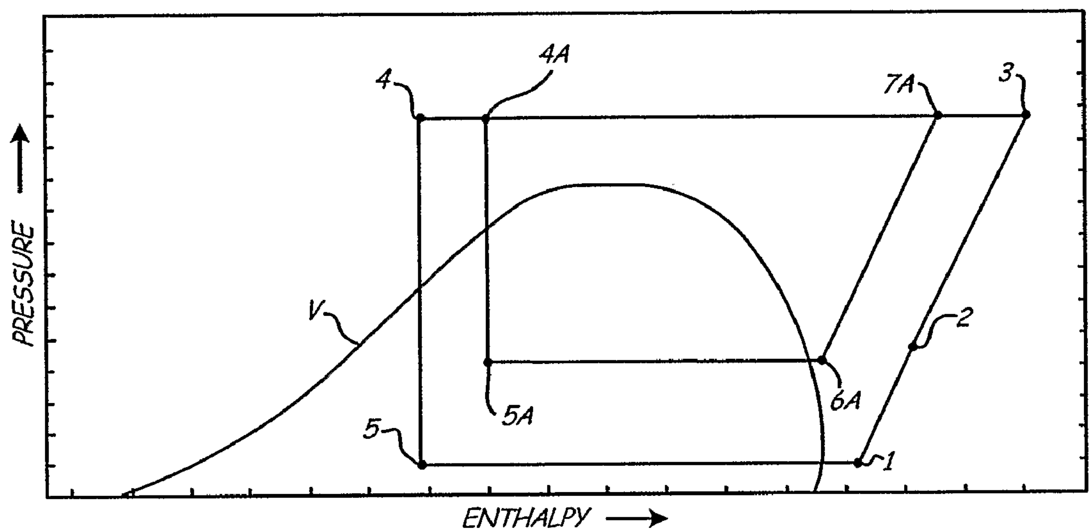
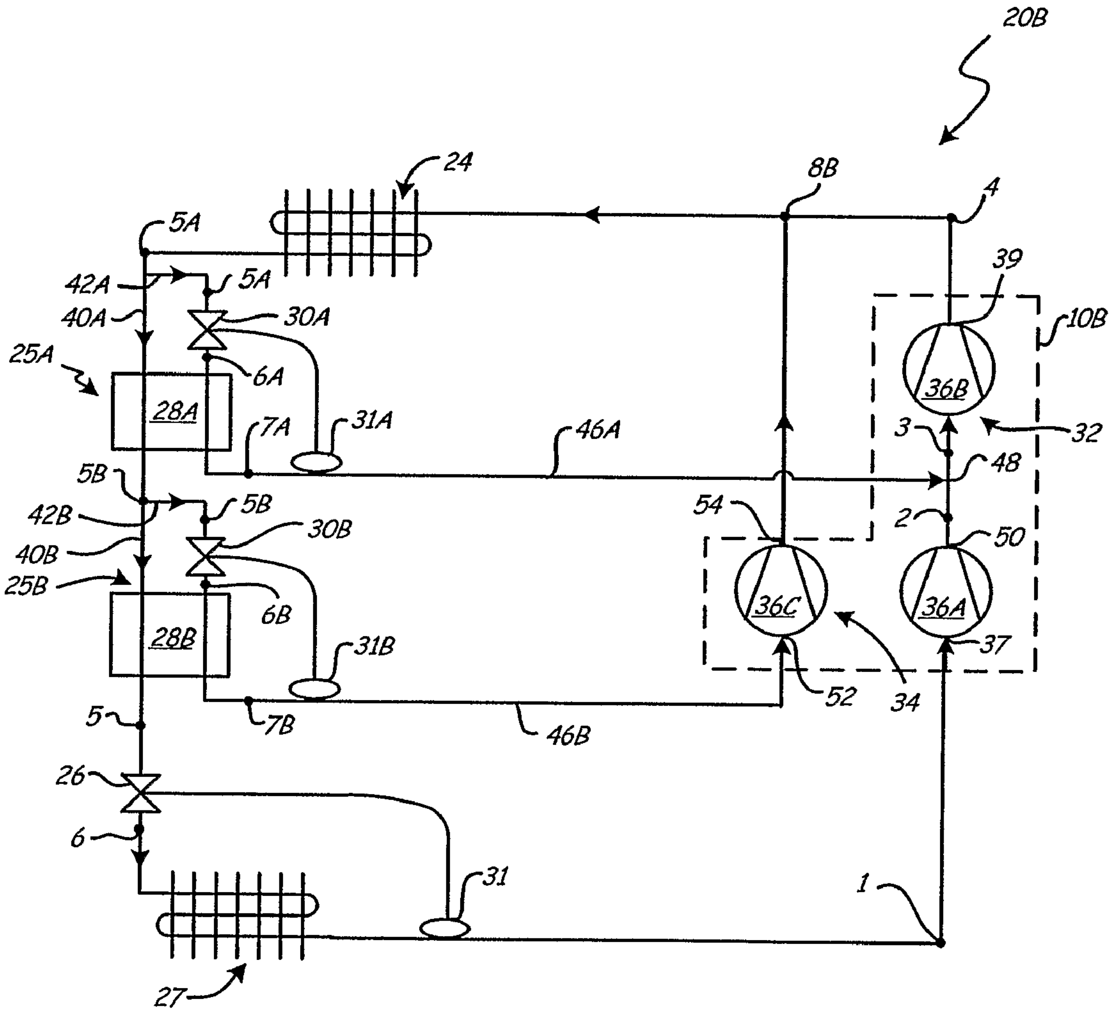


Fig. 1B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8B
4
5A
39
42A
5A
40A
30A
10B
25A
6A
36B
28A
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46A
3
32
5B
48
42B
5B
54
2
30B
50
40B
25B
6B
36C
36A
28B
31B
37
52
34
5
7B
46B
26
6
31
1
27

Fig. 2A

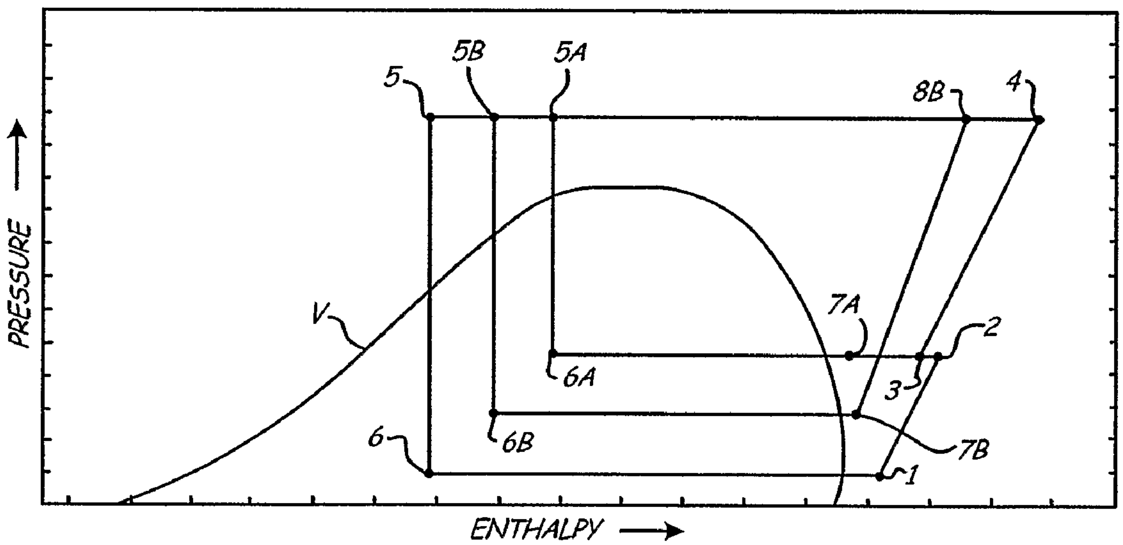
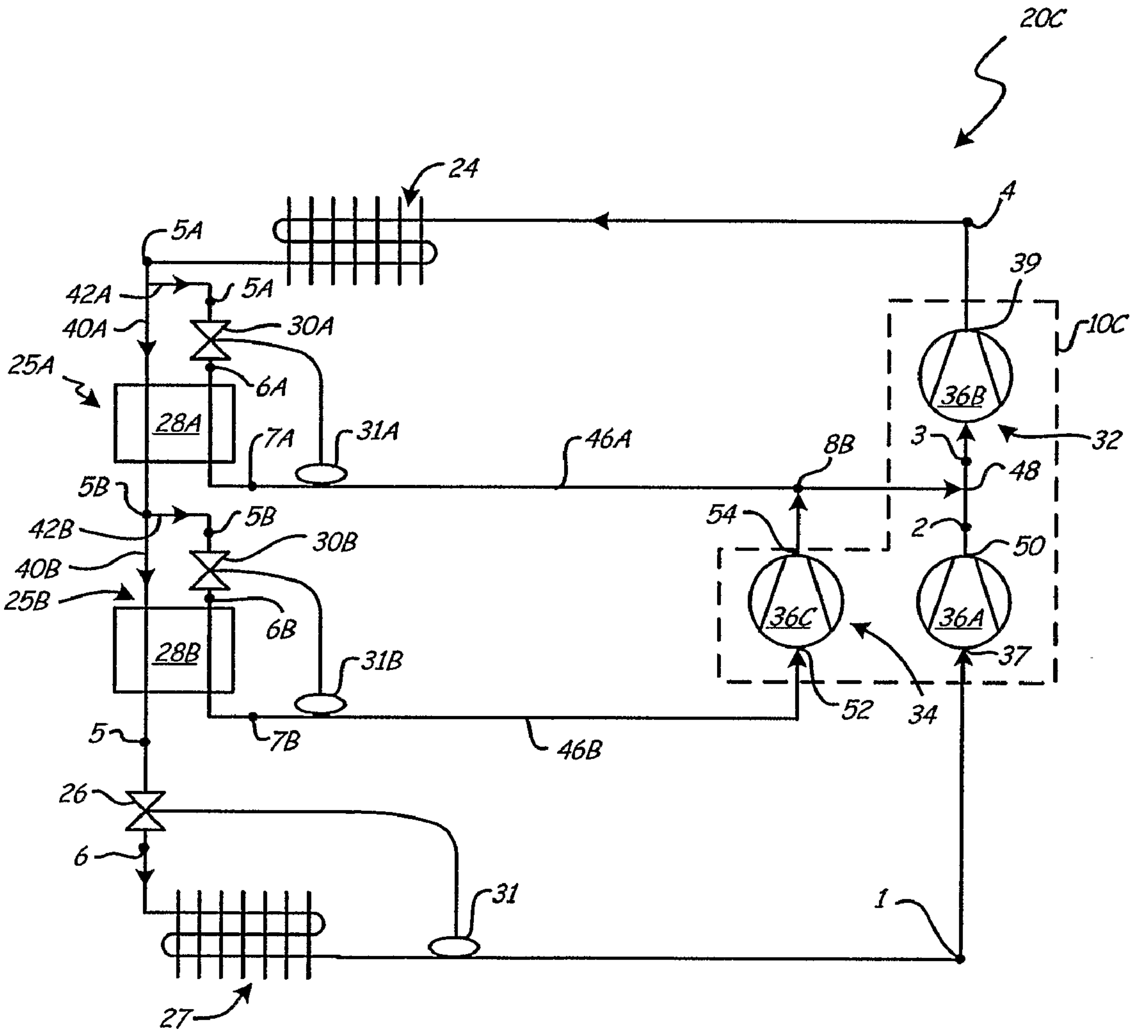


