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(54) **COLD START HELIUM COMPRESSOR**

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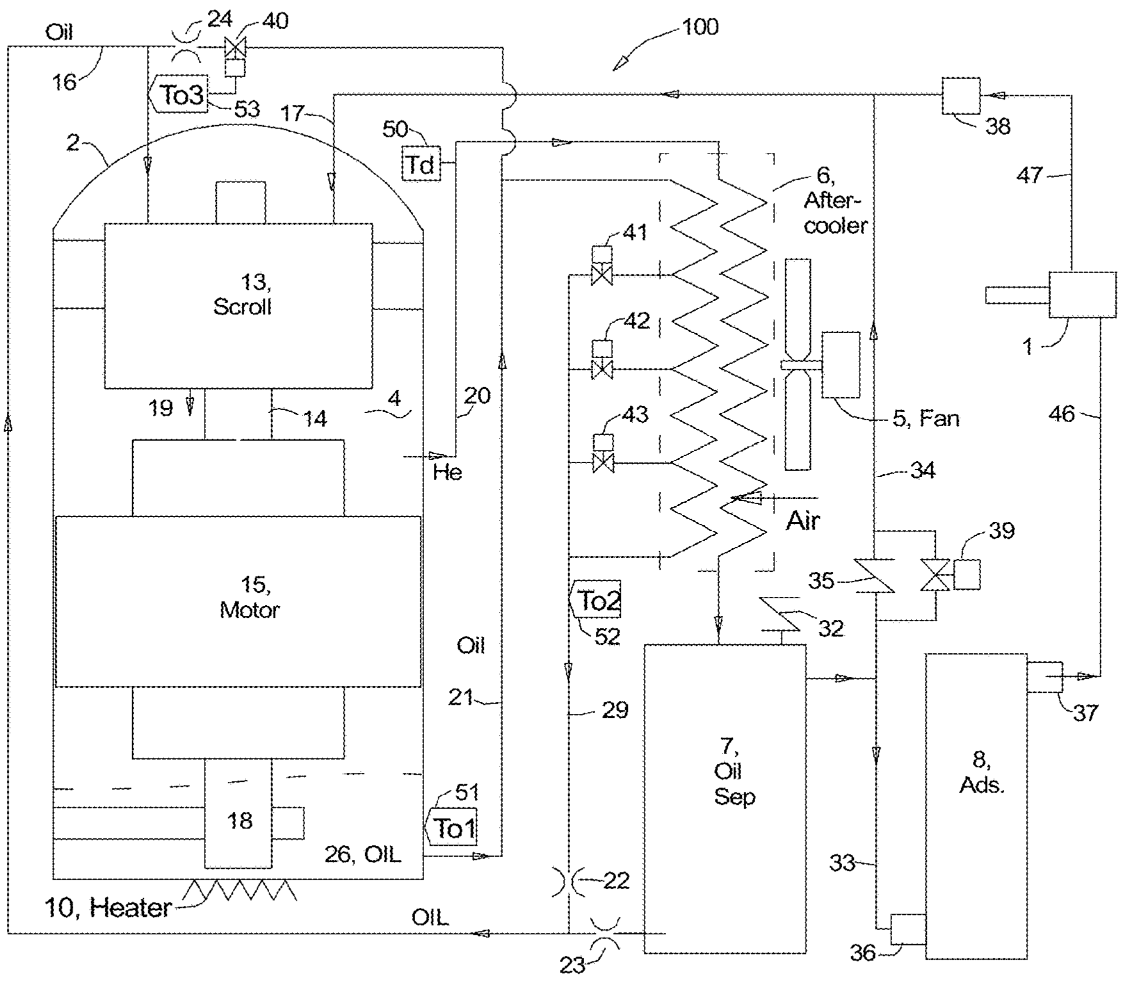
(57) **ABSTRACT**

This invention provides a means to start an oil lubricated air cooled helium compressor at ambient air temperatures in the range from −30° C. to 0° C. by heating the oil in the sump and opening one or more by-pass valves that allows oil to flow to the oil injection port of the compressor without passing through all of the after-cooler.



