TITLE OF THE INVENTION

ENCLOSED COMPRESSOR, FREEZER, AND REFRIGERATOR

BACKGROUND OF THE INVENTION

[Field of the Technology]

The present invention relates to an enclosed compressor, a freezer, and a refrigerator using hydrocarbon as a refrigerant.

[Prior art]

Conventionally, as a refrigerant of a refrigerator and an air conditioner, CFC (chlorofluorocarbon) is used, though the use thereof is internationally restricted from a consideration of the environmental problem, and it is switched to a refrigerant containing no chlorine such HFC (hydrofluorocarbon). Concretely, R134a (1,1,1,2-tetrafluoroethane) having thermodynamic properties close to CFC12 (dichlorodifluoromethane) is used for a refrigerator. At that time, in place of mineral oil having bad compatibility with the R134a refrigerant, ester oil is used as freezer oil, thereby is made fit for practical use. In Patent Document 1, an example is indicated that R134a of HFC series is used as a refrigerant and ester oil is used as freezer oil.

However, the HFC refrigerant does not cause destruction of the ozone layer but has a large

greenhouse effect coefficient, thus from the viewpoint of global warming prevention, in recent years, a natural refrigerant such as an HC (hydrocarbon) refrigerant of hydrocarbon series has been used and has been promoted in practical use in a freezer of a refrigerator. Actually, in Europe, a refrigerator using an HC refrigerant having a small global warming coefficient as a substitute refrigerant is commercialized.

Also in Japan, under the condition that the HFC refrigerant was designated as a greenhouse effect substance in the Kyoto Conference Of Global Warming Prevention (COP3) held in 1997, a refrigerator using isobutane (R600a) as a refrigerant came to be manufactured and sold in around 2002.

With an HC refrigerant such propane (R290) or isobutane, naphthenic or paraffinic mineral oil has high compatibility. Further, it has excellent availability and profitability and in a freezer using the HC refrigerant, mineral oil is used as freezer oil (refer to Patent Document 2). Further, the effect that as freezer oil of the freezer using the HC refrigerant, ester oil can be used is also indicated in Patent Document 3.

On the other hand, the freezer is composed of a

compressor for compressing a refrigerant at high temperature and high pressure, a condenser for condensing the compressed refrigerant to a liquid refrigerant, a decompressing (expansion) mechanism such as a capillary tube for decompressing the refrigerant passing the condenser, and an evaporator for evaporating the decompressed refrigerant which are all connected in series. For a refrigerator and an air conditioner, an enclosed compressor is used and as indicated in Patent Documents 4 to 6, a constitution that a compression element and an electrically driven element are stored in an enclosed container is adopted.

As an enclosed compressor, a reciprocal compressor having a piston moving back and forth as indicated in Patent Documents 4 to 6 is known and the reciprocal compressor has a structure of connecting a crank shaft and the piston with a connecting rod (con rod) and changing the motion of the shaft making a rotary motion to a reciprocating motion.

As a connection method of the piston and con rod, the so-called ball joint method for connecting by a spherical bearing is known and it is adopted in the enclosed compressor indicated in Patent Documents 4 and 5. In Patent Document 4, both a part of the inner spherical surface of the piston and a part of the

outer spherical surface of the con rod are deleted, and the outer spherical portion of the con rod is inserted into the inner spherical portion of the piston, and then the piston is rotated, thus the con rod and piston are connected.

Patent Document 5 uses a structure that the inner spherical surface formed in the piston is molded by plasticizing and the inner spherical surface envelops the spherical portion forming an end of the con rod. And, between the spherical portion and the inner spherical surface, there exists thermoplastic resin.

On the other hand, Patent Document 6 uses a piston pin to connect the piston and con rod. The piston pin method positions the piston and con rod, inserts the piston pin so as to adjust the piston pin in the stretching direction of the crank shaft, thereby connects them. Further, Patent Document 6 uses a structure of feeding a lubricant to the sliding portions of the piston and piston pin.

Patent Document 1: Japanese Patent Application Laid-open Publication No. Hei 4(1992)-183788

Patent Document 2: Japanese Patent Application Laid-open Publication No. 2004-60952

Patent Document 3: Japanese Patent Application Laid-open Publication No. 2002-38135

Patent Document 4: Japanese Patent Application Laid-open Publication No. 2003-184751

Patent Document 5: Japanese Patent Application Laid-open Publication No. 2003-214343

Patent Document 6: Japanese Patent Application Laid-open Publication No. 2004-27969

SUMMARY OF THE INVENTION

The requests for realization of energy-saving, miniaturization, and furthermore high efficiency of a freezer have been severe in recent years and the severity of the internal conditions of the enclosed compressor has been increased. Freezer oil plays roles of lubrication, sealing, and cooling of the sliding portions in the refrigerant compressor, though from the viewpoint of reservation of reliability of the compressor, freezer oil excellent in lubricity and particularly abrasion resistance is requested.

In Patent Document 2, naphthenic or paraffinic mineral oil is used as freezer oil, though the solubility with isobutane (R600a) is excessively high, so that deterioration of the viscosity of a mixed solution of refrigerant and oil is caused easily. In addition, foaming is caused easily, so that the freezer is easily put into a non-oil feed state and defective lubrication is worried about.

Further, naphthenic or paraffinic mineral oil has a molecular structure composed of hydrocarbon and is almost non-polar oil, so that a problem arises that it is not adsorbed to an iron series sliding member and an oil film is hardly formed. Further, the HC refrigerator itself does not contain chlorine and fluorine in the refrigerant molecule, so that the lubricity of the refrigerant itself cannot be expected.

In Patent Document 3, an example that ester oil is used as freezer oil is indicated, though it does not correspond to the severity of the aforementioned internal conditions in the enclosed compressor.

As an electrically driven element for driving the compressor, an electrically driven motor is used. In recent years, under the number of rotations variable control of the electrically driven motor due to inversion, control according to a load has been executed. At that time, a stable operation is required from a high speed rotation area to a low speed rotation area and realization of high efficiency in the respective rotation areas is required.

Further, in the enclosed compressor, the abrasion of the sliding portions in the enclosed container influences the reliability of the compressor. As a sliding portion in the enclosed container, the parts

such as the clearance between the cylinder and the piston, the con rod - piston connection portion, and the crank shaft - con rod connection portion may be cited. Among them, the problem of sliding on the con rod - piston connection portion is caused mostly. On the con rod - piston connection portion of the reciprocal compressor, the load during one rotation of the crank shaft is varied always, so that a problem easily arises that the sliding portions of the con rod and/or piston may be worn away or generation of heat is increased, thus secureness of the material resistance and selection of optimum freezer oil are necessary.

Further, the severity of the internal conditions of the compressor causes a problem of the contact stress at the sliding portions (for example, the con rod - piston connection portion) or temperature rise due to generation of heat. Concretely, for example, a problem of an increase in the contact stress (contact surface pressure) caused by the shape and operation conditions of the compressor, a problem of the seizure limit load caused by the characteristics of a refrigerant and freezer oil and operation conditions of the compressor, or a problem of foaming of the freezer oil may be cited.

As a characteristic required for freezer oil to improve the lubricity of the sliding portions, the viscosity thereof in the compatible state with a refrigerant may be cited. Concretely, when the viscosity increases extremely, it acts as resistance to sliding and there is a tendency to lower the efficiency of the freezer. On the other hand, when the viscosity lowers extremely, the characteristics as a lubricant are deteriorated and a problem arises that the sealability of the sliding portions lowers or generation of heat and abrasion proceed.

In Patent Document 4, the con rod and piston are connected by the ball joint method. And, both a part of the inner spherical surface of the piston and a part of the outer spherical surface of the con rod are deleted, and the assembly capacity is excellent, and the apparatus is structured so as to be miniaturized easily. Further, a space for feeding freezer oil to the con rod - piston connection portion is ensured. However, both a part of the inner spherical surface of the piston and a part of the outer spherical surface of the con rod are deleted, so that the contact area is made smaller, thus the surface pressure of the sliding portions is apt to increase.

In Patent Document 5, the spherical seat of the

ball joint structure is subject to both or either of the nitriding treatment and manganese phosphate treatment, and the spherical surface uses a high-carbon chromium steel material, and furthermore, between the balls and the ball seat, a buffer ring composed of a thermoplastic resin material such as PTFE or PFA is provided separately to improve the abrasion resistance. However, in this structure, the shape is processed by plastic deformation, so that not only it is necessary to ensure the workability but also the cost is apt to increase structurally. Further, in correspondence to the severity of the internal conditions of the enclosed compressor, an increase in abrasion due to a high load of the sliding portions or the characteristics of freezer oil such as foaming and the seizure limit load are not taken into account.

