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(54) **USE OF IONIC LIQUIDS FOR THE LUBRICATION OF COMPONENTS IN WIND POWER PLANTS**

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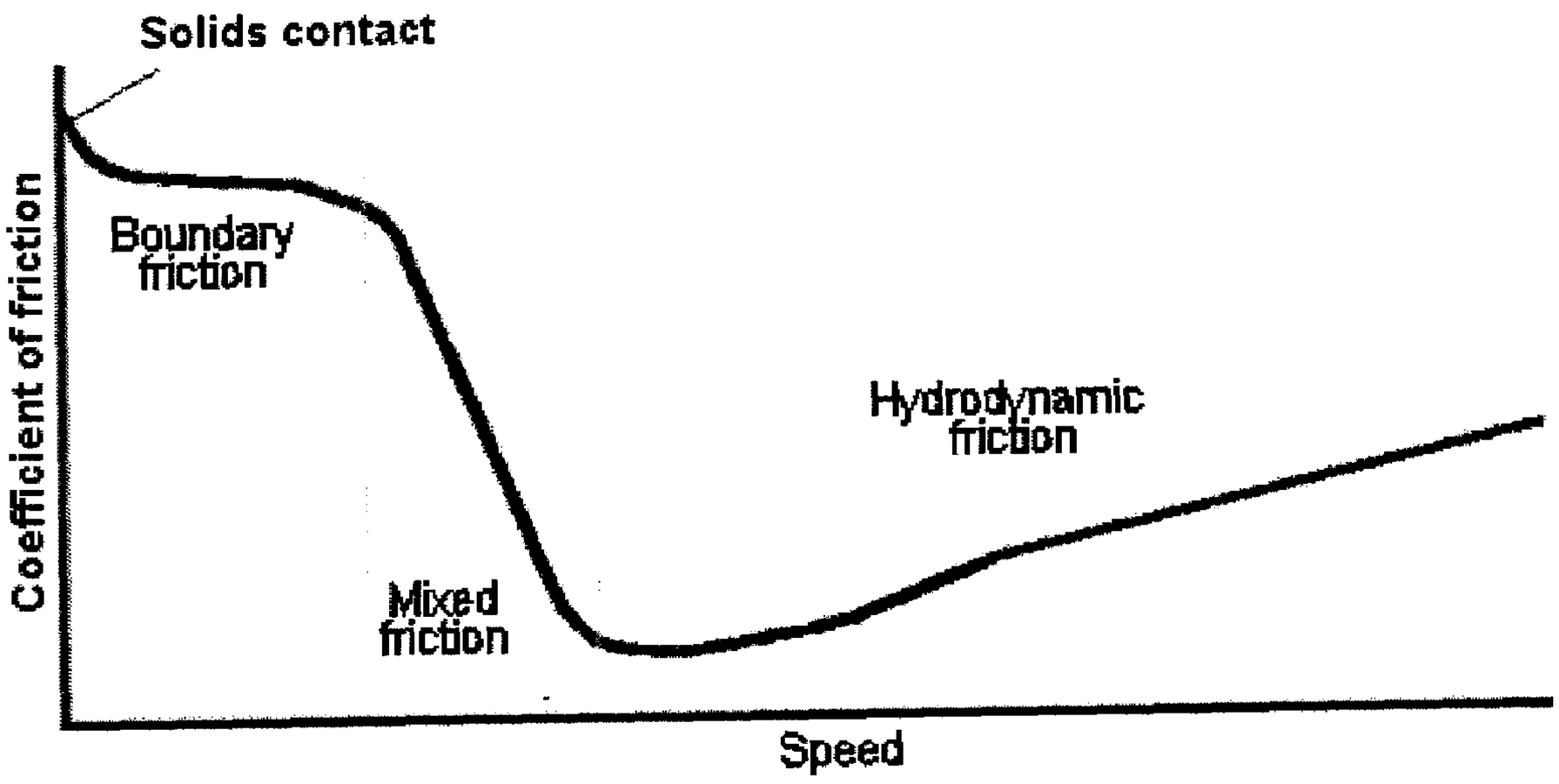
(57) **ABSTRACT**

The invention relates to the use of lubricants containing at least one ionic liquid as lubricants in components of a wind power plant.



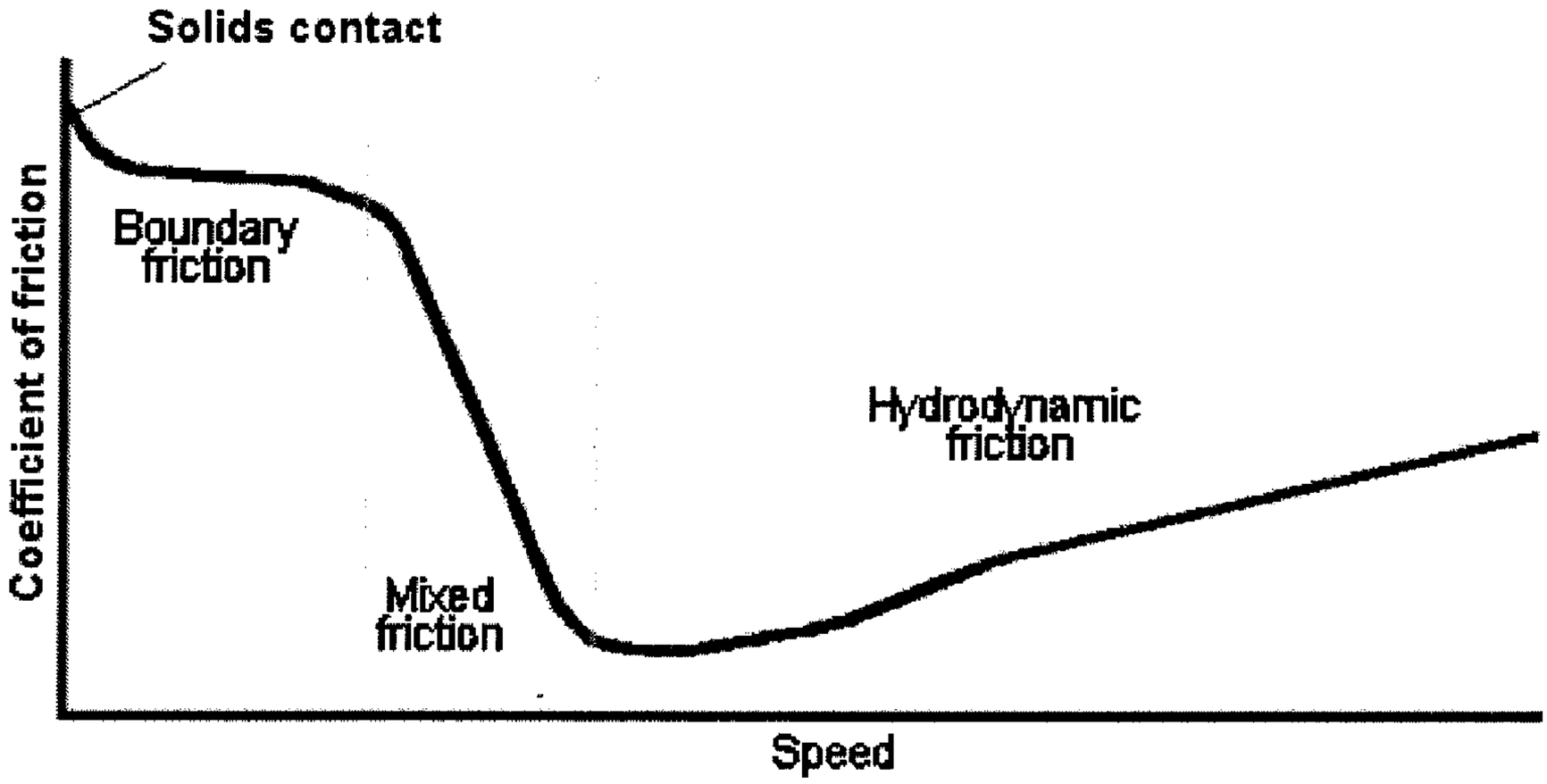

Solids contact
Boundary friction
Mixed friction
Hydrodynamic friction
Coefficient of friction
Speed

Fig. 1

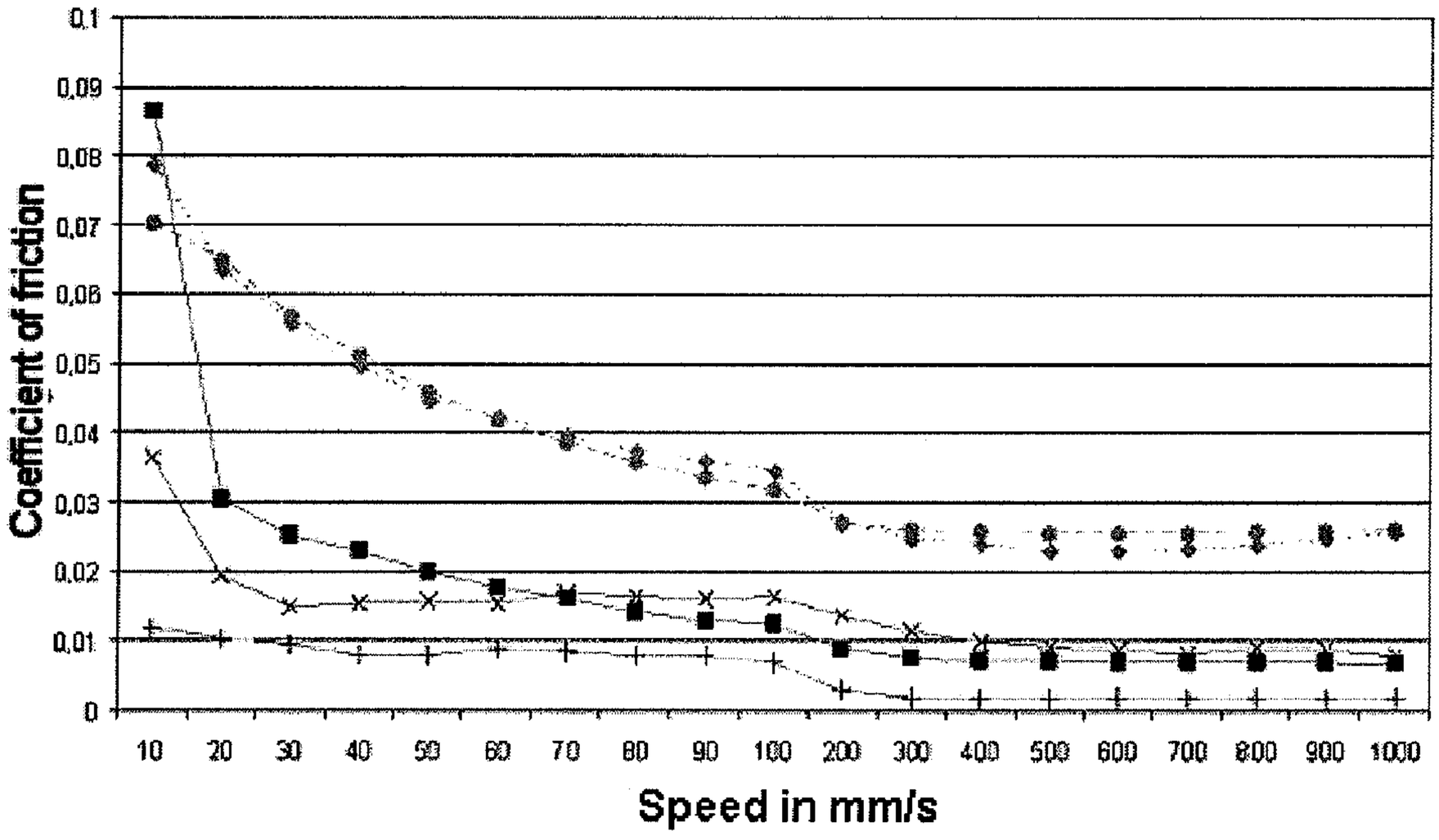

0,1
0,09
0,08
0,07
0,06
0,05
0,04
0,03
0,02
0,01
0
Coefficient of friction
10
20
30
40
50
60
70
80
90
100
200
300
400
500
600
700
800
900
1000
Speed in mm/s