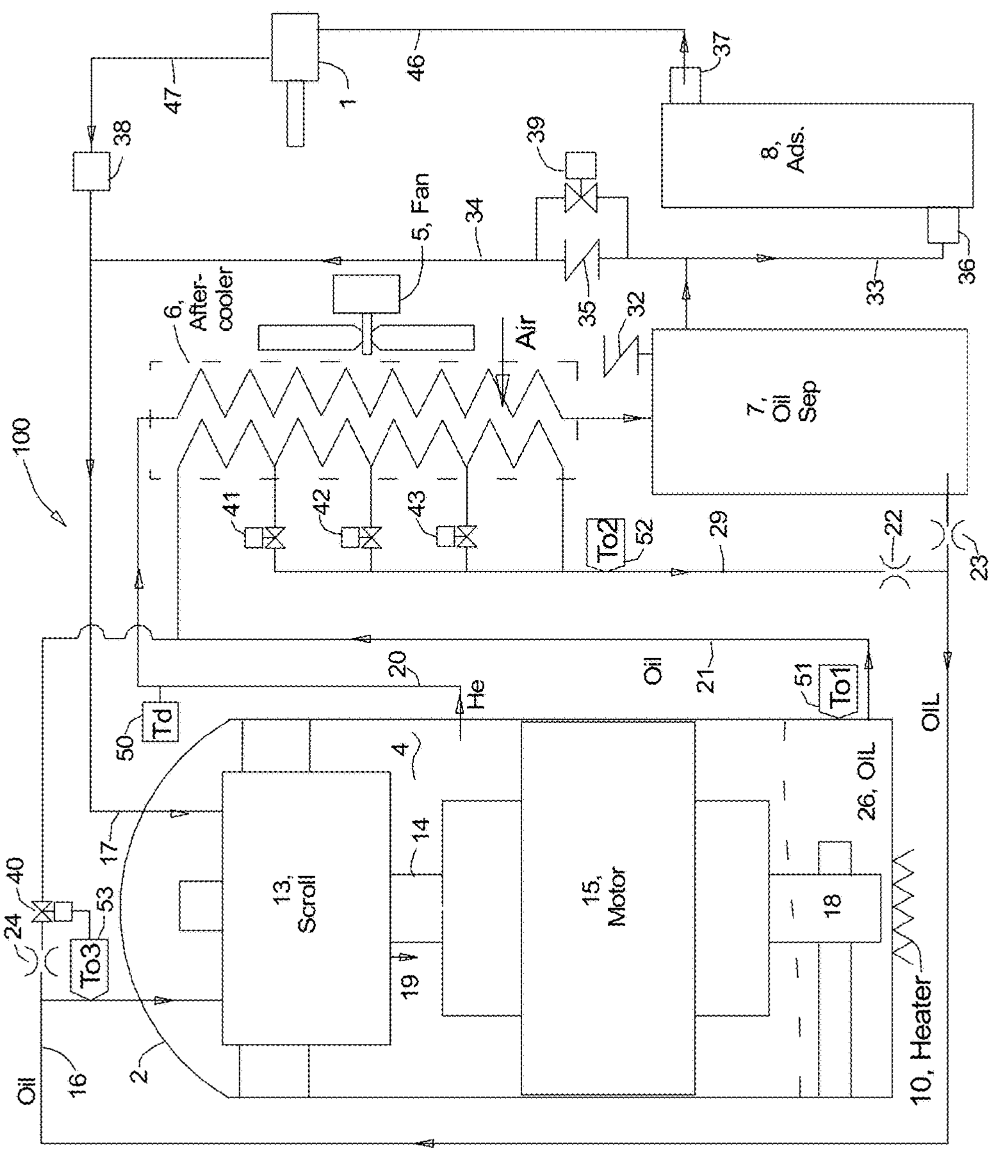

100
1
46
47
37
38
39
8,
Ads.
36
5, Fan
34
35
33
6,
After-
cooler
32
Air
7,
Oil
Sep
41
42
43
To2
52
29
22
23
20
He
Oil
21
51
To1
OIL
Td
50
4
26, OIL
17
14
13,
Scroll
15,
Motor
18
40
24
53
To3
19
Oil
16
2
10, Heater