Patent Document 6 adopts the method for connecting the con rod and piston by the piston pin. And, it uses a structure of ensuring the feed route for feeding freezer oil to the sliding portions, though due to further severity of the internal conditions of the compressor, the problem that the surface pressure is increased or the viscosity of freezer oil is lowered is not particularly taken into account.

The object of the present invention is to provide

an enclosed compressor, a freezer, or a refrigerator using the enclosed compressor or a freezer

for realizing energy-saving, miniaturization, or high efficiency and improving reliability of these devices.

To accomplish the above object, in an enclosed compressor having an enclosed container with a compression element and an electrically driven element stored therein, a crank shaft and a piston driven by the electrically driven element being connected by a con rod, and a connection portion between the con rod and piston being slidable, in the first embodiment of the present invention, isobutane (R600a) is used as a refrigerant compressed by the compression element and fatty ester oil having an ester linkage in the molecule is used as freezer oil.

Further, to accomplish the above object, in the second embodiment, isobutane (R600a) is used as a refrigerant compressed by the compression element and fatty ester oil having a value obtained by converting the seizure limit load by the Falex test to stress larger than Hertz stress converted as contact stress at the connection portion is used as freezer oil. More concretely, the contact surface pressure at the connection portion is 10 MPa or higher and the

connection portion has a structure capable of feeding the freezer oil.

Further, a more preferable structure in the embodiments aforementioned is as indicated below.

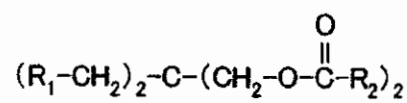
(1) Freezer oil at a seizure limit load of 3000 N or more obtained by the Falex test is used.

(2) The viscosity of the freezer oil is a kinematic coefficient of viscosity of 5 to 15 cSt at 40 °C.

(3) As freezer oil, fatty ester oil having a foaming capacity of 50 mL or lower and a foam stability of 10 mL or lower is used.

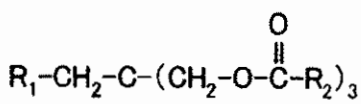
(4) As fatty ester oil, the fatty ester oil expressed by following general formulas (1) to (3) (in the formulas, R_1 indicates an alkyl group of the hydrogen or carbon number 1 to 3, R_2 indicates an alkyl group of the carbon number 5 to 12) is used.

(Chemical formula 1)



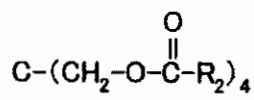
… (1)

(Chemical formula 2)



… (2)

(Chemical formula 3)



$$C\text{-}(CH_2\text{-}O\text{-}\overset{\overset{O}{\|}}{C}\text{-}R_2)_4 \qquad \cdots (3)$$

(5) The fatty ester oil indicated by the general formulas (1) to (3) contains fatty ester oil composed of an unsaturated fatty acid and at this time, an anti-oxidizing agent is added.

(6) The connection portion between the piston and the con rod is formed by connecting the inner spherical surface inside the piston and the spherical portion of the con rod by the ball joint method,

in the con rod, a through-hole interconnected from the eccentric part of the crank shaft to the connection portion for feeding freezer oil to the connection portion is formed, and

the freezer oil is fed to the contact surface between the inner spherical surface of the piston and the spherical portion of the con rod.

(7) The piston and the con rod use an iron series sintering material subject to the vapor treatment or gas soft-nitriding treatment.

Further, in any of the aforementioned, the ten-point average roughness Rz of the sliding surface of the con rod on the connection portion between the

piston and con rod is taken as 0.1 μm to 2.2 μm. Furthermore, the clearance dimension of both of the connection portion between the piston and con rod is taken as 3 μm to 10 μm.

Further, in the third embodiment of the present invention, a freezer having an enclosed compressor with a compression element and an electrically driven element stored therein, a crank shaft and a piston driven by the electrically driven element being connected by a con rod, the compression element being internally included a sliding portion therein, and the enclosed compressor being directly connected to a condenser, a decompressing mechanism, and an evaporator, wherein:

isobutane (R600a) is used as a refrigerant compressed by the compression element and fatty ester oil having an ester linkage in the molecule is used as freezer oil.

Further, in the fourth embodiment of the present invention, a refrigerator, an enclosed compressor having an enclosed container with a compression element and an electrically driven element stored therein, a crank shaft and a piston driven by the electrically driven element being connected by a con rod, the compression element being internally included

a sliding portion, and an evaporator arranged inside a heat insulation space installed across a heat insulation wall from the enclosed compressor for composing a cooling cycle together with the enclosed compressor, wherein:

isobutane (R600a) is used as a refrigerant compressed by the compression element and evaporated by the evaporator, and fatty ester oil having an ester linkage in the molecule is used as freezer oil.

According to the present invention, energy-saving, miniaturization, and high efficiency of an enclosed compressor, a freezer, or a refrigerator are realized, thus the reliability thereof can be improved.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a drawing to show the cooling cycle of the embodiment of the present invention.

Fig. 2 is a conceptual drawing to show the refrigerator of the embodiment of the present invention.

Fig. 3 is a longitudinal cross sectional view to show the enclosed compressor of the embodiment of the present invention.

Fig. 4 is a drawing to show the internal structure of the piston in the enclosed compressor of the embodiment shown in Fig.3.

Fig. 5 is a drawing to show the shape of the con rod in the enclosed compressor of the embodiment shown in Fig.3.

Fig. 6 is a perspective view to show the omission prevention member for the con rod shown in Fig.7.

Fig. 7 is a drawing to show the assembly state of the piston and con rod in the enclosed compressor of the embodiment shown in Fig.3.

Fig. 8 is a graph to show the change of abrasion on the sliding portion of the enclosed compressor by using a plurality of the freezer oil.

Fig. 9 is a graph to show the results of the abrasion sliding test on the sliding portion of the enclosed compressor by using a plurality of the freezer oil.

Fig. 10 is a drawing to show the seizure limit load of the con rod specimen by using a plurality of the freezer oil.

Fig. 11 is a drawing to show the relationship between the surface roughness and the seizure limit load in the con rod test piece.

Fig. 12 is a conceptual drawing to show the load at the contact point in the Falex test.

DETAILED DESCRIPTION OF THE INVENTION

Hereinafter, an embodiment of the present

invention will be explained with reference to the accompanying drawings.

Fig. 1 is a drawing showing the freezer relating to an embodiment of the present invention and Fig. 2 is a conceptual diagram showing the refrigerator relating to an embodiment of the present invention.

As shown in Fig. 1, the freezer has a structure that an enclosed compressor 100 for compressing a refrigerant at high temperature and high pressure, a condenser 110 for radiating heat, thereby condensing the refrigerant, a capillary tube 120 as a decompressing mechanism, and an evaporator 130 for evaporating the refrigerant, thereby absorbing heat, and generating cold air are connected in series by a refrigerant pipe 111. The solid line arrows shown in the drawing indicate the flowing direction of the refrigerant and the dotted line arrows indicate the movement of heat.

The freezer is incorporated into a heat insulation box to form a refrigerator. As shown in Fig. 2, the enclosed compressor 100, the condenser 110, the capillary tube 120, and the evaporator 130 are connected in series. The evaporator 130 is arranged in the refrigerator and by the state change of the refrigerant flowing in the refrigerant pipe 111, the

inside of the refrigerator is cooled. Further, also from the refrigerant pipe 111 arranged along the outer periphery of the heat insulation box, heat is radiated, thus dew condensation caused on the periphery of the opening of the refrigerator can be suppressed. Further, numeral 115 indicates a drier.

Fig. 3 is a longitudinal cross sectional view of the enclosed compressor 100 relating to an embodiment of the present invention. The enclosed compressor 100 of this embodiment is a reciprocal compressor in which the compression element is structured by a piston 4 moving back and forth in a cylinder 1 which is formed integrally with a bearing portion 1a and a frame 1b installed in a enclosed container 101. On the lower part of the frame 1b, as an electrically driven element, a stator 5 and a rotor 6 composing a motor are provided and at the position eccentric from the rotational center of a crank shaft 7, a crank pin 7a is installed.

The crank shaft 7 passes through the bearing portion 1a of the frame and stretches from the lower part of the frame 1b to the upper part thereof and the crank pin 7a is installed so as to be positioned above the frame 1b. The lower part of the crank shaft 7 is directly connected to the rotor 6 and the crank shaft

7 is rotated by the power of the motor. A constitution that the crank pin 7a and piston 4 are connected by a con rod 2 and the piston 4 is moved back and forth via the crank pin 7a and con rod 2 is used.

