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Ionic liquids as selective additives for separating close-boiling or azeotropic mixtures

5 Description

The invention relates to a process and a method for separating close-boiling or azeotropic mixtures by using ionic liquids as selective additives in rectification.

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Numerous liquid mixtures occur in industry which cannot be separated by conventional rectification but rather are preferably separated by extractive rectification [Stichlmair, S. and Fair, J., Distillation, ISBN 0-471-25241-7, page 241 et seq.]. This state of affairs is due to the similar boiling behavior of the components of the mixture, that is to say their property of distributing themselves between the vapor and liquid phase in almost or exactly equimolar proportions at a defined pressure and a defined temperature.

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The effort of separating a binary liquid mixture composed of the components i and j by rectification is reflected in what is known as the separation factor α_{ij} , the distribution coefficient of components i and j . The closer the separation factor approaches

25 the value one the more effort the separation of the components of the mixture by conventional rectification requires, since either the number of theoretical plates in the distillation column and/or the reflux ratio at the top of the column must be increased. If the separation factor assumes the value one an

30 azeotropic point is reached and further enrichment of the components of the mixture is no longer possible, even if the number of theoretical plates or the reflux ratio is increased. In general when making use of the separation factor it has to be borne in mind that it can be greater than or less than 1

35 depending on whether the distribution coefficient of the low boiler is in the numerator or in the denominator. Normally the low boiler is placed in the numerator so that the separation factor is great than 1.

40 A procedure frequently employed in industry for separating close-boiling systems – by which is meant a separation factor less than 1.2 for instance – or azeotropic systems involves adding a selective additive, commonly referred to as the entrainer, to an extractive rectification. A suitable additive
45 influences the separation factor by selective interaction with one or more of the components of the mixture so that separation of the close-boiling or azeotropically boiling components of the



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mixture is made possible. In extractive rectification the components obtained at the top and bottom of the column due to the action of the entrainer are the target components for the column.

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A measure of the intensity of the interactions of the entrainer with one or more of the components of the mixture is provided by what is known as selectivity. Selectivity is defined as the ratio of the limiting activity coefficient of component i to the
10 limiting activity coefficient of component j , components i and j being present at an infinite degree of dilution in the entrainer [Schult, C. J. et. al.; Infinite-dilution activity coefficients for several solutes in hexadecane and in n -methyl-2-pyrrolidone (NMP): experimental measurements and UNIFAC predictions; Fluid
15 Phase Equilibria 179 (2001) pp.117-129]. As expounded by Schult et. al., a higher entrainer selectivity results in a higher relative volatility, a lower reflux ratio and hence in lower separating costs. As disclosed later on, the aim is to achieve as high a selectivity as possible, e.g. greater than 1.3, preferably
20 greater than 2.0.

The surprising discovery of the suitability of some ionic liquids for the separation of azeotropic and/or close-boiling mixtures on the basis of the entrainer selectivity and of the separation
25 factor is shown below. The activity coefficients playing a key role in entrainer selectivity at infinite dilution can be determined by a variety of methods, preferably by using gas-liquid chromatography (GLC or GLPC) [Schult, C. J. et. al.; Infinite-dilution activity coefficients for several solutes in
30 hexadecane and in n -methyl-2-pyrrolidone (NMP): experimental measurements and UNIFAC predictions; Fluid Phase Equilibria 179 (2001) pp.117-129] and equations (4) and (6) used in the latter publication by Schult et. al.

35 On grounds of costs, the aim is to minimize the amount of additive to be employed. The entrainer is advantageously present substantially in the liquid phase in the column. Large volumes might result in an enlargement of the column diameter but would always give rise to an increased pressure loss in the vapor phase
40 in the column and hence also to a greater energy loss. Accordingly, an increase in the quantity of entrainer results in increased capital and operating costs.

For a given column length and the same reflux ratio the higher
45 separation factor yields a purer product or for a given column length and degree of purity of the overhead product the higher separation factor results in a lower reflux ratio and hence in

energy savings. For a given degree of purity and a given reflux ratio an increase in the quantity of entrainer and a higher separation factor results in savings in capital costs due to shortening of the length of the column. By these means the design
5 engineer has the power to minimize capital or running costs (energy costs) on the basis of circumstances specific to the site.

The invention relates to a process and a method in which a novel
10 class of substances, ionic liquids, is employed for separating close-boiling or azeotropic liquid mixtures since these ionic liquids are surprisingly superior to the conventional additives. The superiority can be seen directly in the selectivity and separation factor. When a suitable ionic liquid is used the
15 separation factor at the azeotropic point is further removed from the value of one than is the case when equivalent quantities of a conventional additive are used.

By ionic liquids is meant those defined by Wasserscheid and Keim
20 in *Angewandte Chemie* 2000, 112, 3926-3945. The ionic liquids group of substances represents a new type of solvent. As set out in the above publication ionic liquids are salts of nonmolecular, ionic nature which melt at relatively low temperatures. They are already in the molten state at relatively low temperatures less
25 than 200 °C, preferably less than 150 °C, particularly preferably less than 100 °C and at the same time are of relatively low viscosity. They are highly soluble in a large number of organic, inorganic and polymeric substances.

