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(54) **Oil-free refrigerant circulation technology for air-conditioning and refrigeration system**

(57) An oil-free refrigerant circulation technology for air-conditioning and refrigeration system comprises 99.99% oil-vapor free refrigeration oil, 100% ultra micron oil-aerosol separator built-in with oil reservoir and electronic modulating oil level analyzer. The ultra micron oil-aerosol separator can filter solid contaminant particles down to one micron in size and at the same time can deliver 100% oil-aerosol free refrigerant. With this technology an oil-free refrigerant circulation can be achieved. The problems related to oil carry over, thermal and chemical stability, moisture, oil cleanliness and lubrication in the refrigeration circulation could therefore be avoided. As a result, the energy consumption of the refrigeration system can be largely reduced and the refrigeration efficiency of the system can be significantly enhanced. Thus COP is increased by the use of oil-free refrigerant circulation technology.

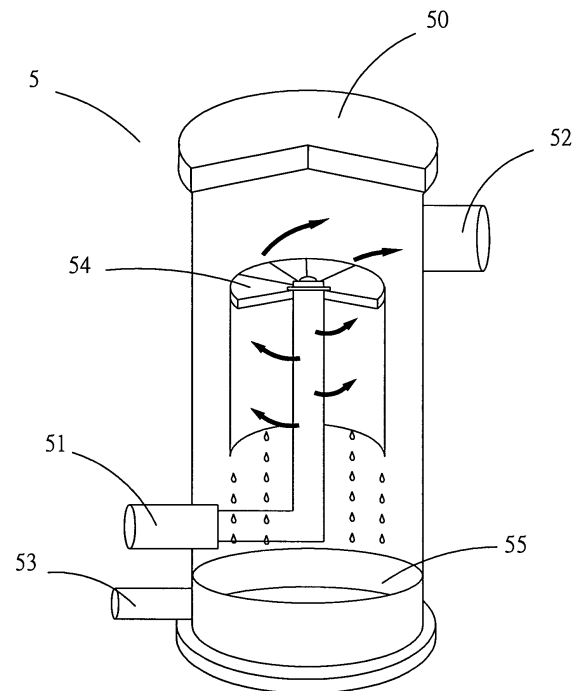


Fig. 3

Description

FIELD OF THE INVENTION

[0001] The present invention relates to oil-free refrigerant (OFR) circulation technology for air-conditioning and refrigeration system. More specifically, the present invention relates to oil-free refrigerant (OFR) circulation technology consisting of frictionless 99.99% oil-vapor free (OVF) refrigeration oil, ultra micron oil-aerosol separator with built-in reservoir, and electronic modulating oil level analyzer to increase energy efficiency and reduce maintenance cost. The oil-aerosol separator can filter solid contaminant particles down to one micron in size and at the same time can deliver 100% oil-aerosol free refrigerant. The electronic modulating oil level analyzer can maintain compressor crankcase oil level recommended by compressor manufacturers for CFC, HCFC, HFC, ammonia and CO₂ refrigeration compressors at any given variable load.

BACKGROUND OF THE INVENTION

[0002] Referring to Fig. 1, which shows schematically the compressor refrigeration cycle, the compressor 1 will drive the refrigerant to the condenser 2 through pipe for condensing, then the liquid refrigerant will go through the expansion device 3 to the evaporator 4 for evaporation by absorbing surrounding heat, and finally the refrigerant vapor will be back to the compressor 1 for recycling.

[0003] Compressor is the heart and oil is the lifeblood of any air-conditioning and refrigeration compressor. The primary function of the compressor is to circulate refrigerant that has high latent heat carrying capacity to condenser, expansion valve and evaporator. Therefore the compressor capacity determines the capacity of the refrigeration system as a whole. Hence its capacity, reliability, and energy efficiency are significantly influenced by the performance of other components like refrigerant, refrigeration oil, condenser, expansion valve and evaporator.

[0004] It has been a common practice in the air-conditioning and refrigeration industry that addition of oil separator, reservoir and oil level controller is a cure to oil carry over problem. This is a misconception. The oil vapor is a gas generated by the shearing action of screw compressor rotors or reciprocating compressor pistons and valves during compression process. This oil vapor is subjected to Dalton's Law of Partial Pressures and cannot be removed by any type of oil separator and is the single largest portion of the refrigeration oil (99.99%) carrying over from compressor to the refrigeration system, and continuously contaminates the refrigerant latent heat carrying capacity.

[0005] This superheated discharge oil vapor on condensing will build-up excess oil layer on the surface areas of the condenser, the expansion valve and the evaporator. As a result, there is a dramatic loss in useful and

effective surface area required for maximum heat transfer efficiency. Coil area will be less, as part of the space is occupied by the oil. Moreover, pressure drop in the heat exchangers, liquid and suction lines will be increased. All of these will result in increase of compressor load and significant loss in refrigeration capacity, and will also make compressor run time longer. Thus energy efficiency and increase maintenance cost will be dramatically reduced.

[0006] Circulation of refrigeration oil with refrigerant has been standard practice in the air-conditioning and refrigeration industry for more than half a century and it has been considered as an inevitable fact that refrigeration oil circulating with refrigerant is essential for adequate oil return to compressor. The only purpose for refrigeration oil is to lubricate compressor bearings and other moving parts. If the refrigeration oil remains in the crankcase where it belongs to, many oil related problems in refrigeration systems would be prevented.

[0007] Accordingly there is a need to resolve oil vapor carry over, thermal and chemical stability, moisture, oil cleanliness and lubrication problem caused by solvent refined mineral oil and POE oil used in air-conditioning and refrigeration system.

[0008] Oil related problems cost the industry millions in terms of service calls, energy cost and compressor burnout as published in the ASHRAE Journal April 1995. The most important oil related problems are:

- Oil Carry Over
- Thermal and Chemical Stability
- Moisture
- Oil Cleanliness
- Lubrication

[0009] It is a well known fact in the industry that oil carry over causes serious problems to the entire refrigeration system. The first pass of the condenser de-superheats the discharge line gas. This prepares the high-pressure superheated refrigerant vapor coming from the compressor's discharge line for condensation, i.e. phase change from refrigerant vapor to liquid. The refrigerant is then said to have reached 100% saturated vapor point. The rejection of heat from superheated refrigerant vapor will determine the utilization of useful or effective "Heat Rejection Factor" [HRF] of the condenser. To that end condenser manufacturers require high latent heat carrying of the refrigerant in order to guarantee designed condenser heat rejection factor.

[0010] The superheated oil vapor will take up the most valuable surface area used for de-superheating and condensing of superheated refrigerant vapor to liquid. At the same time this superheated oil vapor in the condenser will impede heat transfer and dramatically reduce coefficient of conductance on the condenser wall. Both of these factors will produce smaller temperature difference between the superheated refrigerant vapor and the condensing medium such as air or water.

[0011] For these two reasons the rate of heat transfer through the condenser wall is substantially reduced and as a result more heat will start to accumulate in the condenser. This accumulation of heat in the condenser will lead to significant increase in superheated refrigerant vapor's intensity, so the pressure and volume of this superheated refrigerant vapor will increase and saturation of superheated refrigerant vapor will slow down substantially. As a result, condensing of refrigerant vapor to liquid will be suppressed significantly and will end up with generation of more flash gas.

[0012] Furthermore, this superheated oil vapor upon condensing will build-up excess oil layer on useful and effective surface area used for condensing and sub-cooling for phase change from refrigerant vapor to refrigerant liquid, i.e. phase change from vapor to liquid in condenser. As a result, there is a dramatic loss in useful and effective surface area required for maximum heat transfer coefficient efficiency.

[0013] As part of the space is occupied by oil, the useful coil area will be less and the pressure drop in the heat exchanger and liquid line will be increased. It will then further accelerate the increase in refrigerant-lubricant viscosity and oil non-equilibrium behavior.

[0014] The higher viscosity of oil reduces molecular and turbulent transport of liquid refrigerant in the condenser. All of these factors directly translate into excessive load on the condenser Heat Rejection Factor [HRF]. This will cause higher head pressure, higher discharge gas temperature and higher condensing temperature with higher power draw by the refrigeration compressor.

