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(54) **HEAT PUMP APPARATUS**

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(57) **ABSTRACT**

To obtain long-term reliability of a heat pump apparatus by using an insulating material that is less liable to be hydrolyzed even when a refrigerating machine oil having high hygroscopicity and a high water content in oil is used, an electric motor of a compressor includes: a stator fixed to a sealed container with a winding being wound around the stator through intermediation of an insulating material; and a rotator surrounded by the stator. The insulating material includes wholly aromatic liquid crystal polyester (LCP) containing, as an essential component, p-hydroxybenzoic acid (PHB) as a monomer and having a main chain of a molecule formed by linking p-hydroxybenzoic acid and, as another monomer, only a monomer having a benzene ring, through an ester bond. A saturated water amount of the refrigerating machine oil is 1% or less at 40 degrees Celsius and a relative humidity of 80%.

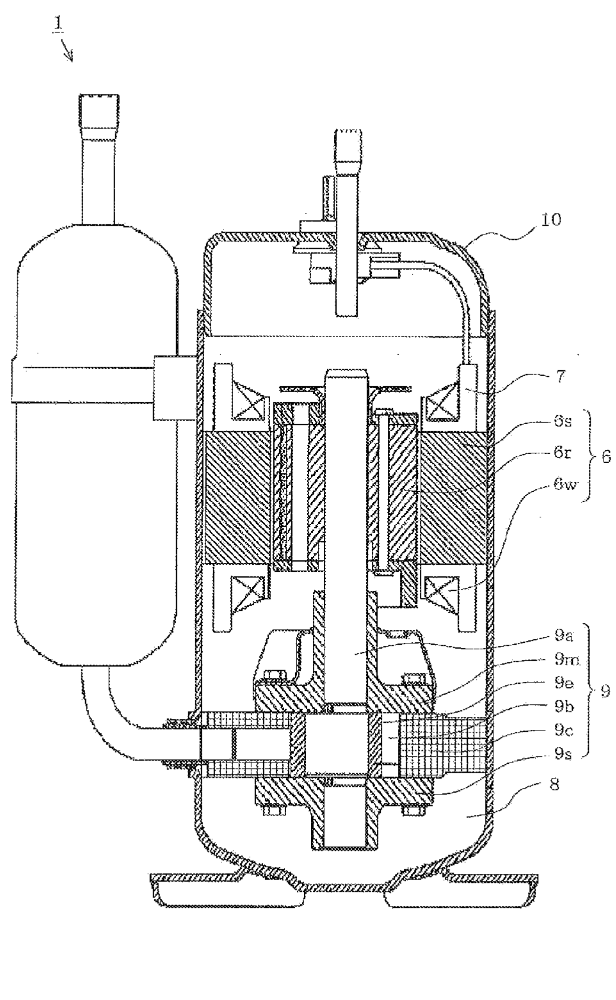


FIG. 1

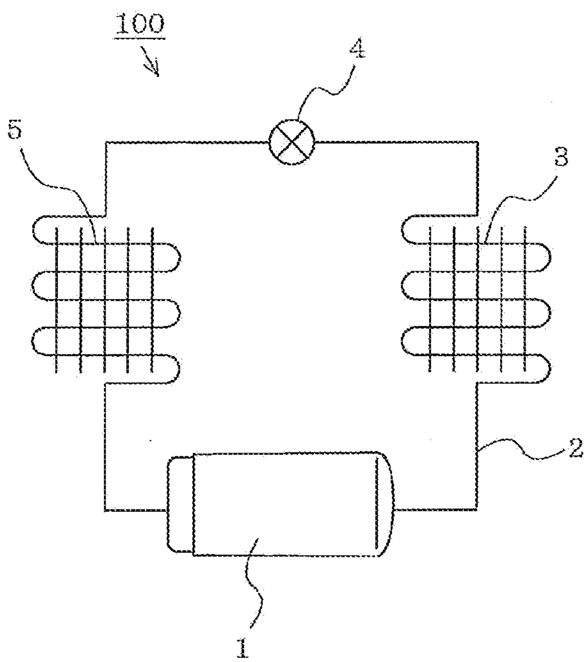


FIG. 2

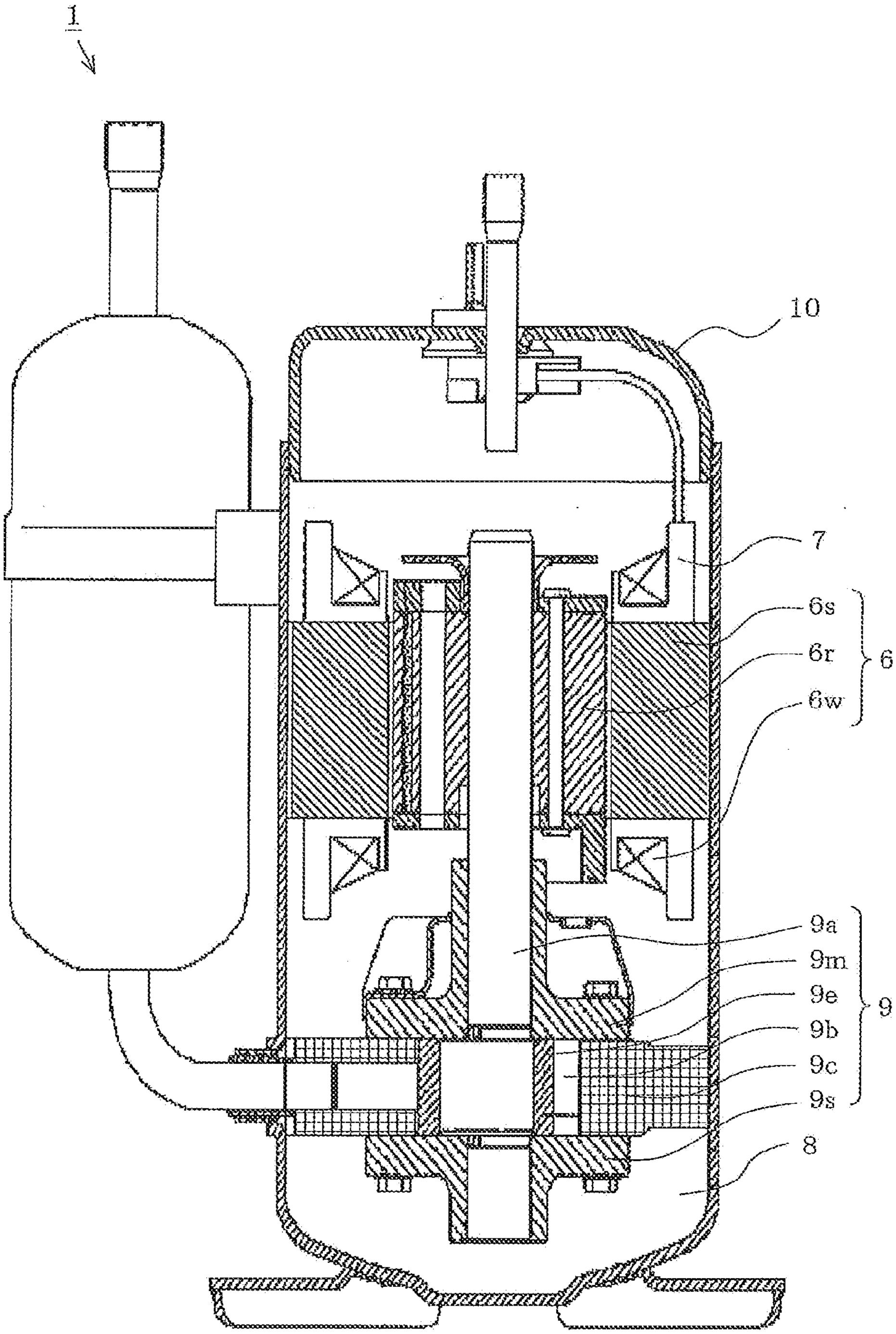
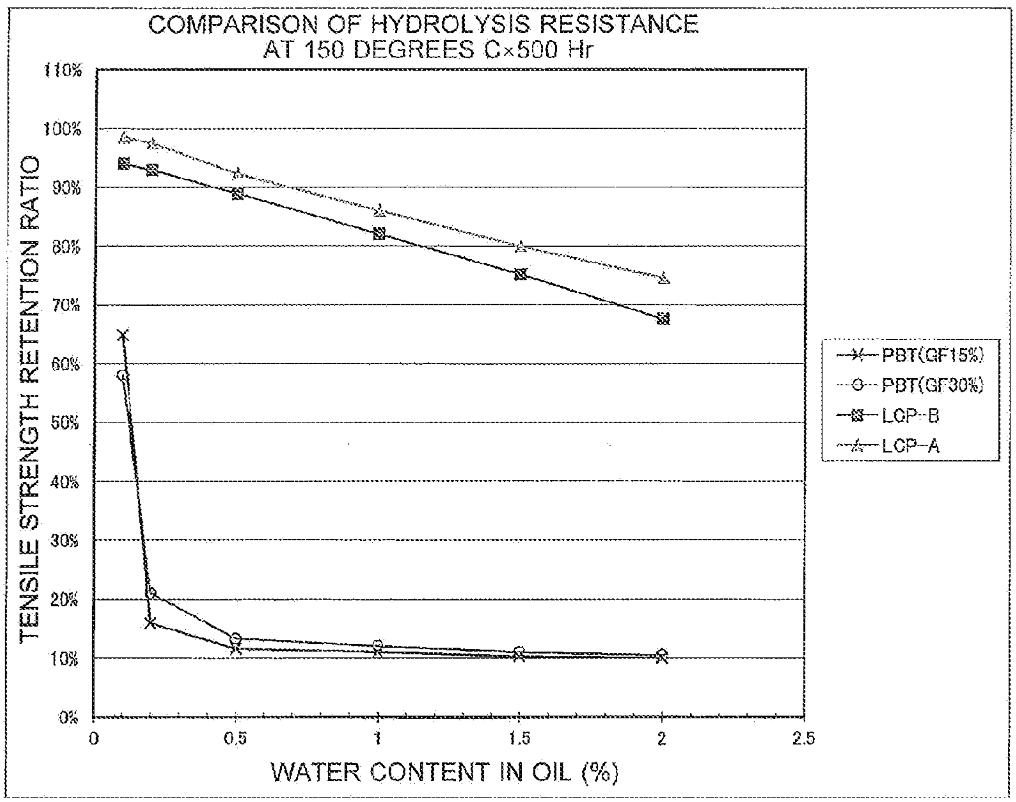