Fig. 2B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5A
42A
40A
30A
39
10C
25A
6A
28A
36B
7A
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8B
3
32
48
5B
5B
54
42B
2
30B
50
40B
25B
6B
36C
36A
28B
31B
37
52
34
5
7B
46B
26
6
31
1
27

Fig. 3A

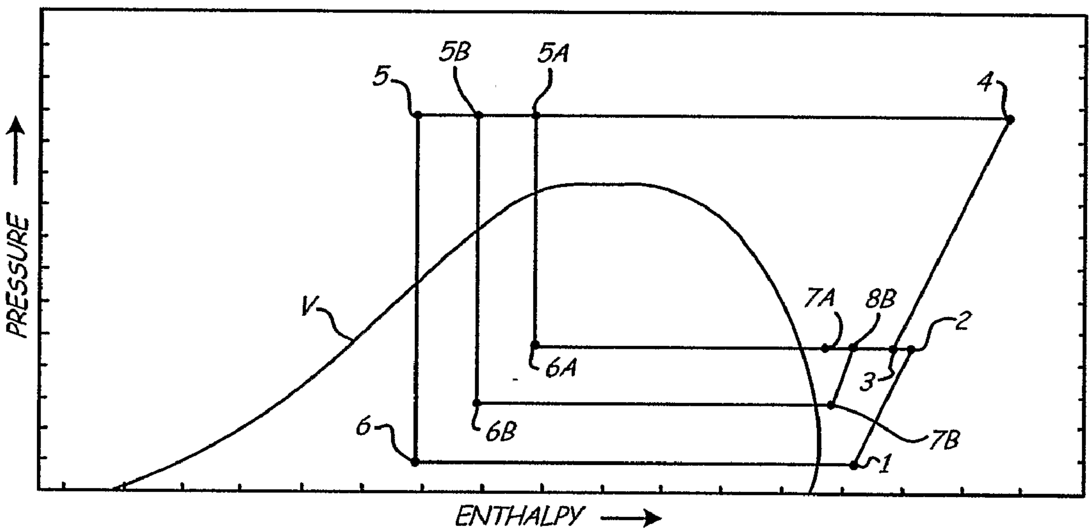
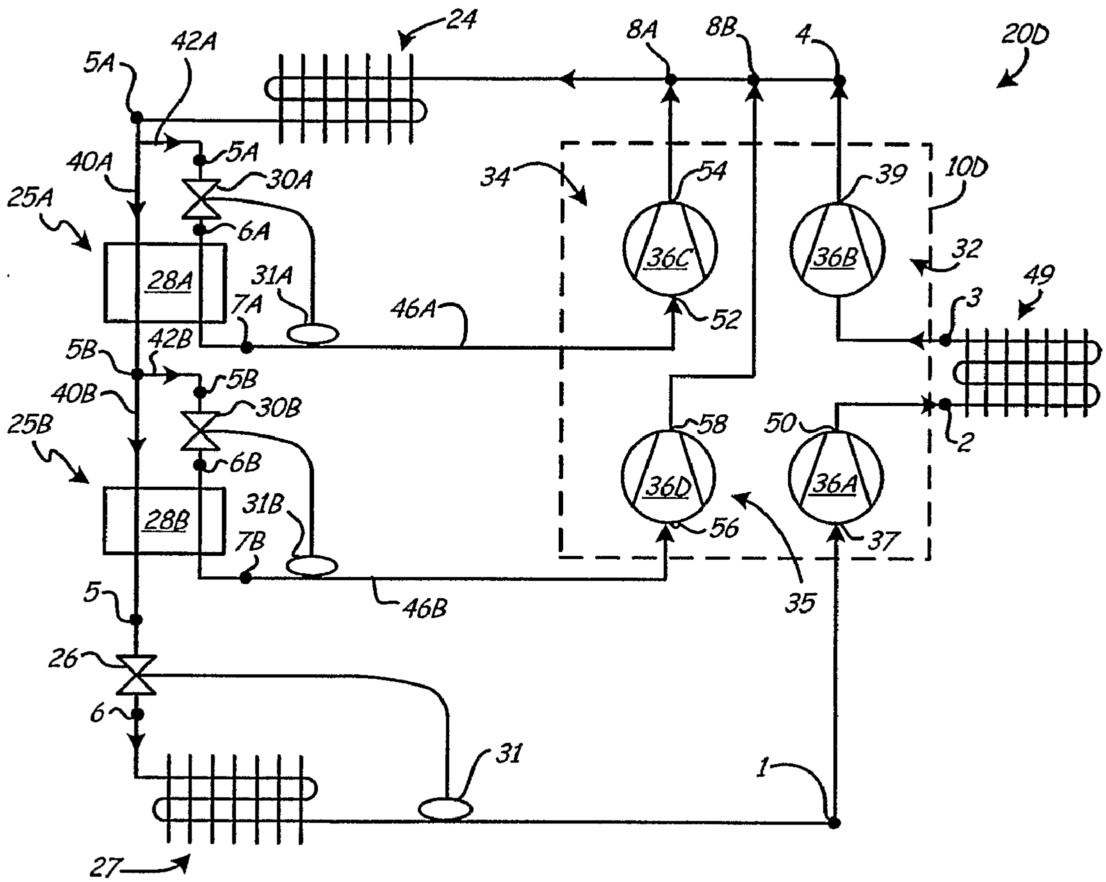


Fig. 3B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8B
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20D
5A
42A
5A
40A
30A
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54
39
10D
25A
6A
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31A
36C
36B
49
7A
46A
52
3
5B
42B
5B
40B
30B
58
50
2
25B
6B
36D
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56
37
7B
46B
35
5
26
6
31
1
27