[0015] This in turn accelerates build-up of viscosity or breakdown of viscosity. Worse than that, the oil will react easier with the refrigerant, metals and contaminants such as dirt, oxide scale, flux, rust, steel, copper and brass chips frequently found in the refrigeration system to form sludge, gums, varnish and carbon deposit on the condenser tube surface area, thermostatic expansion valve or electronic expansion valve, evaporator surface area and compressor.

[0016] Oil contamination in the refrigerant will also reduce the volumetric capacity of the condenser. If 10 percent of the liquid refrigerant and oil solution is oil, then only 90 percent of the solution can be refrigerant and so the unit must operate much longer in order to have the required amount of refrigerant passing through the condenser.

[0017] The primary function of thermostatic and electronic expansion valve is to meter sufficient liquid refrigerant to the evaporator to satisfy the load. TXV and EEV manufacturers require that the refrigerant liquid supplying at the inlet to the valve should be vapor free to guarantee the rated valve capacity but have ignored the effect of oil circulation at the inlet of TXV and EEV. Most of the current correlations of refrigerant-oil mixture are developed from "oil contamination approach". That is not thermodynamically correct.

[0018] The "oil contamination approach" method stud-

ies the performance of refrigerant-oil mixture based on pure refrigerant properties. It ignores the influence of oil on the boiling point temperature, specific heat, latent heat, viscosity, density, etc. This in turn alters energy balance, local boiling temperature, superheat, local vapor quality and so on in the data reduction process to calculate heat transfer coefficient and two-phase pressure drop.

[0019] The tangible method is the "thermodynamic approach" that considers the refrigerant-oil mixture as something like zeotropic refrigerant. The research methods on zeotropic refrigerant have been well understood. It is thermodynamically correct to study the refrigerant-oil mixture as zeotropic refrigerants.

[0020] University research studies have shown that 7% to 10% of oil mass with a very large viscosity circulation in the condenser tube surface area can cause dramatic reduction in "latent heat of vaporization" at the inlet of the thermostatic or electronic expansion valve and thus can dramatically reduce the latent heat carrying capacity of the liquid refrigerant available for useful refrigeration and the rated capacity of TXV or EEV. The thermostatic or electronic expansion valve will have a hard time controlling superheat. TXV or EEV will also see too much oil passing through it. Furthermore, the evaporator's tailpipe will be logged with oil and inside of the tube surface area will be coated with oil. The remote bulb of TXV or EEV sensor at the evaporator outlet will have a hard time to sense a true evaporator outlet temperature because of reduction on heat transfer through the line. TXV or EEV will begin to hunt, starve the evaporator and reduce refrigeration system capacity.

[0021] As a result, constant superheat will not be maintained. TXV remote bulb or EEV sensor may sense a warmer-than-normal temperature and therefore may over feed TXV or EEV to run at a low superheat that can result in flooding or slugging the compressor with refrigerant. The compressor pistons can momentarily pump slugs of liquid oil that can build tremendous hydraulic force because of the incompressibility of most liquids and will lead to serious damage on compressor valves and other lubricating parts.

[0022] Evaporator is the coldest component with largest tubes, thus it has the slowest refrigerant velocity. The higher oil mass fraction (OMF) and thicker oil film viscosity at low temperature can cause excessive oil build-up on the wall of the evaporator tube surface area to cause imperfect refrigerant distribution. The refrigerant-oil mixture enters into evaporator at low temperature and the viscosity of the refrigerant-oil mixture will increase dramatically due to poor viscosity index of the solvent refined mineral oil and POE oil.

[0023] The solvent refined mineral oil has a viscosity index from 0 to 40. The viscosity of solvent refined mineral oil at -40°C is 32,000 cSt for ISO 22 cSt grade and 1,000,000 cSt for ISO 32 cSt grade, and at -30°C is 170,000 cSt for ISO 68 cSt grade. The pour point for solvent refined mineral oil is in the range of - 30 °C to -

40 °C.

[0024] On the other hand, POE oil has a viscosity index from 90 to 130. The viscosity of POE oil at - 40 °C is 22,000 cSt for ISO 22 cSt grade and 45,000 cSt for ISO 32 cSt grade, and at -30°C is 70,000 cSt for ISO 68 cSt grade. The pour point for POE oil is in the range of - 35 °C to - 52 °C.

[0025] There is an excessive loss of energy to overcome the frictional loss due to viscous drag in the evaporator tube surface area that further accelerates the increase of refrigerant-oil mixture viscosity and oil non-equilibrium behavior. The oil excess layer forms during the phase change from liquid to vapor. The oil excess layer has a very large viscosity that causes a large oil volume build-up in the evaporator tube surface area and as a result will take up valuable evaporator surface area used for vaporization. The oil excess layer causes insulation effect to decrease boiling of refrigerant, to increase pressure drop, and to reduce molecular and turbulent transport of refrigerant, therefore dramatically reduces the evaporator heat transfer efficiency.

[0026] All of these factors will produce a larger temperature difference between load and evaporating refrigerant. Increase of temperature difference in evaporator indicates a decrease in COP and refrigeration capacity. Refrigeration capacity and COP are further reduced to the extent that vapor pressure of refrigerant-oil solution is less than that of vapor pressure of the refrigerant alone. If operation of compressor is controlled by suction pressure, it will stop running at a higher temperature when vapor pressure is reduced.

[0027] Therefore for an evaporator to operate with maximum heat transfer efficiency, it must be fed with oil free liquid refrigerant. To accomplish this, TXV or EEV must feed evaporator with oil free liquid refrigerant at the same rate that it evaporates. Studies have shown that oil presence can reduce system performance as much as 30%.

[0028] It is also important to understand how the oil vapor and oil aerosol carry over are generated. The oil vapor exists as mist typically in the size about 0.001 micron and oil aerosol exists as droplets typically in the size ranging from 0.01 to 0.8 micron. The oil aerosol is generated by the shearing action of the compressor during the compression process. Oil vapor and oil aerosol are trapped in the superheated discharge gas vapor.

[0029] Solvent refined mineral oil has extremely high volatility properties such as very high vapor pressure, very low viscosity index, very high pour point and very low flash point. Therefore, along with refrigerant-oil dilution effect, the viscosity will be seriously reduced when solvent refined mineral oil is exposed to high superheated discharge gas temperature. As a result the friction will be increased and in turn there will be more quantity of oil vapor generated. It is for this reason, the compressor lubricating oil plays a very important role as it not only determines the oil vapor content in superheated discharge gas vapor but also determines the frequency of

oil change.

[0030] The quantity of oil vapor in the compressor in a large degree depends on the molecular distribution of the oil. In a gas-chromatographic analysis, solvent refined mineral oil shows a typical broad bell-shaped distribution of the molecular weight with a high proportion of short molecular weight with very large number of short-chain molecules. It is these short-chain molecules that evaporate most easily and at the same time accelerates the generation of oil aerosol.

[0031] The quantity of HFC refrigerants such as R-134a, R-407c, R-410a and R-404a dissolved in POE oil is more than double when compared with solvent refined mineral oil. The very high miscibility factor of POE oil further causes serious reduction in viscosity and in turn accelerates evaporation of more quantity of oil vapor and oil aerosol.

[0032] Moisture in a refrigeration system with HCFC and CFC refrigerants and mineral oil can cause formation of hydrochloric and hydrofluoric acids. In a refrigeration system with POE oil and HFC refrigerant, moisture can also cause formation of significant amount of organic acids which can lead to seal and gasket failure, lubrication break down, blockage of TXV, copper plating and in worst case scenario bearing erosion and compressor motor burn out.

[0033] The solvent refined mineral oil has moisture content in the range of 50 PPM to 90 PPM and, when exposed to high discharge gas temperature, will undergo polymerization or de-polymerization due to lack of proper thermal and chemical stability. POE oil also lacks in proper thermal and chemical stability because of highly hygroscopic in nature and absorbs moisture in the range of 2500 PPM, approximately 10 times more than that of mineral oil. As a result it can undergo hydrolysis. The effect of hydrolysis will reverse the reaction of POE oil to its original components of acid and alcohol.

[0034] In journal bearing lubricated compressor, the incompressibility of water relative to oil can result in loss of hydrodynamic lubricating oil film that in turn leads to excessive wear. As little as 1% of water in oil can reduce the life expectancy of journal bearing by as much as 90%.