Fig. 2

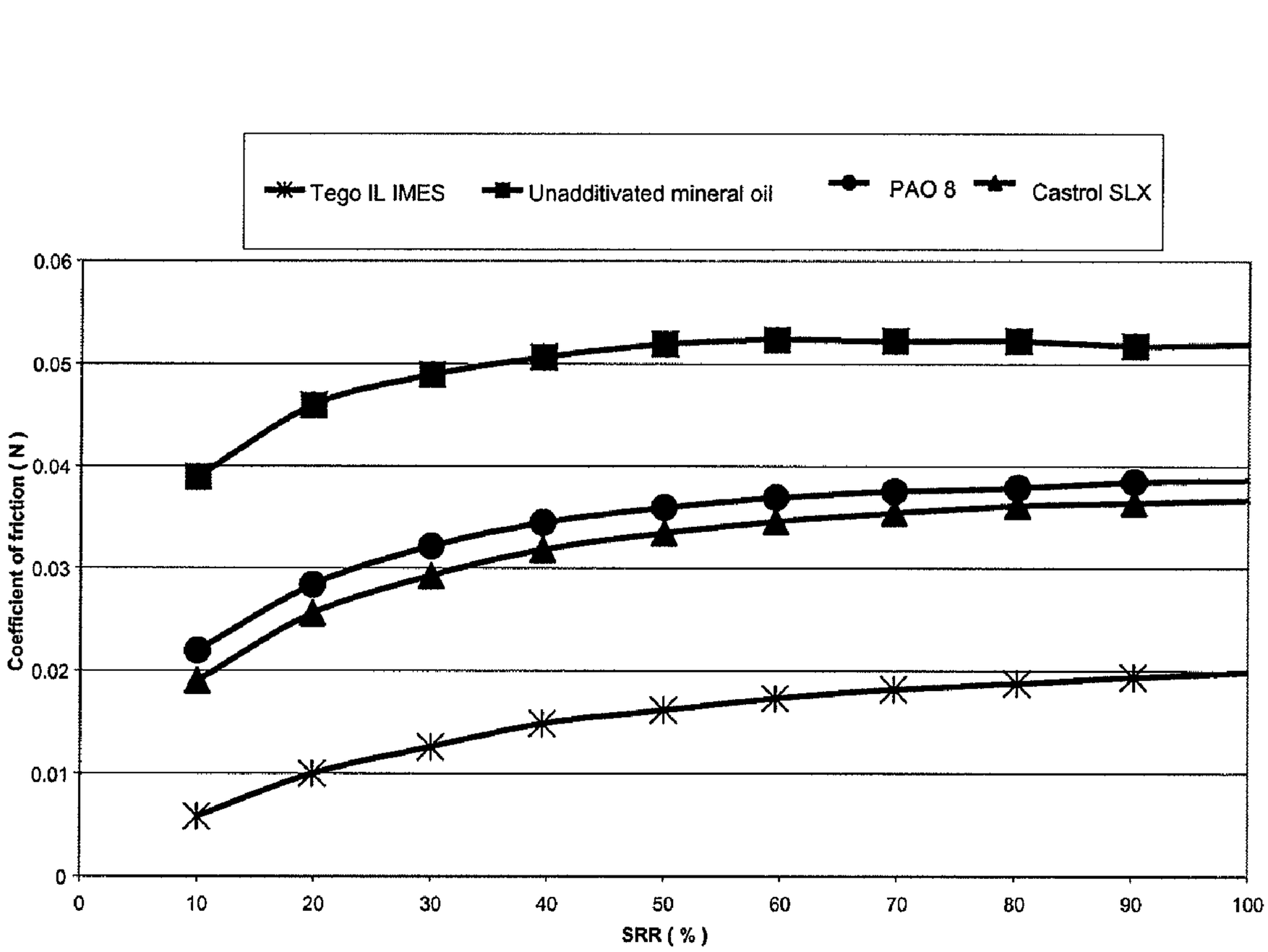

Comparative traction curves at 50°C - 30 N - 1000 mm/s
Tego IL IMES
Unadditivated mineral oil
PAO 8
Castrol SLX
Coefficient of friction (N)
0.06
0.05
0.04
0.03
0.02
0.01
0
0
10
20
30
40
50
60
70
80
90
100
SRR (%)

Fig. 3

USE OF IONIC LIQUIDS FOR THE LUBRICATION OF COMPONENTS IN WIND POWER PLANTS

[0001] The invention relates to the use of ionic liquids for the lubrication of movable parts in wind power plants, in particular for gearbox lubrication.

[0002] Gearboxes are movable combinations of parts for transmitting and converting force or for conducting parts on a track. Within the gearbox, friction occurs between the surfaces of the individual components of the gearbox, which can comprise, for example, drive and offtake shafts and toothed wheels. The friction has to be reduced by use of suitable lubricants since otherwise damage (wear) and malfunctions, in particular of the toothed wheels, can occur. The lubricants can significantly prolong the life of components. In addition, the lubricant can contribute to reducing the force which has to be applied to produce movement and the energy consumption associated therewith, so as to achieve a higher efficiency.

[0003] Wind energy is the kinetic energy of the moving air masses of the atmosphere. Wind energy is kinetic energy of the air particles which move at the velocity v. The power of the wind which, for instance, a wind generator can utilize as electric power is considerably lower because the velocity cannot be brought down to "0" in a wind turbine. This fact is allowed for by the Betz factor.

[0004] This Betz factor is not an efficiency but a "utilization factor" since the wind energy which is not utilized is largely retained, firstly in the abovementioned residual motion energy of the wind passing through the wind turbine and secondly because the wind evades the wind turbine and flows around it without a reduction in its speed.

[0005] A further important parameter is the tip speed ratio λ (lambda). It is the ratio of the circumferential velocity of the rotor (blade tip speed) to the wind speed. Three-blade rotors, as are now standard in large units, reach the greatest efficiency at a tip speed ratio of from 7 to 8. This corresponds to blade tip speeds in the order of about 250-300 km/h regardless of the rotor diameter. The operating point having the highest power coefficient and the design tip speed ratio also gives the design wind velocity.

[0006] A wind energy plant (WEP) converts the kinetic energy of the wind into electric energy and feeds this into the power grid. This is achieved by the kinetic energy of the wind flow acting on the rotor blades and thus setting the rotor into rotational motion. The rotor transmits the rotational energy to a generator which converts it into electric power.

[0007] In everyday speech, and partly also in the technical literature, the term wind power plant (WPP) has likewise become established, and wind power station or wind energy converter (WEC) is sometimes also used.

[0008] Wind energy plants can be used in all climatic zones, at sea and in all land forms (coast, inland, mountains) to generate electric power.

[0009] A wind energy plant consists essentially of a rotor with hub and rotor blades, a machine pod which accommodates the generator and frequently a gearbox (except in the case of some wind energy plant manufacturers such as Enercon, Scanwind and Vensys). It is mounted in a rotatable fashion on a tower whose foundation gives the necessary stability. In addition, there are the monitoring and control systems and the power grid connections in the machine pod and in the base of the tower or outside it.

[0010] Wind energy plants having a horizontal axis of rotation have now become established for power generation. Wind energy plants having a horizontal rotor axis have to be pointed in the direction of the wind. The pod is mounted on the tower so as to be able to be rotated in a horizontal plane by means of an azimuthal bearing. The wind direction is in the case of large units determined via the wind direction indicator. The rotor is then pointed into the wind by means of servomotors.

[0011] Asynchronous or synchronous AC generators are used for electromechanical energy conversion. The rotational speed of the generator can be constant, have two settings (low and high wind velocity) or be able to be adjusted steplessly. Different variants of asynchronous generators and directly coupled, multipolar synchronous generators have become established in industry.

[0012] The generator and any gearbox are optimized in terms of life, weight, size, maintenance requirement and costs. A further parameter is the number of pairs of poles of the generator, which fixes the transmission ratio of any gearbox.

[0013] The power of the rotational motion of the rotor of a wind power plant is transmitted to the generator via the drive shaft, the gearbox and the offtake shaft.

[0014] The most practical solution for transmitting the rotor frequency to an AC generator is the installation of a gearbox, which is customary in precisely the opposite direction in many industrial machines and in conjunction with automobile engines. With the aid of a gearbox, the power at a low rotational speed and a high torque, as is obtained from the rotor of a wind power plant, is converted into power at a high rotational speed and a low torque, as is required for the generator.

[0015] There are multistage gearboxes and wind power plants without gearboxes; most gearboxes are three-stage. The first stage is optimum for low wind velocities (the rotor can turn more easily in the first stage). The intermediate and high-speed stages (second and third stages) are particularly well suited for strong wind (similar to the case of bicycle gears).

[0016] Since the noise level from wind energy plants represents a problem, especially in more densely populated inland regions, the noise level can in some plants be individually matched to the specific site requirements by programming of the plant control.

[0017] The gearbox is usually mounted on the pod by means of rubber elements.

[0018] Movable components in a wind power plant which have to be lubricated comprise, in particular, the following seven important lubrication points:

[0019] the main or tracking gearbox, which achieves gearing up of the rotational speed of the rotor to the rotational speed of the generator,

[0020] the azimuthal gearbox, which is responsible for tracking the wind direction,

[0021] the pitch gearbox, which performs the adjustment of the rotor blades,

[0022] the main bearing, which essentially ensures the mounting of the rotor,

[0023] the pitch bearing, which acts as mounting for the rotor blades,

[0024] the azimuthal bearing, which provides the rotatable connection of the wind power plant between tower and pod and

[0025] the generator bearing, which acts as mounting for the generator shaft.

[0026] During each movement, there is relative motion between components and therefore friction between the surfaces. It is therefore necessary to apply a lubricant between the moving components. Mineral oils, poly-alpha-olefins (PAOs), natural oils (e.g. rapeseed oils), synthetic ester oils or low-viscosity polyglycols are usually used for lubrication.

[0027] When choosing the lubricants for wind power plants, it is generally necessary to ensure that the material has very low coefficients of friction, a satisfactory cold flow capability (down to −60° C.), good thermal stability (at least to 200° C.), good compatibility with surface coatings and seals, low toxicity and ecotoxicity, high shear stability, high viscosity indices, low corrosivity, good compatibility with additives and very good wear protection. The gearbox oil is subjected to particularly demanding requirements since it plays a critical role in determining the life of the gearbox. Grey specks and consequent pitting and also roller bearing damage are frequently occurring problems which increase the frequency of damage. In the offshore area in particular, maintenance and repair work is associated with very high costs. Gearbox oils have to be particularly clean and therefore have to be continually cleaned by means of fine filtration.

[0028] In the gearboxes in particular, the very high pressure stresses at low relative speeds result in boundary friction or extreme mixed friction which places very specific demands on the lubricant.

[0029] The lubricants known from the prior art have various disadvantages. Natural oils have considerable deficiencies in terms of low-temperature behaviour, ageing behaviour and in the heat resistance and water resistance. Mineral oils display low viscosity indices, high vaporization losses, limited suitability at low temperatures and moderate thermal stability. Polyglycols display low thermal stability, a high vaporization loss, low viscosities and poor compatibility with seals. Ester oils are not stable to hydrolysis and display low shear stability.

[0030] It was therefore an object of the present invention to provide an alternative lubricant for the lubrication of movable parts in wind power plants, in particular for gearbox lubrication, which does not have one or more of the abovementioned disadvantages of the lubricants known from the prior art. The alternative lubricant should preferably allow simple handling and display an improved property profile, so that the life of the movable parts can be increased, the intervals between maintenance and repairs can be lengthened and/or the efficiency of the wind power plant can be increased.

[0031] It has surprisingly been found that this object can be achieved by the use of at least one ionic liquid or a mixture of ionic liquids according to Claim **1**.

[0032] The present invention therefore provides for the use of a lubricant in components of a wind power plant or wind energy plant, which is characterized in that the lubricant comprises, in particular as lubricating material, at least one ionic liquid.