Namely, the enclosed compressor 100 of this embodiment stores the compression elements such as the cylinder 1 and piston 4 and the electrically driven element such as the motor in the enclosed container 101 and it is a prior condition to use a constitution that the rotary power from the electrically driven element is transferred by the crank shaft 7. The connection structure of the con rod 2 and piston 4 will be described later, though the piston 4 is opened on the side of the crank shaft 7 and has the inner spherical surface in the opening.

And, the refrigerant fed into the cylinder 1 is compressed by the reciprocating motion of the piston 4 and the compressed gas refrigerant is sent to the discharge pipe interconnecting to the cylinder head side. The refrigerant is returned again into the compressor 100 via the condenser 110, decompressing mechanism 120, and evaporator 130 and the cooling cycle having these mechanisms is formed.

The enclosed container 101 is structured so as to store freezer oil (lubricant), pump up it by the

pumping action by the rotation operation of the crank shaft 7, and send it to the compression element section. Further, the freezer uses a refrigerant (HC refrigerant) of hydrocarbon series such as propane (R290) or isobutane (R600a). Further, a refrigerant used in a refrigerator is desirably isobutane (R600a).

Next, the piston 4 will be explained by referring to Fig. 4. Fig. 4 is a drawing showing the piston 4 of this embodiment, and Fig. 4 is a detailed diagram of the internal structure of the piston 4 when the piston 4 is viewed from the side of the crank shaft 7, and Fig. 4(b) is a sectional view of the line A-A of Fig. 4(a), and Fig. 4(c) is a sectional view of the line B-B of Fig. 4(a).

When the piston 4 is mounted on the enclosed compressor 100 as shown in Fig. 3, the vertical direction of Fig. 4(a) coincides with the vertical direction of the enclosed compressor 100 shown in Fig. 3. Further, the lateral direction of Fig. 4(a) is the horizontal direction connecting this side and innermost side of Fig. 3. Therefore, Fig. 4(b) shows the section A-A which is a section of the horizontal plane viewed from the upper side or lower side of the piston 4 and Fig. 4(c) shows the section B-B which is a section in the vertical direction viewed from the

left side or right side of the piston 4. Further, in Fig. 4(b), the lower side of the drawing is the innermost side of the piston 4 and in Fig. 4(c), the right side of the drawing is the innermost side of the piston 4.

The inner spherical surface 4a of the piston 4, as described later, composes the bearing structure for receiving the outer spherical surface of the spherical portion installed at the front end of the con rod 2 and the section A-A is shaped so as to envelop the outer spherical surface of the con rod 2 at an angle of 180° or more. Therefore, the outer spherical surface of the con rod 2 is enveloped by the inner spherical surface 4a of the piston 4 and the con rod 2 and the piston 4 are connected. On the other hand, the section B-B is shaped so as to envelop the outer spherical surface of the con rod 2 at an angle of 180° or less and the section B-B has a constitution that the sliding area is smaller than that of the section A-A.

As mentioned above, a structure that the central angle of the circular arc of the inner spherical surface 4a in the horizontal direction (the section A-A) is made larger than the central angle of the circular arc in the vertical direction (the section B-

B) is used, so that the ball joint structure that the section has a smaller sliding area in the vertical direction is obtained. Therefore, a lubricant passes easily, and the route itself through which the lubricant passes is made shorter, and the lubricant easily flows in and out from the connection portions, and the abrasion due to sliding can be reduced. Further, the flowing routes of the lubricant from and into the sliding portions are ensured, so that abnormal generation of heat in the sliding portions can be suppressed. Further, there is a concavity on the innermost side of the inner spherical surface 4a, so that the sliding surface can be made smaller.

When the enclosed compressor 100 is in operation, the piston 4 has sliding portions inside and outside. Namely, they are a sliding portion between the outer periphery of the piston 4 and the inner peripheral surface of the cylinder 1 and a sliding portion on the connection portion between the piston 4 and the con rod 2. The inner spherical surface 4a is a sliding portion between the piston 4 and the con rod 2 and when the sliding area becomes smaller, the portion where abrasion occurs becomes smaller, though the contact surface pressure is apt to increase.

As shown in Fig. 4, on the innermost side of the

inner spherical surface 4a, there is a concavity 4a' and the sliding surface in the vertical direction is local. Assuming the portion obtained by removing the concavity 4a' from the circular arc of the inner spherical surface 4a as a sliding portion, when the radius of the inner spherical surface 4a is r, the size of the sliding portion in the horizontal direction is $r \times \theta 41 \times 2$, while the size in the vertical direction is $r \times \theta 42 \times 2$ (refer to Figs. 4(b) and 4(c)). Since $\theta 41 > \theta 42$, above and/or below the inner spherical surface 4a positioned on the innermost side of the inner periphery of the piston 4, there exists a space and in the space, an omission prevention member 10 is arranged.

Next, the con rod 2 connected to the piston 4 will be explained by referring to Fig. 5. The con rod 2 of this embodiment has a structure that one end thereof is a spherical portion 2a connected to the inner spherical surface 4a of the piston 4, and the other end is a bearing portion 2b connected to the crank shaft 7, and a rod portion 2c connects both ends thereof and Fig. 5 is a perspective view of the con rod 2 having this structure.

As shown in the drawing, the con rod 2 is structured so as to include the spherical portion 2a

inserted into the inner spherical surface 4a of the piston 4, the radial bearing portion 2b inserted into the crank pin 7a, and the rod portion 2c for connecting the spherical portion 2a and radial bearing portion 2b and the outer spherical surface of the spherical portion 2a has a structure that a part of the sphere is notched.

As mentioned above, a constitution that one side and the other side of the spherical portion 2a have a plane portion 2a' is used, so that even if the piston 4 and con rod 2 are connected, the route through which a lubricant passes is short and the lubricant flows easily, thus a structure that the lubricant can be fed to the sliding portion is obtained.

To connect the con rod 2 and piston 4, the plane portions 2a' formed on the spherical portion 2a of the con rod 2 are used. As shown in Fig. 4(b), the inner spherical surface 4a of the piston 4 is shaped so as to envelop the spherical portion 2a of the con rod 2 at an angle of 180° or more and an opening dimension L of the inner spherical surface 4a at the section A-A is a dimension smaller than the outside diameter of the spherical portion 2a. On the other hand, the dimension between the two plane portions 2a' of the con rod 2 is set to be smaller than the opening

dimension L of the inner spherical surface 4a. The portion of the opening dimension L is a gap to insert the spherical portion 2a of the con rod 2.

The plane portions 2a' of this embodiment are installed almost in parallel, and the two plane portions 2a' are inserted into the opening of the inner spherical surface 4a, and then the con rod 2 and piston 4 are rotated relatively, thus the both of them are connected.

The con rod 2 and piston 4 connected in this way, if the both are not rotated relatively, since the opening dimension of the inner spherical surface 4a is smaller than the outside diameter of the spherical portion 2a, will not come out and the sliding portion can be made smaller.

However, if the both are rotated relatively due to any action such as a shock, the connection between the con rod 2 and the piston 4 is released, so that in this embodiment, for prevention of disconnection, a omission prevention member 10 is provided.

The omission prevention member 10 will be explained by referring to Figs. 6 and 7. Fig. 6 is a perspective view of the omission prevention member 10 of this embodiment and Fig. 7 is a drawing showing the state of the piston 4 and con rod 2 which are

connected after the omission prevention member 10 is incorporated. It is a characteristic that the omission prevention member 10 is shaped so as to have additionally an action as a rotation restriction member to prevent the relative rotation of the con rod 2 and piston 4 and is fixed on the side of the piston 4 instead of the side of the con rod 2.

As shown in Fig. 6, the omission prevention member (and the rotation restriction member, the same may be said with the following) 10 of this embodiment is structured so as to include a first elastic portion 10a, a second elastic portion 10b, a support section 10c for connecting both elastic portions 10a and 10b, and a rotation restriction section 10d for restricting the relative rotation of the con rod 2. Among these components, the first elastic portion 10a and second elastic portion 10b are in contact with the inner peripheral portion of the opening of the piston 4 and the omission prevention member 10 is supported by the elastic force thereof.

The rotation restriction section 10d, when the con rod 2 and piston 4 intend to rotate relatively, forms walls for restricting it and the walls are installed opposite to each other. When the con rod 2 is mounted, the plane portions 2a' formed on the spherical portion

2a of the con rod 2 and the respective rotation control sections 10d are arranged opposite to each other.