30 By comparison with ionic salts, ionic liquids are molten at substantially lower temperatures (below 200 °C as a rule) and often have a melting point below 0 °C, in some cases down to -96 °C, which is important for the industrial implementation of extractive rectification.

35 Moreover, ionic liquids are usually nonflammable, noncorrosive, of low viscosity and are exceptional by having an immeasurable vapor pressure.

40 Compounds designated according to the invention as ionic liquids are those which have at least one positive and at least one negative charge but are overall neutral in charge and have a melting point below 200 °C, preferably below 100, particularly preferably below 50 °C.

45

Ionic liquids can also exhibit a plurality of positive or negative charges, for example 1 to 5, preferably 1 to 4, particularly preferably 1 to 3, very particularly preferably 1 to 2, but in particular one negative and one positive charge each.

5

The charges may be found at various localized or delocalized regions inside a molecule, that is to say like betaine, or be distributed in each case over a separate anion and cation. Those ionic liquids are preferred which are built up out of at least one cation and at least one anion. As stated above, the cation and anion may be singly or multiply charged, preferably singly charged.

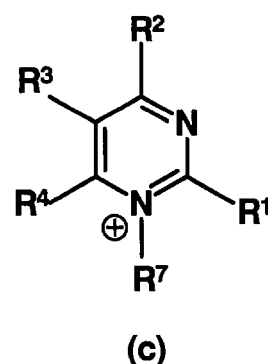
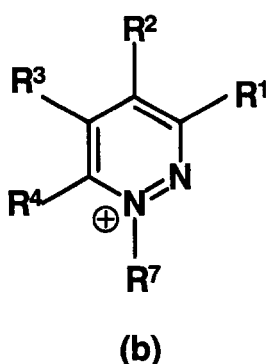
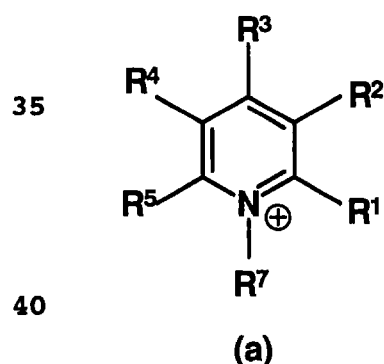
Of course mixtures of different ionic liquids are also conceivable.

Preferred cations are ammonium or phosphonium ions or those cations containing at least a five- to six-membered heterocycle possessing at least one phosphorus or nitrogen atom and optionally an oxygen or sulfur atom, particularly preferably those compounds containing at least one five- to six-membered heterocycle possessing one, two or three nitrogen atoms and a sulfur or an oxygen atom, very particularly preferably those having one or two nitrogen atoms.