Fig. 4A

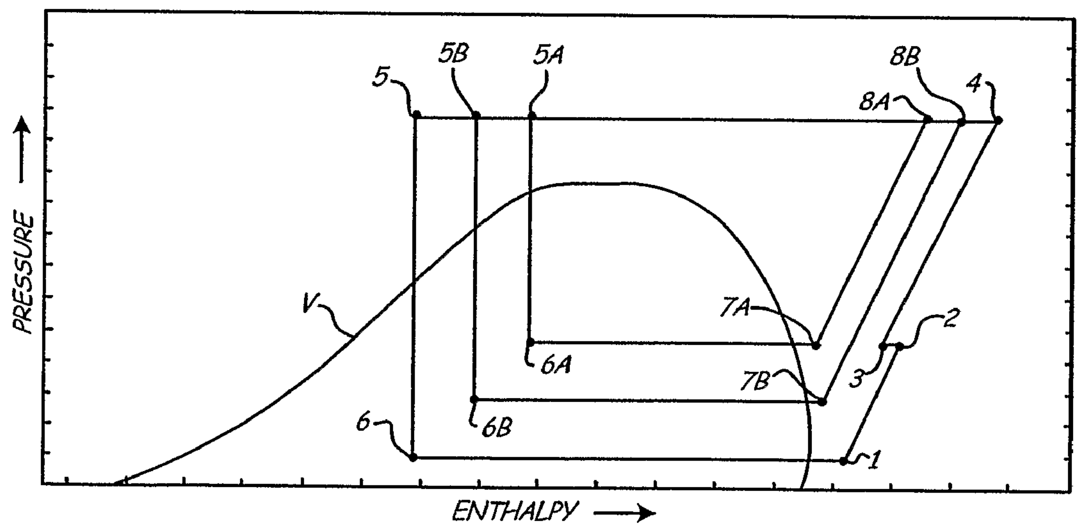
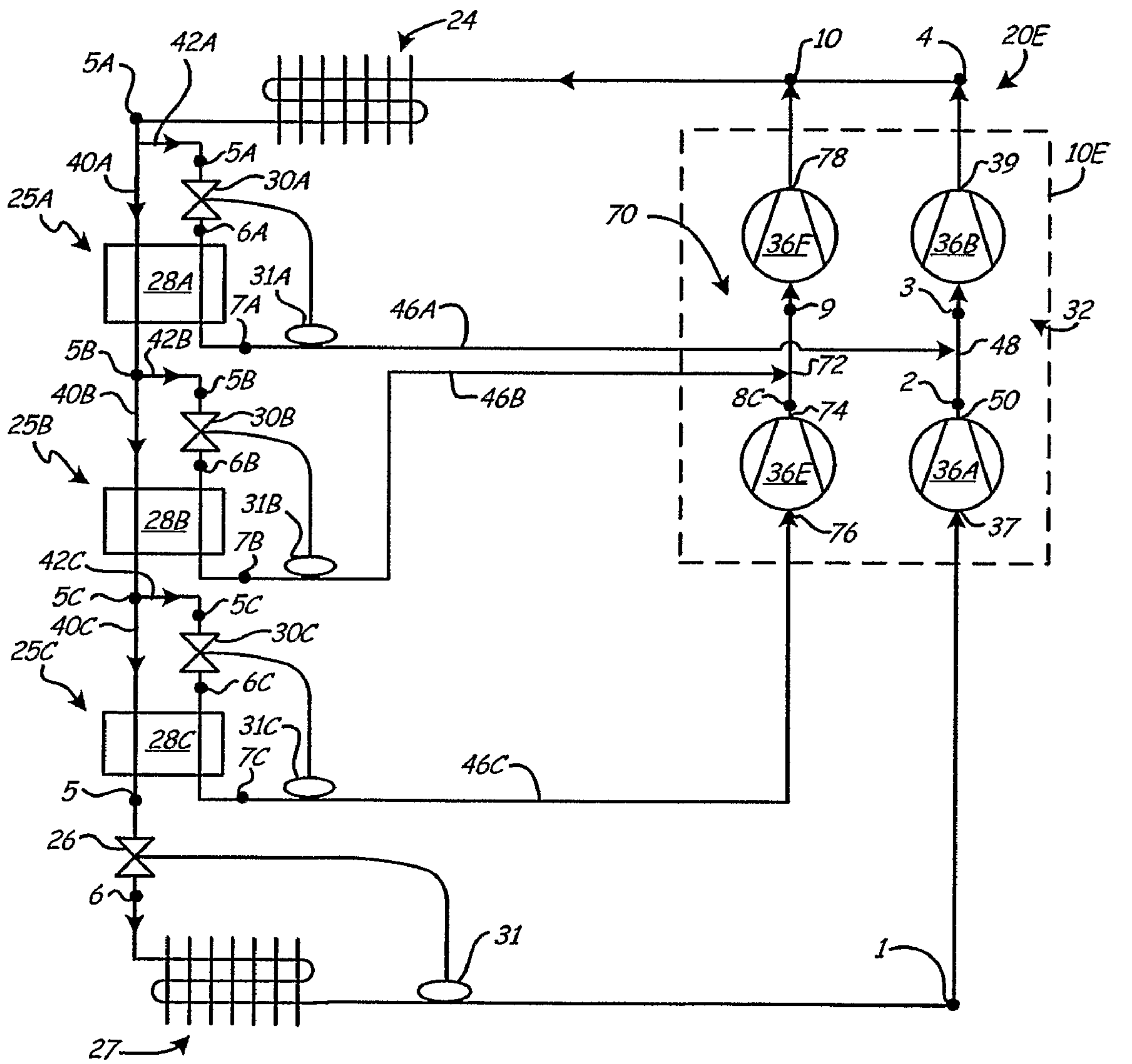


Fig. 4B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10
4
20E
5A
42A
40A
30A
6A
10E
78
39
70
36F
36B
25A
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31A
7A
46A
9
3
32
48
5B
42B
72
46B
40B
30B
8C
74
2
50
25B
6B
36E
36A
28B
31B
7B
76
37
42C
5C
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30C
25C
6C
28C
31C
7C
46C
5
26
6
31
1
27

Fig. 5A

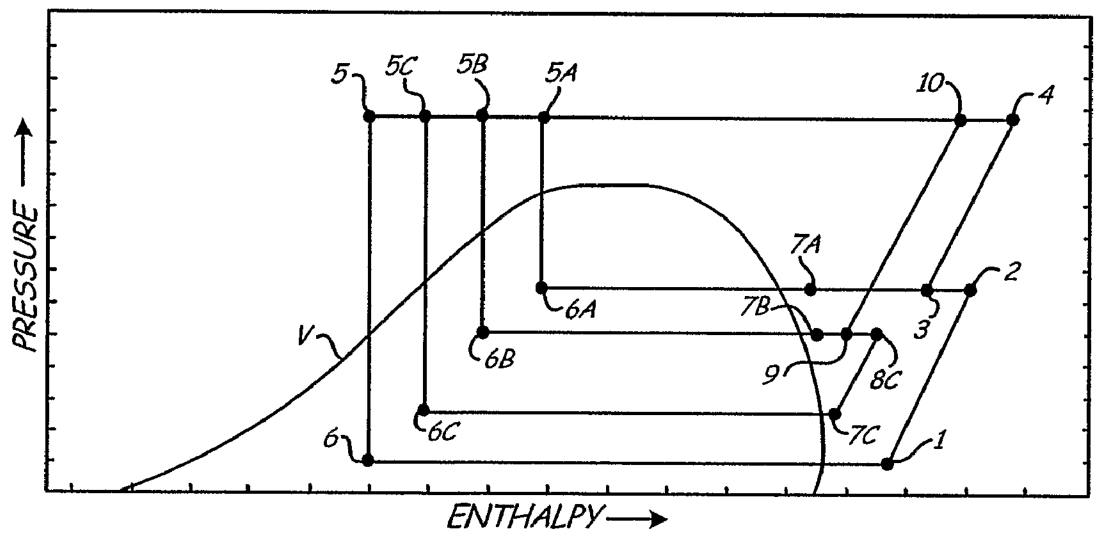

Fig. 5B

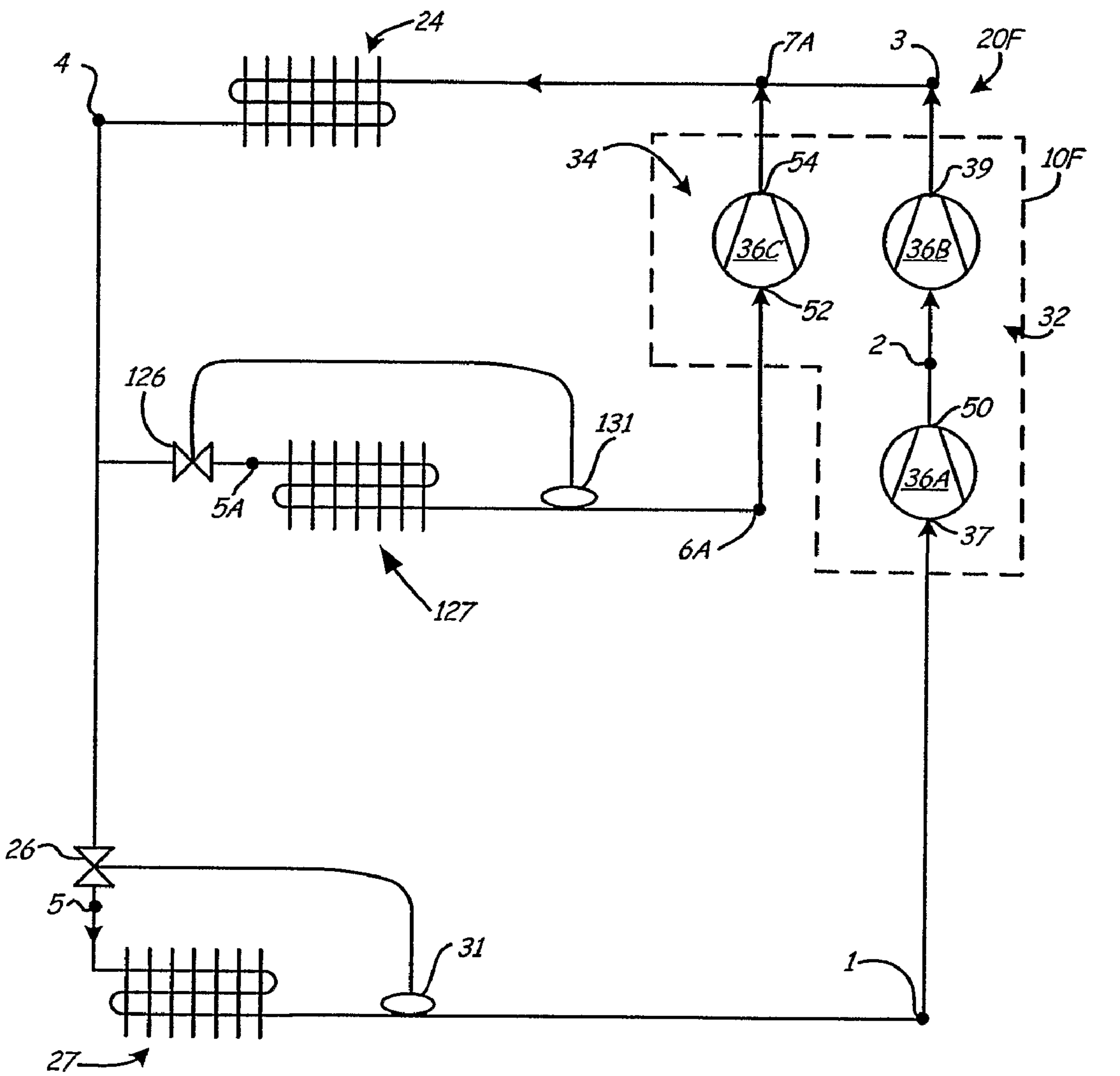
24
4
7A
3
20F
34
54
39
10F
36C
36B
52
32
2
126
131
50
36A
5A
6A
37
127
26
5
31
1
27