FIG. 1

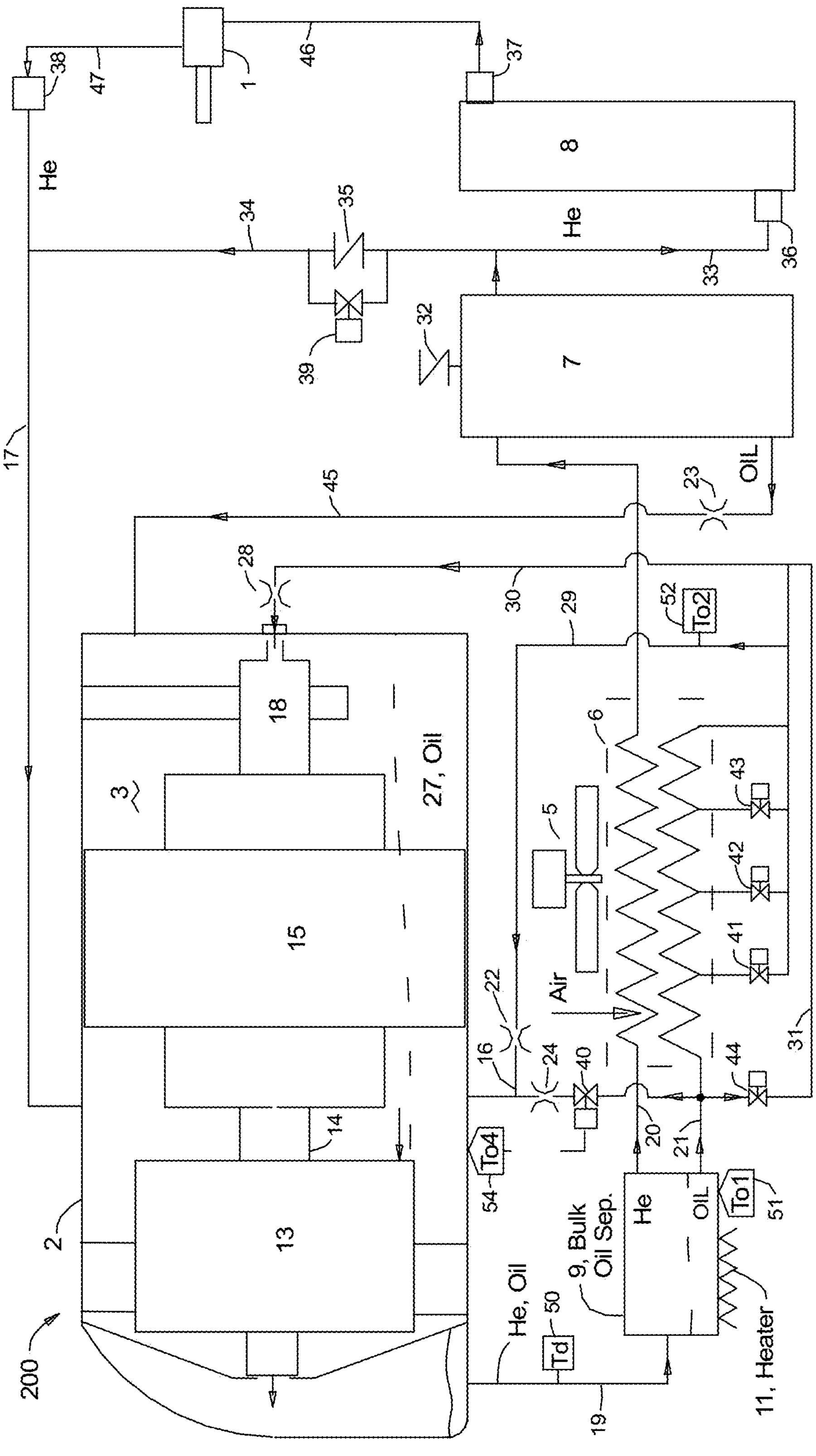

200
2
13
14
15
3
18
27, Oil
He, Oil
Td
50
19
9, Bulk Oil Sep.
He
OIL
To1
51
11, Heater
To4
54
16
22
24
40
20
21
44
31
41
42
43
Air
5
6
29
30
28
52
To2
45
23
OIL
7
32
39
35
34
33
He
36
8
37
46
1
47
38
He
17