FIG. 3



COMPARISON OF HYDROLYSIS RESISTANCE
AT 150 DEGREES C×500 Hr
TENSILE STRENGTH RETENTION RATIO
110%
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.5
1
1.5
2
2.5
WATER CONTENT IN OIL (%)
PBT(GF15%)
PBT(GF30%)
LCP-B
LCP-A

HEAT PUMP APPARATUS

TECHNICAL FIELD

[0001] The present invention relates to a heat pump apparatus, and more particularly, to a heat pump apparatus including a compressor with a sealed container accommodating an electric motor, and being configured to perform a refrigeration cycle.

BACKGROUND ART

[0002] Hitherto, as a heat pump apparatus, there has been provided an apparatus for performing a refrigeration cycle by sequentially connecting a compressor for compressing refrigerant, a condenser, an expansion mechanism, and an evaporator, to thereby transfer heating energy or cooling energy of the refrigerant to a heat medium (perform heat transfer) in the condenser or the evaporator.

[0003] The compressor includes a compression mechanism and an electric motor for rotating and driving the compression mechanism, and the compression mechanism and the electric motor are accommodated in a sealed container. High-pressure and high-temperature refrigerant compressed by the compression mechanism is temporarily discharged into the sealed container. Therefore, the electric motor is exposed to the high-pressure and high-temperature refrigerant. Further, to smooth the rotation of the compression mechanism, a machine oil (hereinafter referred to as "refrigerating machine oil") is stored in the sealed container.

[0004] The electric motor includes a stator fixed to the sealed container and a rotator surrounded by the stator and configured to rotate. The rotator is connected to the compression mechanism. The stator has a tubular shape and includes a back yoke portion forming an outer periphery of the stator, a plurality of tooth portions projecting from the back yoke portion to the center, and a winding (electric wire) wound around the tooth portions through intermediation of an insulating material (insulator).

[0005] In addition, as the insulating material (insulator), there is disclosed an invention using polyphenylene sulfide (PPS) not having an ester bond (see, for example, Patent Literature 1).

[0006] Further, as the insulating material (insulator), there is disclosed an invention using polyethylene terephthalate (PET) or polyethylene naphthalate (PEN) having an ester bond (see, for example, Patent Literature 2).

CITATION LIST

Patent Literature

[0007] Patent Literature 1: Japanese Unexamined Patent Application Publication No. 2000-324728 (Page 6, FIG. **2**.)

[0008] Patent Literature 2: Japanese Unexamined Patent Application Publication No. 2001-227827 (Pages 3-4, FIG. **2**.)