[0033] The present invention likewise provides wind power plants comprising at least one component having movable elements and a lubricant, characterized in that the lubricant contains an ionic liquid.

[0034] The use according to the invention of at least one ionic liquid as lubricating material provides a novel lubricant for wind power plants, in particular for their gearboxes, which has an excellent property profile.

[0035] The use of ionic liquids in or as lubricants also has the advantage that the property profile can be modified over a wide range by selection of appropriate ionic liquids. An appropriate choice of the ionic liquid(s) used enables the property profile to be modified in terms of viscosity, density, thermal stability, anticorrosion properties, oxidation resistance, materials compatibility, wear resistance, low-temperature suitability, V-T behaviour, miscibilities, hydrolysis stabilities, toxicity and ecotoxicity. In this way, a tailored lubricant which fully meets requirements in respect of the abovementioned properties can be provided for each location/climatic zone. Thus, use of a lubricant comprising an ionic liquid or a mixture of ionic liquids in wind power stations, in particular in their gearboxes, enables an increase in the life of the components and a lengthening of the maintenance intervals to be achieved.

[0036] The lubricants according to the invention have, in particular, the advantage that they do not lose their lubrication properties at very low temperatures. Thus, the lubricants according to the invention can, in particular, be used advantageously in climatic zones in which temperatures below 0° C., in particular below −40° C., occur.

[0037] For the purposes of the present invention, ionic liquids are salts which melt at low temperatures (≦100° C.) and represent a novel class of liquids which are made up exclusively of ions. In contrast to classical salt melts, which are high-melting, highly viscous and very corrosive media, ionic liquids are liquid even at low temperatures (<100° C.) (K. R. Seddon J. Chem. Technol. Biotechnol. 1997, 68, 351-356).

[0038] The use according to the invention is described below by way of example, without the invention being restricted to these illustrative embodiments. When ranges, general formulae or classes of compounds are indicated below, these are intended to encompass not only the specific ranges or groups of compounds which are explicitly mentioned, but also all subranges and subgroups of compounds which can be obtained by leaving out individual values (ranges) or compounds. If documents are cited in the present description, their contents are fully incorporated by reference into the disclosure content of the present invention.

[0039] The use according to the invention of a lubricant in components of a wind power station is characterized in that the lubricant comprises at least one ionic liquid. The lubricant can comprise not only one ionic liquid but also a plurality of ionic liquids. Suitable choice of ionic liquids enables the properties of the lubricant to be set.

[0040] According to the invention, the lubricant is preferably used in components such as bearings or gearboxes of wind power plants. When used in these components in particular, the lubricant comprising ionic liquids can achieve a great improvement and simplification. The component of the wind power plant in which the lubricant according to the invention is used can preferably be, for example, a main or tracking gearbox for gearing up the rotational speed of the rotor to the rotational speed of the generator, an azimuthal gearbox for tracking the wind direction, a pitch gearbox for adjusting the rotor blades, a generator bearing for mounting the generator shaft, a pitch bearing for mounting the rotor blades, a main bearing for mounting the rotor or an azimuthal bearing for providing the rotatable connection between tower and pod of the wind power plant.

[0041] It can be advantageous for the lubricant used to contain exclusively one or more ionic liquids as lubricating material.

[0042] However, it is likewise possible for the lubricant used to contain one or more further materials in addition to the

ionic liquid(s). Such materials can be, for example, extreme pressure additives (EP additives; e.g. tricresyl phosphate, zinc dialkyldithiophosphate—Additin RC 3048 from Rheinchemie) to optimize the friction- and wear-producing properties or corrosion inhibitors, e.g. fatty acid diethanolamide —REWOCOROS® AC 28, fatty acid monoethanolamide—REWOCOROS® AC 101 (both products of Evonik Goldschmidt GmbH). In addition to the ionic liquids and any further materials present, the lubricant used according to the invention can contain one or more further lubricating materials. Such lubricating materials can be, for example, mineral oils, poly-α-olefins (PAO), synthetic esters or polyglycols, with the abovementioned groups representing a selection and not a restriction. The addition of further materials and/or lubricating materials enables the property profiles of the lubricants to be adjusted very finely to match them to requirements.

[0043] The lubricant used according to the invention preferably has a pour point of from 0° C. to −80° C., more preferably from −25° C. to −80° C. and particularly preferably from −40° C. to −75° C.

[0044] The proportion of ionic liquids in the lubricant used according to the invention is preferably from 0.1 to 99.98% by weight, more preferably from 75 to 99.95% by weight and particularly preferably from 85 to 99.9% by weight.

[0045] The lubricant can contain all known ionic liquids as ionic liquids. The lubricant preferably contains ionic liquids which give the lubricant a viscosity at operating temperature of from 10 to 5000 mPas, preferably from 50 to 1000 mPas and particularly preferably from 100 to 500 mPas. Overviews of ionic liquids, their preparation and their properties may be found, for example, in "Ionic Liquids in Synthesis", P. Wasserscheid, T. Welton (eds.), Wiley, in "Green Industrial Applications of Ionic Liquids", NATO Science Series. Li. Mathematics, Physics and Chemistry, 92, or in "Ionic Liquids: Industrial Applications for Green Chemistry", Robin D. Rogers (ed.), Acs. Symposium Series, 818.

[0046] Preference is given to at least one salt of the formula (I)

$$[A]_n^+[Y]^{n-} \quad (I)$$

where

[0047] n is 1, 2, 3 or 4,

[0048] $[A]^+$ is a quaternary ammonium cation, an oxonium cation, a sulphonium cation or a phosphonium cation (where these cations can in each case be substituted or unsubstituted) and

[0049] $[Y]_{n-}$ is a monovalent, divalent, trivalent or tetravalent anion, or a

mixed salt having one of the general formulae (IIa) to (IIc)

$$[A^1]^+[A^2]^+[Y]^{2-} \quad (IIa),$$

$$[A^1]^+[A^2]^+[A^3]^+[Y]^{3-} \quad (IIb) \text{ or}$$

$$[A^1]^+[A^2]^+[A^3]^+[A^4]^+[Y]^{4-} \quad (IIc),$$

where

[0050] $[A^1]^+$, $[A^2]^+$ $[A^3]^+$ and $[A^4]^+$ are selected independently from the groups mentioned for $[A]^+$ and

[0051] $[Y]^{2-}$ to $[Y]^{4-}$ have the meanings given for $[Y]^{n-}$ in formula (I), or

a mixed salt having one of the general formulae (IIIa) to (IIIj)

$$[A^1]^+[A^2]^+[A^3]^+[M^1]^+[Y]^{4-} \quad (IIIa),$$

$$[A^1]^+[A^2]^+[M^1]^+[M^2]^+[Y]^{4-} \quad (IIIb),$$

$$[A^1]^+[M^1]^+[M^2]^+[M^3]^+[Y]^{4-} \quad (IIIc),$$

$$[A^1]^+[A^2]^+[M^1]^+[Y]^{3-} \quad (IIId),$$

$$[A^1]^+[M^1]^+[M^2]^+[Y]^{3-} \quad (IIIe),$$

$$[A^1]^+[M^1]^+[Y]^{2-} \quad (IIIf),$$

$$[A^1]^+[A^2]^+[M^4]^{2+}[Y]^{4-} \quad (IIIg),$$

$$[A^1]^+[M]^+[M^{4]2+}[Y]^{4-} \quad (IIIh),$$

$$[A^1]^+[M^5]^{3+}[Y]^{4-} \quad (IIIi) \text{ or}$$

$$[A^1]^+[M^4]^{2+}[Y]^{3-} \quad (IIIj),$$

where

[0052] $[A^1]^+$, $[A^2]^+$ and $[A^3]^+$ are selected independently from the groups mentioned for $[A]^+$,

[0053] $[Y]^{2-}$ to $[Y]^{4-}$ have the meanings given for $[Y]^{n-}$ in formula I, and

[0054] $[M^1]^+$, $[M^2]^+$, $[M^3]^+$ are monovalent metal cations,

[0055] $[M^4]^{2+}$ is a divalent metal cation and

[0056] $[M^{5]3+}$ is a trivalent metal cation,

or a mixture of a plurality of salts of the formulae I to IIIj being present as ionic liquid in the lubricants according to the invention.

[0057] Preferred ionic liquids have substituted or unsubstituted, preferably substituted, ammonium, phosphonium, pyridinium or imidazolium cations as cations.

[0058] The ionic liquids which are preferably used according to the invention preferably comprise at least one cation of the general formulae:

$$R^1R^2R^3R^4N^+ \quad (IV)$$

$$R^1R^2N^+{=}CR^3R^4 \quad (V)$$

$$R^1R^2R^3R^4P^+ \quad (VI)$$

$$R^1R^2P^+{=}CR^3R^4 \quad (VII)$$

$$R^1R^2R^3S^+ \quad (VIII)$$

where

[0059] R^1, R^2, R^3, R^4 are identical or different and are each hydrogen, a linear or branched aliphatic hydrocarbon radical which has from 1 to 30 carbon atoms and may contain a double bond, a cycloaliphatic hydrocarbon radical which has from 5 to 40 carbon atoms and may contain a double bond, an aromatic hydrocarbon radical having from 6 to 40 carbon atoms, an alkylaryl radical having from 7 to 40 carbon atoms, a linear or branched aliphatic hydrocarbon radical which has from 2 to 30 carbon atoms and is interrupted by one or more heteroatoms (oxygen, NH, NR' where R' is a C_1-C_{30}-alkyl radical which may contain double bonds, in particular —CH_3) and may contain double bonds, a linear or branched aliphatic hydrocarbon radical which has from 2 to 30 carbon atoms and is interrupted by one or more functions selected from the group consisting of —O—C(O)—, —(O)C—O—, —NH—C(O)—, —(O)C—NH, —(CH_3)N—C(O)—, —(O)C—N(CH_3)—, —$S(O_2)$—O—, —O—$S(O_2)$—, —$S(O_2)$—NH—, —NH—$S(O_2)$—, —$S(O_2)$—N(CH_3)—, —N(CH_3)—$S(O_2)$—, and may contain double bonds, a terminally by OH, OR', NH_2, N(H)R', $N(R')_2$,

[0060] where

[0061] R' is a C_1-C_{30}-alkyl radical which may contain double bonds, a functionalized linear or branched aliphatic or cycloaliphatic hydrocarbon radical which has from 1 to 30 carbon atoms and may contain double bonds or a polyether which may have a block or random structure and has the formula —$(R^5—O)_n—R^6$,

[0062] where

[0063] R^5 is a linear or branched hydrocarbon radical containing from 2 to 4 carbon atoms,

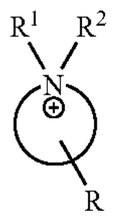
[0064] n is from 1 to 100, preferably from 2 to 60, and

[0065] R^6 is hydrogen, a linear or branched aliphatic hydrocarbon radical which has from 1 to 30 carbon atoms that may contain double bonds, a cycloaliphatic hydrocarbon radical which has from 5 to 40 carbon atoms and may contain double bonds, an aromatic hydrocarbon radical having from 6 to 40 carbon atoms, an alkylaryl radical or arylalkyl radical having from 7 to 40 carbon atoms or a —C(O)—R^7 radical where

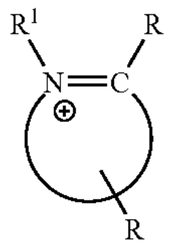
[0066] R^7 is a linear or branched aliphatic hydrocarbon radical which has from 1 to 30 carbon atoms and may contain double bonds, a cycloaliphatic hydrocarbon radical which has from 5 to 40 carbon atoms and may contain double bonds, an aromatic hydrocarbon radical having from 6 to 40 carbon atoms, an alkylaryl radical or arylalkyl radical having from 7 to 40 carbon atoms.