Fig. 6A

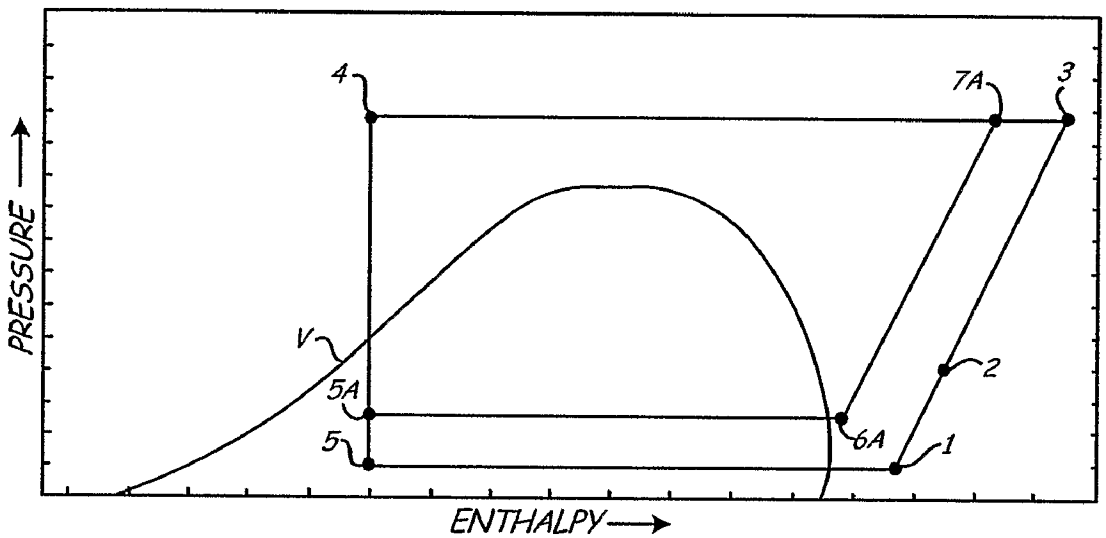

Fig. 6B

MULTI-STAGE COMPRESSOR UNIT FOR REFRIGERATION SYSTEM

BACKGROUND OF THE INVENTION

[0001] The present invention relates generally to compressors used in refrigeration systems. More particularly, the present invention relates to a multi-stage compressor unit for a refrigeration system that includes at least one two-stage compressor sub-unit.

[0002] A typical refrigeration system includes an evaporator, a compressor, a condenser, and a throttle valve. A refrigerant, such as a hydrofluorocarbon (HFC), typically enters the evaporator as a two-phase liquid-vapor mixture. Within the evaporator, the liquid portion of the refrigerant changes phase from liquid to vapor as a result of heat transfer into the refrigerant. The refrigerant is then compressed within the compressor, thereby increasing the pressure of the refrigerant. Next, the refrigerant passes through the condenser, where it changes phase from a vapor to a liquid as it cools within the condenser. Finally, the refrigerant expands as it flows through the throttle valve, which results in a decrease in pressure and a change in phase from a liquid to a two-phase liquid-vapor mixture.

[0003] While natural refrigerants such as carbon dioxide have recently been proposed as alternatives to the presently used HFCs, the high side pressure of carbon dioxide typically ends up in the supercritical region where there is no transition from vapor to liquid as the high pressure refrigerant is cooled. For a typical single stage vapor compression cycle, this leads to poor efficiency due to the loss of the subcritical constant temperature condensation process and to the relatively high residual enthalpy of supercritical carbon dioxide at normal high side temperatures.

[0004] Thus, there exists a need for a compressor unit for a refrigeration system that is capable of utilizing any refrigerant, including a transcritical refrigerant, while helping to maintain a high level of system efficiency.

BRIEF SUMMARY OF THE INVENTION

[0005] The present invention is a multi-stage compressor unit for a refrigeration system configured to circulate a refrigerant. The multi-stage compressor unit comprises a first compressor sub-unit having a first stage and a second stage, and a second compressor sub-unit in parallel with the first compressor sub-unit and having a first stage. The first and second stages of the first compressor sub-unit each have a suction port and a discharge port. The first compressor sub-unit is configured to receive and compress a first portion of the refrigerant from an evaporator. The first stage of the second compressor sub-unit has a suction port and a discharge port. The second compressor sub-unit is configured to compress a second portion of the refrigerant

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] FIG. **1**A illustrates a schematic diagram of a first alternative embodiment of a multi-stage compressor unit connected to a refrigeration system.

[0007] FIG. **1**B illustrates a graph relating enthalpy to pressure for the refrigeration system of FIG. **1**A.

[0008] FIG. **2**A illustrates a schematic diagram of a second alternative embodiment of a multi-stage compressor unit connected to a refrigeration system.

[0009] FIG. **2**B illustrates a graph relating enthalpy to pressure for the refrigeration system of FIG. **2**A.

[0010] FIG. **3**A illustrates a schematic diagram of a third alternative embodiment of a multi-stage compressor unit connected to a refrigeration system.

[0011] FIG. **3**B illustrates a graph relating enthalpy to pressure for the refrigeration system of FIG. **3**A.

[0012] FIG. **4**A illustrates a schematic diagram of a fourth alternative embodiment of a multi-stage compressor unit connected to a refrigeration system.

[0013] FIG. **4**B illustrates a graph relating enthalpy to pressure for the refrigeration system of FIG. **4**A.

[0014] FIG. **5**A illustrates a schematic diagram of a fifth alternative embodiment of a multi-stage compressor unit connected to a refrigeration system.

[0015] FIG. **5**B illustrates a graph relating enthalpy to pressure for the refrigeration system of FIG. **5**A.

[0016] FIG. **6**A illustrates a schematic diagram of a sixth alternative embodiment of a multi-stage compressor unit connected to a refrigeration system.

[0017] FIG. **6**B illustrates a graph relating enthalpy to pressure for the refrigeration system of FIG. **6**A.

DETAILED DESCRIPTION

[0018] FIG. **1**A illustrates a schematic diagram of multi-stage compressor unit **10**A connected to refrigeration system **20**A, which includes heat rejecting heat exchanger **24**, first economizer circuit **25**A, main expansion valve **26**, evaporator **27**, and sensor **31**. First economizer circuit **25**A includes first economizer heat exchanger **28**A, expansion valve **30**A, and sensor **31**A. Although first economizer heat exchanger **28**A is depicted as a parallel flow tube-in-tube heat exchanger, multi-stage compressor unit **10**A is useful in refrigeration systems utilizing other types of economizer heat exchangers including, but not limited to, counter flow tube-in-tube heat exchangers, shell-in-tube heat exchangers, flash tanks, and brazed plate heat exchangers.

[0019] Multi-stage compressor unit **10**A includes two-stage compressor sub-unit **32** and single-stage compressor sub-unit **34**. As shown in FIG. **1**, two-stage compressor sub-unit **32** is a reciprocating compressor and includes cylinders **36**A and **36**B connected in series. Similarly, single-stage compressor sub-unit **34** is also a reciprocating compressor and includes cylinder **36**C. Although two-stage compressor sub-unit **32** and single-stage compressor sub-unit **34** are shown as reciprocating compressors, other types of compressors (in various combinations) may be used including, but not limited to, scroll, screw, rotary vane, standing vane, variable speed, hermetically sealed, and open drive compressors. However, for purposes of example, embodiments of the present invention will be described as including reciprocating-type compressor units having multiple stages represented by compression cylinders.

[0020] In refrigeration system **20**A, two distinct refrigerant paths are formed by connection of the various elements in the system. A main refrigerant path is created by a loop defined by the points **1**, **2**, **3**, **4**, and **5**. A first economized refrigerant path is created by a loop defined by the points **4**A, **5**A, **6**A, and **7**A. It should be understood that the paths are all closed paths that allow for continuous flow of refrigerant through refrigeration system **20**A.

[0021] In reference to the main refrigerant path, after refrigerant exits two-stage compressor sub-unit **32** at high pressure and enthalpy through discharge port **39** (point **3**), the refrigerant loses heat in heat rejecting heat exchanger **24**, exiting heat rejecting heat exchanger **24** at low enthalpy and high pressure (point **4**A). The refrigerant then splits into two flow paths **40**A and **42**A prior to entering first economizer heat exchanger **28**A. The main path continues along path **40**A through first economizer heat exchanger **28**A (point **4**). As the refrigerant in path **40**A flows through first economizer heat exchanger **28**A, it is cooled by the refrigerant in path **42**A of the first economized path.

[0022] Refrigerant from path **40**A is then throttled in main expansion valve **26**. Main expansion valve **26**, along with economizer expansion valve **30**A, is preferably a thermal expansion valve (TXV) or an electronic expansion valve (EXV). After going through an expansion process within main expansion valve **26** (point **5**), the refrigerant is a two-phase liquid-vapor mixture and is directed toward evaporator **27**. After evaporation of the remainder of the liquid (point **1**), the refrigerant enters two-stage compressor sub-unit **32** through suction port **37**. The refrigerant is compressed within cylinder **36**A, which is the first stage of two-stage compressor sub-unit **32**, and is then directed out discharge port **50** (point **2**). After the second stage of compression, the refrigerant is discharged through discharge port **39** (point **3**).

[0023] In reference to the first economized path, after refrigerant exits heat rejecting heat exchanger **24** at low enthalpy and high pressure (point **4**A) and splits into two flow paths **40**A and **42**A, the first economized path continues along path **42**A. In path **42**A, the refrigerant is throttled to a lower pressure by economizer expansion valve **30**A (point **5**A) prior to flowing through first economizer heat exchanger **28**A. The refrigerant from path **42**A that flowed through first economizer heat exchanger **28**A (point **6**A) is then directed along economizer return path **46**A and injected into suction port **52** of single-stage compressor sub-unit **34** for compression in single-stage compressor sub-unit **34**. After compression within single-stage compressor sub-unit **34**, refrigerant is discharged through discharge port **54** (point **7**A) where it merges with the refrigerant discharged from two-stage compressor sub-unit **32**.