SUMMARY OF INVENTION

Technical Problem

[0009] PPS not having an ester bond, which is a heat insulator disclosed in Patent Literature 1, is a thermoplastic crystalline engineering plastic having a repeating unit of [-ph-S-] obtained by allowing p-dichlorobenzene and an alkali sulfide to react with each other under high temperature and high pressure. PPS has characteristics of relatively excellent heat resistance, no risk of hydrolysis, high heat resistance, satisfactory moldability, and high strength and stiffness. However, there are problems in that, during melt molding, the productivity is degraded owing to a low solidification speed, burrs are liable to occur, and PPS is decomposed in a trace amount to generate a sulfur gas, to thereby corrode a mold.

[0010] On the other hand, PET and PEN each having an ester bond, which are heat insulators disclosed in Patent Literature 2, and polybutylene terephthalate (PBT) have hydrolyzability. Therefore, it is necessary to absorb water in a refrigerant circuit during circulation of refrigerant in the refrigerant circuit through use of a refrigerating machine oil having water absorbability, and there is a problem in that, in the case where the refrigerating machine oil has high hygroscopicity and a large saturated water amount, hydrolysis may be caused.

[0011] The present invention has been made to solve the above-mentioned problems, and a first object thereof is to obtain long-term reliability of a heat pump apparatus by using an insulating material that is less liable to be hydrolyzed even when a refrigerating machine oil having high hygroscopicity and a high water content in oil is used.

[0012] Further, a second object of the present invention is to obtain the long-term reliability of the heat pump apparatus at low cost by using an insulating material having satisfactory productivity without causing burrs and generating a gas containing sulfur during a production step of the insulating material, such as melt molding.

Solution to Problem

[0013] According to one embodiment of the present invention, there is provided a heat pump apparatus, including: a compressor; a condenser; an expansion mechanism; and an evaporator, the compressor, the condenser, the expansion mechanism, and the evaporator being configured to perform a refrigeration cycle, the heat pump apparatus being configured to perform heat transfer in the condenser or the evaporator, in which the compressor includes: a sealed container; a compression mechanism mounted inside the sealed container; and an electric motor for rotating and driving the compression mechanism, the compression mechanism being configured to compress refrigerant, and to be lubricated by a refrigerating machine oil, in which the electric motor includes: a stator fixed to the sealed container with a winding being wound around the stator through intermediation of an insulating material; and a rotator surrounded by the stator, in which the insulating material includes wholly aromatic liquid crystal polyester (LCP) containing, as an essential component, p-hydroxybenzoic acid (PHB) as a monomer and having a main chain of a molecule formed by linking p-hydroxybenzoic acid and, as another monomer, only a monomer having a benzene ring, through an ester bond, and in which a saturated water amount of the refrigerating machine oil is 1% or less at 40 degrees Celsius and a relative humidity of 80%.

Advantageous Effects of Invention

[0014] According to the one embodiment of the present invention, the insulating material for the electric motor is wholly aromatic liquid crystal polyester (LCP) containing, as an essential component, p-hydroxybenzoic acid (PHB) as a monomer component having an ester bond and having a main chain of a molecule formed by linking p-hydroxybenzoic acid and, as another monomer, only a monomer having a benzene ring, through an ester bond. Therefore, the insulating material has a very low water absorption rate of 0.01% and a degradation in insulation function caused by hydrolysis is less liable to occur through use of a refrigerating machine oil having a water content in oil of 1% or less, and hence a heat pump apparatus excellent in long-term reliability can be provided.

BRIEF DESCRIPTION OF DRAWINGS

[0015] FIG. **1** is a refrigerant circuit diagram illustrating a basic configuration of a heat pump apparatus according to Embodiment 1 of the present invention.

[0016] FIG. **2** is a side sectional view illustrating a part (compressor) of the heat pump apparatus illustrated in FIG. **1**.

[0017] FIG. **3** is a characteristic graph showing hydrolysis resistance of a part (heat insulator) of the heat pump apparatus illustrated in FIG. **1**.

DESCRIPTION OF EMBODIMENTS

Embodiment 1

[0018] FIG. **1** and FIG. **2** illustrate a heat pump apparatus according to Embodiment 1 of the present invention. FIG. **1** is a refrigerant circuit diagram illustrating a basic configuration of the heat pump apparatus, and FIG. **2** is a side sectional view illustrating a part of the heat pump apparatus (compressor). Note that, each figure is illustrated schematically, and the present invention is not limited to the illustrated forms.