The rotation restriction sections 10d have almost plane portions and the two rotation restriction portions opposite to each other are installed almost in parallel. Namely, between the two rotation restriction sections 10d opposite to each other, the respective rotation restriction sections 10d and the plane portions 2a' on the side of the con rod 2 are arranged so as to face each other. Between the plane portions 2a' and the rotation restriction sections 10d, gaps are provided and in the normal operation state, the both of them do not make contact with each other.

Further, the omission prevention member 10 has a stretching portion 10e stretching outside from the support section 10c. The end of the stretching section 10e is formed so as to be bent on the opposite side of the elastic portions 10a and 10b.

Fig. 7 is a drawing showing the mounting state of the omission prevention member 10, and Fig. 7(a) is a perspective view, and Fig. 7(b) is a transverse cross sectional view. When the omission prevention member 10 is mounted, the first elastic portion 10a generates pressing force to the inner peripheral part 4b of the

piston 4 and the omission prevention member 10 is fixed to the inside of the opening of the piston 4 by frictional force. Similarly, the second elastic portion makes contact with the inner peripheral part 4b and the omission prevention member 10 is strongly fixed to the inside of the opening of the piston 4.

The omission prevention member 10 is fixed like this, thus even if the piston 4 is rotated in the cylinder 1 and the con rod 2 and piston 4 are intended to rotate relatively, the con rod 2 can be structured so as not to reach the position omitted from the piston 4.

Further, when the end of the stretching section 10e is inserted in a groove 4c, from the relationship between the bent shape of the stretching section 10e and the omission direction of the omission prevention member 10, by supporting by the front end of the stretching section 10e, omission of the con rod 2 can be prevented from the piston 4. On the other hand, when mounting the omission prevention member 10, if the end of the stretching section 10e is pressed in up to the position of the groove 4c, the both of them are connected simply and the mountability can be improved. Therefore, even when force is acted in the direction of omission of the omission prevention member 10 from

the piston 4, it is prevented and the piston 4 and con rod 2 can be prevented from disconnection.

Next, the structure for feeding a lubricant (freezer oil) to the sliding portion will be explained. As shown in Fig. 7(b), in the con rod 2, a through-hole 2g is formed. The through-hole 2g passes through from the bearing portion 2b to the end of the spherical portion 2a via the rod portion 2c. The lubricant collected in the enclosed container 101 is pulled up by rotation of the crank shaft 7 and a part thereof is scattered from above the crank shaft 7a. The scattered lubricant is fed to the sliding portion between the cylinder 1 and the piston 4 and another one part of the lubricant is led to the sliding portion between the piston 4 and the con rod 2 via the through-hole 2g.

On the innermost side of the inner spherical surface 4a, as mentioned above, the concavity 4a' is provided. The concavity 4a' plays a role of temporarily collecting the lubricant fed to the sliding portion from the through-hole 2g or the lubricant scattered from the upper part of the crank pin 7a, arrived at the plane portion 2a' formed on the upper side of the spherical portion 2a, and fed from the upper plane portion 2a' to the sliding portion.

Further, as mentioned above, the omission prevention member 10 is installed opposite to the plane portion 2a', though a gap is provided between the plane portion 2a' and the omission prevention member 10, so that the lubricant can be fed to the sliding portion via the upper plane portion 2a'.

Next, the sliding portion will be explained. Due to the severity of the internal conditions of the enclosed compressor, the problem of abrasion of the sliding portion is actualized and a problem arises that the reliability is apt to be lowered. And, as a result of repetitive investigation, it is found that the problems are caused by an increase in the contact surface pressure, insufficient feed of lubricant, or generation of heat in the sliding portion.

Particularly, under the aforementioned severity conditions, it is found that the contact stress at the sliding portion is apt to increase. Therefore, to search for an optimum shape of the connection portion, the abrasion sliding test was executed in various shapes using the actual machine and as a result, it is found that when the value converted to Hertz stress is increased high so as to exceed 10 MPa, the abrasion of the sliding portion becomes conspicuous and furthermore, a reduction in the reliability of the

whole apparatus is caused easily. The knowledge thereof will be described below in detail.

In the reciprocal compressor as described in this embodiment, as a main sliding portion, the con rod - piston connection portion, the piston - cylinder sliding portion, the crank shaft - con rod sliding portion, and the crank shaft as a main shaft - bearing sliding portion may be cited. The abrasion sliding test was executed for the enclosed compressor as shown in Fig. 3 and as a result, it is found that among these sliding portions, the abrasion of the con rod - piston connection portion is most conspicuous.

The cause of increasing the abrasion loss of the con rod - piston connection portion was investigated and as a result, it is found that the con rod - piston connection portion is different in the sliding form from the other sliding portions. And, it is found that the difference in the sliding form is caused by the motion of the sliding portion at time of operation of the enclosed compressor.

Here, the sliding distance of one cycle of each sliding portion will be considered. (A) The con rod - piston connection portion is a sliding portion generated by the relative motion of the con rod and piston. Viewed from the piston side, the con rod

executes the reciprocating rotary motion at a predetermined angle at the ball joint structure portion. (B) The piston - cylinder sliding portion is a sliding portion generated by the relative motion of the piston and cylinder and executes the reciprocating motion at a distance according to the amount of eccentricity of the crank pin. (C) The crank shaft - con rod sliding portion is a sliding portion generated by the relative motion of the crank shaft (crank pin) and con rod and makes one rotation in one cycle at the radial bearing portion of the con rod. (D) The sliding portion of the main shaft portion is a sliding portion generated by the rotary motion of the crank shaft by the electrically driven element and makes one rotation in one cycle.

When the motion forms of the sliding portions of (A) to (D) are classified, (A) the con rod - piston connection portion executes a low-speed reciprocating motion, while (B) the piston - cylinder sliding portion executes a high-speed reciprocating motion, and (C) the crank shaft - con rod sliding portion and (D) the sliding portion of the main shaft portion execute a high-speed rotary motion. And, the con rod - piston connection portion executing the low-speed reciprocating motion is easily applied with the load

at time of refrigerant compression, thus boundary lubrication is caused easily. On the other hand, on the other sliding portions, from the relationship of the motion form or the direction of the load, fluid lubrication is maintained easily. These relationships are summarized as shown in Table 1.

Further, the high speed and low speed mentioned above are relative, though in this embodiment, as a sliding portion at the minimum sliding speed, the con rod - piston sliding portion is cited. Further, the reciprocating motion includes not only the linear reciprocating motion by sliding between the cylindrical surfaces like the piston - cylinder sliding portion but also the rotary reciprocating motion by sliding between the spherical surfaces like the con rod - piston sliding portion, so that it indicates a motion with the forward path and backward path shared.

Table 1

Sliding part		Motion classification	Sliding form
(A)	Con rod - piston	Low-speed reciprocating motion	Boundary lubrication
(B)	Piston - cylinder	High-speed reciprocating motion	Fluid lubrication
(C)	Crank shaft - Con rod	High-speed rotary motion	Fluid lubrication
(D)	Main shaft portion	High-speed rotary motion	Fluid lubrication

When the sliding form becomes boundary lubrication, mutual contact of the metallic surfaces is worried about and at this time, abrasion and generation of heat become conspicuous. Therefore, a countermeasure for preventing the sliding form at the con rod - piston connection portion from becoming boundary lubrication, thereby suffering remarkable damage is necessary. Therefore, in the enclosed compressor of this embodiment, further investigation was executed for the sliding portion of the low-speed reciprocating motion.

In the enclosed compressor 100 of this embodiment, the inner spherical surface 4a of the piston 4 and the spherical portion 2a of the con rod 2 are equivalent to the con rod - piston connection portion. As mentioned above, on the innermost side of the inner spherical surface 4a, the concavity 4a' is formed, and the spherical portion 2a of the con rod 2 is partially notched to form the plane portion 2a', so that the portion actually relating to sliding becomes smaller. Concretely, the sliding portion of the inner spherical surface 4a is the $\theta 41$ angular portion shown in Fig. 4(b) and the $\theta 42$ angular portion shown in Fig. 4(c) and the sliding portion of the spherical portion 2a is the portion excluding the plane portion 2a'.

When the contact stress at the con rod - piston connection portion is increased, it is assumed that boundary lubrication is apt to occur and it is evaluated by Hertz stress.