[0035] For the rolling bearings, the situation is even worse. Not only will water destroy the oil film strength, but both free and emulsified water under the extreme high temperature and pressure generated in the load zone of a rolling bearing can result in instantaneous flash vaporization to cause erosive wear. This will result in corrosion of metals in compressor and other lubricating parts and cause friction increase. This will then accelerate wear and tear of compressor parts and will raise discharge gas temperature and compression ratio with higher power draw.

[0036] Compressor manufacturers clearly caution in their technical bulletins that POE oil is suitable for HFC application, but significant increase in risk exists regarding compressor wear and chemical stability of the system. This even applies to compressors that are construct-

ed with high quality materials such as surface hardened shaft, specially treated bearings, hard chrome plated compression rings and high alloy steel valve reeds.

[0037] Compressor bearing manufacturer demand that rolling and journal bearings used in air-conditioning and refrigeration compressors should operate with lubricant that meet lubricating oil cleanliness standard to minimize surface wear. 70% of the compressor bearing failure is caused by surface wear. The recommended lubricating oil cleanliness codes for journal and rolling bearings as per ISO 4406 should be 16/14 and 15/14 respectively. In reality most of the finished refrigeration oils supplied in the refrigeration industries do not meet this requirement and the cleanliness is usually about 18/11. Apparently oil with better cleanliness is needed.

[0038] The primary method of defense against degrading force is the lubricant film. Lubricating oil forms film to fill up the clearance between the bearing and journal. The load on the journal is carried by the layer of oil and transmitted to bearing. The pressurized oil is sent through drilled holes in the crankshaft to supply oil to all bearings. Since journal is supported or floats on the oil layer, there is no metal-to-metal contact. Excessive oil is relieved by the pressure regulating valve, usually to seal chamber to provide lubrication to the shaft seal assembly.

[0039] Analysis of refrigeration oil samples taken from refrigeration and air-conditioning operating systems shows a high concentration of 5 to 20 micron particles, with largest percentage in 15 microns. Bearing life can be doubled when the contaminant particulate size in the oil is reduced to three microns or less. These 5 to 20 micron hard particles can circulate through the drilled holes of crankshaft, because the oil screen filter in the crankcase, liquid and suction line filter drier can only filter down to 40 microns. 5 to 20 micron particles form deposit that can result in restriction of oil flow to crankshaft and other lubricating moving parts, and in turn can cause loss of oil pressure and increase in pressure drop in lubricating oil feed line. The hydrodynamic or elastohydrodynamic lubrication film between the metal surfaces can be disrupted, leading to premature wear of the metal surfaces and high overall operating cost.

[0040] Moreover, solvent refined mineral oil contains chemical impurities such as 40% wax, 38% aromatics, 13400 PPM sulfur, 160 PPM nitrogen, 1.64 PPM polar compounds and 90 PPM moisture. All of these can lead to the formation of sludge and deposit via oxidation and other chemical reaction. At the same time the cross linkage of the chloroprene polymer with sulfur forms neoprene elastomer. The presence of sulfur in the lubricant will result in additional cross linkage of the chloroprene and subsequent hardening of the elastomer. This will lead to seal leakage in the compressor.

[0041] The transition from CFC refrigerants to HFC refrigerants has also created lubrication and energy efficiency problem due to the fact that the new refrigerants such as R-134a, R-404a, R-407C, R-507 and R-410a have no more lubrication properties as a result of the

absence of chlorine. The chlorine in the system is responsible for the ferro chloride film that lubricates moving parts of the compressor. Without this ferro chloride film, friction and temperature will be increased considerably and reliability, corrosion protection and efficiency of the components will be deteriorated. The replacement of the chlorine by hydrogen will cause increased energy consumption and maintenance cost.

[0042] With what have been briefly reviewed above, it is clear that there is a need to resolve the problems related to oil vapor and oil aerosol carry over, thermal and chemical stability, moisture, oil cleanliness and lubrication to avoid unnecessary waste on energy consumption and maintenance cost. There have been quite a few suggestions in the past to minimize the problems mentioned above. Those suggestions are focused on partial solution to the problems and are often with serious drawback.

[0043] One method is to partially de-superheat the discharge gas vapor with liquid refrigerant injection with centrifugal pump known as liquid pressure amplification. This method has many drawbacks. First of all, it increases compressor head pressure and therefore increases power consumption as reported in technical data sheet by US Navy. Secondly, heavier molecular weight refrigerants HCFC and HFC, for example R-22, R-134a and Propane, will result in higher dilution characteristics of 15 % to 20% due to its chemical composition. If discharge gas temperature is further reduced with liquid refrigerant injection, refrigerant dilution becomes extreme and can cause a complete compressor failure.

[0044] This type of de-superheating, often called liquid refrigerant injection, has been practiced for years and was thought to be a free method of de-superheating. This is simply not the case. Most of the lubricant cooling in the liquid refrigerant injection system takes place in the oil separator. The oil separator is designed to separate lubricant from refrigerant. By injecting liquid refrigerant into the compressor discharge gas, one has a mixture of liquid refrigerant and lubricant. The liquid refrigerant dilutes the lubricant and causes serious reduction in bearing oil supply viscosity and oil pressure that will result in increased friction. This will then accelerate evaporation of more quantity of oil vapor.

[0045] Some of this liquid refrigerant is pumped with the lubricant into the bearings causing a washing effect and decreasing the MTBF (mean time between failures). Also, some of this refrigerant will flash into the rotor sealing screw compressor causing capacity loss. The more refrigerant in the lubricant, the higher the capacity loss and the more other oil related problems.

[0046] Thirdly, the most serious deficiency of the centrifugal pumping method [as disclosed by U.S. Patent No. 6,076,367], however, is caused by the refrigerant at the outlet of the condenser or receiver. The liquid refrigerant at this location in the system is commonly at or very near the saturation point. Any vapor that forms at the inlet of the centrifugal pump due to poor condensation or slight drop in pressure caused by the pump suction or any other

reason will cause the centrifugal pump to cavitate or vapor lock and lose its prime. This renders the centrifugal pump ineffective until the system is stopped and restarted again. This will shorten the lifespan of the pump.

[0047] U.S. Patent No. 6,076,367 disclosed a further development. Again, as system pressure increases and refrigerant flow rate increases at higher load, the increased flow rate of refrigerant causes more pressure loss through the condenser. This same increased flow rate causes less pressure to be added to the liquid by the centrifugal pump in the liquid line. Thus, less liquid is bypassed into the compressor discharge line and less superheat is eliminated at the time when more reduction is needed. At some point the pressure loss through the condenser is greater than the pressure added by the centrifugal pump and therefore the effect is lost entirely.

[0048] Another method used in the industry to reduce saturated condensing temperature is by floating the head pressure with Electronic Expansion Valve (EEV) or with Liquid Pressure Amplification (LPA) as disclosed in U.S. Pat. No. 5,386,700, which uses a small centrifugal pump to reduce compression ratio. A drawback to this method is that low compression ratio can cause valve damage as found by manufacturers of reciprocating compressors. As compression ratio decreases, the volume of gas pumped increases which in turn imposes excessive stress on the valves and causes the valves to bend or flex beyond their designed limits, leading to metal fatigue and breakage. It is for this reason compressor manufacturers have not warranted their compressors, if the head pressure is allowed to float below 80°F (26.6°C).

[0049] Furthermore, compressor manufacturers also found that floating the head pressure can cause oil logging in the evaporator, because the refrigerant mass flow rate in the evaporator will start to decrease. This in turn reduces the refrigerant velocity in the suction riser to the extent that the refrigerant velocity is simply too slow for oil to return to the suction riser and therefore oil will be logged in the evaporator.

[0050] Logging of oil in the evaporator not only occupies valuable evaporator surface area necessary for heat transfer, but, if serious enough, may also rob the available oil from the compressor needed for adequate lubrication. This will lead to compressor lubrication failure due to low oil level in the crankcase. Moreover, there may be a short temporary period while the load is high enough, for example after a defrost cycle, to have velocity allowing logged oil to return. Large amount of oil sitting in the evaporator, if allowed to return in bulk, could seriously damage the compressor.

[0051] Another approach to overcome oil logging into condenser and evaporator is to inject chemical additive into the refrigeration system operating with solvent refined mineral oil to produce electromagnetic propagation to push the logged oil out of the condenser and evaporator in order to enhance refrigeration capacity as disclosed, e.g., in U.S. Pat. No. 4,963,280.