[0067] As cations, the ionic liquid can likewise contain cations derived from saturated or unsaturated cyclic compounds or aromatic compounds having in each case at least one trivalent nitrogen atom in a 4- to 10-membered, preferably 5- or 6-membered, heterocyclic ring which may be substituted. Such cations can be described in simplified form (i.e. without indication of precise position and number of the double bonds in the molecule) by the general formulae (IX), (X) and (XI) below, where the heterocyclic rings may also contain a plurality of heteroatoms.

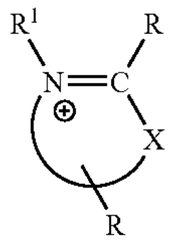
(IX)



(X)



(XI)



[0068] Here, R^1 and R^2 are as defined above,

[0069] R may be a hydrogen atom, a linear or branched aliphatic hydrocarbon radical which has from 1 to 30 carbon atoms and may contain double bonds, a cycloaliphatic hydrocarbon radical which has from 5 to 40 carbon atoms and may contain double bonds, an aromatic hydrocarbon radical having from 6 to 40 carbon atoms or an alkylaryl radical or arylalkyl radical having from 7 to 40 carbon atoms.

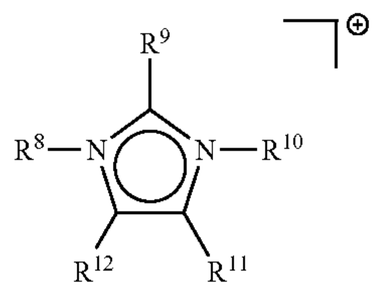
[0070] X may be an oxygen atom, a sulphur atom or a substituted nitrogen atom (X═O, S, NR^1).

[0071] Examples of cyclic nitrogen compounds of the above-mentioned type are pyrrolidine, dihydropyrrole, pyrrole, imidazoline, oxazoline, oxazole, thiazoline, thiazole, isoxazole, isothiazole, indole, carbazole, piperidine, pyridine, the isomeric picolines and lutidines, quinoline and isoquinoline. The cyclic nitrogen compounds of the general formulae (IX), (X) and (XI) can be unsubstituted (R═H) or monosubstituted or polysubstituted by the radical R, and in the case of multiple substitution by R, the individual radicals R can be different.

[0072] As cations, the ionic liquid can also contain ions derived from saturated acyclic, saturated or unsaturated cyclic compounds or from aromatic compounds having in each case more than one trivalent nitrogen atom in a 4- to 10-membered, preferably 5- or 6-membered, heterocyclic ring. These compounds can be substituted both on the carbon atoms and on the nitrogen atoms. They can also be fused with unsubstituted or substituted benzene rings and/or cyclohexane rings to form polycyclic structures. Examples of such compounds are pyrazole, 3,5-dimethylpyrazole, imidazole, benzimidazole, N-methylimidazole, dihydropyrazole, pyrazolidine, pyridazine, pyrimidine, pyrazine, 2,3-, 2,5- and 2,6-dimethylpyrazine, cinnoline, phthalazine, quinazoline, phenazine and piperazine. Cations derived from imidazole and its alkyl and phenyl derivatives have been found to be particularly useful as constituents of ionic liquids.

[0073] As cations, the ionic liquid can likewise contain cations which contain two nitrogen atoms and have the general formula (XII)

(XII)



where

[0074] R^8, R^9, R^{10}, R^{11}, R^{12} are identical or different and are each hydrogen, a linear or branched aliphatic hydrocarbon radical which has from 1 to 30 carbon atoms and may contain double bonds, a cycloaliphatic hydrocarbon radical which has from 5 to 40 carbon atoms and may contain double bonds, an aromatic hydrocarbon radical having from 6 to 40 carbon atoms, an alkylaryl radical or arylalkyl radical having from 7 to 40 carbon atoms, a linear or branched aliphatic hydrocarbon radical which has from 1 to 30 carbon atoms and is interrupted by one or more heteroatoms (oxygen, NH, NR' where R' is a C_1-C_{30}-alkyl radical which may contain double bonds) and may contain double bonds, a linear or branched aliphatic hydrocarbon radical which has from 1 to 30 carbon atoms and is interrupted by one or more functions selected from the group consisting of —O—C(O)—, —(O)C—O—, —NH—C(O)—, —(O)C—NH, —(CH_3)N—C(O)—, —(O)C—N(CH_3)—, —$S(O_2)$—O—, —O—$S(O_2)$—, —(O_2)—

NH—, —NH—S(O_2)—, —S(O_2)—N(CH_3)—, —N(CH_3)—S(O_2)—, and may contain double bonds, a linear or branched aliphatic or cycloaliphatic hydrocarbon radical which has from 1 to 30 carbon atoms and is functionalized terminally by OH, OR', NH_2, N(H)R', N(R')$_2$, where R' is a C_1-C_{30}-alkyl radical which may contain double bonds, and may contain double bonds or a polyether which may have a block or random structure and is made up of —(R^5—O)$_n$—R^6,

[0075] where

[0076] R^5 is a hydrocarbon radical containing from 2 to 4 carbon atoms,

[0077] n is from 1 to 100 and

[0078] R^6 is hydrogen, a linear or branched aliphatic hydrocarbon radical which has from 1 to 30 carbon atoms and may contain double bonds, a cycloaliphatic hydrocarbon radical which has from 5 to 40 carbon atoms and may contain double bonds, an aromatic hydrocarbon radical having from 6 to 40 carbon atoms, an alkylaryl radical having from 7 to 40 carbon atoms or a —C(O)—R^7 radical where

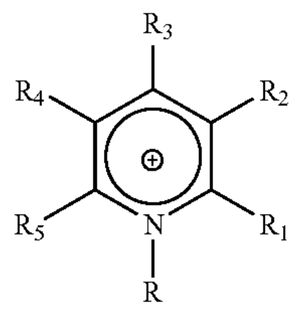
[0079] R^7 is a linear or branched aliphatic hydrocarbon radical which has from 1 to 30 carbon atoms and may contain double bonds, a cycloaliphatic hydrocarbon radical which has from 5 to 40 carbon atoms and may contain double bonds, an aromatic hydrocarbon radical having from 6 to 40 carbon atoms, an alkylaryl radical having from 7 to 40 carbon atoms.

[0080] As cations of the formula (XII), the ionic liquids particularly preferably contain imidazolium ions selected from among 1-methylimidazolium, 1-ethylimidazolium, 1-(1-butyl)imidazolium, 1-(1-octyl)imidazolium, 1-(1-dodecyl)imidazolium, 1-(1-tetradecyl)imidazolium, 1-(1-hexadecyl)imidazolium, 1,3-dimethylimidazolium, 1-ethyl-3-methylimidazolium, 1-(1-butyl)-3-methylimidazolium, 1-(1-butyl)-3-ethylimidazolium, 1-(1-hexyl)-3-methylimidazolium, 1-(1-hexyl)-3-ethylimidazolium, 1-(1-hexyl)-3-butylimidazolium, 1-(1-octyl)-3-methylimidazolium, 1-(1-octyl)-3-ethylimidazolium, 1-(1-octyl)-3-butylimidazolium, 1-(1-dodecyl)-3-methylimidazolium, 1-(1-dodecyl)-3-ethylimidazolium, 1-(1-dodecyl)-3-butylimidazolium, 1-(1-dodecyl)-3-octylimidazolium, 1-(1-tetradecyl)-3-methylimidazolium, 1-(1-tetradecyl)-3-ethylimidazolium, 1-(1-tetradecyl)-3-butylimidazolium, 1-(1-tetradecyl)-3-octylimidazolium, 1-(1-hexadecyl)-3-methylimidazolium, 1-(1-hexadecyl)-3-ethylimidazolium, 1-(1-hexadecyl)-3-butylimidazolium, 1-(1-hexadecyl)-3-octylimidazolium, 1,2-dimethylimidazolium, 1,2,3-trimethylimidazolium, 1-ethyl-2,3-dimethylimidazolium, 1-(1-butyl)-2,3-dimethylimidazolium, 1-(1-hexyl)-2,3-dimethylimidazolium, 1-(1-octyl)-2,3-dimethylimidazolium, 1,4-dimethylimidazolium, 1,3,4-trimethylimidazolium, 1,4-dimethyl-3-ethylimidazolium, 3-butylimidazolium, 1,4-dimethyl-3-octylimidazolium, 1,4,5-trimethylimidazolium, 1,3,4,5-tetramethylimidazolium, 1,4,5-trimethyl-3-ethylimidazolium, 1,4,5-trimethyl-3-butylimidazolium and 1,4,5-trimethyl-3-octylimidazolium.

[0081] As cations, the ionic liquid can likewise contain ions which, in particular, are made up of the abovementioned cations as a result of dimerization, trimerization or polymerization to form dications, trications or polycations. These include, in particular, dications, trications and polycations which have a polymeric backbone, for example one based on siloxanes, polyethers, polyesters, polyamides or polyacrylates, in particular branched and hyperbranched polymers.

[0082] In a preferred embodiment of the present invention, the lubricant contains ionic liquids in which the cation [A]+is a pyridinium ion (XIIIa)

(XIIIa)



where

[0083] R is as defined above for formula IX, one of the radicals

[0084] R_1 to R_5 is methyl, ethyl or chlorine and the remaining radicals R_1 to R_5 are hydrogen;

[0085] R_3 is dimethylamino and the remaining radicals R_1, R_2, R_4 and R_5 are hydrogen;

[0086] all radicals R_1 to R_5 are hydrogen;

[0087] R_2 is carboxy or carboxamide and the remaining radicals R_1, R_2, R_4 and R_5 are hydrogen; or

[0088] R_1 and R_2 or R_2 and R_3 are 1,4-buta-1,3-dienylene and the remaining radicals R_1, R_2, R_4 and R_5 are hydrogen. The cation $[A]^+$ is preferably a pyridinium ion (XIIIa) in which

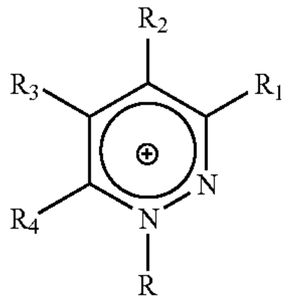
[0089] R_1 to R_5 are hydrogen; or one of the radicals

[0090] R_1 to R_5 is methyl or ethyl and the remaining radicals R_1 to R_5 are hydrogen.

[0091] The ionic liquid very particularly preferably has a pyridinium ion (XIIIa) selected from among 1-methylpyridinium, 1-ethylpyridinium, 1-(1-butyl)pyridinium, 1-(1-hexyl)pyridinium, 1-(1-octyl)pyridinium, 1-(1-hexyl)pyridinium, 1-(1-octyl)pyridinium, 1-(1-dodecyl)pyridinium, 1-(1-tetradecyl)pyridinium, 1-(1-hexadecyl)pyridinium, 1,2-dimethylpyridinium, 1-ethyl-2-methylpyridinium, 1-(1-butyl)-2-methylpyridinium, 1-(1-hexyl)-2-methylpyridinium, 1-(1-octyl)-2-methylpyridinium, 1-(1-dodecyl)-2-methylpyridinium, 1-(1-tetradecyl)-2-methylpyridinium, 1-(1-hexadecyl)-2-methylpyridinium, 1-methyl-2-ethylpyridinium, 1,2-diethylpyridinium, 1-(1-butyl)-2-ethylpyridinium, 1-(1-hexyl)-2-ethylpyridinium, 1-(1-octyl)-2-ethylpyridinium, 1-(1-dodecyl)-2-ethylpyridinium, 1-(1-tetradecyl)-2-ethylpyridinium, 1-(1-hexadecyl)-2-ethylpyridinium, 1,2-dimethyl-5-ethylpyridinium, 1,5-diethyl-2-methylpyridinium, 1-(1-butyl)-2-methyl-3-ethylpyridinium, 1-(1-hexyl)-2-methyl-3-ethylpyridinium and 1-(1-octyl)-2-methyl-3-ethylpyridinium, 1-(1-dodecyl)-2-methyl-3-ethylpyridinium, 1-(1-tetradecyl)-2-methyl-3-ethylpyridinium and 1-(1-hexadecyl)-2-methyl-3-ethylpyridinium as cation.