[0024] Refrigeration system **20**A also includes sensor **31** disposed between evaporator **27** and multi-stage compressor unit **10**A along the main refrigerant path. In general, sensor **31** acts with expansion valve **26** to sense the temperature of the refrigerant leaving evaporator **27** and the pressure of the refrigerant in evaporator **27** to regulate the flow of refrigerant into evaporator **27** to keep the combination of temperature and pressure within some specified bounds. In a preferred embodiment, expansion valve **26** is an electronic expansion valve and sensor **31** is a temperature transducer such as a thermocouple or thermistor. In another embodiment, expansion valve **26** is a mechanical thermal expansion valve and sensor **31** includes a small tube that terminates in a pressure vessel filled with a refrigerant that differs from the refrigerant running through refrigeration system **20**A. As refrigerant from evaporator **27** flows past sensor **31** on its way toward multi-stage compressor unit **10**A, the pressure vessel will either heat up or cool down, thereby changing the pressure within the pressure vessel. As the pressure in the pressure vessel changes, sensor **31** sends a signal to expansion valve **26** to modify the pressure drop caused by the valve. Similarly, in the case of the electronic expansion valve, sensor **31** sends an electrical signal to expansion valve **26** which responds in a similar manner to regulate refrigerant flow. For example, if a return gas coming from evaporator **27** is too hot, sensor **31** will then heat up and send a signal to expansion valve **26**, causing the valve to open further and allow more refrigerant per unit time to flow through evaporator **27**, thereby reducing the heat of the refrigerant exiting evaporator **27**.

[0025] Economizer circuit **25**A also includes sensor **31**A that operates in a similar manner to sensor **31**. However, sensor **31**A senses temperature along economizer return path **46**A and acts with expansion valve **30**A to control the pressure drop within expansion valve **30**A instead. It should also be noted that sensors other than the ones previously described may be substituted for sensors **31** and **31**A.

[0026] By controlling the expansion valves **26** and **30**A, the operation of refrigeration system **20**A can be adjusted to meet the cooling demands and achieve optimum efficiency. In addition to adjusting the pressure drops associated with expansion valves **26** and **30**A, the displacements of cylinders **36**A, **36**B, and **36**C may also be adjusted to help achieve optimum efficiency of refrigeration system **20**A.

[0027] FIG. **1**B illustrates a graph relating enthalpy to pressure for the refrigeration system **20**A of FIG. **1**A. Vapor dome V is formed by a saturated liquid line and a saturated vapor line, and defines the state of the refrigerant at various points along the refrigeration cycle. Underneath vapor dome V, all states involve both liquid and vapor coexisting at the same time. At the very top of vapor dome V is the critical point. The critical point is defined by the highest pressure where saturated liquid and saturated vapor coexist. In general, compressed liquids are located to the left of vapor dome V, while superheated vapors are located to the right of vapor dome V.

[0028] Once again, in FIG. **1**B, the main refrigerant path is the loop defined by the points **1**, **2**, **3**, **4**, and **5**, and the first economized path is the loop defined by the points **4**A, **5**A, **6**A, and **7**A. The cycle begins in the main path at point **1**, where the refrigerant is at a low pressure and high enthalpy prior to entering multi-stage compressor unit **10**A. After a first stage of compression within cylinder **36**A of two-stage compressor sub-unit **32**, both the enthalpy and pressure increase as shown by point **2**. After a second stage of compression within cylinder **36**B, the refrigerant exits multi-stage compressor unit **10**A at high pressure and even higher enthalpy, as shown by point **3**. Then, as the refrigerant flows through heat rejecting heat exchanger **24**, enthalpy decreases while pressure remains constant. Prior to entering first economizer heat exchanger **28**A, the refrigerant splits into a main portion and a first economized portion as shown by point **4**A. The main portion is then throttled in main expansion valve **26**, decreasing pressure as shown by point **5**. Finally, the main portion of the refrigerant is evaporated, exiting evaporator **27** at a higher enthalpy as shown by point **1**.

[0029] As stated previously, the first economized portion splits off of the main portion as indicated by point **4**A. The first economized portion is throttled to a lower pressure in expansion valve **30**A as shown by point **5**A. The first economized portion of the refrigerant then exchanges heat with the main portion in first economizer heat exchanger **28**A, cooling down the main portion of the refrigerant as indicated by point **4**, and heating up the first economized portion of the refrigerant as indicated by point **6**A. The first economized portion is then compressed within single-stage compressor sub-unit **34** and merged with the main portion of the refrigerant discharged from two-stage compressor sub-unit **32**, as shown by point **7**A.

[0030] As shown in FIG. **1**B, cylinders **36**A, **36**B, and **36**C of multi-stage compressor unit **10**A are configured to receive and compress refrigerant to different pressures. In particular, cylinder **36**A receives and compresses refrigerant from the main refrigerant path to an intermediate pressure, as indicated by point **2**. Then, cylinder **36**B receives and compresses the refrigerant from an intermediate pressure to an exit pressure, as indicated by point **3**. Similarly, cylinder **36**C receives and compresses refrigerant from the first economized refrigerant path to an exit pressure, as indicated by point **7**A. As shown in FIG. **1**B, the exit pressure of cylinder **36**C is substantially equivalent to the exit pressure of cylinder **36**B. In refrigeration system **20**A, the exit pressures are determined by the inlet pressure required by heat rejecting heat exchanger **24**.

[0031] FIG. **2**A illustrates a schematic diagram of multi-stage compressor unit **10**B connected to refrigeration system **20**B. Multi-stage compressor unit **10**B is similar to multi-stage compressor unit **10**A. However, as will be discussed in more detail below, two-stage compressor sub-unit **32** further includes interstage port **48** configured to receive refrigerant from an economizer circuit to cool down the refrigerant in the main refrigerant path prior to a second stage of compression. Refrigeration system **20**B is similar to refrigeration system **20**A, but further includes second economizer circuit **25**B. Second economizer circuit **25**B includes second economizer heat exchanger **28**B, expansion valve **30**B, and sensor **31**B.

[0032] In refrigeration system **20**B, three distinct refrigerant paths are formed by connection of the various elements in the system. A main refrigerant path is created by a loop defined by the points **1**, **2**, **3**, **4**, **5**, and **6**. A first economized refrigerant path is created by a loop defined by the points **5**A, **6**A, **7**A, **3**, and **4**. Finally, a second economized refrigerant path is created by a loop defined by the points **5**B, **6**B, **7**B, and **8**B.

[0033] In reference to the main refrigerant path, after refrigerant exits two-stage compressor sub-unit **32** at high pressure and enthalpy through discharge port **39** (point **4**), the refrigerant loses heat in heat rejecting heat exchanger **24**, exiting heat rejecting heat exchanger **24** at low enthalpy and high pressure (point **5**A). The refrigerant then splits into two flow paths **40**A and **42**A prior to entering first economizer heat exchanger **28**A. The main path continues along paths **40**A and **40**B through first economizer heat exchanger **28**A (point **5**B) and second economizer heat exchanger **28**B (point **5**), respectively. As the refrigerant in path **40**A flows through first economizer heat exchanger **28**A, it is cooled by the refrigerant in path **42**A of the first economized path. Similarly, as the refrigerant in path **40**B flows through second economizer heat exchanger **28**B, it is cooled by the refrigerant in path **42**B of the second economized path.

[0034] Refrigerant from path **40**B is then throttled in main expansion valve **26**. After going through an expansion process within main expansion valve **26** (point **6**), the refrigerant is a two-phase liquid-vapor mixture and is directed toward evaporator **27**. After evaporation of the remainder of the liquid (point **1**), the refrigerant enters two-stage compressor sub-unit **32** through suction port **37**. The refrigerant is compressed within cylinder **36**A, which is the first stage of two-stage compressor sub-unit **32**, and is then directed out of discharge port **50** (point **2**), where it merges with the cooler refrigerant from economizer return path **46**A that is injected into interstage port **48** (point **3**). Thus, the refrigerant from economizer return path **46**A functions to cool down the refrigerant discharged from cylinder **36**A prior to the second stage of compression within cylinder **36**B. After the second stage of compression, the refrigerant is discharged through discharge port **39** (point **4**).

[0035] In reference to the first economized path, after refrigerant exits heat rejecting heat exchanger **24** at low enthalpy and high pressure (point **5**A) and splits into two flow paths **40**A and **42**A, the first economized path continues along path **42**A. In path **42**A, the refrigerant is throttled to a lower pressure by economizer expansion valve **30**A (point **6**A) prior to flowing through first economizer heat exchanger **28**A. The refrigerant from path **42**A that flowed through first economizer heat exchanger **28**A (point **7**A) is then directed along economizer return path **46**A and injected into interstage port **48** of two-stage compressor sub-unit **32** where it merges with refrigerant flowing through the main path to cool down the refrigerant (point **3**) prior to a second stage of compression in cylinder **36**B.

[0036] In reference to the second economized path, after being cooled in the higher pressure first economizer heat exchanger **28**A (point **5**B), the refrigerant in path **40**A splits into two flow paths **40**B and **42**B. The second economized path continues along flow path **42**B where the refrigerant is throttled to a lower pressure by economizer expansion valve **30**B (point **6**B) prior to flowing through second economizer heat exchanger **28**B. The refrigerant from path **42**B that flowed through second economizer heat exchanger **28**B (point **7**B) is then directed along economizer return path **46**B and injected into suction port **52** of single-stage compressor sub-unit **34** for compression in single-stage compressor sub-unit **34**. After compression within single-stage compressor sub-unit **34**, refrigerant is discharged through discharge port **54** (point **8**B) where it merges with the refrigerant discharged from two-stage compressor sub-unit **32**.