[0052] Adding of such chemical additive to solvent re-

finer mineral oil is ineffective, because solvent refined mineral oil contains chemical contaminants such as 1.64 PPM Polar compounds, 38% aromatics, 40% Wax, 160 PPM Nitrogen, 90 PPM Moisture and 13400 PPM Sulfur. These chemical contaminants in solvent refined mineral oil lead to formation of sludge and deposits via oxidation and chemical reactions.

[0053] Solvent refined mineral oil has zero or extremely low viscosity index. Moreover, solvent refined mineral oil contains polar molecules which increase the solubility of CFC, HFC and Ammonia refrigerants, and as a result, decrease the effective viscosity of the solvent refined mineral oil. Studies have shown that 3% dilution of CFC, HFC and Ammonia refrigerants in solvent refined mineral oil of ISO 68 grade would result in a loss of viscosity of over 5 cSt at 60 °C oil supply temperatures.

[0054] Therefore when exposed to superheated discharge gas temperature at 100 °C there will be serious reduction in bearing oil supply viscosity and oil pressure. This will result in poor hydrodynamic and elastohydrodynamic lubrication film between the metal surfaces leading to increased friction and will in turn result in premature wear of the metal surfaces, acceleration of evaporation of more quantity of oil vapor, and consumption of more energy.

[0055] This polar compound causes potential system problems such as poor lubrication and serious lubricant carry over. Solvent refined mineral oil lacks thermal and chemical stability and will undergo polymerization or depolymerization. The lack of thermal and chemical stability can build-up or break down of viscosity and also can lead to reaction of mineral oil with refrigerant, metals and contaminants in the system to form sludge and gums as well as carbon deposits on valves. As a result the operating life of solvent refined mineral oil is 3000 hours for air-conditioning application and 1000 hours for refrigeration application.

[0056] Furthermore, the viscosity of the solvent refined mineral oil at - 30 °C for ISO 68 Grade is 170000 cSt in the evaporator. Therefore, it will be technically and theoretically impossible for a chemical additive to push the 170000 cSt viscous oil logged in evaporator with a help of electromagnetic propagation back to the compressor crankcase.

[0057] It has been claimed that the chemical additives is also used to reduced the friction of the compressor bearings by 1500 % improvement in lubricity as disclosed, e.g., in U.S. Pat. No. 4,963,280. "Improvement in lubricity" is usually a descriptive term that can refer, in general, to a reduction in the coefficient of friction. Here a change in viscosity is essential. It is not the case with the injection of chemical additives as reported by Washington State University - Energy Extension in Energy Ideas.

[0058] Over the last several years, compressor manufacturer, Copeland, Hermetic Chemistry and Tribology groups, as a result of internal and external requests, have tested several oil additive products and has not been able

to detect any meaningful change in compressor power consumption when measurements were made under controlled laboratory conditions with properly broken-in compressors on laboratory calorimeters at constant condensing and evaporator temperatures and pressures.

[0059] Furthermore, the long term chemical stability of any additive in the presence of refrigerant, low and high temperatures, and materials commonly found in refrigeration systems is complex and difficult to evaluate without rigorous controlled chemical laboratory testing. Use of additives without adequate testing may result in malfunction or premature failure of components in the system and, in specific cases, may result in voiding the warranty on the components as reported in Copeland technical bulletin.

[0060] All of these suggestions so far are as a band-aid repair to treat the oil-carry over problem. It is clear that a new approach is needed to resolve the problems related to oil carry over, thermal and chemical stability, moisture, oil cleanliness, and lubrication. The best approach is to prevent the problem, instead of treating the problems with band-aid repairs.

SUMMARY OF THE INVENTION

[0061] The present invention relates to oil-free refrigerant (OFR) circulation technology for air-conditioning and refrigeration system. More specifically, the present invention relates to oil-free refrigerant (OFR) circulation technology consisting of frictionless 99.99% oil-vapor free (OVF) refrigeration oil, ultra micron oil-aerosol separator with built-in reservoir, and electronic modulating oil level analyzer to increase energy efficiency and reduce maintenance cost. The oil-aerosol separator can filter solid contaminant particles down to one micron in size and at the same time can deliver 100% oil-aerosol free refrigerant. The electronic modulating oil level analyzer can maintain compressor crankcase oil level recommended by compressor manufacturers for CFC, HCFC, HFC, ammonia and CO₂ refrigeration compressors at any given variable load.

[0062] The frictionless 99.99% oil-vapor free (OVF) refrigeration oil provides excellent hydrodynamic and elastohydrodynamic lubrication film for wear protection at high discharge gas temperature and at the same time provides excellent low temperature fluidity for better oil return by maintaining very low viscosity.

[0063] Moreover, frictionless 99.99% oil vapor free (OVF) refrigeration oil has zero moisture content, 13/11 oil cleanliness and low friction coefficient. Low friction coefficient correlates well with thick film formation, even under extreme load and variable condition. The energy efficiency of a compressor is highly affected by lubricant friction loss. Therefore the use of frictionless oil vapor free (OVF) refrigeration oil with extremely low friction coefficient can enhance energy efficiency of a compressor.

BRIEF DESCRIPTION OF THE DRAWINGS

[0064]

Fig. 1 shows schematically a conventional refrigeration system.

Fig. 2 shows schematically the oil-free refrigerant circulation technology according to the present invention.

Fig. 3 shows schematically the structure of ultra micron oil-aerosol separator according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0065] Referring to Fig. 2, which shows schematically the oil-free refrigerant circulation system according to the present invention, the compressor 1 drives the contaminated refrigerant to the ultra micron oil-aerosol separator 5 through pipe 51, and then the ultra micron oil-aerosol separator 5 will collect 100% of the oil aerosol to be fed back via pipe 53 to the compressor 1 through the electronic modulating oil level analyzer 6. The 99.99% oil-vapor free (OVF) refrigerant vapor will first be de-superheated and then enter the condenser 2 through pipe 52 for condensation. The liquid refrigerant will then pass through the expansion device 3 and enter the evaporator 4 for evaporation by absorbing surrounding heat. The evaporated refrigerant vapor will then be sucked back into compressor 1.

[0066] Fig. 3 shows schematically the structure of ultra micron oil-aerosol separator according to the present invention. The compressor 1 will drive the contaminated refrigerant to the ultra micron oil-aerosol separator 5 through pipe 51. An exceptionally pure and extremely fine matrix borosilicate micron fiber filter 54 covers the pipe 51, so that the oil aerosol and 99.99% oil-vapor free refrigerant will go through filter 54. The oil-aerosol will be collected by the filter 54 completely and forms droplets to dropping down to the reservoir 55 on the bottom of the ultra micron oil-aerosol separator 5. The refrigeration oil accumulated in the reservoir of the separator will be fed back to the crankcase through pipe 53 by the electronic modulating oil level analyzer 6 for maintaining proper oil level of the crankcase. The 99.99% oil-vapor free refrigerant will pass through the filter 54 and the de-superheating zone 52 to the condenser 2, then to the expansion device 3 and the evaporator 4 for absorbing surrounding heat for evaporation. Finally the 99.99% oil-vapor free refrigerant will be sucked back to the compressor 1 for recycling.

The exceptionally pure and extremely fine borosilicate micro fiber filter 54 can remove 100% of refrigeration oil aerosol mist down to 0.01 micron in size and at the same time will filter solid contaminant particles down to one micron in size trapped in the superheated discharge gas. The ultra micron oil-aerosol separator 5 has an anti-re-entrainment barrier on the downstream side of the sep-

arator to prevent refrigeration oil carry over or re-entrainment of the coalesced liquid after passing the borosilicate micro fiber. The anti-re-entrainment barrier is a special barrier which will hold large volume of coalesced lubricant. As the lubricant concentration within the anti-re-entrainment barrier increases, the lubricant gravitates through the re-entrainment barrier to a built-in reservoir at the bottom of the ultra micron oil-aerosol separator 5, where the lubricant will be metered from the built-in reservoir directly into the compressor crankcase through the electronic modulating oil level analyzer 6.

[0067] The electronic modulating oil level analyzer 6 maintains an oil level in the compressor crankcase for any given variable load condition. The electronic modulating oil level analyzer 6 feeds oil from the reservoir to the compressor crankcase when the oil level falls below recommended level and stops to feed oil from the reservoir back to the compressor crankcase when the oil level is too high. The oil level can therefore be maintained as per compressor manufacturer's recommendation.