FIG. 2

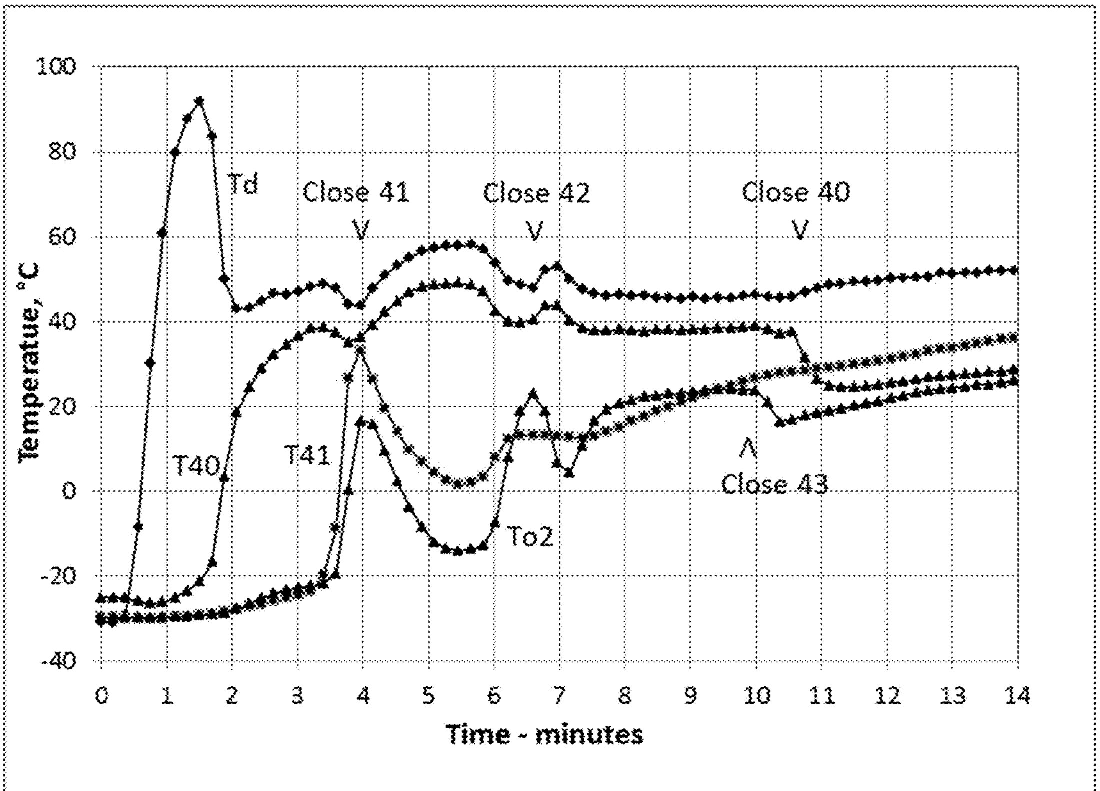

100
80
60
40
20
0
-20
-40
Temperatue, °C
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Time - minutes
Td
Close 41
V
Close 42
V
Close 40
V
T40
T41
To2
Λ
Close 43

FIG. 3

COLD START HELIUM COMPRESSOR

[0001] This invention relates generally to oil lubricated helium compressor units for use in cryogenic refrigeration systems. More particularly, the invention relates to an oil management system that enables an air cooled compressor to start when the ambient air temperature is low, e.g. −30° C.

BACKGROUND OF THE INVENTION

[0002] The GM cycle has become the dominant means of producing cryogenic temperatures, temperatures below 120K, in small commercial refrigerators primarily because it can utilize mass produced oil-lubricated air-conditioning compressors to build reliable, long life, refrigerators at minimal cost. The basic principal of operation of a GM cycle refrigerator is described in U.S. Pat. No. 2,906,101. GM cycle refrigerators operate well at pressures and power inputs within the design limits of air-conditioning compressors, even though helium is substituted for the design refrigerants. Typically, GM refrigerators operate at a high pressure of about 2 MPa, and a low pressure of about 0.8 MPa. The cold expander in a GM refrigerator is typically separated from the compressor by 5 m to 20 m long gas lines. Cryogenic expanders that operate on the Brayton cycle, and valved pulse tube expanders, have also used these same compressors. It is preferred to mount the expander and compressor indoors where the air temperature is kept in the range of 15° C. to 30° C. Air cooled and water cooled compressors are available for these applications. Some applications however require mounting compressors outdoors where the temperature of the air can be in the range of −30° C. to 40° C.