[0037] FIG. **2**B illustrates a graph relating enthalpy to pressure for the refrigeration system **20**B of FIG. **2**A. As shown in FIG. **2**B, the main refrigerant path is the loop defined by the points **1**, **2**, **3**, **4**, **5**, and **6**; the first economized path is the loop defined by the points **5**A, **6**A, **7**A, **3**, and **4**; and the second economized path is the loop defined by the points **5**B, **6**B, **7**B, and **8**B.

[0038] As shown in FIG. **2**B, cylinders **36**A, **36**B, and **36**C of multi-stage compressor unit **10**B are configured to receive and compress refrigerant to different pressures. In particular, cylinder **36**A receives and compresses refrigerant from the main refrigerant path to an intermediate pressure, as indicated by point **2**. Then, cylinder **36**B receives and compresses refrigerant from the main refrigerant path and the first economized path from an intermediate pressure to an exit pressure, as indicated by point **4**. Similarly, cylinder **36**C receives and compresses refrigerant from the second economized refrigerant path to an exit pressure, as indicated by point **8**B. As shown in FIG. **2**B, the exit pressure of cylinder **36**C is substantially equivalent to the exit pressure of cylinder **36**B.

[0039] FIG. **3**A illustrates a schematic diagram of multi-stage compressor unit **10**C connected to refrigeration system **20**C. Multi-stage compressor unit **10**C is similar to multi-stage compressor unit **10**B. However, as will be discussed in more detail below, single-stage compressor sub-unit **34** is configured to discharge into first economizer return path **46**A instead of into heat rejecting heat exchanger **24**, as depicted by multi-stage compressor unit **10**B of FIG. **2**A.

[0040] In refrigeration system **20**C, three distinct refrigerant paths are formed by connection of the various elements in the system. A main refrigerant path is created by a loop defined by the points **1**, **2**, **3**, **4**, **5**, and **6**. A first economized refrigerant path is created by a loop defined by the points **5**A, **6**A, **7**A, **3**, and **4**. Finally, a second economized refrigerant path is created by a loop defined by the points **5**B, **6**B, **7**B, **8**B, **3**, and **4**.

[0041] In reference to the main refrigerant path, after refrigerant exits two-stage compressor sub-unit **32** at high pressure and enthalpy through discharge port **39** (point **4**), the refrigerant loses heat in heat rejecting heat exchanger **24**, exiting heat rejecting heat exchanger **24** at low enthalpy and high pressure (point **5**A). The refrigerant then splits into two flow paths **40**A and **42**A prior to entering first economizer heat exchanger **28**A. The main path continues along paths **40**A and **40**B through first economizer heat exchanger **28**A (point **5**B) and second economizer heat exchanger **28**B (point **5**), respectively. As the refrigerant in path **40**A flows through first economizer heat exchanger **28**A, it is cooled by the refrigerant in path **42**A of the first economized path. Similarly, as the refrigerant in path **40**B flows through second economizer heat exchanger **28**B, it is cooled by the refrigerant in path **42**B of the second economized path.

[0042] Refrigerant from path **40**B is then throttled in main expansion valve **26**. After going through an expansion process within main expansion valve **26** (point **6**), the refrigerant is a two-phase liquid-vapor mixture and is directed toward evaporator **27**. After evaporation of the remainder of the liquid (point **1**), the refrigerant enters two-stage compressor sub-unit **32** through suction port **37**. The refrigerant is compressed within cylinder **36**A, which is the first stage of two-stage compressor sub-unit **32**, and is then directed out discharge port **50** (point **2**), where it merges with the cooler refrigerant from economizer return path **46**A that is injected into interstage port **48** (point **3**). Thus, the refrigerant from economizer return path **46**A functions to cool down the refrigerant discharged from cylinder **36**A prior to the second stage of compression within cylinder **36**B. After the second stage of compression, the refrigerant is discharged through discharge port **39** (point **4**).

[0043] In reference to the first economized path, after refrigerant exits heat rejecting heat exchanger **24** at low enthalpy and high pressure (point **5**A) and splits into two flow paths **40**A and **42**A, the first economized path continues along path **42**A. In path **42**A, the refrigerant is throttled to a lower pressure by economizer expansion valve **30**A (point **6**A) prior to flowing through first economizer heat exchanger **28**A. The refrigerant from path **42**A that flowed through first economizer heat exchanger **28**A (point **7**A) is then directed along economizer return path **46**A and injected into interstage port **48** of two-stage compressor sub-unit **32** where it merges with refrigerant flowing through the main path to cool down the refrigerant (point **3**) prior to a second stage of compression in cylinder **36**B.

[0044] In reference to the second economized path, after being cooled in the higher pressure first economizer heat exchanger **28**A (point **5**B), the refrigerant in path **40**A splits into two flow paths **40**B and **42**B. The second economized path continues along flow path **42**B where the refrigerant is throttled to a lower pressure by economizer expansion valve **30**B (point **6**B) prior to flowing through second economizer heat exchanger **28**B. The refrigerant from path **42**B that flowed through second economizer heat exchanger **28**B (point **7**B) is then directed along economizer return path **46**B and injected into suction port **52** of single-stage compressor sub-unit **34** for compression in single-stage compressor sub-unit **34**. After compression within single-stage compressor sub-unit **34**, the refrigerant is discharged through discharge port **54** where it is mixed with the refrigerant in economizer return path **46**A (point **8**B) prior to injection into interstage port **48** of two-stage compressor sub-unit **32** (point **3**).

[0045] FIG. **3**B illustrates a graph relating enthalpy to pressure for the refrigeration system **20**C of FIG. **3**A. As shown in FIG. **3**B, the main refrigerant path is the loop defined by the points **1**, **2**, **3**, **4**, **5**, and **6**; the first economized path is the loop defined by the points **5**A, **6**A, **7**A, **3**, and **4**; and the second economized path is the loop defined by the points **5**B, **6**B, **7**B, **8**B, **3**, and **4**.

[0046] As shown in FIG. **3**B, cylinders **36**A, **36**B, and **36**C of multi-stage compressor unit **10**C are configured to receive and compress refrigerant to different pressures. In particular, cylinder **36**A receives and compresses refrigerant from the main refrigerant path to an intermediate pressure, as indicated by point **2**. Similarly, cylinder **36**C receives and compresses refrigerant from the second economized refrigerant path to an exit pressure, as indicated by point **8**B. Then, cylinder **36**B receives and compresses refrigerant from the main refrigerant path, the first economized path, and the second economized path to an exit pressure, as indicated by point **4**. As shown in FIG. **3**B, the exit pressure of cylinder **36**C is substantially equivalent to the intermediate pressure of cylinder **36**A.

[0047] FIG. **4**A illustrates a schematic diagram of multi-stage compressor unit **10**D connected to refrigeration system **20**D. Multi-stage compressor unit **10**D is similar to multi-stage compressor unit **10**A. However, multi-stage compressor unit **10**D further includes single-stage compressor sub-unit **35** having cylinder **36**D.

[0048] Refrigeration system **20**D is similar to refrigeration system **20**C, except that interstage port **48** is replaced by intercooler **49**, which is configured to cool the main portion of the refrigerant between the first and second stages of compression in two-stage compressor sub-unit **32**.

[0049] In refrigeration system **20**D, three distinct refrigerant paths are formed by connection of the various elements in the system. A main refrigerant path is created by a loop defined by the points **1**, **2**, **3**, **4**, **5**, and **6**. A first economized refrigerant path is created by a loop defined by the points **5**A, **6**A, **7**A, and **8**A. Finally, a second economized refrigerant path is created by a loop defined by the points **5**B, **6**B, **7**B, and **8**B.

[0050] In reference to the main refrigerant path, after refrigerant exits two-stage compressor sub-unit **32** at high pressure and enthalpy through discharge port **39** (point **4**), the refrigerant loses heat in heat rejecting heat exchanger **24**, exiting heat rejecting heat exchanger **24** at low enthalpy and high pressure (point **5**A). The refrigerant then splits into two flow paths **40**A and **42**A prior to entering first economizer heat exchanger **28**A. The main path continues along paths **40**A and **40**B through first economizer heat exchanger **28**A (point **5**B) and second economizer heat exchanger **28**B (point **5**), respectively. As the refrigerant in path **40**A flows through first economizer heat exchanger **28**A, it is cooled by the refrigerant in path **42**A of the first economized path. Similarly, as the refrigerant in path **40**B flows through second economizer heat exchanger **28**B, it is cooled by the refrigerant in path **42**B of the second economized path.

[0051] Refrigerant from path **40**B is then throttled in main expansion valve **26**. After going through an expansion process within main expansion valve **26** (point **6**), the refrigerant is a two-phase liquid-vapor mixture and is directed toward evaporator **27**. After evaporation of the remainder of the liquid (point **1**), the refrigerant enters two-stage compressor sub-unit **32** through suction port **37**. The refrigerant is compressed within cylinder **36**A, which is the first stage of two-stage compressor sub-unit **32**, and is then directed out discharge port **50** (point **2**), where it flows through intercooler **49** prior to a second stage of compression in cylinder **36**B. Intercooler **49** is configured to cool down the refrigerant discharged from cylinder **36**A prior to the second stage of compression within cylinder **36**B. After the second stage of compression, the refrigerant is discharged through discharge port **39** (point **4**).