[0068] To understand how oil-vapor free (OVF) refrigerant circulation can be achieved, we must first analyze how oil-vapor free (OVF) refrigeration oil, ultra micron oil-aerosol separator and electronic modulating oil level analyzer can overcome the problems in the conventional refrigeration circulation related to oil vapor and oil aerosol carry over, thermal and chemical stability, moisture, oil cleanliness and lubrication. The air-conditioning and refrigeration industry can then utilize the oil free refrigerant circulation technology for CFC, HCFC, HFC, ammonia and CO₂ refrigeration compressors to reduce energy cost, break down cost, maintenance cost and green house gas emission.

[0069] As mentioned before, the most important factors that affect dynamics of refrigeration circulation and in turn affect the compressor capacity and energy efficiency are:

- Oil carry over
- Thermal and chemical stability
- Moisture
- Oil cleanliness
- Lubrication

[0070] The present invention uses oil-vapor free (OVF) refrigeration oil which prevents the oil vapor carry over by 99.99% because of its excellent lubricant properties such as very low vapor pressure and very high flash point in the range of 200°C to 450 °C and contains no short-chain molecules.

[0071] The oil-vapor free (OVF) refrigeration oil used in present invention has a very high viscosity index in the range of 200 to 450. This high viscosity index ensures adequate bearing oil supply viscosity at a superheated discharge gas temperature and the refrigerant-oil dilution characteristics. Therefore OVF refrigeration oil provides excellent wear protection, prevents further evaporation of oil vapor, and minimizes the generation of oil aerosol

carry over. The oil-vapor free (OVF) refrigeration oil used in this invention provides 99.99% evaporation resistance and has 99.99% less oil vapor content at superheated discharge gas temperature leaving the compressor, therefore there will be effectively 99.99% oil-vapor free refrigerant entering the condenser.

[0072] Conventional oil separator used in refrigeration application heavily relies on centrifugal force and needs compressor operating constantly under full load condition to capture oil aerosol carry over. The draw back to this method is that it works effectively only on relatively large oil aerosol droplets ranging from 5 to 15 microns.

[0073] Oil aerosol leaves compressor discharge line in the form of droplets typically in the size ranging from 0.01 to .8 micron and will not be captured by the conventional oil separator. Furthermore the centrifugal and impingement screen oil separators are highly velocity dependent and are highly inefficient at part load condition.

[0074] Screen filter of conventional oil separator can only remove solid contaminants down to 40 microns in size and can easily get blocked permanently in a few hundred hours of operation. Analysis on refrigeration oil samples taken from refrigeration and air-conditioning systems shows that there is a high concentration of 5 to 20 micron solid contaminant particles in general, with the largest percentage of solid contaminant particles in the range around 15 microns. Furthermore, conventional oil separators are hermetically sealed and cannot be accessed for cleaning.

[0075] Therefore conventional oil separators can't provide effective oil aerosol separation and solid contaminant filtration for the refrigeration system continuously. Re-entrainment of oil at pickup tube can also cause serious problem. The oil aerosol separation efficiency is lost as soon as the impingement screen filter is blocked. The blockage on the filter also causes excessive pressure drops. This will cause higher head pressure, higher discharge gas temperature and higher condensing temperature. As a result higher power draw by the refrigeration compressor is needed and higher maintenance cost is required.

[0076] The present invention uses a specially designed ultra micron oil-aerosol separator built in with exceptionally pure and extremely fine matrix borosilicate ultra micron fiber filter. This micron fiber filter can remove 100% of oil aerosol mist as low as 0.1 micron trapped in the superheated discharge gas vapor leaving the compressor. This micron fiber filter can also filter solid contaminants as small as 1 micron in size and therefore doubles the compressor bearing life.

[0077] Based on the principle of coalescing and Brownian motion, the ultra micron oil-aerosol separator provides 100% oil aerosol separation efficiency by continuously exciting oil aerosol molecules to collide with each other to form larger oil aerosol droplets. Therefore oil aerosol carry over or re-entrainment of the coalesced liquid after passing through borosilicate ultra micron fiber filter can be prevented.

[0078] The present invention has an anti-re-entrainment barrier on the downstream side of the ultra micron oil aerosol separator. The anti re-entrainment barrier is specially designed and provides tough barrier to hold large volume of coalesced lubricant. As the lubricant concentration within the anti-re-entrainment barrier increases, the lubricant gravitates through the anti-re-entrainment barrier to the bottom of the ultra micron oil-aerosol separator. The separator has a built-in oil reservoir with oil level sight glass. Then the coalesced lubricant from the oil-reservoir is metered directly into the compressor crankcase through electronic modulating oil level analyzer.

[0079] It has been a common practice in the industry that refrigeration compressor operating with "too high" oil level in the compressor crankcase during the high load, for example after defrost or frequent start-stops, there should be an adequate refrigerant velocity in the evaporator to allow the logged oil to return. However, allowing large amount of oil sitting in the evaporator to return in bulk could seriously damage the compressor.

[0080] Refrigeration compressor operating with oil level in the compressor crankcase higher than recommended level can result in running at cylinder temperature 4.4°C to 15°C higher than normal. As a result the heat of compression will be increased and the cool suction gas will expand at a quicker rate. Consequently, the volumetric efficiency of the refrigeration compressor will be reduced.

[0081] The excess oil in the compressor crankcase can result in valve plate and cylinder head gasket failure. It can also raise discharge gas temperature and condensing temperature, causing higher power consumption and oil equalization problem.

[0082] On the other hand, if refrigeration compressor operates with "low oil" level in the compressor crankcase during the part load, floating head pressure and high oil carry over with the use of solvent refined mineral oil or POE oil can lead to poor elastohydrodynamic lubrication. As a result there will be a higher heat of compression as well as increase on friction. The higher heat of compression and increase on friction will increase wear and tear in the compressor and other moving parts and in turn will raise discharge gas temperature and condensing temperature with higher power consumption. Further more, oil carry over from compressor crankcase to the refrigeration circulation will be accelerated and refrigeration capacity will be further reduced.

[0083] To maintain proper oil level in the compressor crankcase, the present invention uses 99.99% oil-vapor free (OVF) refrigeration oil and ultra micron oil-aerosol separator in combination with electronic modulating oil level analyzer which continuously monitors the oil level in compressor crankcase and modulates recommended oil level in the compressor crankcase at part load as well as at any variable load by metering the coalesced lubricant drawn from the bottom of oil reservoir directly into the compressor crankcase.

[0084] The present invention uses 99.99% oil-vapor free (OVF) refrigeration oil that has less than 0.01% oil mass fraction in refrigerant circulation and has an extremely low viscosity for excellent low temperature fluidity in the evaporator. This is quite different from the case with solvent refined mineral oil or POE oil. At low temperature solvent refined oil or POE oil has very high viscosity and can even lose its fluidity. With oil-vapor free (OVF) refrigeration oil the compressor crankcase oil level does not fluctuate under part load and floating head pressure. This would further enhance the smooth operation of the modulating oil level analyzer to maintain the oil level equilibrium in the refrigeration compressor crankcase under any variable load. As a result energy consumption and maintenance cost will be reduced.

[0085] The use of oil vapor free (OVF) refrigeration oil that has less than 0.01% oil vapor content and ultra micron oil-aerosol separator that delivers 100% aerosol free refrigerant along with electronic modulating oil level analyzer that maintains oil level equilibrium in the refrigeration compressor crankcase under any variable load are able to accomplish oil free refrigerant circulation.

[0086] In this invention, compressor pumps 99.99% pure refrigerant vapor carrying high latent heat capacity to enter the condenser. After condensation the 99.99% pure liquid refrigerant carrying high latent heat capacity circulates through receiver, liquid line, thermostatic expansion valve or electronic expansion valve. The TXV or EEV then feeds the 99.99% pure liquid refrigerant carrying high latent heat capacity to the evaporator with balanced and even distribution flow at the same rate as it evaporates.

[0087] Finally the 99.99% pure high quality refrigerant vapor is returned through suction line to compressor for compression. The volumetric efficiency of the compressor is largely enhanced. Thus oil free refrigerant circulation technology can dramatically improve the COP and refrigeration capacity of the system by 20% to 30%.

[0088] The oil-free refrigeration circulation technology of present invention allows condenser and evaporator to remain 100% efficient all the time. Therefore with the use of oil free refrigerant circulation technology there is no need to include oil fouling factors in condenser and evaporator design and can save 15% to 20% of initial capital cost on air conditioning and refrigeration equipment.