The contact stress (Hertz stress) at the con rod - piston connection portion having the structure aforementioned is given by the curvature of the contact portion, the load (N) of the contact portion, and the material characteristics (Young's modulus E, Poisson's ratio ν). Namely, assuming the curvature of the inner spherical surface 4a of the piston 4 which is a contact portion as R, the curvature of the spherical portion 2a of the con rod 2 which is a contact portion as r, the load of the contact portion as P, the Young's modulus of the piston material as E_R, the Young's modulus of the con rod material as E_r, the Poisson's ratio of the piston material as ν_R, and the Poisson's ratio of the con rod material as ν_r, the radius a_1 of the contact surface is indicated by the formula indicated below. At this time, Hertz stress $P_{max} = 3\ P/(2\pi\ a_1^2)$. However, the curvature of a concavity is calculated as a negative value. Hereinafter, P_{max} is referred to as Hertz stress.

$$a_1 = \sqrt[3]{\frac{3P}{4}\left(\frac{1-\upsilon_R{}^2}{E_R}+\frac{1-\upsilon_r{}^2}{E_r}\right)\Big/\left(\frac{1}{R}+\frac{1}{r}\right)}$$

As mentioned above, in this embodiment, a part of the spherical portion 2a is notched, and furthermore, on the innermost side of the inner spherical surface 4a, the concavity 4a' is provided, so that the contact surface of the sliding portion is apt to be made smaller in correspondence to it. Further, the spherical portion 2a and inner spherical surface 4a are evaluated by approaching to a true sphere, though in consideration of a machining error, an assembly error, or the amount of eccentricity of rotation in the actual operation state, the contact stress (contact surface pressure) at the con rod - piston connection portion in the actual machine is expected to locally grow higher. Namely, it is expected that the contact stress (contact surface pressure) of the actual machine becomes higher than the theoretical contact stress obtained from the formula indicated above.

The cause of reduction in the reliability will be considered furthermore. As shown in Fig. 3, the piston 4 and con rod 2 are connected by the ball joint

mechanism. At this time, the diameter of the inner spherical surface 4a of the piston 4 is set slightly larger than the diameter of the spherical portion 2a of the con rod 2 and there exists a clearance between the two. In the clearance, freezer oil forms an oil film, thus the abrasion is suppressed and the enclosed compressor is operated stably.

When the difference between the diameter of the inner spherical surface 4a and the diameter of the spherical portion 2a becomes smaller, the contact of them approaches "surface contact", so that the Hertz force becomes smaller. On the other hand, the clearance between them becomes smaller, so that freezer oil hardly flows in. Further, in consideration of a manufacture error, it is difficult to make the clearance smaller than a predetermined dimension.

When the difference between the diameter of the inner spherical surface 4a and the diameter of the spherical portion 2a becomes larger, the contact of them approaches "point contact", so that the Hertz force becomes larger. Further, in the calculation, although the clearance between them apparently becomes larger, the contact is apt to be local and freezer oil cannot be fed sufficiently to the contact portion.

Therefore, the clearance between the inner

spherical surface 4a and the spherical portion 2a is defined as a difference between the radii of them, and the relation between the Hertz stress when the defined clearance is taken as 0.5 μm to 10 μm and the reliability evaluation by the abrasion sliding test at the concerned Hertz stress was investigated and as a result, Table 2 is obtained. The load of the contact portion, in consideration of local contact, is taken as 411 N as a representative load. Further, as freezer oil, mineral oil compatible with an HC refrigerant such as isobutane is used.

Table 2

Radius of spherical portion r[mm]	Radius of inner spherical surface R[mm]	Clearance [μm]	Contact surface a_1[mm]	Hertz stress P_{max}[MPa]	Results of abrasion sliding test
6.5045	6.5050	0.5	6.237	5.0	⊙
6.5040		1	4.950	8.0	
6.5030		2	3.929	12.7	○-△
6.5020		3	3.432	16.7	
6.5010		4	3.118	20.2	
6.5000		5	2.894	23.4	×
6.4990		6	2.724	26.5	
6.4980		7	2.587	29.3	
6.4970		8	2.474	32.1	
6.4960		9	2.379	34.7	
6.4950		10	2.297	37.2	
6.5000	6.5005	0.5	6.234	5.0	⊙
	6.5010	1	4.948	8.0	
	6.5020	2	3.928	12.7	○-△
	6.5030	3	3.431	16.7	
	6.5040	4	3.118	20.2	
	6.5050	5	2.894	23.4	×
	6.5060	6	2.724	26.4	
	6.5070	7	2.588	29.3	
	6.5080	8	2.475	32.0	
	6.5090	9	2.380	34.6	
	6.5100	10	2.293	37.2	

The numerals used in the results mean respectively the followings.

⊙: Good

○-△: Practically available level

×: Practically unavailable level

These results show that to decrease the Hertz stress to 10 MPa or lower, it is necessary to set the clearance to about 1 μm or smaller. Namely, to suppress abrasion of the sliding portion existing in

the enclosed compressor and improve the reliability, use of a structure of suppressing the Hertz stress of the sliding portion to 10 MPa or lower is effective.

However, for non-mass products such as manufacture of one article, to make the clearance smaller, grinding is available. However, if mass production is a precondition, as mentioned above, a manufacture error or an assembly error is caused, thus it is difficult to make the clearance smaller than a predetermined dimension. Further, when performing a vapor treatment or a nitriding treatment for the con rod 2 and piston 4 as a sliding surface, the film thickness of the surface such as a nitrided film must be controlled, thus from the viewpoint of manufacture, the cost is increased extremely. Therefore, other factors for increasing the contact surface pressure were investigated.

As other causes of increasing the contact surface pressure, causes due to mixture of foreign substances and shape of the sliding portion are considered to be severe. Therefore, for the problem of sliding on the piston - con rod connection portion, a structure for ensuring the lubricant feed route (the concavity 4a', through-hole 2g, plane portion 2a', etc.) is adopted and the shape of the sliding portion is optimized.

Concretely, a structure of avoiding the contact of the portion causing abrasion such as the edge of the periphery of the concavity 4a' with the spherical portion 2a of the con rod 2 is used. Further, an ejection groove for retreating foreign substances easily collected in the concavity 4a' from the concavity may be provided on the spherical portion 2a of the con rod 2.

Next, the lubricant was investigated. With respect to insufficient feed of lubricant to the sliding portions, secureness of the lubricant feed structure (the concavity 4a', through-hole 2g, plane portion 2a' aforementioned, etc.) and also avoidance of generation of foaming were investigated (foaming will be described later). Further, with respect to the problem of generation of heat, insufficient resistance of the material of sliding portions and freezer oil is considered to be a cause of progress of abrasion, so that selection of the sliding portion material and characteristics of freezer oil were investigated. As a characteristic of freezer oil, the Falex seizure limit load (test method: ASTM D3233) was evaluated. Hereinafter, expression of seizure limit load indicates a one obtained by the Falex test.

The Hertz stress of the con rod - piston

connection portion (the ball joint connection portion) of the enclosed compressor suited to mass production was investigated. Assuming the outside diameter of the cylindrical piston 4 as 26.2 mm, the maximum value of the pressure load applied to the front end of the piston 4 at this time reaches almost 1 MPa and the load applied to the ball joint portion is about 400 to 500 N.

When selecting iron series materials of the piston and con rod in consideration of mass productivity, from the strength and adequacy of processability, (A) a steel material by forging (forging material), (B) a casting by casting (casting material), or (C) a sintering material by sintering may be considered. The sintering material is processed easily, so that the cost thereof can be suppressed low, though from the viewpoint of the abrasion sliding characteristics, (A) the forging material is most excellent and (C) the sintering material is most inferior. Therefore, by use of the sintering material, if the resistance of abrasion sliding can be ensured, it can be considered that firstly, the cost can be decreased and secondly, by use of another material, abrasion suppression is possible.

In this embodiment, for the piston 4, an iron

series sintering material (JIS Standard, SMF4040) of Young's modulus E of 110 GPa and Poisson's ratio ν of 0.23 is used and for the con rod 2, an iron series sintering material (JIS Standard, SMF4020) of Young's modulus E of 100 GPa and Poisson's ratio ν of 0.21 is used. And, the inner spherical diameter of the inner spherical surface 4a of the piston 4 is taken as 13 mm and the clearance dimension is taken as 3 μm or more. Namely, the Hertz stress is taken as 10 MPa or higher.

As shown in Table 2, when the Hertz stress (theoretical contact stress) becomes higher than 10 MPa, the reliability is apt to lower due to abrasion. And, for the enclosed compressor generating Hertz stress of higher than 10 MPa, the sliding abrasion test was executed for the sliding portions using several kinds of freezer oil. Table 3 shows the measured results of the abrasion loss between the piston and the con rod when the long-term sliding abrasion test is executed under the condition of a discharge pressure of a refrigerant of 1.7 MPa and the number of rotations of 4900 rpm.

Table 3

Freezer oil	Paraffin series mineral oil (VG8)	Paraffin series mineral oil (VG10)	Ester oil
Sliding abrasion test results	×	×	○

When mineral oil is used as freezer oil, large abrasion is caused under the condition of a discharge pressure of 1.7 MPa and the number of rotations of 4900 rpm, so that it results in that the reliability is worried about, while when ester oil (VG8, VG10) is used, conspicuous abrasion cannot be confirmed.