[0003] Compressors designed for air-conditioning service require additional cooling when compressing helium because monatomic gases including helium get a lot hotter when compressed than standard refrigerants. For example when helium at 20° C. is compressed isentropically from 0.8 MPa to 2.0 MPA the temperature increases 129° C., while nitrogen, a diatomic molecule, increases 88° C., and Refrigerant 22 increases 61° C. U.S. Pat. No. 7,674,099 describes a means of adapting a scroll compressor manufactured by Copeland Corp. to compressing helium by injecting oil along with helium into the scroll such that about 2% of the displacement is used to pump oil when the air temperature is approximately 20° C. The oil injection rate increases as the temperature increases because the viscosity of the oil decreases as it gets hotter and flows through the orifice that controls the oil flow rate at a higher rate. For oil and helium entering at the same temperature, compressing the mixture from 0.8 to 2 MPa, and an oil injection rate of 2% of the displacement, the mixture leaves 19° C. warmer than it entered. For an oil injection rate of 2% approximately 70% of the heat of compression leaves the compressor in the hot oil and the balance in the hot helium. The objective is to keep the temperature of the helium/oil mixture leaving the compressor at a temperature of less than 100° C. The primary claim of the '099 patent is to divert most of the oil from returning to an end port of the compressor, where it lubricates a bearing, to return through a port near the entrance to the scroll. This turns out to be beneficial in adapting the compressor to start at low ambients for reasons to be described later.

[0004] The Copeland compressor is oriented horizontally and requires an external bulk oil separator to remove most of the oil from the helium. Another scroll compressor that is widely used for compressing helium is manufactured by Hitachi Inc. The Hitachi compressor is oriented vertically and brings the helium and oil directly into the scroll through separate ports at the top of the compressor and discharges it inside the shell of the compressor. Most of the oil separates from the helium inside the shell and flows out of the shell near the bottom while the helium flows out near the top. Helium compressor systems that use the Copeland and Hitachi scroll compressors have separate channels in an after-cooler for the helium and oil. The power input to these compressors is typically in the range of 2 to 15 kW.

[0005] A problem arises when starting these oil lubricated compressors after they have cooled to low ambient temperatures. The lubricating oil can become so viscous that the thick oil in the lines moves so slowly that an insufficient amount flows into the compression chamber along with the helium to cool the helium enough to keep the discharge temperature below 100° C., the cut-out temperature of the switch that shuts down the compressor to prevent the helium from getting to hot.

[0006] UCON™ oils, manufactured by Dow Chemicals, are commonly used in helium compressors for cryogenic applications because they have very low vapor pressures and residual oil vapors are easily removed in an adsorber to prevent oil from freezing in the cold piping. UCON™ LB-300 has a pour point of −40° C. and UCON™ LB-170 which is less viscous has a pour point of −46° C. The test for determining the pour point is defined in ASTM D97-12. Some helium compressors use the lower viscosity oil because they can be designed to start at low ambient temperatures without having to make as many accommodations as are needed to overcome the problems of the more viscous LB-300 oil. At high ambient temperatures however the less viscous oil does not have as good lubricating properties thus resulting in higher compressor failure rates.

SUMMARY OF THE INVENTION

[0007] The objective of this invention is to provide an oil management system to start an oil lubricated air cooled helium compressor, which has oil that has a pour point within −10° C. of the minimum starting temperature, by heating the oil in the sump and opening one or more by-pass valves that allow oil to flow to the oil injection port of the compressor without passing through all of the air cooled after-cooler. A preferred system uses an oil with a pour point of −40° C. to start at ambient air temperatures in the range from −30° C. to 0° C. and has four by-pass valves, the first by-passes the entire after-cooler and the other three by-pass sections of the after-cooler.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIG. **1** is a schematic diagram of an oil-lubricated air cooled helium compressor system that uses an Hitachi scroll compressor which has a vertical orientation.