[0092] In a further preferred embodiment of the present invention, the lubricant contains ionic liquids in which the cation $[A]^+$ is a pyridazinium ion (XIIIb)

(XIIIb)



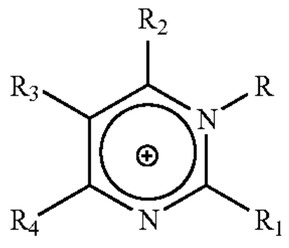
where

[0093] R is as defined above for formula IX,

[0094] R_1 to R_4 are each hydrogen, or one of the radicals R_1 to R_4 is methyl or ethyl and the remaining radicals R_1 to R_4 are hydrogen.

[0095] In a further preferred embodiment of the present invention, the lubricant contains ionic liquids in which the cation $[A]^+$ is a pyrimidinium ion (XIIIc)

(XIIIc)



where

[0096] R is as defined above for formula IX,

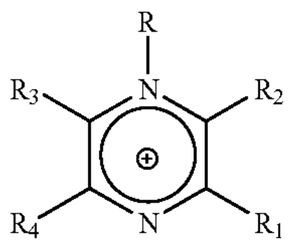
[0097] R_1 is hydrogen, methyl or ethyl and

[0098] R_2 to R_4 are each, independently of one another, hydrogen or methyl or

[0099] R_1 is hydrogen, methyl or ethyl, R_2 and R_4 are each methyl and R_3 is hydrogen.

[0100] In a further preferred embodiment of the present invention, the lubricant contains ionic liquids in which the cation $[A]^+$ is a pyrazinium ion (XIIId)

(XIIId)



where

[0101] R is as defined above for formula IX,

[0102] R_1 is hydrogen, methyl or ethyl and

[0103] R_2 to R_4 are each, independently of one another, hydrogen or methyl,

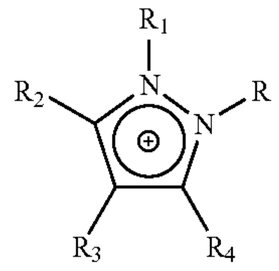
[0104] R_1 is hydrogen, methyl or ethyl, R_2 and R_4 are each methyl and R_3 is hydrogen,

[0105] R_1 to R_4 are each methyl or

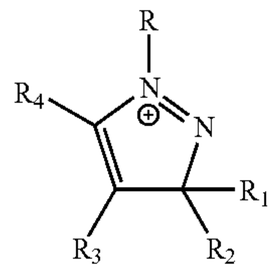
[0106] R_1 to R_4 are each methyl or hydrogen.

[0107] In a further preferred embodiment of the present invention, the lubricant contains ionic liquids in which the cation $[A]^+$ is a pyrazolium ion (XIIIf), (XIIIg) or (XIIIg')

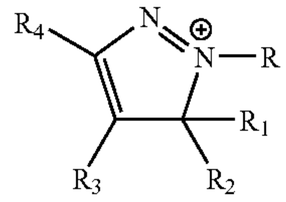
(XIIIf)



(XIIIg)



(XIIIg')



where

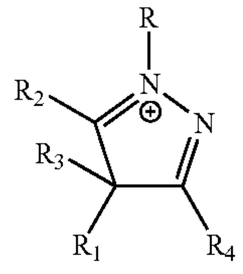
[0108] R is as defined above for formula IX,

[0109] R^1 is hydrogen, methyl or ethyl and

[0110] R_2 to R_4 are each, independently of one another, hydrogen or methyl.

[0111] In a further preferred embodiment of the present invention, the lubricant contains ionic liquids in which the cation $[A]^+$ is a pyrazolium ion (XIIIh)

(XIIIh)



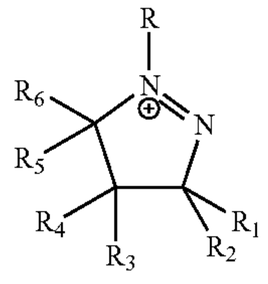
where

[0112] R is as defined above for formula IX

[0113] R_1 to R_4 are each, independently of one another, hydrogen or methyl.

[0114] In a further preferred embodiment of the present invention, the lubricant contains ionic liquids in which the cation $[A]^+$ is a 1-pyrazolinium ion (XIIIi)

(XIIIi)



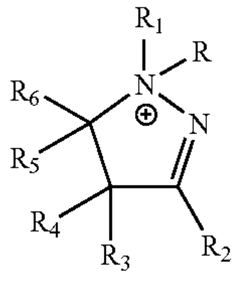
where

[0115] R is as defined above for formula IX,

[0116] R_1 to R^6 are each, independently of one another, hydrogen or methyl.

[0117] In a further preferred embodiment of the present invention, the lubricant contains ionic liquids in which the cation $[A]^+$ is a 2-pyrazolinium ion (XIIIj)

(XIIIj)



where

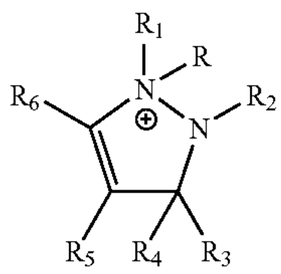
[0118] R is as defined above for formula IX,

[0119] R_1 is hydrogen, methyl, ethyl or phenyl and

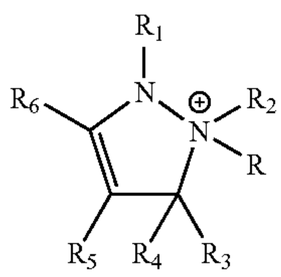
[0120] R_2 to R_6 are each, independently one another, hydrogen or methyl.

[0121] In a further preferred embodiment of the present invention, the lubricant contains ionic liquids in which the cation $[A]^+$ is a 3-pyrazolinium ion (XIIIk) or (XIIIk')

(XIIIk)



(XIIIk')



where

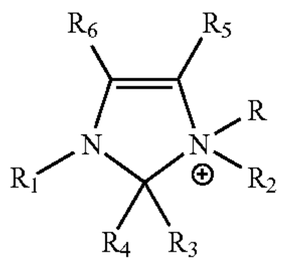
[0122] R is as defined above for formula IX,

[0123] R_1 and R_2 are each, independently of one another, hydrogen, methyl, ethyl or phenyl and

[0124] R_3 to R_6 are each, independently of one another, hydrogen or methyl.

[0125] In a further preferred embodiment of the present invention, the lubricant contains ionic liquids in which the cation $[A]^+$ is an imidazolinium ion (XIIIl)

(XIIIl)



where

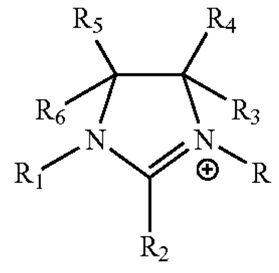
[0126] R is as defined above for formula IX,

[0127] R_1 and R_2 are each, independently of one another, hydrogen, methyl, ethyl, 1-butyl or phenyl, R_3 and R_4 are each, independently of one another, hydrogen, methyl or ethyl and

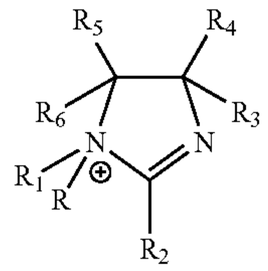
[0128] R_5 and R_6 are each, independently of one another, hydrogen or methyl.

[0129] In a further preferred embodiment of the present invention, the lubricant contains ionic liquids in which the cation $[A]^+$ is an imidazolinium ion (XIIIm) or (XIIIm')

(XIIIm)



(XIIIm')



where

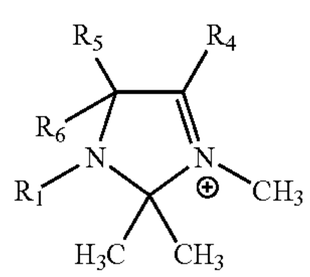
[0130] R is as defined above for formula IX,

[0131] R_1 and R_2 are each, independently of one another, hydrogen, methyl or ethyl and

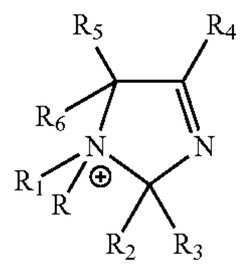
[0132] R_3 to R_6 are each, independently of one another, hydrogen or methyl.

[0133] In a further preferred embodiment of the present invention, the lubricant contains ionic liquids in which the cation $[A]^+$ is an imidazolinium ion (XIIIn) or (XIIIn')

(XIIIn)



(XIIIn')



where

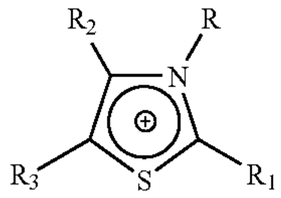
[0134] R is as defined above for formula IX,

[0135] R_1 to R_3 are each, independently of one another, hydrogen, methyl or ethyl and

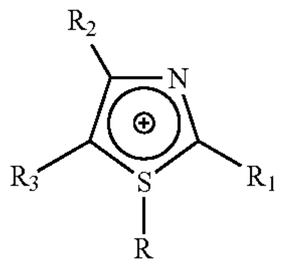
[0136] R_4 to R_6 are each, independently of one another, hydrogen or methyl.

[0137] In a further preferred embodiment of the present invention, the lubricant contains ionic liquids in which the cation $[A]^+$ is a thiazolium ion (XIIIo) or (XIIIo') or an oxazolium ion (XIIIp)

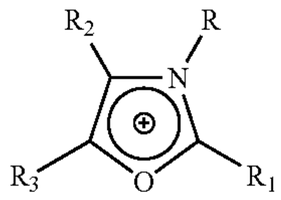
(XIIIo)



(XIIIo′)



(XIIIp)



where

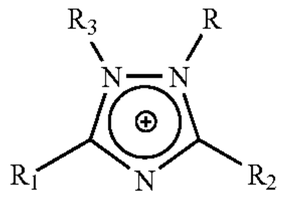
[0138] R is as defined above for formula IX,

[0139] R_1 is hydrogen, methyl, ethyl or phenyl and

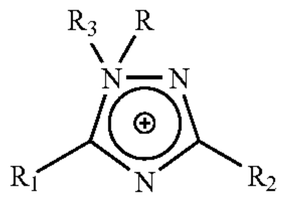
[0140] R_2 and R_3 are each independently of one another, hydrogen or methyl.

[0141] In a further preferred embodiment of the present invention, the lubricant contains ionic liquids in which the cation $[A]^+$ is a 1,2,4-triazolium ion (XIIIq), (XIIIq') or (XIIIq")

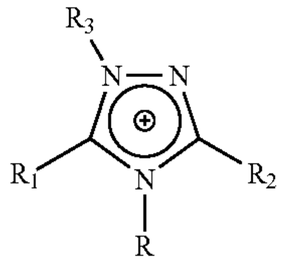
(XIIIq)



(XIIIq′)



(XIIIq″)



where

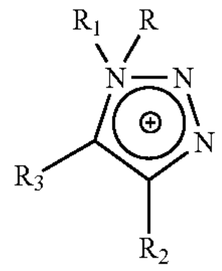
[0142] R is as defined above for formula IX,

[0143] R_1 and R_2 are each, independently of one another, hydrogen, methyl, ethyl or phenyl and

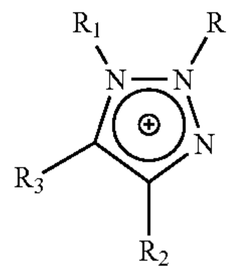
[0144] R_3 is hydrogen, methyl or phenyl.

[0145] In a further preferred embodiment of the present invention, the lubricant contains ionic liquids in which the cation $[A]^+$ is a 1,2,3-triazolium ion (XIIIr), (XIIIr') or (XIIIr")

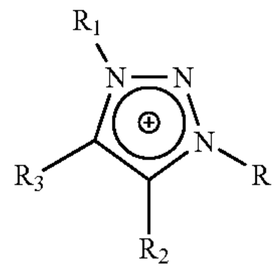
(XIIIr)



(XIIIr′)



(XIIIr″)



where

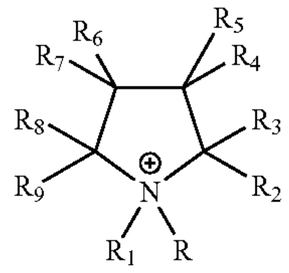
[0146] R is as defined above for formula IX,

[0147] R_1 is hydrogen, methyl or ethyl and

[0148] R_2 and R_3 are each, independently of one another, hydrogen or methyl or R_2 and R_3 together are 1,4-butyl-1, 3-dienylene.