Fig. 8 is a graph showing the change of abrasion when the test is conducted under various pressure conditions. The discharge pressure of a refrigerant is closely related to the load at the sliding portion. The reason is that when the discharge pressure is increased, the force of the con rod 2 for pressing the piston 4 is increased. Therefore, when the discharge pressure is increased, the contact stress at the con rod - piston connection portion is increased.

As shown in Fig. 8, when mineral oil is used as freezer oil, the abrasion proceeds with time. The drawing shows the change with time of the abrasion loss when the discharge pressure is changed to 1.7 MPa, 1.6 MPa, and 1.39 MPa, though even if the discharge

pressure is reduced, the abrasion proceeds just slowly and the trend is not changed particularly.

On the other hand, when ester oil is used as freezer oil, the trend is greatly different from that of mineral oil. It is found that although the abrasion proceeds slightly, the progress is moderated slowly, and the abrasion loss is controlled within a fixed range. And, in the respective tests under the condition of a clearance of 5 to 10 μm, the same trend is obtained. Namely, even if the clearance is 5 μm or more and the Hertz stress is higher than 20 MPa, a result that the abrasion can be suppressed is obtained.

Fig. 9 shows the results of the abrasion sliding test on the assumption of boundary lubrication when paraffinic mineral oil (VG10) and ester oil are used and shows the change in the friction coefficient and the temperature of the lubricant when the abrasion testing machine is given a load and is slidden. The axis of ordinate indicates a friction coefficient μ, an oil temperature (°C), and a load (kgf), and for reason of indication, the unit of load is taken as kgf. For the piston material and con rod material, without changed particularly from the aforementioned, iron series sintering materials of JIS Standard SMF4040 and JIS Standard SMF4020 are used, and iron series

sintering materials in which inter-particle gaps of the respective sintering particles are sealed by forming ferrous ferric oxide by the vapor treatment or iron series sintering materials subject to composition treatment of the vapor treatment and gas soft-nitriding treatment are used.

In the drawing, when mineral oil and ester oil are compared, in the case of mineral oil, the change in the friction coefficient and oil temperature is great and in the case of ester oil, the friction coefficient and oil temperature are changed stably. The change in the friction coefficient and oil temperature is considered to indicate the change in the state of the sliding surface and the behavior of frictional heat generation.

After all, in the example of mineral oil, the surface state is changed greatly and the possibility causing abrasion is high. Further, when the lubricity of the sliding surface is inferior, a rise of the oil temperature is caused. When the oil temperature rises excessively, from the performance or reliability, it is not desirable, so that it is necessary to avoid it. In the example of ester oil, when the load is applied, although varied slightly, both friction coefficient and oil temperature are controlled within a fixed

range. It indicates that the sliding surface is lubricated sufficiently.

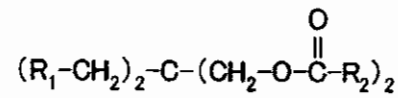
These results are considered and the following knowledge is obtained. Firstly, it is found that generation of heat in the sliding portion which is considered as a factor of abrasion is caused by insufficient resistance of the material, the lubricity of freezer oil, and particularly the seizure limit load. Secondly, ester oil is suitable for freezer oil, and to retain the lubricity at the sliding portion, it is found that among ester oil, a one excellent in the heat stability is effective. On the basis of these knowledges, the following may be said for preferable freezer oil.

As ester oil suited to the freezer in this embodiment, the hindered type which is composed from polyhydroxy alcohol and monohydric fatty acid and is excellent in the heat stability is preferable. Here, the hindered type ester is referred to as ester having no hydrogen atom on the beta carbon of the hydroxide group. In alcohol ester (non-hindered) having a hydrogen atom on the beta carbon, the hydrogen atom on the beta carbon and the oxygen atom of the ester linkage approach by heating and form a chemical intermediate of the six-membered ring structure, so

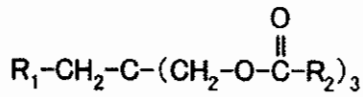
that they are apt to be pyrolytically decomposed by low energy. The hindered ester has no hydrogen atom on the beta carbon, so that it cannot form the six-membered ring structure, so that it is not pyrolytically decomposed by low energy but causes free-radical heat decomposition at high temperature (Keiichi Inaba, Jiro Hirano, "New Fatty Acid Chemistry, 2nd Edition", Saiwai Shobo). Therefore, in this embodiment, the hindered ester having a structure excellent in the heat stability is used.

For example, as polyhydroxy alcohol, there are neopentyl glycol, trimethylolpropane, and pentaerythritol available. As monohydric fatty acid, there are pentanoic acid, hexanoic acid, peptanoic acid, octanoic acid, 2-methylbutanoic acid, 2-methylpentanoic acid, 2-methylhexanoic acid, 2-ethylhexanoic acid, isooctanoic acid, and 3,5,5-trimethylhexanoic acid available and these are individually used or mixed fatty acid of two kinds or more is used.

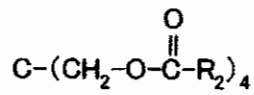
Particularly, as basic oil of freezer oil, at least one kind selected from the group of fatty ester oil indicated by the following general formulas (1) to (3) retaining at least two ester linkages in a molecule is preferable.



… (1)



… (2)



… (3)

However, in the formulas, R_1 and R_2 are as indicated below.

R_1: Alkyl group of hydrogen or the number of carbon atoms 1 to 3.

R_2: Alkyl group of the number of carbon atoms 5 to 12.

Ester obtained by chemical synthesizing the representative monohydric fatty acid and polyhydroxy alcohol indicates the kinetic viscosity or kinetic coefficient of viscosity (40 °C, cSt) as shown in Table 4.

Table 4

	Neopentyl glycol	Trimethylol-propane	Pentaerythritol
2-ethylbutanoic acid	4.7	18.7	45.4
Heptanoic acid	5.0	-	-
2-methylhexanoic acid 2-ethylpentanoic acid 2-ethylhexanoic acid	5.3	15.6	28.4
2-ethylhexanoic acid	7.4	24.8	47.6
3,5,5-trimethylhexanoic acid	12.9	51.5	112.9

When these fatty esters are mixed in a proper quantity as basic oil of a lubricant, the standard kinetic viscosity grade (VG: kinetic coefficient viscosity (cSt) at 40 °C) is adjusted.

For example, the standard viscosity VG5 is obtained independently from neopentyl glycol and ester oil of heptanoic acid or is obtained by mixing and adjusting 2-ethylbutanoic acid of low-viscosity oil, ester of neopentyl glycol, and another high-viscosity ester oil, and VG8, VG10, VG15, VG22, and VG32, on the basis of the similar concept, are obtained by mixing neopentyl glycol ester oil of low viscosity and pentaerythritol ester oil of high viscosity in a proper quantity and finely adjusting them to a desired viscosity.

Further, to ester oil, an oxidation inhibitor, an acid seizure agent, an anti-foaming agent, or a metal inert agent may be added. Fatty acid contains unsaturated fatty acid, though when using unsaturated fatty acid, it is effective to particularly add an oxidation inhibitor. When oil using unsaturated fatty acid is used as freezer oil, the lubricity may be improved and at this time, the sliding characteristics can be improved.

From the aforementioned test results, it is ascertained that the resistance of freezer oil greatly influences the reliability, so that the seizure limit load of each freezer oil was evaluated and the results are shown in Table 5.

Table 5

Freezer oil	Paraffin series mineral oil (VG8)	Paraffin series mineral oil (VG10)	Hindered ester
Seizure load (N)	1400	1600	3800

The results show that the seizure limit load of hindered ester oil (VG8, VG10) is very high compared with that of mineral oil and from the results of the sliding abrasion test, it is found that even in the enclosed compressor having Hertz stress of higher than 10 MPa, the reliability can be improved.

Therefore, when using the hindered ester oil (hereinafter, abbreviated to ester oil) as freezer oil, for further consideration, the high pressure test was executed at a viscosity grade within the range of VG5, VG10, VG15, VG22, and VG32 and at a discharge pressure of 2.0 MPa. Under such a severe condition, the sliding portion is not seized and an occurrence of abrasion can be prevented. Further, from the results of the test using freezer oils different in the seizure limit load, it can be confirmed that if freezer oil at a seizure limit load of larger than 3000 N is used, under an environment that the Hertz stress of the sliding portion is higher than 10 MPa, high reliability can be maintained. The technical meaning of 3000 N will be investigated later.