[0052] In reference to the first economized path, after refrigerant exits heat rejecting heat exchanger **24** at low enthalpy and high pressure (point **5**A) and splits into two flow paths **40**A and **42**A, the first economized path continues along path **42**A. In path **42**A, the refrigerant is throttled to a lower pressure by economizer expansion valve **30**A (point **6**A) prior to flowing through first economizer heat exchanger **28**A. The refrigerant from path **42**A that flowed through first economizer heat exchanger **28**A (point **7**A) is then directed along economizer return path **46**A and injected into suction port **52** of single-stage compressor sub-unit **34** for compression in single-stage compressor sub-unit **34**. After compression within single-stage compressor sub-unit **34**, the refrigerant is discharged through discharge port **54** (point **8**A) where it merges with the refrigerant discharged from two-stage compressor sub-unit **32** and single-stage compressor sub-unit **35**.

[0053] In reference to the second economized path, after being cooled in the higher pressure first economizer heat exchanger **28**A (point **5**B), the refrigerant in path **40**A splits into two flow paths **40**B and **42**B. The second economized path continues along flow path **42**B where the refrigerant is throttled to a lower pressure by economizer expansion valve **30**B (point **6**B) prior to flowing through second economizer heat exchanger **28**B. The refrigerant from path **42**B that flowed through second economizer heat exchanger **28**B (point **7**B) is then directed along economizer return path **46**B and injected into suction port **56** of single-stage compressor sub-unit **35** for compression in single-stage compressor sub-unit **35**. After compression within single-stage compressor sub-unit **35**, the refrigerant is discharged through discharge port **58** (point **8**B) where it merges with the refrigerant discharged from two-stage compressor sub-unit **32** and single-stage compressor sub-unit **34**.

[0054] FIG. **4**B illustrates a graph relating enthalpy to pressure for the refrigeration system **20**D of FIG. **4**A. As shown in FIG. **4**B, the main refrigerant path is the loop defined by the points **1**, **2**, **3**, **4**, **5**, and **6**; the first economized path is the loop defined by the points **5**A, **6**A, **7**A, and **8**A; and the second economized path is the loop defined by the points **5**B, **6**B, **7**B, and **8**B.

[0055] As shown in FIG. **4**B, cylinders **36**A, **36**B, **36**C, and **36**D of multi-stage compressor unit **10**D are configured to receive and compress refrigerant to different pressures. In particular, cylinder **36**A receives and compresses refrigerant from the main refrigerant path to an intermediate pressure, as indicated by point **2**. After being cooled within intercooler **49**, cylinder **36**B receives and compresses refrigerant from the main refrigerant path from an intermediate pressure to an exit pressure, as indicated by point **4**. Cylinder **36**C receives and compresses refrigerant from the first economized refrigerant path to an exit pressure, as indicated by point **8**A. Similarly, cylinder **36**D receives and compresses refrigerant from the second economized refrigerant path to an exit pressure, as indicated by point **8**B. As shown in FIG. **4**B, the exit pressures of cylinders **36**C and **36**D are substantially equivalent to the exit pressure of cylinder **36**B.

[0056] FIG. **5**A illustrates a schematic diagram of multi-stage compressor unit **10**E connected to refrigeration system **20**E. In addition to two-stage compressor sub-unit **32**, multi-stage compressor unit **10**E further includes two-stage compressor sub-unit **70**. Two-stage compressor sub-unit **70** includes cylinders **36**E and **36**F connected in series. Refrigeration system **20**E is similar to refrigeration system **20**D, except that third economizer circuit **25**C is added to the system.

[0057] In refrigeration system **20**E, four distinct refrigerant paths are formed by connection of the various elements in the system. A main refrigerant path is created by a loop defined by the points **1**, **2**, **3**, **4**, **5**, and **6**. A first economized refrigerant path is created by a loop defined by the points **5**A, **6**A, **7**A, **3**, and **4**. A second economized refrigerant path is created by a loop defined by the points **5**B, **6**B, **7**B, **9**, and **10**. Finally, a third economized refrigerant path is created by a loop defined by the points **5**C, **6**C, **7**C, **8**C, **9**, and **10**.

[0058] In reference to the main refrigerant path, after refrigerant exits two-stage compressor sub-unit **32** at high pressure and enthalpy through discharge port **39** (point **4**), the refrigerant loses heat in heat rejecting heat exchanger **24**, exiting heat rejecting heat exchanger **24** at low enthalpy and high pressure (point **5**A). The refrigerant then splits into two flow paths **40**A and **42**A prior to entering first economizer heat exchanger **28**A. The main path continues along paths **40**A, **40**B, and **40**C through first economizer heat exchanger **28**A (point **5**B), second economizer heat exchanger **28**B (point **5**C), and third economizer heat exchanger **28**C (point **5**), respectively. As the refrigerant in path **40**A flows through first economizer heat exchanger **28**A, it is cooled by the refrigerant in path **42**A of the first economized path. As the refrigerant in path **40**B flows through second economizer heat exchanger **28**B, it is cooled by the refrigerant in path **42**B of the second economized path. Finally, as the refrigerant in path **40**C flows through third economizer heat exchanger **28**C, it is cooled by the refrigerant in path **42**C of the third economized path.

[0059] Refrigerant from path **40**C is then throttled in main expansion valve **26**. After going through an expansion process within main expansion valve **26** (point **6**), the refrigerant is a two-phase liquid-vapor mixture and is directed toward evaporator **27**. After evaporation of the remainder of the liquid (point **1**), the refrigerant enters two-stage compressor sub-unit **32** through suction port **37**. The refrigerant is compressed within cylinder **36**A, which is the first stage of two-stage compressor sub-unit **32**, and is then directed out discharge port **50** (point **2**), where it merges with the cooler refrigerant from economizer return path **46**A that is injected into interstage port **48** (point **3**). Thus, the refrigerant from economizer return path **46**A functions to cool down the refrigerant discharged from cylinder **36**A prior to the second stage of compression within cylinder **36**B. After the second stage of compression, the refrigerant is discharged through discharge port **39** (point **4**).

[0060] In reference to the first economized path, after refrigerant exits heat rejecting heat exchanger **24** at low enthalpy and high pressure (point **5**A) and splits into two flow paths **40**A and **42**A, the first economized path continues along path **42**A. In path **42**A, the refrigerant is throttled to a lower pressure by economizer expansion valve **30**A (point **6**A) prior to flowing through first economizer heat exchanger **28**A. The refrigerant from path **42**A that flowed through first economizer heat exchanger **28**A (point **7**A) is then directed along economizer return path **46**A and injected into interstage port **48** of two-stage compressor sub-unit **32** where it merges with refrigerant flowing through the main path to cool down the refrigerant (point **3**) prior to a second stage of compression in cylinder **36**B.

[0061] In reference to the second economized path, after being cooled in the higher pressure first economizer heat exchanger **28**A, the refrigerant in path **40**A splits into two flow paths **40**B and **42**B (point **5**B). The second economized path continues along flow path **42**B where the refrigerant is throttled to a lower pressure by economizer expansion valve **30**B prior to flowing through second economizer heat exchanger **28**B (point **6**B). The refrigerant from path **42**B that flowed through second economizer heat exchanger **28**B (point **7**B) is then directed along economizer return path **46**B and injected into interstage port **72** of two-stage compressor sub-unit **70** where it mixes with refrigerant exiting discharge port **74** (point **9**) to cool down the refrigerant prior to a second stage of compression in cylinder **36**F.

[0062] In reference to the third economized path, after being cooled in the higher pressure second economizer heat exchanger **28**B, the refrigerant in path **40**B splits into two flow paths **40**C and **42**C (point **5**C). The third economized path continues along flow path **42**C where the refrigerant is throttled to a lower pressure by economizer expansion valve **30**C prior to flowing through third economizer heat exchanger **28**C (point **6**C). The refrigerant from path **42**C that flowed through third economizer heat exchanger **28**C (point **7**C) is then directed along economizer return path **46**C and injected into suction port **76** of two-stage compressor sub-unit **70**. After a first stage of compression in cylinder **36**E (point **8**C), the refrigerant is cooled prior to a second stage of compression by the refrigerant from economizer return path **46**B that was injected into interstage port **72** (point **9**). After the second stage of compression in cylinder **36**F, the refrigerant is discharged through discharge port **78** (point **10**), where it merges with the compressed refrigerant discharged from two-stage compressor sub-unit **32**.

[0063] FIG. **5**B illustrates a graph relating enthalpy to pressure for the refrigeration system **20**E of FIG. **5**A. As shown in FIG. **5**B, the main refrigerant path is the loop defined by the points **1**, **2**, **3**, **4**, **5**, and **6**; the first economized path is the loop defined by the points **5**A, **6**A, **7**A, **3**, and **4**; the second economized path is the loop defined by the points **5**B, **6**B, **7**B, **9**, and **10**; and the third economized path is the loop defined by the points **5**C, **6**C, **7**C, **8**C, **9**, and **10**.

[0064] As shown in FIG. **5**B, cylinders **36**A, **36**B, **36**E, and **36**F of multi-stage compressor unit **10**E are configured to receive and compress refrigerant to different pressures. In particular, cylinder **36**A receives and compresses refrigerant from the main refrigerant path to an intermediate pressure, as indicated by point **2**. Then, cylinder **36**B receives and compresses refrigerant from the main refrigerant path and the first economized path from the intermediate pressure to an exit pressure, as indicated by point **4**. Similarly, cylinder **36**E receives and compresses refrigerant from the third economized refrigerant path to an intermediate pressure, as indicated by point **8**C. Cylinder **36**F then receives and compresses refrigerant from the second and third economized paths from the intermediate pressure to an exit pressure, as indicated by point **10**. As shown in FIG. **5**B, the exit pressure of cylinder **36**B is substantially equivalent to the exit pressure of cylinder **36**F.