[0149] In a further preferred embodiment of the present invention, the lubricant contains ionic liquids in which the cation $[A]^+$ is a pyrrolidinium ion (XIIIs)

(XIIIs)



where

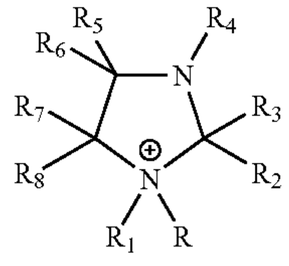
[0150] R is as defined above for formula IX,

[0151] R_1 is hydrogen, methyl, ethyl or phenyl and

[0152] R_2 to R_9 are each, independently of one another, hydrogen or methyl.

[0153] In a further preferred embodiment of the present invention, the lubricant contains ionic liquids in which the cation $[A]^+$ is an imidazolidinium ion (XIIIt)

(XIIIt)



where

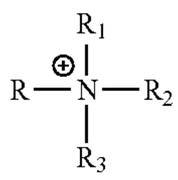
[0154] R is as defined above for formula IX,

[0155] R_1 and R_4 are each, independently of one another, hydrogen, methyl, ethyl or phenyl and

[0156] R_2 and R_3 and also R_5 to R_8 are each, independently of one another, hydrogen or methyl.

[0157] In a further preferred embodiment of the present invention, the lubricant contains ionic liquids in which the cation $[A]^+$ is an ammonium ion (IV)

(IV)



where

[0158] R is as defined above for formula IX,

[0159] R_1 to R_3 are each, independently of one another, C_1-C_{18}-alkyl or

[0160] R_1 to R_3 are each, independently of one another, hydrogen or C_1-C_{18}-alkyl and

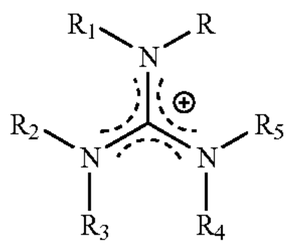
[0161] R_4 is 2-hydroxyethyl, or

[0162] R_1 and R_2 together are 1,5-pentylene or 3-oxa-1,5-pentylene and

[0163] R_3 is C_1-C_{18}-alkyl, 2-hydroxyethyl or 2-cyanoethyl. As particularly preferred ammonium ions (IV), mention may be made, in particular, of methyltri(1-butyl)ammonium, 2-hydroxyethylammonium, bis(2-hydroxyethyl) dimethylammonium, N,N-dimethylpiperidinium and N,N-dimethylmorpholinium.

[0164] In a further preferred embodiment of the present invention, the lubricant contains ionic liquids in which the cation $[A]^+$ is a guanidinium ion (IVv),

(IVv)



where

[0165] R is as defined above for formula IX,

[0166] R_1 to R_5 are each methyl,

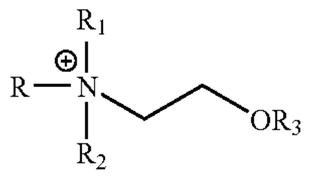
[0167] R_1 to R_5 are each, independently of one another, C_1-C_{18}-alkyl or

[0168] R_1 to R_5 are each, independently of one another, hydrogen or C_1-C_{18}-alkyl or 2-hydroxyethyl.

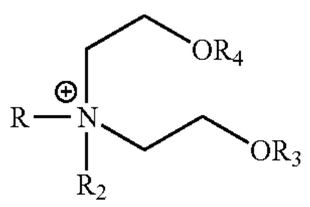
[0169] A very particularly preferred guanidinium ion (IVv) is N,N,N',N',N'',N''-hexamethylguanidinium.

[0170] In a further preferred embodiment of the present invention, the lubricant contains ionic liquids in which the cation $[A]^+$ is a derivative of an ethanolamine, e.g. a cholinium ion (XIIIw) or of a diethanolamine (XIIIw') or of a triethanolamine (XIIIw")

(XIIIw)



(XIIIw')



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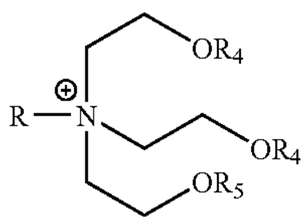
(XIIIw")



where

[0171] R is as defined above for formula IX,

[0172] R_1 and R_2 are each, independently of one another, methyl, ethyl, 1-butyl or 1-octyl and

[0173] R_3 is hydrogen, methyl, ethyl, acetyl, —SO_2OH or —$PO(OH)_2$, or

[0174] R_1 is methyl, ethyl, 1-butyl or 1-octyl, R_2 is a —CH_2—CH_2—OR_4 group and

[0175] R_3 and R_4 are each, independently of one another, hydrogen, methyl, ethyl, acetyl, —SO_2OH or —$PO(OH)_2$, or

[0176] R_1 is a —CH_2—CH_2—OR_4 group,

[0177] R_2 is a —CH_2—CH_2—OR_5 group and

[0178] R_3 to R_5 are each, independently of one another, hydrogen, methyl, ethyl, acetyl, —SO_2OH or —$PO(OH)_2$, or

[0179] R_1 is methyl, ethyl, 1-butyl, 1-octyl, acetyl, —SO_2OH, or —$PO(OH)_2$ and

[0180] R_3 to R_5 are each, independently of one another, hydrogen, methyl, ethyl, acetyl, —SO_2OH, —$PO(OH)_2$, or —$(C_nH_{2n}O)_mR_1$ where n=1 to 5 and m=1 to 100.

[0181] In a further preferred embodiment of the present invention, the lubricant contains ionic liquids in which the cation $[A]^+$ is a phosphonium ion (VI) in which R_1 to R_3 are each, independently of one another, C_1-C_{18}-alkyl, in particular butyl, isobutyl, 1-hexyl or 1-octyl.

[0182] Among the abovementioned cations, the pyridinium ions (XIIIa), imidazolium ions (XII) and ammonium ions (IV) are particularly preferred as cations. The lubricants according to the invention very particularly preferably contain ionic liquids which have one or more cations selected from among 1-methylpyridinium, 1-ethylpyridinium, 1-(1-butyl)pyridinium, 1-(1-hexyl)pyridinium, 1-(1-octyl)pyridinium, 1-(1-hexyl)pyridinium, 1-(1-octyl)pyridinium, 1-(1-dodecyl)pyridinium, 1-(1-tetradecyl)pyridinium, 1-(1-hexadecyl)pyridinium, 1,2-dimethylpyridinium, 1-ethyl-2-methylpyridinium, 1-(1-butyl)-2-methylpyridinium, 1-(1-hexyl)-2-methylpyridinium, 1-(1-octyl)-2-methylpyridinium, 1-(1-dodecyl)-2-methylpyridinium, 1-(1-tetradecyl)-2-methylpyridinium, 1-(1-hexadecyl)-2-methylpyridinium, 1-methyl-2-ethylpyridinium, 1,2-diethylpyridinium, 1-(1-butyl)-2-ethylpyridinium, 1-(1-hexyl)-2-ethylpyridinium, 1-(1-octyl)-2-ethylpyridinium, 1-(1-dodecyl)-2-ethylpyridinium, 1-(1-tetradecyl)-2-ethylpyridinium, 1-(1-hexadecyl)-2-ethylpyridinium, 1,2-dimethyl-5-ethylpyridinium, 1,5-diethyl-2-methylpyridinium, 1-(1-butyl)-2-methyl-3-ethylpyridinium, 1-(1-hexyl)-2-methyl-3-ethylpyridinium, 1-(1-octyl)-2-methyl-3-ethylpyridinium, 1-(1-dodecyl)-2-methyl-3-ethylpyridinium, 1-(1-tetradecyl)-2-methyl-3-ethylpyridinium, 1-(1-hexadecyl)-2-methyl-3-ethylpyridinium, 1-methylimidazolium, 1-ethylimidazolium, 1-(1-butyl)imidazolium, 1-(1-octyl) imidazolium, 1-(1-dodecyl)imidazolium, 1-(1-tetradecyl) imidazolium, 1-(1-hexadecyl)imidazolium, 1,3-dimethylimidazolium, 1-ethyl-3-methylimidazolium, 1-(1-butyl)-3-

methylimidazolium, 1-(1-hexyl)-3-methylimidazolium, 1-(1-octyl)-3-methylimidazolium, 1-(1-dodecyl)-3-methylimidazolium, 1-(1-tetradecyl)-3-methylimidazolium, 1-(1-hexadecyl)-3-methylimidazolium, 1,2-dimethylimidazolium, 1,2,3-trimethylimidazolium, 1-ethyl-2,3-dimethylimidazolium, 1-(1-butyl)-2,3-dimethylimidazolium, 1-(1-hexyl)-2,3-dimethylimidazolium, and 1-(1-octyl)-2,3-dimethylimidazolium, 1,4-dimethylimidazolium, 1,3,4-trimethylimidazolium, 1,4-dimethyl-3-ethylimidazolium, 3-butylimidazolium, 1,4-dimethyl-3-octylimidazolium, 1,4,5-trimethylimidazolium, 1,3,4,5-tetramethylimidazolium, 1,4,5-trimethyl-3-ethylimidazolium, 1,4,5-trimethyl-3-butylimidazolium, 1,4,5-trimethyl-3-octylimidazolium and 2-hydroxyethylammonium as cations.

[0183] The metal cations $[M^1]^+$, $[M^2]^+$, $[M^3]^+$, $[M^4]^{2+}$ and $[M^5]^{3+}$ mentioned in the formulae (IIIa) to (IIIj) are preferably metal cations of Groups 1, 2, 6, 7, 8, 9, 10, 11, 12 and 13 of the Periodic Table. Particularly preferred metal cations are, for example, Li^+, Na^+, K^+, Cs^+, Mg^{2+}, Ca^{2+}, Ba^{2+}, Cr^{3+}, Fe^{2+}, Fe^{3+}, Co^{2+}, Ni^{2+}, Cu^{2+}, Ag^+, Zn^{2+} and Al^{3+}.

[0184] The ionic liquids which are preferably used according to the invention comprise at least one of the abovementioned cations in combination with at least one anion in each case. As anions, it is in principle possible to use all anions which in combination with the cation lead to an ionic liquid.