[0009] FIG. **2** is a schematic diagram of an oil-lubricated air cooled helium compressor system that uses a Copeland scroll compressor which has a horizontal orientation.

[0010] FIG. **3** shows the temperature vs. time at key points in the compressor system of FIG. **2** from a test when it was started in an ambient of −30° C.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0011] FIG. **1** is a schematic diagram of oil-lubricated air cooled helium compressor system **100** which has a vertically oriented Hitachi compressor and FIG. **2** is a schematic diagram of oil-lubricated air cooled helium compressor system **200** which has a horizontally mounted Copeland compressor.

[0012] Compressor system components that are common to both of the figures and are used in compressors operating in an indoor environment are: compressor shell **2**, compressor scroll **13**, drive shaft **14**, motor **15**, oil pump **18**, after-cooler **6**, fan **5**, oil return line **16**, helium return line **17**, helium/oil mixture discharge from the scroll **19**, oil separator **7**, adsorber **8**, main oil flow control orifice **22**, orifice **23** which controls the flow rate of oil from the oil separator, gas line **33** from oil separator **7** to adsorber **8**, internal relief valve **35** and pressure equalization solenoid valve **39**, gas line **34** from internal relief valve **35** and pressure equalization solenoid valve **39** to helium return line **17**, pressure relief valve **32**, adsorber inlet gas coupling **36**, adsorber outlet gas coupling **37** which supplies high pressure helium to the expander **1** through gas line **46** and returns it through line **47** to coupling **38** which receives low pressure helium from the expander, and discharge temperature sensor Td, **50**.

[0013] Additional compressor system components that are common to both of the figures and are used in compressors operating in an outdoor environment are: orifice **24** that limits the flow through first oil by-pass valve **40**, second oil by-pass valve **41** that allows oil to exit after-cooler **6** after flowing through a first section, third oil by-pass valve **42** that allows oil to exit after-cooler **6** after flowing through a first and second section, fourth oil by-pass valve **43** that allows oil to exit after-cooler **6** after flowing through a first, second, and third section, temperature sensor To**1**, **51**, which is used to control oil heaters **10** and **11**, and temperature sensor To**2**, **52**, which is used to control the speed of fan **5**.

[0014] The components that are unique to system **100**, FIG. **1**, are volume **4** at high pressure internal to the Hitachi compressor, heater **10** that heats oil **26** in the compressor sump, and temperature sensor To**3**, **53**, which is used to control by-pass valve **40**.

[0015] The components that are unique to system **200**, FIG. **2**, are volume **3** at low pressure internal to the Copeland compressor, heater **11** that heats oil in the sump of bulk oil separator **9**, temperature sensor To**4**, **54**, which is used to control by-pass valve **40**, oil by-pass valve **44** which on startup takes heated oil through lines **31** and **30** to orifice **28** which controls the flow of oil into the bearing on the end of shaft **14**, and line **45** which takes oil from orifice **23** directly to volume **3** in the compressor.

[0016] It is noted that the Hitachi compressor of system **100** has an oil injection port from line **16** that is separate from the suction port for helium from line **17**. The Copeland compressor of system **200** has a common pickup point into the scroll for oil and helium and the rate of flow of oil into the scroll depends on the oil level. For this reason the oil return port is near the pickup point and heated oil preferentially flows into the scroll while some mixes with and heats the rest of the oil in the sump. Temperature sensor To**4**, **54** is thus located near the point where the oil is entering the scroll and is measuring a temperature comparable to To**3**, **53** in system **100**. It is also noted that most of the oil, more than 99%, separates from the helium after compression in volumes at high pressure in which oil collects in a sump. For the Hitachi compressor this is volume **4** inside the compressor and for the Copeland compressor it is in bulk oil separator **9**. Prior to starting the compressor in cold ambients the oil in the sump is heated by heaters **10** and **11** respectively which are turned off when sensor To**1**, **51** reaches a preset temperature, e.g. 20° C.