OIL FREE REFRIGERANT CIRCULATION IN CONDENSER

[0089] With the oil free refrigerant circulation technology present of invention the refrigeration compressor discharges superheated 99.99% oil-vapor free refrigerant vapor with small amount of oil aerosol. After the oil-aerosol separator, the aerosol is filtered out and at the same time the solid contaminant particles down to one micron in size are also filtered. Therefore only 100% oil aerosol free refrigerant with less than 0.01% oil mass fraction enters the condenser. This 99.99% oil-vapor free refrigerant

erant is virtually non-hygroscopic and has 13/11 oil cleanliness standard, free of solid contaminants with particle size below 1 micron.

[0090] This means that the present invention uses practically 99.99% oil free, 100% oil aerosol free and therefore 99.99% contaminant free superheated refrigerant vapor carrying high latent heat capacity to enter the de-superheating zone, condensing zone and sub-cooling zone of the condenser.

[0091] As a result the rate of heat transfer and conductance coefficient through the condenser wall is dramatically increased, which will lead to significant decrease in heat intensity of the superheated oil free refrigerant vapor, so the pressure and volume of this superheated oil free refrigerant vapor will decrease and the superheated oil free refrigerant vapor will reach saturation state faster. This will result in even distribution of 100% saturated oil free refrigerant vapor across the entire condenser surface area and therefore condensing of the oil free refrigerant vapor to liquid will begin closer to de-superheating zone at a rapid rate.

[0092] The rejection of unwanted heat from superheated oil free refrigerant vapor to the cooling medium of the condenser will be less and therefore reduces the load on condenser "Heat Rejection Factor" (HRF). All of these factors will produce more valuable surface area available for condensing of 100% saturated oil free refrigerant vapor to liquid. This will result in lower condensing and discharge gas temperature, greater percentage of condensation of oil free refrigerant vapor to liquid and more ambient sub-cooling. It can thus prevent generation of flash gas in the liquid line and in turn can significantly enhance turbulent transport of oil free liquid refrigerant.

[0093] Discharge gas temperature is of considerable important in refrigeration system, particularly in the condenser. The rate of chemical reactions approximately doubles when the discharge gas temperature is increased by 10°C. The present invention of oil free refrigerant circulation technology prevents formation of excessive discharge gas temperature and therefore there is less fouling within the water cooled condenser and the amplification of legionella growth rate in the water cooled condenser is also dramatically reduced.

[0094] The present invention of oil free refrigerant circulation technology achieves maximum condenser heat transfer efficiency, and therefore can increase COP and refrigeration capacity with greater pull down time. All of these factors directly translate into reduction on compressor run time and peak demand charge. Thus energy cost, breakdown cost and maintenance cost are largely reduced.

[0095] It is important to point out that the maximum heat transfer efficiency of the condenser can be retained under all ambient and variable load condition and does not call for liquid refrigerant injection. Liquid injection is ambient dependent and will lead to bearing oil supply viscosity dilution and requires additional energy and capital cost.

OIL FREE REFRIGERANT CIRCULATION IN THERMOSTATIC OR ELECTRONIC EXPANSION VALVE

[0096] The oil free refrigerant circulation technology of present invention will have 99.99% oil free and 99.99% solid contaminant free liquid refrigerant with high latent heat capacity entering thermostatic expansion valve or electronic expansion valve. Therefore, the thermostatic or electronic expansion valve will be able to maintain accurate superheat control at all the time. The remote bulb of the TXV or EEV sensor at the evaporator outlet will sense a true evaporator outlet temperature due to high quality oil free refrigerant vapor leaving the evaporator outlet. Therefore overfeeding by TXV or EEV to run at a low superheat and flooding or slugging on the compressor with refrigerant can be prevented. At the same time erosion of thermostatic expansion valve seat is also prevented due to 99.99% solid contaminant-free liquid refrigerant. All of these factors again directly translate into reduction of compressor run time and peak demand charge. Thus energy cost, break down cost and maintenance cost can be reduced.

OIL FREE REFRIGERANT CIRCULATION IN EVAPORATOR

[0097] The oil free refrigerant circulation technology of present invention will further have practically 99.99% oil free and 99.99% solid contaminant free liquid refrigerant carrying high latent heat capacity entering the evaporator with balanced and even distribution flow at the same rate as it evaporates. Therefore the rate of heat transfer and conductance coefficient through the evaporator wall is dramatically increased, that will lead to 100% boiling of the oil free liquid refrigerant to vapor. Consequently the maximum designed heat transfer efficiency of the evaporator is attained.

[0098] The small amount of oil vapor free (OVF) refrigeration oil circulating with the refrigerant in the evaporator has 0.01% oil mass fraction with extremely low viscosity due to very high viscosity index in the range of 200 to 450 to overcome the short fall of solvent refined mineral oil and POE oil for the given designed mass flow rate. This extremely low viscosity further prevents friction loss and pressure drop due to viscous drag and oil build-up in the evaporator surface area and suction line.

[0099] The oil vapor free (OVF) refrigeration oil circulation of present invention will have refrigerant in the evaporator with very low pour point in the range of - 60°C to - 90°C to provides excellent fluidity for the 0.01% oil mass fraction across the entire evaporator surface area under very low temperature condition. This will then enhance turbulent transportation of the 0.01% oil mass fraction of the oil vapor free (OVF) refrigeration oil at a very rapid rate of returning to the compressor crankcase to maintain the recommended oil level in the compressor for effective lubrication.

[0100] More valuable surface area is available for

100% evaporation of the oil free refrigeration liquid to vapor. Therefore maximum evaporator heat transfer efficiency as well as increase on COP and refrigeration capacity with greater pull down time can be attained. The number of start and stop of the compressor during part load and pull down load condition can therefore be significantly reduced and the high inrush current during the start up of the compressor motor can also be avoided as much as possible. Furthermore, wear and tear of compressor lubricating parts and motor bearings can be reduced. All of these directly translate into reduction of compressor run time and peak demand charge. Thus energy consumption, break down cost and maintenance cost can be reduced.

[0101] The liquid droplets carried over from the evaporator to the compressor crankcase can also be prevented due to even and balanced heat transfer distribution of the oil free liquid refrigerant across the entire evaporator surface area.

[0102] Even and balanced heat transfer distribution of the oil free liquid refrigerant across the entire evaporator surface area can result into complete boil off of the refrigerant into vapor and only high quality refrigerant vapor returns to the compressor crankcase which again prevents compressor wear during start up and enhances compressor volumetric efficiency. This in turn prevents excess formation of frost on the external surface area of the evaporator fins and therefore retains 100% maximum evaporator heat transfer efficiency all the time and prevents liquid flood back to the compressor.

MOISTURE

[0103] The oil vapor free (OVF) refrigeration oil present of invention has zero moisture and virtually non-hygroscopic by nature. The zero moisture content and non-hygroscopic nature of oil vapor free (OVF) refrigeration oil provides high dielectric strength, therefore prevents compressor motor burn out in hermetic and semi-hermetic compressors and increases the reliability and durability of the compressor, refrigerant, lubricant and associated components such as TXV, moisture indicator sight glass, liquid and suction line filter driers. The frequency of oil change as well as liquid and suction line filter drier replacement can therefore be largely reduced. At the same time, the moisture removal efficiency of the liquid and suction line drier, if present in the system, can further be enhanced.

[0104] The zero moisture content and non-hygroscopic nature of the oil vapor free refrigeration oil prevents its thermal and chemical degradation as well as formation of hydrochloric and hydrofluoric acid by mineral oil with HCFC and CFC refrigerants and significant amount of organic acids by POE oil with HFC refrigerants.

[0105] Thus seal and gasket failure, lubrication break down, blockage of TXV, copper plating and, in worst case, bearing erosion and compressor motor burn out and formation of sludge and varnish can be prevented.

Oil vapor free (OVF) refrigeration oil provides superior corrosion, oxidation and chemical protection, and excellent resistance to long-term oil thickening.

[0106] The zero moisture content and non-hygroscopic nature of oil vapor free (OVF) refrigeration oil prevents loss of hydrodynamic and elastohydrodynamic lubricating oil film in journal bearing lubrication and in rolling bearing lubrication to prevent erosive wear. Oil vapor free (OVF) refrigeration oil can prevent friction loss, wear and tear of compressor parts, excessive discharge temperature and higher compression ratio with higher power draw.