[0019] (Refrigerant Circuit)

[0020] In FIG. **1**, a heat pump apparatus **100** includes a compressor **1** for compressing refrigerant, a condenser **3** for condensing the refrigerant flowing out from the compressor, an expansion mechanism **4** for subjecting the refrigerant flowing out from the condenser **3** to adiabatic expansion, an evaporator **5** for evaporating the refrigerant flowing out from the expansion mechanism **4**, and a refrigerant pipe **2** that sequentially connects the compressor **1**, the condenser **3**, the expansion mechanism **4**, and the evaporator **5** to circulate the refrigerant. Note that, as necessary, a switching valve (such as a four-way valve) for changing a flow direction of the refrigerant may be installed in the refrigerant pipe **2**, or an air-sending device for sending air to the condenser **3** and the evaporator **5** or other devices may be arranged in the refrigerant pipe **2**.

[0021] (Compressor)

[0022] In FIG. **2**, the compressor **1** includes a sealed container **10**, a compression mechanism **9** arranged in the sealed container **10**, and an electric motor **6** for rotating and driving the compression mechanism **9**. High-pressure and high-temperature refrigerant compressed by the compression mechanism **9** is temporarily discharged into the sealed container **10**. Thus, the electric motor **6** is exposed to the high-pressure and high-temperature refrigerant.

[0023] Further, to smooth the rotation of the compression mechanism **9**, an oil reservoir **8** for storing a machine oil (hereinafter referred to as "refrigerating machine oil") is formed in a bottom portion of the sealed container **10**.

[0024] (Compression Mechanism)

[0025] The compression mechanism **9** includes a sealed space (to be exact, an inflow port for the inflow of the refrigerant and an outflow port for the outflow of the refrigerant are formed) formed by a main bearing (upper bearing) **9***m*, an auxiliary bearing (lower bearing) **9***s*, and a cylinder **9***c* having both end surfaces in close contact with the main bearing **9***m* and the auxiliary bearing **9***s*, and an eccentric cylinder **9***e* arranged in the sealed space.

[0026] A drive shaft **9***a* is fixed to the eccentric cylinder **9***e*, and is rotatably supported by the main bearing **9***m* and the auxiliary bearing **9***s*. Therefore, the eccentric cylinder **9***e* is rotated eccentrically by the rotation of the drive shaft **9***a*.

[0027] Further, a plurality of vanes **9***b* are arranged in a freely advancing and retracting manner in a plurality of grooves (not shown) formed radially in the cylinder **9***c*, and are pressed against an outer peripheral surface of the eccentric cylinder **9***e*. That is, a plurality of spaces are each formed between a pair of vanes, and the volume of the space is changed by the rotation of the eccentric cylinder **9***e*, to thereby form a compression chamber.

[0028] (Electric Motor)

[0029] The electric motor **6** includes a stator **6***s* fixed to the sealed container and a rotator **6***r* surrounded by the stator **6***s* and configured to rotate. The drive shaft **9***a* forming the compression mechanism **9** is fixed to the rotator **6***r*.

[0030] The stator **6***s* has a tubular shape, and includes a back yoke portion (not shown) forming an outer periphery of the stator **6***s*, a plurality of tooth portions (not shown) projecting from the back yoke portion to the center, and a winding (electric wire) **6***w* wound around the tooth portions through intermediation of an insulating material (insulator) **7**.

[0031] (Refrigerant)

[0032] The refrigerant contains at least one kind of the following substances (a single substance of the following substances or a combination of two or more kinds thereof).

[0033] Difluoromethane (HFC-32)

[0034] 1,1,1,2,2-Pentafluoroethane (HFC-125)

[0035] 1,1,1,2-Tetrafluoroethane (HFC-134a)

[0036] 1,1,1-Trifluoroethane (HFC-143a)

[0037] 2,2-Dichloro-1,1,1-trifluoroethane (HFC-123)

[0038] Trifluoromethane (HFC-23)

[0039] 1,1-Difluoroethane (HFC-152a)

[0040] 1,1,2 Trifluoroethylene (R1123)

[0041] trans-1,2, Difluoroethylene (R1132(E))

[0042] cis-1,2 Difluoroethylene (R1132(Z))

[0043] 1,1 Difluoroethylene (R1132a)