[0017] According to the present invention, when system **100** or **200** is off and cools to a temperature below about 10° C., by-pass valves **40**, **41**, **42**, **43**, and **44**, open. Valves **41**, **42**, **43**, and **44** are controlled by their temperature if they are thermally actuated valves or by the temperature of a line near them if they are actively controlled. Thermally actuated valves have a member in them that changes shape as its temperature changes and causes a port to open or close. Valves **41**, **42**, **43**, and **44** close when they warm to about 10° C. Valve **40** is an active valve, e.g. a solenoid valve, which is controlled by sensor To**3**, **53** on the oil injection line, after oil from lines **16** and **21** have mixed, in system **100**, and by sensor To**4**, **54** on the compressor shell in system **200**.

[0018] The oil management system results in the following sequence of events for starting system **100** when the ambient temperature is less than about 0° C. Heater **10** is turned on until oil **26** in the sump of the compressor reaches a temperature of about 20° C. before starting the compressor. When the compressor is turned on the pressures within a few seconds come to the normal operating pressures and the gas in discharge line **30** heats within a minute or two towards a cutout temperature of less than 100° C. During the first minute cold thick oil in line **21** is being pushed through valve **40** and orifice **24** at a low rate until heated oil reaches orifice **24** and an oil flow rate into the injection port is sufficient to bring the discharge temperature down to an acceptable operating temperature. During the next few minutes cold thick oil is slowly being pushed through the after-cooler but the discharge temperature continues to rise as oil **27** in the sump warms while it absorbs most of the heat of compression. Cool oil flows slowly through orifice **22** and line **16** to the injection port but it is followed by heated oil leaving after-cooler **6** which then establishes a normal oil injection flow rate. An acceptable flow rate is typically established at a temperature greater than 0° C. as measured by To**2** at main orifice **22**. By-pass valve **40** is closed when the injection temperature as measured by sensor To**3**, **53** reaches about 20° C.

[0019] Having one or more valves that by-pass sections of the after-cooler brings warm oil into line **29** sooner than if the cold thick oil has to be pushed through the entire heat exchanger. By-pass valve **41** is shown at a point where oil exits the after-cooler after passing through about a quarter of it. Valve **41** closes when the oil flowing through it reaches a temperature of about 10° C. then the oil flow rate drops in line **29** until warm oil reaches by-pass valve **42**, then the process repeats for by-pass valve **43**, and sometime after by-pass valve **43** closes, warm oil exits the after-cooler and the compressor approaches a steady state operating condition. During startup, fan **5** is off until the temperature at To**2**, **52**, reaches a temperature of about 20° C. then is operated in an on/off or variable speed mode to keep To**2**, **52**, from dropping below about 20° C. Even with the fan off during startup the helium exiting after-cooler **6** is cooled to temperature near that of the oil by heat transfer through the fins. It is noted that a common plate-fin type heat exchanger with a row of tubes for helium in front one of more rows is preferred for this application. Not only is heat transferred from the helium to the oil when the air is cold but the helium is cooled to a lower temperature than the oil when the air is hot.

[0020] The number and location of oil by-pass valves that are needed depends on a number of factors including the type of oil, the length and diameter of the tubing in the oil circuits, the amount of oil in the system and the temperature limits that are set to provide long life. For example if by-pass valve **41** is a type that adjusts the flow rate such that temperature To**2** is maintained at about 20° C. then by-pass valves **42** and **43** are not needed. The orifices shown in FIGS. **1** and **2** are typically fixed but could be variable. Having main orifice **22** in particular be variable is another option that can used to help start the compressor in cold ambients.

[0021] The oil management system for starting system **200** when the ambient temperature is less than about 0° C. turns on heater **11** until oil in the sump of bulk oil separator **9** reaches a temperature of about 20° C. before starting the compressor. FIG. **3** shows temperatures at key points during a test with the air temperature held at −30° C. When the compressor is turned on the pressures within a few seconds come to the normal operating pressures and the gas in discharge line **19** heats in about a minute to a temperature of 90° C. During the first minute cold thick oil in line **21** is being pushed through valve **40** and orifice **24** at a low rate until oil that has been heated to only −20° C. reaches orifice **24** and the oil flow rate into the injection port becomes sufficient enough to start bringing the discharge temperature down. The discharge temperature Td continues to drop to a temperature of about 45° C. while heating the oil in bulk oil separator **9** and the oil flowing through by-pass valve **40**. Over the next minute the discharge temperature Td increases slightly but then drops when oil that has been warming as it flows through by-pass valve **41** increases the flow rate of oil through orifice **22**. When by-pass valve **41** reaches 30° C. it closes thus forcing the colder oil in the next section of the after-cooler to flow through orifice **22** and thus temperature To**2** and the flow rate drop and Td increases. As warmer oil reaches by-pass valve **42** the flow rate increases and Td drops until by-pass valve **42** closes. This cycle repeats one more time until by-pass valve **43** closes and the flow rate and temperature of the oil flowing into the injection port is sufficient to keep the discharge temperature, Td, at favorable temperature of about 50° C. The test shown in FIG. **3** shows that by-pass valve **40** closes shortly after by-pass valve **43** closes. Valve **40** drops in temperature because it no longer has warm oil flowing through it. At this point the speed of fan **5** is adjusted to keep To**2** at about 50° C.