Next, the material and seizure limit load of the piston 4 and con rod 2 were investigated. Fig. 10 shows the results when the seizure limit load of freezer oil when an iron series sintering material (JIS Standard, SMF4040) subject to the hole-sealing treatment by the vapor treatment is used as a piston 4 is measured using con rod specimens. As freezer oil, paraffinic mineral oil (VG10) and ester oil are used.

Further, as a con rod material, an iron series sintering material (JIS Standard, SMF4020) subject to

the vapor treatment and gas soft-nitriding treatment is used and the ten-point average roughness Rz thereof is 0.1 to 0.2 μm. One of the reasons for performing the gas soft-nitriding treatment for the con rod material is to increase the hardness. Namely, in the sliding system of the piston 4 and con rod 2, the con rod 2 moves for the stationary piston 4 and sliding is caused by the relative motion of them, though when the both of them have similar hardness, a fault may be caused often. Accordingly, the hardness of the con rod material on the motion side in the sliding system is increased.

As shown in Fig. 10, even in the shape conforming to the actual machine, the seizure limit load of ester oil is very high compared with that of mineral oil and it is found that ester oil has excellent resistance as freezer oil. Actually, in correspondence to the severity of the operation environment of the compressor, even if the load to the sliding portion is increased and high speed rotation of the compressor is realized, it can be confirmed that a sufficient lubrication performance is displayed.

Fig. 11 shows the relationship between the surface roughness of the sliding surface (the spherical portion 2a) of the con rod 2 and the seizure limit

load when ester oil is used as a lubricant. Concretely, the seizure limit load when the ten-point average roughness Rz is assumed as 0.1 to 0.2 μm, 0.4 to 0.6 μm, and 1.2 to 1.5 μm is evaluated using test materials. As shown in Fig. 11, even if the surface roughness of the con rod 2 is varied slightly, no large difference is recognized in the seizure limit load.

Therefore, the ten-point average roughness Rz of the sliding surface is varied within the range from 0.4 μm to 2.2 μm after the conditioning operation, thus the actual machine test was executed. Concretely, 180 g of refrigerant R600a is charged, and the apparatus is operated under the condition of a discharge pressure of 2.0 MPa and the number of rotations of 4900 rpm, and then the abrasion of the sliding portion is confirmed. As a result, in every surface roughness, no large progress of abrasion is seen in the inner spherical surface 4a of the piston 4 and the spherical portion 2a of the con rod 2 and satisfactory results are obtained. The reason seems to be that due to high adsorptivity of ester oil to the metallic surface, regardless of slight differences in the surface roughness, the lubricity is ensured. As mentioned above, when the ten-point average roughness

Rz after the conditioning operation is 0.1 to 2.2 μm, it is found that the abrasion suppression effect is obtained.

Further, although detailed explanation is omitted, when mineral oil is used, the seizure limit load is varied greatly with the surface roughness. Therefore, it is supposed that the abrasion characteristics are varied with the surface roughness. Namely, by use of ester oil, when at least Rz is controlled within the range from 0.1 to 2.2 μm, it is found that the influence of the surface roughness on the lubricity can be made smaller.

From the above-mentioned, regardless of slight variations in the surface roughness, it is found that the abrasion suppression effect by ester oil is maintained and the evaluation of freezer oil by the seizure limit load is effective.

Then, the relationship between the Hertz stress of the sliding portion and the seizure limit load indicating the resistance of freezer oil is considered on the basis of the test results. From the previous test results, even if a sintering material is used, if freezer oil at a seizure limit load of larger than 3000 N is used, an estimate that a sufficient abrasion suppression effect is produced is obtained, though

furthermore, from the relationship between the Hertz stress and the seizure limit load, additional consideration will be taken.

Fig. 12 is a conceptual diagram of the load at the contact point in the Falex test. When a specimen 102 clamped by a testing machine 101 is pressed by a load P, the testing machine 101 makes contact with the specimen 102 at four points. Therefore, at these contact points, a load of P/4 is applied in the same direction as that of the load P. In Fig. 12, as a representative contact point, the upper right contact point will be explained as an example. A load Pf in the vertical direction, when expressing it using the load P, is taken as $P\sqrt{2}/8$. Therefore, when ester oil at a seizure limit load of 3000 N is used, the contact point is equivalent to the state that a load of about 530 N is applied.

From this investigation, the following knowledge is led. As mentioned above, the load applied to the ball joint portion is about 400 to 500 N in the ordinary use aspect. Therefore, an estimate of "if ester oil at a seizure limit load of larger than 3000 N is used, a sufficient abrasion suppression effect is obtained" obtained from the abrasion test results can be explained by the following fact.

- The load (about 530 N) at which the fluid lubrication can be ensured by a lubricant is larger than the load (about 400 to 500 N) applied to the actual ball joint portion.

- Mineral oil, since the seizure limit load thereof is smaller than that on such a level that the fluid lubrication can be maintained, is promoted in abrasion.

In other words, by use of freezer oil in which the value obtained by converting the seizure limit load to stress is larger than the Hertz stress converted as contact stress at the sliding portion (for example, the sliding portion between the con rod 2 and the piston 4) executing the low-speed reciprocating motion apt to cause boundary lubrication, excessive progress of abrasion can be suppressed.

These are evaluation when an iron series sintering material is used. Therefore, when a forging material or a casting material is used, although the shapes are the same, the physical properties are different, and the abrasion sliding characteristics are changed. However, as mentioned above, in view of suppression of proceed of abrasion in a sintering material, also in the forging material or casting material, it is obvious that abrasion suppression is realized

naturally. Actually, on the test level using specimens, it is confirmed that even other materials indicate high resistance to abrasion.

Further, to improve the seizure limit load, in addition to use of ester oil, a method using an additive may be considered. For example, by adding phosphoric ester (TCP) of a very high pressure additive of phosphorus series to mineral oil, the seizure limit load can be increased and the resistance to sliding can be increased. Further, with respect to polyalkylene glycol (PAG), by a similar additive, the seizure limit load thereof is made higher than that of ester oil and the resistance thereof is excellent.

However, ester oil has an ester linkage in the molecular structure and also has an adsorption action to the metallic surface, while if an additive is used, when a freezer is used continuously, the additive is consumed slowly. Therefore, the reliability is lowered inevitably due to long-term use. Further, PAG suffers in inferior lubricity. They are all inferior in the viewpoint of secureness of the long-term reliability and use of ester oil is desirable. Actually, as shown in Fig. 8, even if the operation time exceeds 1000 hours, no reduction is seen in the lubrication performance and a stable operation can be realized.

Next, the foaming of freezer oil was investigated. As foaming in the enclosed container, foaming due to bumping and foaming by the agitation action may be cited. When freezer oil foams, a lubricant is not fed sufficiently to the sliding portion, so that it is necessary to avoid it. Particularly, when a lubricant foams easily or it is hardly returned from the foaming state, it is difficult to ensure feed of oil to the sliding portion.

Therefore, from the results of the foaming test (JIS K2518), the influence on the lubricity in the enclosed compressor or freezer was evaluated and confirmed. As freezer oil, when ester oil in which the foaming capacity in the JIS K2518 test is 50 mL or less (24 °C, 93.5 °C, from 93.5 °C to 24 °C) and the foam stability is 10 mL or less (24 °C, 93.5 °C, from 93.5 °C to 24 °C) is used, no strong influence on the reliability of the enclosed compressor and freezer is recognized.

Bumping, by use of ester oil, is suppressed more clearly than mineral oil. As a reason, a difference in the compatibility with the refrigerant may be cited. Namely, ester oil is excellent in the compatibility with the HC refrigerant but is not dissolved so much as mineral oil. Therefore, bumping at start time of

the compressor can be suppressed and an occurrence of noise can be prevented. Further, ester oil is dissolved in a refrigerant less than mineral oil, so that it can maintain the actual viscosity in the compatible state and can contribute to improvement of the reliability. Actually, by use of ester oil in which the viscosity of freezer oil is a kinetic coefficient of viscosity at 40 °C of 5 to 32 cSt, it can be confirmed that the reliability can be ensured and a kinetic coefficient of viscosity of 5 to 15 cSt can desirably realize high efficiency of a freezer.

Concretely, to the freezer as shown in Fig. 1, when the enclosed compressor 100 using the refrigerant and freezer oil which are explained above is connected, if the viscosity of ester oil is smaller than 5 cSt, slight progress of abrasion is recognized, though by use of ester oil of 5 cSt or higher, no particular problem is imposed. Further, in the so-called low-pressure chamber type compressor composed of an enclosed container at a low pressure, it is confirmed that by reducing the viscosity of ester oil to 15 cSt or lower, the efficiency as a freezer is controlled within a no-questionable range.