[0065] Although each of the embodiments of a multi-stage compressor unit shown and described above have been connected to a refrigeration system that includes one or more economizer circuits, the multi-stage compressor unit of the present invention may also be used in refrigerating systems that do not include economizer circuits. FIG. **6**A illustrates a schematic diagram of multi-stage compressor unit **10**F connected to refrigeration system **20**F, which includes heat rejecting heat exchanger **24**, first expansion valve **26**, first evaporator **27**, first sensor **31**, second expansion valve **126**, second evaporator **127**, and second sensor **131**. Multi-stage compressor unit **10**F includes two-stage compressor sub-unit **32** and single-stage compressor sub-unit **34**. Two-stage compressor sub-unit **32** includes cylinders **36**A and **36**B connected in series, while single-stage compressor sub-unit **34** includes cylinder **36**C.

[0066] In refrigeration system **20**F, two distinct refrigerant paths are formed by connection of the various elements in the system. A first main refrigerant path is created by a loop defined by the points **1**, **2**, **3**, **4**, and **5**. A second main refrigerant path is created by a loop defined by the points **4**, **5**A, **6**A, and **7**A.

[0067] In reference to the first main refrigerant path, after refrigerant exits two-stage compressor sub-unit **32** at high pressure and enthalpy through discharge port **39** (point **3**), the refrigerant loses heat in heat rejecting heat exchanger **24**, exiting heat rejecting heat exchanger **24** at low enthalpy and high pressure (point **4**). The refrigerant in the main path is then throttled in first expansion valve **26**. After going through an expansion process within first expansion valve **26** (point **5**), the refrigerant is a two-phase liquid-vapor mixture and is directed toward first evaporator **27**. After evaporation of the remainder of the liquid (point **1**), the refrigerant enters two-stage compressor sub-unit **32** through suction port **37**. The refrigerant is compressed within cylinder **36**A, which is the first stage of two-stage compressor sub-unit **32**, and is then directed out discharge port **50** (point **2**). After the second stage of compression in cylinder **36**B, the refrigerant is discharged through discharge port **39** (point **3**).

[0068] In reference to the second main refrigerant path, after exiting heat rejecting heat exchanger **24**, the refrigerant is throttled in second expansion valve **126**. After going through an expansion process within second expansion valve **126** (point **5**A), the refrigerant is a two-phase liquid-vapor mixture and is directed toward second evaporator **127**. After evaporation in second evaporator **127** (point **6**A), the refrigerant enters single-stage compressor sub-unit **34** through suction port **52**. The refrigerant is compressed within cylinder **36**C, and is then directed out discharge port **54** point **7**A) where it mixes with the refrigerant discharged through discharge port **39** of two-stage compressor sub-unit **32**.

[0069] FIG. **6**B illustrates a graph relating enthalpy to pressure for the refrigeration system **20**F of FIG. **6**A. As shown in FIG. **6**B, the first main refrigerant path is the loop defined by the points **1**, **2**, **3**, **4**, and **5**, and the second main refrigerant path is the loop defined by the points **4**, **5**A, **6**A, and **7**A.

[0070] As shown in FIG. **6**B, cylinders **36**A, **36**B, and **36**C of multi-stage compressor unit **10**F are configured to receive and compress refrigerant to different pressures. In particular, cylinder **36**A receives and compresses refrigerant from the first main refrigerant path to an intermediate pressure, as indicated by point **2**. Then, cylinder **36**B receives and compresses the refrigerant from the intermediate pressure to an exit pressure, as indicated by point **3**. Similarly, cylinder **36**C receives and compresses refrigerant from the second main refrigerant path to an exit pressure, as indicated by point **7**A. As shown in FIG. **6**B, the exit pressure of cylinder **36**C is substantially equivalent to the exit pressure of cylinder **36**B.

[0071] While the alternative embodiments of the multi-stage compressor unit have been described as including a number of compressor sub-units ranging from two to three, it should be understood that a multi-stage compressor unit with more than three compressor sub-units is within the intended scope of the present invention. Furthermore, although the embodiments of the multi-stage compressor unit were described as including only single-stage and two-stage compressor sub-units, compressor sub-units having more than two stages are within the intended scope of the present invention. Thus, single-stage and two-stage compressor sub-units were shown merely for purposes of example and not for limitation. In addition, alternative embodiments that include compressor sub-units connected in various combinations other than those depicted above are also contemplated.

[0072] Although the multi-stage compressor unit of the present invention is useful to increase system efficiency in a refrigeration system using any type of refrigerant, it is especially useful in refrigeration systems that utilize transcritical refrigerants, such as carbon dioxide. Because carbon dioxide is such a low critical temperature refrigerant, refrigeration systems using carbon dioxide typically run transcritical. Furthermore, because carbon dioxide is such a high pressure refrigerant, there is more opportunity to provide multiple pressure steps between the high and low pressure portions of the circuit to include multiple economizers and multiple compressor cylinders, each of which contributes to increase the efficiency of the system. Thus, the multi-stage compressor unit of the present invention may be used to increase the efficiency of systems utilizing transcritical refrigerants such as carbon dioxide, making their efficiency comparable to that of typical refrigerants. However, the multi-stage compressor unit of the present invention is useful to increase the efficiency in refrigeration systems using any refrigerant, including those that run subcritical as well as those that run transcritical.

[0073] Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention.

1. A multi-stage compressor unit for a refrigeration system configured to circulate a refrigerant, the multi-stage compressor unit comprising:

a first compressor sub-unit having a first stage and a second stage, wherein the first and second stages of the first compressor sub-unit each have a suction port and a discharge port, and wherein the first compressor sub-unit is configured to receive and compress a first portion of the refrigerant from an evaporator; and

a second compressor sub-unit in parallel with the first compressor sub-unit and having a first stage, wherein the first stage of the second compressor sub-unit has a suction port and a discharge port, and wherein the second compressor sub-unit is configured to compress a second portion of the refrigerant prior to the compressed second portion being combined with the compressed first portion.

2. The multi-stage compressor unit of claim **1**, wherein the first stage of the second compressor sub-unit is configured to receive the second portion of the refrigerant from a second evaporator.

3. The multi-stage compressor unit of claim **1**, wherein the first stage of the second compressor sub-unit is configured to receive the second portion of the refrigerant from a first economizer circuit.

4. The multi-stage compressor unit of claim **3**, wherein the first compressor sub-unit further comprises an interstage port disposed between the discharge port of the first stage and the suction port of the second stage, and wherein the interstage port is configured to receive a third portion of the refrigerant from a second economizer circuit.

5. The multi-stage compressor unit of claim **1**, wherein the first compressor sub-unit and the second compressor sub-unit comprise reciprocating compressors.

6. The multi-stage compressor unit of claim **1**, wherein the refrigerant is a transcritical refrigerant.

7. The multi-stage compressor unit of claim **1**, and further comprising an intercooler configured to cool the first portion of the refrigerant between the first and second stages of the first compressor sub-unit.

8. The multi-stage compressor unit of claim **1**, wherein the second compressor sub-unit is configured to discharge into an interstage port of the first compressor sub-unit.

9. The multi-stage compressor unit of claim **1**, wherein the second compressor sub-unit further comprises a second stage having a suction port and a discharge port, and wherein the first and second stages of the second compressor sub-unit are connected in series.

10. A multi-stage compressor unit for a refrigeration system having a first economizer circuit and configured to circulate a refrigerant, the multi-stage compressor unit comprising:

a first compressor sub-unit having a first stage and a second stage, wherein the first compressor sub-unit is configured to receive and compress a first portion of the refrigerant from an evaporator; and

a second compressor sub-unit in parallel with the first compressor sub-unit, wherein the second compressor sub-unit is configured to compress a second portion of the refrigerant from the first economizer circuit prior to the compressed second portion being combined with the compressed first portion.

11. The multi-stage compressor unit of claim **10**, and further comprising an intercooler configured to cool the first portion of the refrigerant between the first and second stages of the first compressor sub-unit.

12. The multi-stage compressor unit of claim **10**, wherein the first compressor sub-unit is configured to discharge refrigerant at a first exit pressure, and wherein the second compressor sub-unit is configured to discharge refrigerant at a second exit pressure.

13. The multi-stage compressor unit of claim **12**, wherein the first and second exit pressures are substantially equivalent.

14. The multi-stage compressor unit of claim **10**, wherein the first compressor sub-unit further comprises an interstage port disposed between the first and second stages and configured to receive a third portion of the refrigerant from a second economizer circuit, and wherein the second stage of the first compressor sub-unit is configured to compress a mixture of the first and third portions of the refrigerant.

15. The multi-stage compressor unit of claim **10**, wherein the second compressor sub-unit is a single-stage compressor.

16. The multi-stage compressor unit of claim **10**, wherein the second compressor sub-unit is a two-stage compressor.

17. The multi-stage compressor unit of claim **16**, wherein the second compressor sub-unit further comprises an interstage port configured to receive a fourth portion of the refrigerant from a third economizer circuit.

18. A multi-stage compressor unit for a refrigeration system configured to circulate a refrigerant, the multi-stage compressor unit comprising:

a first compressor sub-unit having a first stage, a second stage, and an interstage port disposed between the first and second stages, wherein the first stage of the first compressor sub-unit is configured to compress a first portion of the refrigerant to an intermediate pressure, and wherein the second stage of the first compressor sub-unit is configured to compress the first portion of the refrigerant to an exit pressure of the first compressor sub-unit; and

a second compressor sub-unit having a first stage, wherein the second compressor sub-unit is configured to compress a second portion of the refrigerant to an exit pressure of the second compressor sub-unit prior to the compressed second portion being combined with the compressed first portion.

19. The multi-stage compressor unit of claim **18**, wherein the exit pressures of the first compressor sub-unit and the second compressor sub-unit are substantially equivalent.

20. The multi-stage compressor unit of claim **18**, wherein the second compressor sub-unit discharges the second portion of the refrigerant into the interstage port of the first compressor sub-unit, and wherein the exit pressure of the second compressor sub-unit is substantially equivalent to the intermediate pressure of the first compressor sub-unit.

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