[0044] 2,3,3,3-Tetrafluoro-1-propane (HFO-1234yf)

[0045] Chlorodifluoromethane (HFC-22)

[0046] Carbon dioxide

[0047] Ammonia

[0048] Dimethyl ether

[0049] Propane (R-290)

[0050] Isobutane (R-600a)

[0051] Butane (R-600)

[0052] (Refrigerating Machine Oil)

[0053] The refrigerating machine oil is stored in the oil reservoir **8** of the sealed container **10**, and is at least one kind of an ester-based mineral oil, an ether-based mineral oil, a glycol-based mineral oil, an alkyl benzene-based mineral oil, a poly-α-olefin-based mineral oil, a polyvinyl ether-based mineral oil, a fluorine-based mineral oil, a naphthene-based mineral oil, and a paraffin-based mineral oil. That is, the refrigerating machine oil is a single substance of any one kind thereof or a combination of any two or more kinds thereof.

[0054] (Insulating Material)

[0055] The insulating material **7** is formed of "LCP". LCP is a collective term of polymers that exhibit liquid crystallinity during melting. LCP has a plurality of molecular structures, and the heat resistance and strength thereof are not constant because the heat resistance and strength depend on monomers for forming LCP.

[0056] LCP for forming the insulating material **7** is a thermoplastic resin obtained by copolymerization (polycondensation) of a total of two or more components, the components containing, as an essential component, p-hydroxybenzoic acid (PHB) as a monomer component and having added thereto at least one of the following additive components.

[0057] That is, the additive component is at least one component of the following five kinds.

[0058] 4,4'-Biphenol (BP)

[0059] Hydroquinone (HQ)

[0060] Terephthalic acid (TPA)

[0061] Isophthalic acid (IPA)

[0062] 6-Hydroxy-2-naphthoic acid (BON6)

[0063] For example, the insulating material **7** is formed of "LCP-A" that is a two-component system of PHB and BON6 or "LCP-B" obtained by polycondensation of monomers (PHB, BP, HQ, TPA, IPA, BON6) of a six-component system including the essential component and all the additive components.

TABLE 1

Kind of	Raw material monomer of LCP						Water absorption	Latent heat of
resin	PHB	BP	BON6	HQ	TPA	IPA	rate	crystallization
LCP-A	○	—	○	—	—	—	0.01%	3 J/g
LCP-B	○	○	○	○	○	○	0.01%	3 J/g
PBT	—	—	—	—	—	—	0.10%	30 J/g

[0064] In Table 1, the absorption rate and the latent heat of crystallization of LCP-A and LCP-B are smaller values than those of PBT alone (polybutylene terephthalate). Thus, LCP-A and LCP-B each have the following characteristics. The heat resistance and extractability are excellent, and the flow characteristics in the case of being thin is excellent by virtue of a low melt viscosity during molding. The heat transfer amount from a molten state to a solidified state is small, and hence the solidification speed is very high and burrs are less liable to occur during a production step.

[0065] Further, LCP-A and LCP-B each have a latent heat of crystallization measured by a differential scanning calorimeter (DSC) of 10 J/g or less, and hence their solidification speeds are high and burrs are less liable to occur during their production steps. Thus, LCP-A and LCP-B each have features of enabling high-cycle molding and having satisfactory productivity.

[0066] Specifically, although LCP is hydrolyzed in terms of a molecular structure owing to the ester bond, LCP is not in a state in which molecules are tangled in a rubber form as in an ordinary resin but a liquid crystal resin in which stiff molecules are linearly oriented densely. Thus, LCP has a very low water absorption rate. The water absorption rate of an engineering plastic, such as PBT, is "0.1%", whereas the water absorption rate of LCP is "0.01% (after immersion in water at 23 degrees Celsius for 24 hours), which is a value smaller by a digit or more than the former.

[0067] Thus, LCP for forming the insulating material **7** is excellent in heat resistance and extractability, and hence the stability thereof is high with respect to any of the above-mentioned refrigerating machine oils and refrigerant.

[0068] FIG. **3** is a characteristic graph showing hydrolysis resistance of a part (heat insulator) of the heat pump apparatus according to Embodiment 1 of the present invention.

[0069] In FIG. **3**, the vertical axis represents a tensile strength retention ratio (ratio of strength after a test with respect to the initial strength), and the horizontal axis represents a water content in oil of the refrigerating machine oil, that is, water content in oil (%) at 40 degrees Celsius and a relative humidity of 80%.