[0022] While this invention has been described, it will be understood that this invention can be applied to helium compressor systems with different configurations and with different numbers and locations of by-pass valves. It can also be applied to compressing other monatomic gases. Also, it is to be understood that the phraseology and terminology employed herein, as well as the abstract, are for the purpose of description and should not be regarded as limiting.

[0023] It is also understood that the following claims are intended to cover all of the generic and specific features of the invention described herein.

What is claimed is:

1. An oil lubricated air cooled compressor which supplies helium to a cryogenic expander when the ambient temperature is in the range of −30° C. to 45° C., said system comprising;

- a compressor having a port in which oil is injected and mixed with the helium during compression,
- a volume in which the discharge mixture of helium and oil separate such that most of the oil collects in a sump,
- a heater in the sump,
- an air cooled after-cooler having separate channels for helium and oil,
- piping that directs all of the oil to flow from the sump through the after-cooler to the injection port in the compressor when the ambient temperature is greater than 0° C.,
- at least one by-pass valve that connects a point in the oil piping between the sump and an intermediate point in the after-cooler to the oil injection port when the ambient temperature is less than 0° C.,
- an oil management system that maintains a discharge temperature of less than 100° C. when the ambient air temperature is between −30° C. to 45° C.

2. An oil lubricated helium compressor system in accordance with claim **1** in which a by-pass valve connects the oil piping between the sump and the after-cooler to the oil injection port.

3. An oil lubricated helium compressor system in accordance with claim **1** in which a by-pass valve connects the oil piping between the entrance to the after-cooler and an intermediate point in the after-cooler to the oil injection port.

4. An oil lubricated helium compressor system in accordance with claim **1** in which a by-pass valve is one of an active and a passive valve.

5. A method to start an oil lubricated air cooled compressor which supplies helium to a cryogenic expander when the ambient temperature is in the range of −30° C. to 0° C., said system comprising;

- a compressor having a port in which oil is injected and mixed with the helium during compression,
- a volume in which the discharge mixture of helium and oil separate such that most of the oil collects in a sump,
- a heater in the sump,
- an air cooled after-cooler having separate channels for helium and oil,
- piping that directs all of the oil to flow from the sump through the after-cooler to the injection port in the compressor when the ambient temperature is greater than 0° C.,
- a by-pass valve that connects a point in the oil piping between the sump and an intermediate point in the after-cooler to the oil injection port

the method comprising;

1. heating the oil in the sump to a temperature greater than 0° C.,
2. starting the compressor,
3. opening the oil by-pass valve when the compressor is started.

6. A method to start an oil lubricated air cooled compressor which supplies helium to a cryogenic expander when the lubricating oil has a pour point higher than −45° C. and the ambient temperature is more than 10° C. warmer than the pour point, said system comprising;

a compressor having a port in which oil is injected and mixed with the helium during compression,

a volume in which the discharge mixture of helium and oil separate such that most of the oil collects in a sump,

a heater in the sump,

an air cooled after-cooler having separate channels for helium and oil,

piping that directs all of the oil to flow from the sump through the after-cooler to the injection port in the compressor when the ambient temperature is greater than 0° C.,

a by-pass valve that connects a point in the oil piping between the sump and an intermediate point in the after-cooler to the oil injection port the method comprising;

4. heating the oil in the sump to a temperature greater than 0° C.,
5. starting the compressor,
6. opening the oil by-pass valve when the compressor is started.

* * * * *