As a reason that even if the viscosity of ester oil is low such as 5 to 15 cSt, secureness of

reliability and realization of high efficiency are made available, the following may be considered. Ester oil is excellent in the adsorptivity with the metallic surface, so that even if the viscosity is low such as 5 cSt, it produces an abrasion suppression effect at the sliding portion. When a high-viscosity lubricant exists at the sliding portion, the operation efficiency is apt to lower due to resistance to sliding, while a low-viscosity lubricant has a low resistance, thereby can increase the efficiency. From these investigations, by use of ester oil having a kinetic coefficient of viscosity at 40 °C of 5 to 15 cSt, the resistance of sliding is reduced, and furthermore the abrasion is suppressed, and as a result, the secureness of reliability and realization of high efficiency can be made compatible with each other.

Similarly from these investigation results, as a characteristic possessed by ester oil itself, it has a high adsorptivity with the metallic surface, so that even if freezer oil mixed with mineral oil is used, a similar action efficiency can be expected.

Next, the refrigerant charging amount will be described. The HC refrigerant used in this embodiment is combustible and it is required to reduce the amount

to be charged into the freezer. If ester oil is used as freezer oil, it is effective in reducing the refrigerant charging amount and improving the safety of the freezer. The reason is as indicated below.

When using an HC refrigerant such as isobutane, ester oil is reduced more in solubility than mineral oil. Due to the difference in solubility, as mentioned above, a foaming suppression effect is produced, though in addition to it, it is effective also in reducing the refrigerant charging amount. The reason is that if the refrigerant is charged in the same amount, the net refrigerant amount for acting the cooling cycle is increased in correspondence to the amount not dissolved in the freezer oil. Namely, when the freezer oil is changed from the mineral oil to the ester oil, the refrigerant charging amount for displaying the capacity necessary as a freezer can be reduced. Therefore, a freezer having high safety for suppressing the charging amount of a combustible refrigerant can be provided.

Further, it can be confirmed that the COP (result coefficient) is on the same level equal to that when mineral oil is used. Namely, unless the efficiency reduction due to use of ester oil is caused, a similar or higher efficiency can be realized. Further, in the

so-called capacity variable enclosed compressor capable of changing the number of rotations, the temperature change inside the enclosed container due to change of the number of operation rotations, that is, high speed of rotation or low speed of rotation is apt to increase, though by use of hindered ester for maintaining a stable lubrication performance in a wide temperature zone, in the area of each number of rotations, a high-efficient operation can be performed.

In the aforementioned examples, the case that the reciprocal compressor connected by the ball joint mechanism is used is explained, though the present invention is not particularly limited to it. Even if the so-called Scotch yoke type or piston pin type reciprocating compressor is used, when the contact stress at the sliding portion (particularly, the sliding portion of a low-speed reciprocating motion) is increased, it can be applied.

WHAT IS CLAIMED IS

1. An enclosed compressor having an enclosed container with a compression element and an electrically driven element stored therein, a crank shaft and a piston driven by the electrically driven element being connected by a con rod, and a connection portion between the con rod and the piston being slidable, wherein:

isobutane (R600a) is used as a refrigerant compressed by the compression element and fatty ester oil having an ester linkage in a molecule is used as freezer oil.

2. An enclosed compressor having an enclosed container with a compression element and an electrically driven element stored therein, and the compression element driven by power of the electrically driven element, and a sliding portion for changing a relative motion to a low-speed reciprocating motion being installed between the electrically driven element and the compression element, wherein:

isobutane (R600a) is used as a refrigerant compressed by the compression element and

fatty ester oil having a value obtained by converting a seizure limit load by Falex test to

stress larger than Hertz stress converted as contact stress at the sliding portion executing the low-speed reciprocating motion is used as freezer oil.

3. An enclosed compressor having an enclosed container with a compression element and an electrically driven element stored therein, a crank shaft and a piston driven by the electrically driven element connected by a con rod, and a connection portion between the con rod and the piston being slidable, wherein:

isobutane (R600a) is used as a refrigerant compressed by the compression element and

fatty ester oil having a value obtained by converting a seizure limit load by Falex test to stress larger than Hertz stress converted as contact stress at the connection portion is used as freezer oil.

4. An enclosed compressor according to Claim 3, wherein a contact surface pressure at the connection portion is 10 MPa or higher and the connection portion has a structure capable of feeding the freezer oil.

5. An enclosed compressor according to Claim 3, wherein the freezer oil at a seizure limit load of 3000 N or more obtained by the Falex test is used.

6. An enclosed compressor according to Claim 4,

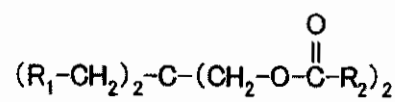
wherein the freezer oil at a seizure limit load of 3000 N or more obtained by the Falex test is used.

7. An enclosed compressor according to any of Claims 1 to 6, wherein viscosity of the freezer oil is a kinematic coefficient of viscosity of 5 to 15 cSt at 40 °C.

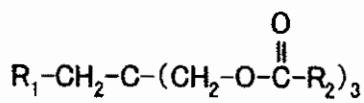
8. An enclosed compressor according to any of Claims 1 to 6, wherein as the freezer oil, fatty ester oil having a foaming capacity of 50 mL or lower and a foam stability of 10 mL or lower is used.

9. An enclosed compressor according to Claim 7, wherein as the freezer oil, fatty ester oil having a foaming capacity of 50 mL or lower and a foam stability of 10 mL or lower is used.

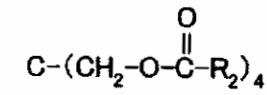
10. An enclosed compressor according to any of Claims 1 to 6, wherein the fatty ester oil is expressed by following general formulas (1) to (3) (in the formulas, R_1 indicates an alkyl group of the hydrogen or carbon number 1 to 3, R_2 indicates an alkyl group of the carbon number 5 to 12).



… (1)



… (2)



… (3)

11. An enclosed compressor according to Claim 10, wherein the fatty ester oil contains fatty ester oil composed of an unsaturated fatty acid and an anti-oxidizing agent is added.

12. An enclosed compressor according to any of Claims 1, 3, 4, 5, and 6, wherein:

the connection portion between the piston and the con rod is formed by connecting the inner spherical surface inside the piston and the spherical portion of the con rod by a ball joint method,

in the con rod, a through-hole interconnected from an eccentric part of the crank shaft to the connection portion for feeding freezer oil to the connection portion is formed, and

the freezer oil is fed to the contact surface between the inner spherical surface of the piston and the spherical portion of the con rod.

13. An enclosed compressor according to Claim 10, wherein:

the connection portion between the piston and the con rod is formed by connecting the inner spherical surface inside the piston and the spherical portion of

the con rod by a ball joint method,

in the con rod, a through-hole interconnected from an eccentric part of the crank shaft to the connection portion for feeding freezer oil to the connection portion is formed, and

the freezer oil is fed to the contact surface between the inner spherical surface of the piston and the spherical portion of the con rod.

14. An enclosed compressor according to Claim 10, wherein for the piston and the con rod, iron series sintering materials sealed by forming ferrous ferric oxide by a vapor treatment or iron series sintering materials subject to a composition treatment of the vapor treatment and a gas soft-nitriding treatment are used.

15. An enclosed compressor according to Claim 14, wherein a ten-point average roughness Rz of the sliding surface of the con rod on the connection portion between the piston and the con rod is taken as 0.1 μm to 2.2 μm.

16. An enclosed compressor according to Claim 15, wherein a clearance dimension of both of the connection portion between the piston and the con rod is taken as 3 μm to 10 μm.

17. A freezer having an enclosed compressor with

a compression element and an electrically driven element stored therein, a crank shaft and a piston driven by the electrically driven element being connected by a con rod, the compression element being internally included a sliding portion therein,

and the enclosed compressor being directly connected to a condenser, a decompressing mechanism, and an evaporator, wherein:

isobutane (R600a) is used as a refrigerant compressed by the compression element and fatty ester oil having an ester linkage in a molecule is used as freezer oil.

18. A refrigerator comprising:

an enclosed compressor having an enclosed container with a compression element and an electrically driven element stored therein, a crank shaft and a piston driven by the electrically driven element being connected by a con rod, the compression element being internally included a sliding portion, and an evaporator arranged inside a heat insulation space installed across a heat insulation wall from the enclosed compressor for composing a cooling cycle together with the enclosed compressor, wherein:

isobutane (R600a) is used as a refrigerant compressed by the compression element and evaporated

by the evaporator, and fatty ester oil having an ester linkage in a molecule is used as freezer oil.