[0070] Ether oil having high hygroscopicity is used as the refrigerating machine oil, and R32 refrigerant is used as the refrigerant. LCP-A, LCP-B, and PBT for comparison are each immersed in a container in which the ether oil and R32 refrigerant are put at 150 degrees Celsius for 500 hours to determine a tensile strength retention ratio.

[0071] In this case, as is apparent from FIG. **3**, the tensile strength retention ratio of PBT, which is a comparative material, is only about 60%, even when the water content in oil is 0.1%. Further, when the water content in oil reaches 0.2%, the tensile strength retention ratio decreases drastically. When the water content in oil reaches 0.5% or more, the tensile strength retention ratio is a low value of 10%.

[0072] On the other hand, each tensile strength retention ratio of LCP-A and LCP-B of the present invention decreases along with an increase in water content in oil. However, the tensile strength retention ratio is kept at 70% or more when the saturated water amount falls within a range of 2% or less.

[0073] Thus, LCP-A and LCP-B of the present invention keep a sufficient insulation function as long as the saturated water amount of the refrigerating machine oil is 2% or less, and can provide the electric motor **6** with high reliability and the heat pump apparatus 100 with high reliability.

[0074] Note that, in the foregoing, LCP-A that is a two-component system and LCP-B that is a six-component system exhibit similar hydrolysis resistance characteristics. Thus, the similar hydrolysis resistance characteristics are obtained in the case of monomers of all the combinations of a three-component system and monomers of all the combinations of a four-component system or a five-component system as long as PHB is included.

[0075] Note that, LCP is a resin that exhibits an intermediate state between a solid and a liquid in a molten state, that is, a resin in a state in which a number of rod-like molecules are arranged, and has a feature of being solidified in a state close to the molten state. Specifically, LPC is excellent in hydrolyzability for the following reason. LPC is subjected to a shearing force caused by injection or extrusion in a molten state, and molecules are oriented further densely, with the result that water molecules are prevented from entering or permeating a gap between the molecules. Thus, only with LCP, the hydrolyzability is significantly advantageous with respect to an ordinary resin having an ester bond, such as PET or PBT.

[0076] Further, LCP is wholly aromatic LCP formed of a molecule having a strong skeleton in which all the six monomer components themselves have aromatic rings, and hence is less liable to be hydrolyzed.

REFERENCE SIGNS LIST

[0077] **1** compressor **2** refrigerant pipe **3** condenser **4** expansion mechanism **5** evaporator **6** electric motor **6***r* rotator **6***s* stator **6***w* winding **7** insulating material **8** oil reservoir **9** compression mechanism **9***a* drive shaft **9***b* vane **9***c* cylinder **9***e* eccentric cylinder

[0078] **9***m* main bearing (upper bearing) **9***s* auxiliary bearing (lower bearing) **10** sealed container **100** heat pump apparatus

1. A heat pump apparatus, comprising:

a compressor;

a condenser;

an expansion mechanism; and

an evaporator,

the compressor, the condenser, the expansion mechanism, and the evaporator being configured to perform a refrigeration cycle,

the heat pump apparatus being configured to perform heat transfer in the condenser or the evaporator,

wherein the compressor includes

a sealed container,

a compression mechanism mounted inside the sealed container, and

an electric motor configured to rotate and drive the compression mechanism,

the compression mechanism being configured to compress refrigerant, and to be lubricated by a refrigerating machine oil,

wherein the electric motor includes

a stator fixed to the sealed container with a winding being wound around the stator through intermediation of an insulating material, and

a rotator surrounded by the stator,

wherein the insulating material includes a liquid crystal polymer having a main chain of a molecule obtained by ester bonding, the liquid crystal polymer being obtained by polycondensation of a total of two or more kinds of monomers, the monomers containing, as an essential component, p-hydroxybenzoic acid (PHB) as a monomer component having an ester bond and containing, as an additive component, one or more kinds of a following five kinds: 4,4'-biphenol (BP), hydroquinone (HQ), terephthalic acid (TPA), isophthalic acid (IPA), and 6-hydroxy-2-naphthoic acid (BON6), and

wherein a saturated water amount of the refrigerating machine oil is 0.5% or more and 1% or less at 40 degrees Celsius and a relative humidity of 80%.

2. The heat pump apparatus of claim **1**, wherein a liquid crystal polymer serving as the insulating material has a latent heat of crystallization measured by a differential scanning calorimeter (DSC) of 10 J/g or less.