[0107] The present invention of oil vapor free (OVF) refrigeration oil can reject water 20 times faster than POE oil and solvent refined mineral oil, and, as a result, can increase latent heat carry capacity of the refrigerant for maintaining maximum heat transfer efficiency for condensation and evaporation. For every 1% of water there will be 2% reduction in refrigeration capacity and 1% increase in energy consumption.

[0108] All of these factors directly translate into reduction of compressor run time and peak demand charge. Thus, energy cost, break down cost and maintenance cost can be largely reduced.

OIL CLEANLINESS

[0109] The oil-vapor free (OVF) refrigeration oil of present invention is exceptionally pure and clean and exceeds industrial oil cleanliness standard. It has oil cleanliness of ISO 13/11. Therefore it doubles the compressor bearing life and protects the shaft seal face from circulating particle damage and extends seal life dramatically. Oil-vapor free (OVF) refrigeration oil thus can remove heat of compression rapidly, reduce friction and prevent surface wear in journal and roller element bearings. As a result it lowers discharge gas temperature and compression ratio with lower power draw on the refrigeration compressor motor.

[0110] Since there are fewer particles in the oil-vapor free (OVF) refrigeration oil, there will be less abrasion, adhesion and corrosion, and the equipment will last longer. If the equipment lasts longer, it will perform its designed function over a longer period of time and the equipment will be more reliable. Better oil cleanliness can lower the effects of solid particle contamination that interfere with the lubricating oil film. It also maintains better separation of the metal surfaces.

[0111] The exceptionally clean oil-vapor free (OVF) refrigeration oil of present invention has cleanliness of ISO 13/11 that provides excellent oil flow through the drilled holes of crankshaft and other lubricating moving parts. It reduces pressure drop in lubricating oil feed line and also provides tough hydrodynamic and elastohydrodynamic lubrication film between the metal surfaces and prevents friction loss on metal surfaces. Therefore the energy cost and maintenance cost can significantly be reduced.

EFFECT OF VISCOSITY ON COMPRESSOR OIL LUBRICATION

[0112] The oil-vapor free (OVF) refrigeration oil of present invention has excellent viscosity to provide tough hydrodynamic and elastohydrodynamic film at the superheated discharge gas temperature to provide excellent wear protection to all moving parts and give satisfactory sealing and lubrication in the compressor.

[0113] The oil-vapor free (OVF) refrigeration oil of present invention has very high viscosity index. This means that there is a relatively small change in viscosity across the temperature range for the compressor bearing lubrication. Therefore a higher viscosity index provides lower wear. It is worth mentioning that improper lubrication is responsible for 50% to 80% of all mechanical and electromechanical compressor failures.

[0114] The oil-vapor free (OVF) refrigeration oil of present invention is "resistant to dilution" because of its controlled miscibility and solubility. Resistant to dilution can improve volumetric efficiency in compressor and provide efficient oil return from the system. In addition, test on oil-vapor free (OVF) refrigeration oil of present invention shows that there is no loss of lubricant film under diluted condition with rolling and journal bearing elements at extreme operating condition.

[0115] High viscosity index of the oil-vapor free (OVF) refrigeration oil of present invention provides a high viscosity for effective lubrication and good sealing wedge on the leading edges of piston rings against the leak back of the discharge gas in reciprocating compressor and compressor rotors in screw compressor. On the other hand, the high viscosity index can retain a low viscosity needed for good oil return from the low temperature side of the refrigeration system.

[0116] Test on the oil-vapor free (OVF) refrigeration oil of present invention with rotary screw compressor shows 20% improvement in refrigeration capacity over solvent refined mineral oils. Test on low temperature reciprocating compressor shows 35% improvement in refrigeration capacity over POE oil.

EFFECT OF FRICTION CO-EFFICIENT ON COMPRESSOR OIL LUBRICATION

[0117] The oil-vapor free (OVF) refrigeration oil of present invention has lower friction co-efficient and provides with thick enough film even under extreme load and variable condition. It can therefore prevent friction loss and can greatly reduce friction and viscous drag.

[0118] At ISO Grade 68 cSt viscosity and 100°C, solvent refined mineral oil has friction coefficient 0.08 and POE oil has friction coefficient 0.05. At the same test condition the oil-vapor free (OVF) refrigeration oil of present invention has the lowest friction coefficient 0.02 at ISO Grade 68 cSt viscosity. That amounts to 300 times less friction loss than mineral oil and 150 times less friction loss than POE oil.

[0119] This means that the oil-vapor free (OVF) refrigeration oil of present invention has high load carrying capacity without causing skidding, dragging or overheating, and has less friction generated by the oil itself while in lubrication, thus results in less power required to overcome friction.

[0120] Better frictional performance of the oil-vapor free (OVF) refrigeration oil of present invention causes less frictional heat in contact zone and hence provides thicker lubricating film. At the same time the oil-vapor free (OVF) refrigeration oil of present invention has a higher thermal and chemical stability. Therefore oil change interval is significantly extended and temperature of discharge gas and other lubricating parts are lowered. Consequently the oil-vapor free (OVF) refrigeration oil of present invention can provide better wear protection and therefore better reliability on the compressor and other moving components. All of these factors can directly translate into about 50% reduction in maintenance and break down cost.

[0121] While we have shown and described various embodiments in accordance with the present invention, it should be clear to those skilled in the art that further embodiments may be made without departing from the scope of the present invention.

Claims

1. An oil-free refrigerant circulation system for air-conditioning and refrigeration, **characterized in that** the system comprising of oil-vapor free (OVF) refrigeration oil, ultra micron oil-aerosol separator built in with oil reservoir, and electronic modulating oil level analyzer.
2. The system of claim 1, **characterized in that** the OVF refrigerant oil has a viscosity index in the range of 200 to 450.
3. The system of claim 1, **characterized in that** the OVF refrigeration oil has viscosity at -40°C to -54°C for an ISO 22 cSt grade in the range of 250 cSt to 4500 cSt, for an ISO 32 cSt grade in the range of 450 cSt to 20000 cSt, and for an ISO 68 cSt grade in the range of 1850 cSt to 30000 cSt.
4. The system of claim 1, **characterized in that** the OVF refrigeration oil at 100°C has viscosity 5.0 cSt for an ISO 22 grade, 6.0 cSt for an ISO 32 grade and 10.0 cSt for an ISO 68 grade.
5. The system of claim 1, **characterized in that** the OVF refrigeration oil has flash point in the range of 250°C to 450°C.
6. The system of claim 1, **characterized in that** the OVF refrigeration oil has pour point in the range of -

60°C to - 90°C.