[0185] The anion $[Y]^{n-}$ of the ionic liquid can, for example, be selected from:

the group of halides and halogen-containing compounds of the formulae: F^-, Cl^-, Br^-, I^-, BF_4^-, PF_6^-, $AlCl_4^-$, $Al_2Cl_7^-$, $Al_3Cl_{10}^-$, $AlBr_4^-$, $FeCl_4^-$, BCl_4^-, SbF_6^-, AsF_6^-, $ZnCl_3^-$, $SnCl_3^-$, $CuCl_2^-$, $CF_3SO_3^-$, $(CF_3SO_3)_2N^-$, $CF_3CO_2^-$, $CCl_3CO_2^-$, CN^-, SCN^-, OCN^-, NO_2^-, NO_3^-, $N(CN)^-$;

the group of sulphates, sulphites and sulphonates of the general formulae: SO_4^{2-}, HSO_4^-, S_3^{2-}, HSO_3^-, $R^aOSO_3^-$, $R^aSO_3^-$; the group of phosphates of the general formulae: PO_4^{3-}, HPO_4^{2-}, $H_2PO_4^-$, $R^aPO_4^{2-}$, $HR^aPO_4^-$, $R^aR^bPO_4^-$;

the group of the phosphonates and phosphinates of the general formulae: $R^aHPO_3^-$, $R^aR^bPO_2^-$, $R^aR^bPO_3^-$;

the group of phosphites of the general formulae: PO_3^{3-}, HPO_3^-, $H_2PO_3^-$, $R^aPO_3^{2-}$, $R^aHPO_3^-$, $R^aR^bPO_3^-$;

the group of phosphonites and phosphinites of the general formulae: $R^aR^bPO_2^-$, $R^aHPO_2^-$, $R^aR^bPO^-$, R^aHPO^-;

the group of carboxylates of the general formula: R^aCOO^-;

the group of borates of the general formulae: BO_3^{3-}, HBO_3^{2-}, $H_2BO_3^-$, $R^aR^bBO_3^-$, $R^aHBO_3^-$, $R^aBO_3^{2-}$, $B(OR^a)(OR^b)(OR^c)(OR^d)^-$, $B(HSO_4)^-$, $B(R^aSO_4)^-$;

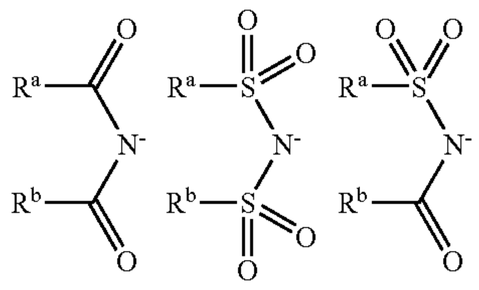
the group of boronates of the general formulae $R^aBO_2^{2-}$, $R^aR^bBO^-$;

the group of carbonates and carbonic esters of the general formulae: HCO_3^-, CO_3^{2-}, $R^aCO_3^-$;

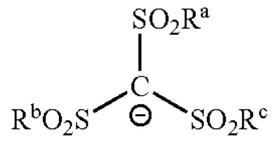
the group of silicates and silicic esters of the general formulae: SiO_4^{4-}, $HSiO_4^{3-}$, $H_2SiO_4^{2-}$, $H_3SiO_4^-$, $R^aSiO_4^{3-}$, $R^aR^bSiO_4^{2-}$, $R^aR^bR^cSiO_4^-$, $HR^aSiO_4^{2-}$, $H_2R^aSiO_4^-$, $HR^aR^bSiO_4^-$;

the group of alkylsilane or arylsilane salts of the general formulae: $R^aSiO_3^{3-}$, $R^aR^bSiO_2^{2-}$, $R^aR^bR^cSiO^-$, $R^aR^bR^cSiO_3^-$, $R^aR^bR^cSiO_2^-$, $R^aR^bSiO_3^{2-}$;

the group of carboximides, bis(sulphonyl)imides and sulphonylimides of the general formulae:



the group of methides of the general formula:



the group of alkoxides and aryloxides of the general formula: R^aO^-;

the group of the halometalates of the general formula $[M_rHal_t]^{s-}$, where M is a metal and Hal is fluorine, chlorine, bromine or iodine, r and t are positive integers and indicate the stoichiometry of the complex and s is a positive integer and indicates the charge on the complex;

the group of sulphides, hydrogensulphides, polysulphides, hydrogenpolysulphides and thiolates of the general formulae: S^{2-}, HS^-, $[S_v]^{2-}$, $[HS_v]^-$, $[R^aS]^-$, where v is a positive integer from 2 to 10;

the group of complex metal ions such as $Fe(CN)_6^{3-}$, $Fe(CN)_6^{4-}$, MnO_4^-, $Fe(CO)_4^-$,

where R^a, R^b, R^c and R^d can each be, independently of one another:

hydrogen;

C_1-C_{30}-alkyl or an aryl-, heteroaryl-, cycloalkyl-, halogen-, hydroxy-, amino-, carboxy-, formyl-, —O—, —CO—, —CO—C— or —CO—N-substituted derivative thereof, for example methyl, ethyl, 1-propyl, 2-propyl, 1-butyl, 2-butyl, 2-methyl-1-propyl (isobutyl), 2-methyl-2-propyl (tert-butyl), 1-pentyl, 2-pentyl, 3-pentyl, 2-methyl-1-butyl, 3-methyl-1-butyl, 2-methyl-2-butyl, 3-methyl-2-butyl, 2,2-dimethyl-1-propyl, 1-hexyl, 2-hexyl, 3-hexyl, 2-methyl-1-pentyl, 3-methyl-1-pentyl, 4-methyl-1-pentyl, 2-methyl-2-pentyl, 3-methyl-2-pentyl, 4-methyl-2-pentyl, 2-methyl-3-pentyl, 3-methyl-3-pentyl, 2,2-dimethyl-1-butyl, 2,3-dimethyl-1-butyl, 3,3-dimethyl-1-butyl, 2-ethyl-1-butyl, 2,3-dimethyl-2-butyl, 3,3,-dimethyl-2-butyl, heptyl, octyl, nonyl, decyl, undecyl, dodecyl, tridecyl, tetradecyl, pentadecyl, hexadecyl, heptadecyl, octadecyl, nonadecyl, icosyl, henicosyl, docosyl, tricosyl, tetracosyl, pentacosyl, hexacosyl, heptacosyl, octacosyl, nonacosyl, triacontyl, phenylmethyl (benzyl), diphenylmethyl, triphenylmethyl, 2-phenylethyl, 3-phenylpropyl, cyclopentylmethyl, 2-cyclopentylethyl, 3-cyclopentylpropyl, cyclohexylmethyl, 2-cyclohexylethyl, 3-cyclohexylpropyl, methoxy, ethoxy, formyl, acetyl or $C_qF_{2(q-a)+(1-b)}H_{2a+b}$ where $q<30$, $0 \leqq a \leqq q$ and $b=0$ or 1 (for example CF_3, C_2F_5, CH_2CH_2—$C_{(q-2)}F_{2(q-2)+1}$, C_6F_{13}, C_8F_{17}, $C_{10}F_{21}$, $C_{12}F_{25}$);

C_3-C_{12}-cycloalkyl or an aryl-, heteroaryl-, cycloalkyl-, halogen-, hydroxy-, amino-, carboxy-, formyl-, —O—, —CO— or —CO—O-substituted derivative thereof, for example cyclopentyl, 2-methyl-1-cyclopentyl, 3-methyl-1-cyclopentyl, cyclohexyl, 2-methyl-1-cyclohexyl, 3-methyl-1-cyclohexyl, 4-methyl-1-cyclohexyl or $C_qF_{2(q-a)-(1-b)}H_{2a-b}$ where $q \leqq 30$, $0 \leqq a \leqq q$ and $b=0$ or 1;

C_2-C_{30}-alkenyl or an aryl-, heteroaryl-, cycloalkyl-, halogen-, hydroxy-, amino-, carboxy-, formyl-, —O—, —CO— or —CO—O-substituted derivative thereof, for example 2-propenyl, 3-butenyl, cis-2-butenyl, trans-2-butenyl or $C_qF_{2(q-a)-(1-b)}H_{2a-b}$ where $q \leqq 30$, $0 \leqq a \leqq q$ and $b=0$ or 1;

C_3-C_{12}-cycloalkenyl or an aryl-, heteroaryl-, cycloalkyl-, halogen-, hydroxy-, amino-, carboxy-, formyl-, —O—, —CO— or —CO—O-substituted derivative thereof, for example 3-cyclopentenyl, 3-cyclohexenyl, 3-cyclohexenyl, 2,5-cyclohexadienyl or $C_qF_{2(q-a)-3(1-b)}H_{2a-3b}$ where $q \leqq 30$, $0 \leqq a \leqq q$ and $b=0$ or 1;

aryl or heteroaryl having from 2 to 30 carbon atoms or an alkyl-, aryl-, heteroaryl-, cycloalkyl-, halogen-, hydroxy-, amino-, carboxy-, formyl-, —O—, —CO— or —CO—O-substituted derivative thereof, for example phenyl, 2-methylphenyl (2-tolyl), 3-methylphenyl (3-tolyl), 4-methylphenyl, 2-ethylphenyl, 3-ethylphenyl, 4-ethylphenyl, 2,3-dimethylphenyl, 2,4-dimethylphenyl, 2,5-dimethylphenyl, 2,6-dimethylphenyl, 3,4-dimethylphenyl, 3,5-dimethylphenyl, 4-phenylphenyl, 1-naphthyl, 2-naphthyl, 1-pyrrolyl, 2-pyrrolyl, 3-pyrrolyl, 2-pyridinyl, 3-pyridinyl, 4-pyridinyl or $C_6F_{(5-a)}H_a$ where $0 \leqq a \leqq 5$; or

two radicals form an unsaturated, saturated or aromatic ring which may be substituted by functional groups, aryl, alkyl, aryloxy, alkyloxy, halogen, heteroatoms and/or heterocycles and may be interrupted by one or more oxygen and/or sulphur atoms and/or one or more substituted or unsubstituted imino groups.

[0186] The ionic liquids used according to the invention preferably have anions selected from among halides, carboxylates, phosphates, thiocyanates, isothiocyanates, dicyanamides, sulphates, alkylsulphates, sulphonates, alkylsulphonates, tetrafluoroborate, hexafluorophosphate and bis(trifluoromethylsulphonyl)imide.

[0187] Preferred anions are chloride, bromide, iodide, thiocyanate, hexafluorophosphate, trifluoromethanesulphonate, methanesulphonate, formate, acetate, glycolate, lactate, mandelate, nitrate, nitrite, trifluoroacetate, sulphate, hydrogensulphate, methyl sulphate, ethyl sulphate, 1-propyl sulphate, 1-butyl sulphate, 1-hexyl sulphate, 1-octyl sulphate, phosphate, dihydrogenphosphate, hydrogenphosphate, C_1-C_4-dialkylphosphates, propionate, tetrachloroaluminate, $Al_2Cl_7^-$, chlorozincate, chloroferrate, bis(trifluoromethylsulphonyl)imide, bis(pentafluoroethylsulphonyl)imide, bis(methylsulphonyl)imide, bis(p-toluenesulphonyl)imide, tris(trifluoromethylsulphonyl)methide, bis(pentafluoroethylsulphonyl)methide, p-toluenesulphonate, tetracarbonylcobaltate, dimethylene glycol monomethyl ether sulphate, oleate, stearate, acrylate, methacrylate, maleate, hydrogencitrate, vinylphosphonate, bis(pentafluoroethyl)phosphinate, borates such as bis-[salicylato(2-)]borate, bis[oxalato(2-)]borate, bis[1,2-benzoldiolato(2-)-O,O']borate, tetracyanoborate, tetrafluoroborate, dicyanamide, tris(pentafluoroethyl)trifluorophosphate, tris(heptafluoropropyl)trifluorophosphate, cyclic arylphosphates such as catecholphosphate $(C_6H_4O_2)P(O)O^-$ or chlorocobaltate.

[0188] Particularly preferred anions are anions from the group consisting of halides, bis(perfluoroalkylsulphonyl)amides and bis(perfluoroalkylsulphonyl)imides such as bis(trifluoromethylylsulphonyl)imide, alkyltosylates and aryltosylates, perfluoroalkyltosylates, nitrate, sulphate, hydrogensulphate, alkylsulphates and arylsulphates, polyether sulphates and sulphonates, perfluoroalkylsulphates, sulphonate, alkylsulphonates and arylsulphonates, perfluorinated alkylsulphonates and arylsulphonates, alkylcarboxylates and arylcarboxylates, perfluoroalkylcarboxylates, perchlorate, tetrachloroaluminate, saccharinate, dicyanamide, thiocyanate, isothiocyanate, tetraphenylborate, tetrakis(pentafluorophenyl)borate, tetrafluoroborate, hexafluorophosphate, polyether phosphates, dialkylphosphates and phosphates.

[0189] Very particularly preferred anions are chloride, bromide, hydrogensulphate, tetrachloroaluminate, thiocyanate, methylsulphate, ethylsulphate, methanesulphonate, formate, acetate, glycolate, lactate, dimethylphosphate, diethylphosphate, p-toluenesulphonate, tetrafluoroborate and hexafluorophosphate.