3. (canceled)

4. The heat pump apparatus of claim **1**, wherein the refrigerating machine oil includes a single substance or a combination of substances including at least one kind of an ester-based mineral oil, an ether-based mineral oil, a glycol-based mineral oil, an alkyl benzene-based mineral oil, a poly-α-olefin-based mineral oil, a polyvinyl ether-based mineral oil, a fluorine-based mineral oil, a naphthene-based mineral oil, and a paraffin-based mineral oil.

5. The heat pump apparatus of claim **1**, wherein the refrigerant includes a single substance or a combination of substances including at least one kind of difluoromethane (HFC-32), 1,1,1,2,2-pentafluoroethane (HFC-125), 1,1,1,2-tetrafluoroethane (HFC-134a), 1,1,1-trifluoroethane (HFC-143a), 2,2-dichloro-1,1,1-trifluoroethane (HFC-123), trifluoromethane (HFC-23), 1,1-difluoroethane (HFC-152a), 1,1,2 trifluoroethylene (R1123), trans-1,2-difluoroethylene (R1132(E)), cis-1,2 difluoroethylene (R1132(Z)), 1,1-difluoroethylene (R1132a), 2,3,3,3-tetrafluoro-l-propane (HFO-1234yf), chlorodifluoromethane (HFC-22), carbon dioxide, ammonia, dimethyl ether, propane (R-290), isobutane (R-600a), and butane (R-600).

6. A heat pump apparatus, comprising:

a compressor;

a condenser;

an expansion mechanism; and

an evaporator,

the compressor, the condenser, the expansion mechanism, and the evaporator being configured to perform a refrigeration cycle,

the heat pump apparatus being configured to perform heat transfer in the condenser or the evaporator,

wherein the compressor includes

a sealed container,

a compression mechanism mounted inside the sealed container, and

an electric motor configured to rotate and drive the compression mechanism,

the compression mechanism being configured to compress refrigerant, and to be lubricated by a refrigerating machine oil,

wherein the electric motor includes

a stator fixed to the sealed container with a winding being wound around the stator through intermediation of an insulating material, and

a rotator surrounded by the stator,

wherein the insulating material includes a liquid crystal polymer having a main chain of a molecule obtained by ester bonding, the liquid crystal polymer being obtained by polycondensation of monomers, the monomers containing, as an essential component, p-hydroxybenzoic acid (PHB) as a monomer component having an ester bond and containing, as an additive component, a following five kinds: 4,4'-biphenol (BP), hydroquinone (HQ), terephthalic acid (TPA), isophthalic acid (IPA), and 6-hydroxy-2-naphthoic acid (BON6), and

wherein a saturated water amount of the refrigerating machine oil is 0.5% or more and 1% or less at 40 degrees Celsius and a relative humidity of 80%.

7. The heat pump apparatus of claim **6**, wherein a liquid crystal polymer serving as the insulating material has a latent heat of crystallization measured by a differential scanning calorimeter (DSC) of 10 J/g or less.

8. The heat pump apparatus of claim **6**, wherein the refrigerating machine oil includes a single substance or a combination of substances including at least one kind of an ester-based mineral oil, an ether-based mineral oil, a glycol-based mineral oil, an alkyl benzene-based mineral oil, a poly-α-olefin-based mineral oil, a polyvinyl ether-based mineral oil, a fluorine-based mineral oil, a naphthene-based mineral oil, and a paraffin-based mineral oil.

9. The heat pump apparatus of claim **6**, wherein the refrigerant includes a single substance or a combination of substances including at least one kind of difluoromethane (HFC-32), 1,1,1,2,2-pentafluoroethane (HFC-125), 1,1,1,2-tetrafluoroethane (HFC-134a), 1,1,1-trifluoroethane (HFC-143a), 2,2-dichloro-1,1,1-trifluoroethane (HFC-123), trifluoromethane (HFC-23), 1,1-difluoroethane (HFC-152a), 1,1,2 trifluoroethylene (R1123), trans-1,2-difluoroethylene (R1132(E)), cis-1,2 difluoroethylene (R1132(Z)), 1,1-difluoroethylene (R1132a), 2,3,3,3-tetrafluoro-1-propane (HFO-1234yf), chlorodifluoromethane (HFC-22), carbon dioxide, ammonia, dimethyl ether, propane (R-290), isobutane (R-600a), and butane (R-600).

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