7. The system of claim 1, **characterized in that** the OVF refrigeration oil has zero moisture content. 5
8. The system of claim 1, **characterized in that** the OVF refrigeration oil has oil cleanliness of ISO 13/11 standard.
9. The system of claim 1, **characterized in that** the OVF refrigeration oil has friction coefficient value of 0.02 for ISO Grade 22, 32 and 68 cSt viscosity at oil temperature 100°C. 10
10. The system of claim 1, **characterized in that** said OVF refrigerant oil with properties of claim 1 to claim 9 has oil vapor less than 0.01% in the refrigerant circulation. 15
11. The system of claim 1, **characterized in that** the ultra micron oil-aerosol free separator is built-in with an exceptionally pure and extremely fine borosilicate micro fiber filter that can remove 100% of OVF refrigeration oil aerosol mist down to 0.01 micron and solid particles down to one micron in size trapped in the discharge gas; the ultra micron oil-aerosol free separator has an anti re-entrainment barrier on the downstream side of the separator to prevent refrigeration oil carry over or re-entrainment of the coalesced liquid after passing the borosilicate micro fiber; the anti re-entrainment barrier is a special barrier which will hold large volume of coalesced lubricant; as a lubricant concentration within anti re-entrainment barrier increases, the lubricant gravitates through the re-entrainment barrier to a built-in reservoir at the bottom of the ultra micron oil-aerosol free separator, where it is metered from the built-in reservoir directly in to the compressor crankcase through the electronic modulating oil level analyzer. 20
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12. The system of claim 1, **characterized in that** the electronic modulating oil level analyzer maintains an oil level in the compressor for any given variable load conditions; the electronic modulating oil level analyzer feeds oil from the reservoir to the compressor crankcase when the oil level fluctuates during part load or falls below recommended level and stops feeding oil from the reservoir to the compressor crankcase when the oil level is too high during defrost period or for various reasons, so that the oil level is maintained as per compressor manufacturer's recommendations at all time. 45
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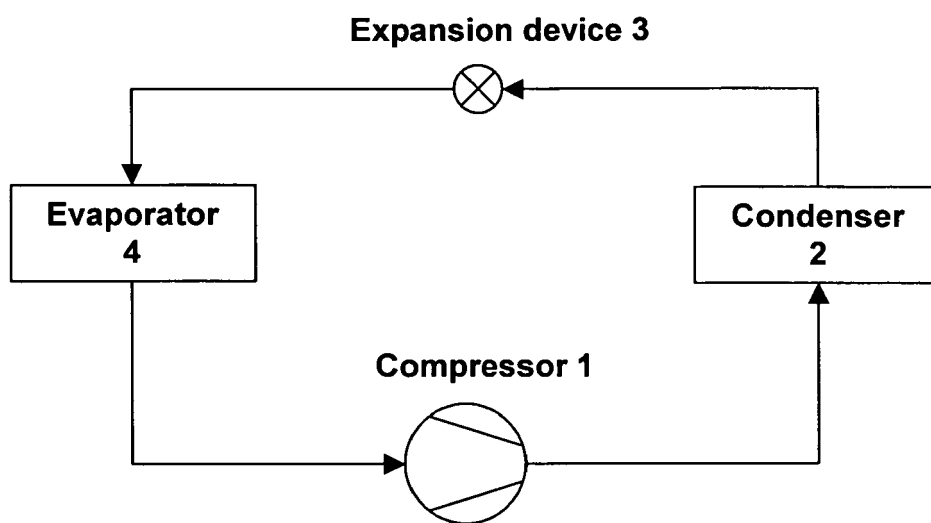


Fig. 1 (prior art)

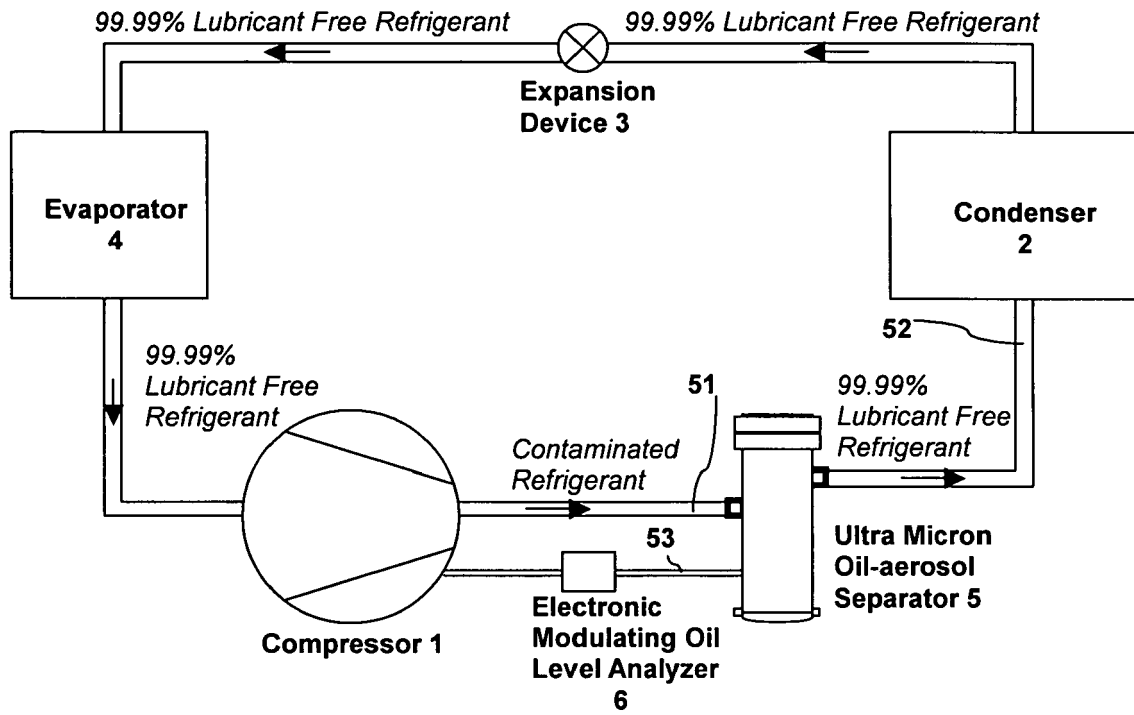


Fig. 2

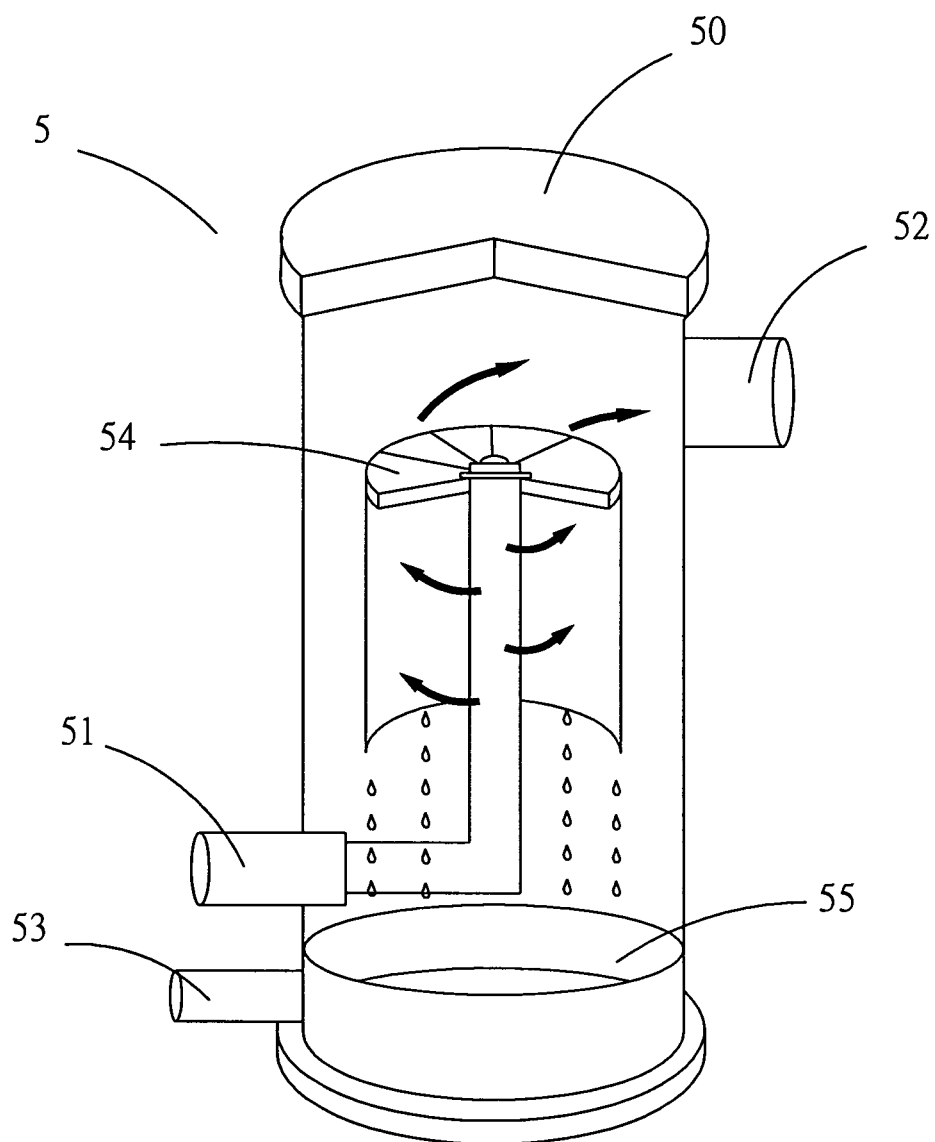


Fig. 3



European Patent
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EUROPEAN SEARCH REPORT

Application Number
EP 06 02 0986

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Place of search Munich		Date of completion of the search 26 March 2007	Examiner Ritter, Christoph
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EUROPEAN SEARCH REPORT

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**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

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