[0190] The lubricant very particularly preferably contains ionic liquids or mixtures thereof which contain a combination of a 1,3-dialkylimidazolium, 1,2,3-trialkylimidazolium, 1,3-dialkylimidazolinium or 1,2,3-trialkylimidazolinium cation with an anion selected from the group consisting of halides, bis(trifluoromethylylsulphonyl)imide, perfluoroalkyltosylates, alkylsulphates and alkylsulphonates, perfluorinated alkylsulphonates and alkylsulphates, perfluoroalkylcarboxylates, perchlorate, dicyanamide, thiocyanate, isothiocyanate, tetraphenylborate, tetrakis(pentafluorophenyl)borate, tetrafluoroborate, hexafluorophosphate, dimethylphosphate and diethylphosphate.

[0191] It is also possible to use commercially available, acyclic quaternary ammonium salts such as TEGO® IL T16ES [quaternary fatty amine ethoxylate], TEGO® IL K5MS [coconut alkylpentaethoxymethylammonium ethosulphate], TEGO® IL DS [distearyldimethylammonium chloride] or TEGO® IL 2MS [dimethyldiethanolammonium methylsulphonate] (all products of Evonik Goldschmidt GmbH) and also cyclic quaternary nitrogen compounds selected from the groups of imidazolium salts, pyridinium salts, pyrrolidinium salts, etc., e.g. TEGO® IL IM ES [1-ethyl-3-methylimidazolium ethylsulphate] (product of Evonik Goldschmidt GmbH) as ionic liquids in the lubricant according to the invention.

[0192] Owing to the fact that some ionic liquids can be selected according to their property profile so that they are stable at high temperatures, noncombustible, corrosion-inhibiting and in terms of viscosity, density, oxidation stability, materials compatibility, wear protection, suitability for use at low temperatures, V-T behaviour, miscibility and hydrolysis resistance can be matched precisely to the respective specifications, these ionic liquids can be used particularly advantageously as lubricants in wind power plants, in particular in their gearboxes.

[0193] It can be advantageous to use ionic liquids which are biodegradable and/or nontoxic, e.g. imidazolium salts and pyridinium salts, in particular 1-butyl-3-methylimidazolium tetrafluoroborate, 1-ethyl-3-methylimidazolium ethylsulphate. Apart from the abovementioned advantages, it is precisely these two additional properties which are important criteria in the selection of lubricants for wide use in the industrial environment, in particular use of the lubricants in wind power plants which are operated in ecologically sensitive places, e.g. in drinking water catchment areas, bodies of water (e.g. offshore plants) and permafrost regions. The lubricant used according to the invention preferably contains ionic liquids which either on their own or when mixed with others have a melting point of <100° C., preferably <80° C., particularly preferably <50° C. and very particularly preferably <room temperature.

[0194] The lubricant used according to the invention more preferably contains ionic liquids which either on their own or when mixed with others are liquid at a temperature of from −85° C. to 400° C., preferably from −70° C. to 250° C., particularly preferably from −60° C. to 150° C. and very particularly preferably from −55° C. to 100° C.

[0195] Ionic liquids which are liquid at low temperatures are, for example, imidazolium salts or pyridinium sulphates, in particular 1-ethyl-3-methylimidazolium ethylsulphate, 1-methyl-3-octylimidazolium tetrafluoroborate or 1-ethyl-3-methylpyridinium ethylsulphate.

[0196] The lubricant used according to the invention preferably contains ionic liquids which either on their own or when mixed with others have a decomposition temperature of >150° C., preferably >250° C., more preferably 200° C. and particularly preferably >300° C.

[0197] The choice of the ionic liquid or the mixture of ionic liquids depends on the property profile of the machinery selected and the respective climatic and environmental conditions (locations).

[0198] The present invention is illustrated by FIGS. **1** to **3**, without the invention being restricted to the embodiment presented there.

[0199] FIG. **1** shows the typical curve of the coefficient of friction as a function of the rubbing speed, divided into the regions of solids contact, boundary friction, mixed friction and hydrodynamic friction. This depiction is referred to as the Stribeck curve.

[0200] An ideal lubricant should display a very low level of friction in all the regions mentioned, in particular in the region of boundary friction. The Stribeck curve ideally runs parallel to the x axis.

[0201] FIG. **2** shows the results of the comparative experiments of the example comparing a commercially available completely additivated poly-alpha-olefin, a commercially available completely additivated mineral oil of group 3 (Castrol SLX 0W-30 from Castrol), TEGO® IL IMES, TEGO® IL IMES containing an EP additive from Evonik Goldschmidt GmbH (lubricant 4) and TEGO® IL IMES containing a commercially available EP additive (lubricant 5). The measured values for lubricant 1 (PAO) are shown as dots, those for lubricant 2 (mineral oil) as diamonds, those for lubricant 3 (ionic liquid 1-ethyl-3-methylimidazolium ethylsulphate) as squares, those for lubricant 4 as crosses and those for lubricant 5 as plus signs.

[0202] In the examples described below, the present invention is described by way of example without the invention, whose scope is determined by the total description and the claims, being restricted to the embodiments mentioned in the examples.

EXAMPLES

[0203] The choice of ionic liquids generally depends on the expected lubrication requirements, the load uptake (load uptake capability) and the temperature prevailing in the lubrication region. To reduce the energy consumption in apparatuses/machines/gearboxes and thus increase the efficiency, it is useful to work at low viscosities which nevertheless do not run the risk of increasing the mixed friction. If there is a risk of solids contact friction, for instance at high loads and/or low speeds of the moving surfaces, it may be necessary to achieve boundary lubrication by means of friction-reducing additives (EP additives). Apart from a high viscosity index (VI), which describes the stability of the viscosity at relatively high temperatures, it is therefore also necessary to ensure boundary lubrication. A high VI is a guarantee that a constant lubricating action is achieved with increasing speed of the moving surfaces and an associated temperature increase. This region of lubrication is referred to as hydrodynamic lubrication. The film which is then formed between the surfaces to be lubricated displays the lowest friction which is then dependent essentially only on the viscosity of the liquids.

[0204] The viscosity index is a dimensionless parameter and is used to characterize the viscosity-temperature behaviour (VT) of a liquid (mainly lubricating oils). A high viscosity index means good VT behaviour, i.e. the viscosity changes only slightly with temperature. Good oils should have a VI of >150. This can be set by means of additives. In general, a very high VI at a relatively low viscosity of the oil is sought. The lower the viscosity of the oil, the lower the energy consumption, since the oil has a lower frictional resistance. A good mineral oil of group 3 has a VI of about 130, so that it has to be increased by means of additives.

[0205] The following lubricants were examined in the examples: lubricant 1: poly-alpha-olefin (PAO 8), lubricant 2: a commercially available completely additivated mineral oil having a KV 40 of 31 cSt (Castrol SLX 0W-30 from Castrol), lubricant 3: TEGO® IL IMES [ionic liquid from Evonik Goldschmidt GmbH having a KV 40 (kinematic viscosity at 40° C.) of 39 cSt], lubricant 4: TEGO® IL IMES containing 0.3% by mass of REWOCOROS® EAK 8190 (Evonik Goldschmidt GmbH), lubricant 5: TEGO® IL IMES containing 0.3% by mass of the commercially available EP additive tricresyl phosphate.

Example 1

Determination of the Viscosity Index (VI)

[0206] The viscosity indices shown in Table 1 were calculated in accordance with DIN ISO 2909 from the kinematic viscosities at 40° C. and 100° C.

TABLE 1

Viscosity indices (in accordance with DIN ISO 2909)

Lubricant	Viscosity index
Lubricant 1	ca. 170
Lubricant 2	ca. 160
Lubricant 3	ca. 172
Lubricant 4	ca. 172
Lubricant 5	ca. 172

Example 2

Determination of the Frictional Force as a Function of the Frictional Speed

[0207] The dependence of the frictional force (the coefficient of friction) on the frictional speed was measured using a "mini traction machine" (MTM2 from PCS Instruments) at 80° C. and 30 N. FIG. **1** shows an idealized Stribeck curve. In FIG. **2**, the measurement points obtained in the studies on the various lubricant compositions are shown in the form of a Stribeck curve.

[0208] The Stribeck curves at 80° C. show that the mixed friction part, i.e. increasing coefficient of friction, commences at speeds of <250 mm/s in the case of lubricants 1 and 2 and lubricants 3 to 5. The coefficients of friction of the

lubricants 3 to 5 are significantly below those of the conventional lubricants 1 and 2. Only in the boundary region at speeds of <20 mm/s does the coefficient of friction of the ionic liquid without additives (lubricant 3) rise above that of the commercial lubricants 1 and 2. Addition of cresyl phosphate as EP additive (lubricant 5) or REWOCOROS® EAK 8190 (lubricant 4) enables the boundary friction to be reduced below the values for the commercial lubricants.

[0209] Over virtually the entire speed range, the lubricants containing ionic liquids (lubricants 3 to 5) display a significantly lower coefficient of friction than commercially available lubricants. When additives are added to the ionic liquids, the ionic liquids display significantly lower coefficients of friction than commercially available lubricants over the entire speed range.

Example 3

Determination of the Traction Curves

[0210] Traction curves can also be measured by means of the MTM2. Here, the slide-to-roll ratio varies continuously at a constant temperature and constant pressure. The slide-to-roll ratio is the ratio of the sliding speed to the rolling speed. At a slide-to-roll ratio of 0, the plate and the ball move at the same surface speed (pure rolling). At a slide-to-roll ratio of 2, one of the two surfaces remains still (pure sliding). Since various proportions of sliding can occur in the case of different components, the traction curve makes it possible to show the lubricant behaviour under these different conditions. Conditions with a high proportion of sliding at the toothed wheel contacts prevail in gearboxes in particular. The measurements show that ionic liquids display significantly lower coefficients of friction than mineral oils, fully additivated mineral oils and poly-alpha-olefins (PAOs) at comparable viscosities over the entire range of slide-to-roll ratios (SRRs). The results for Tego IL IMES (ionic liquid from Evonik Goldschmidt GmbH), Castrol SLX 0W-30 (fully additivated mineral oil from Castrol), PAO 8 (poly-alpha-olefin) and a nonadditivated mineral oil (CAS No. 8042-47-5) are shown in FIG. **3**.

1. A method of lubricating components of a wind power plant, comprising applying a lubricant between surfaces of the components, wherein the lubricant comprises at least one ionic liquid.

2. The method according to claim **1**, wherein the component of the wind power plant is a main or tracking gearbox for gearing up the rotational speed of the rotor to the rotational speed of the generator.

3. The method according to claim **1**, wherein the component of the wind power plant is an azimuthal gearbox for tracking the wind direction.

4. The method according to claim **1**, wherein the component of the wind power plant is a pitch gearbox for adjusting the rotor blades.

5. The method according to claim **1**, wherein the component of the wind power plant is a generator bearing for mounting the generator shaft.

6. The method according to claim **1**, wherein the component of the wind power plant is a pitch bearing for mounting the rotor blades.

7. The method according to claim **1**, wherein the component of the wind power plant is a main bearing for mounting the rotor.

8. The method according to claim **1**, wherein the component of the wind power plant is an azimuthal bearing for providing the rotatable connection between tower and pod of the wind power plant.

9. The method according to claim **1**, wherein the lubricant contains EP additives.

10. The method according to claim **1**, wherein the lubricant contains corrosion inhibitors.

11. The method according to claim **1**, wherein the lubricant contains one or more further lubricating materials in addition to at least one ionic liquid.

12. The method according to claim **1**, wherein the proportion of ionic liquids in the lubricant is from 0.1 to 99.98% by weight, based on the lubricant.

13. The method according to claim **1**, wherein the lubricant comprises exclusively one or more ionic liquid(s) as lubricating material.

14. The method according to claim **1**, wherein the ionic liquid used has a melting point of <50° C.

15. The method according to claim **1**, wherein the ionic liquid used is liquid at a temperature of from −85° C. to 400° C.

16. The method according to claim **1**, wherein the ionic liquid used has a decomposition temperature of >200° C.

17. Wind power plant comprising at least one component having movable elements and a lubricant, characterized in that the lubricant contains an ionic liquid.

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