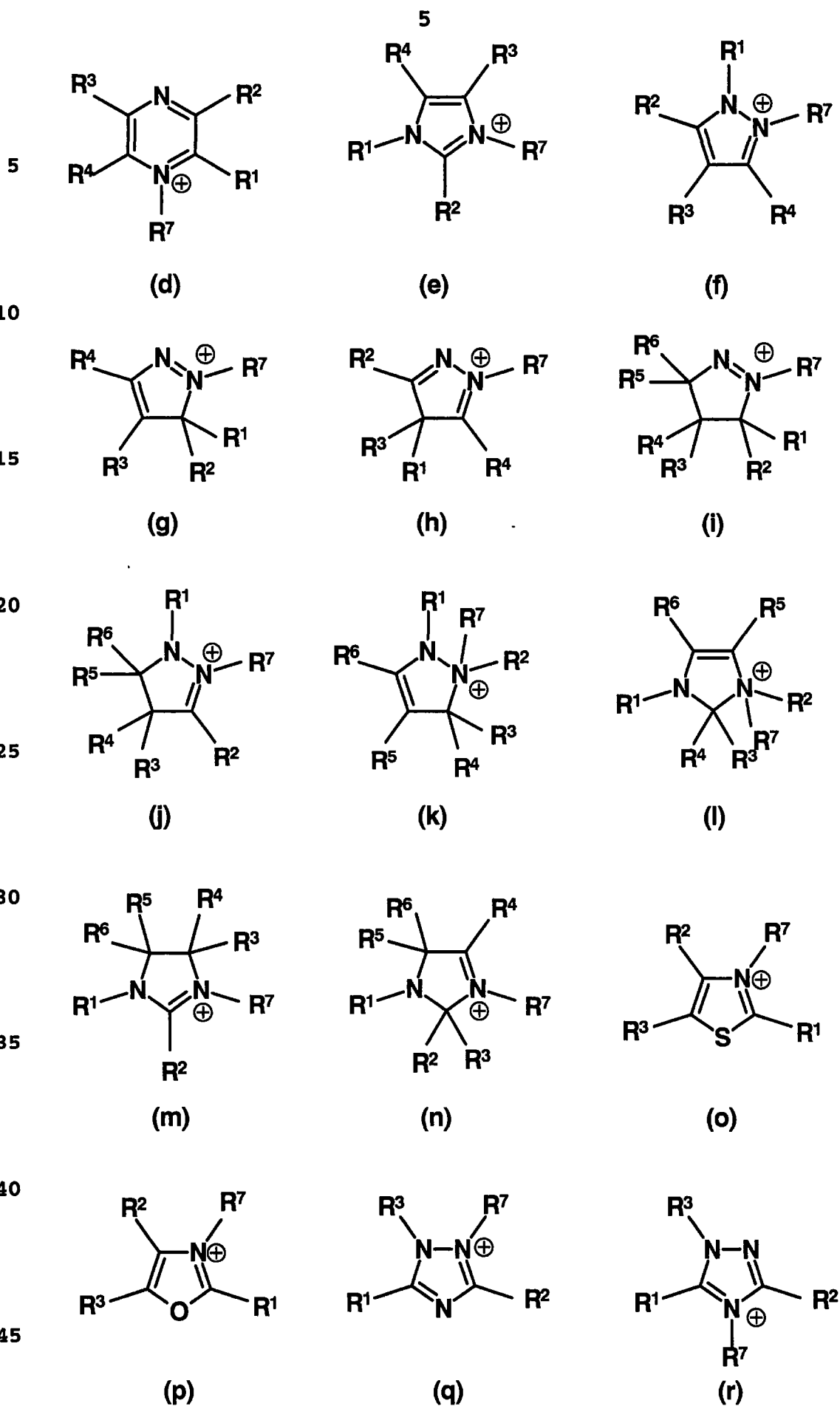
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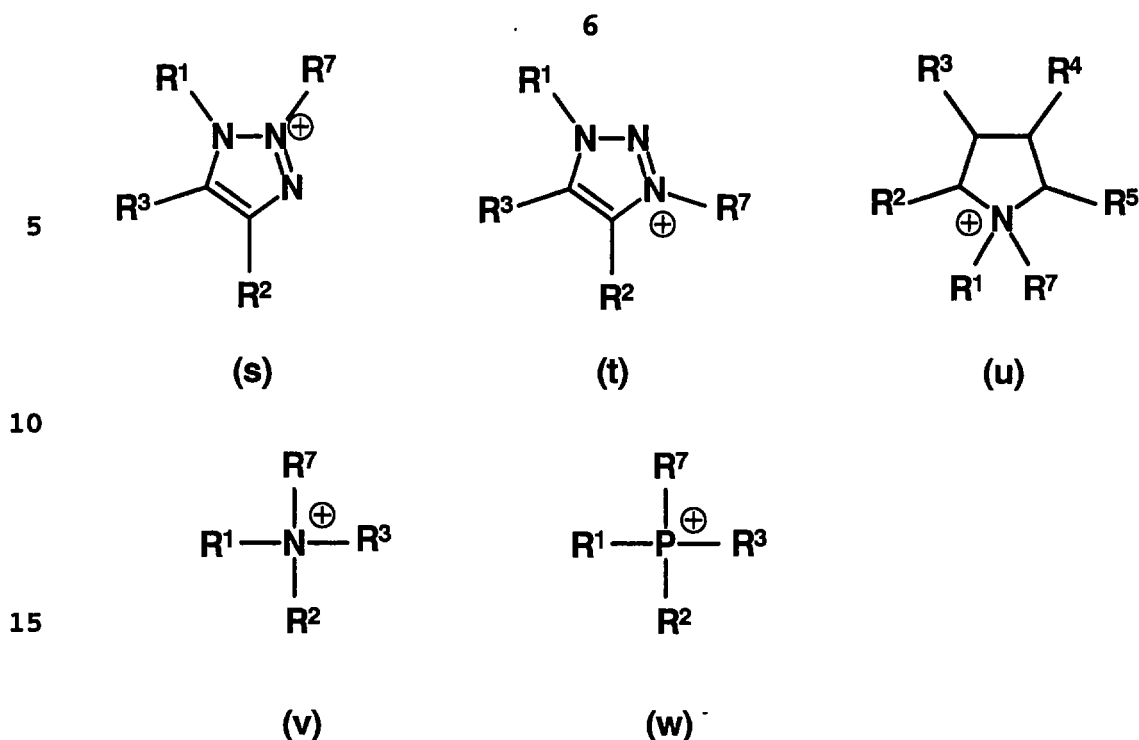
Particularly preferred ionic liquids are those having a molecular weight of less than 1,000 g/mol, very particularly preferably less than 350 g/mol.

Furthermore those cations are preferred which are selected from compounds of the formulae (Ia) to (Iw):



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20 as well as oligopolymers or polymers containing these structures,

where

25 R^1 , R^2 , R^3 , R^4 , R^5 , R^6 and R^7 independently of one another each stand for $C_1 - C_{18}$ alkyl, $C_2 - C_{18}$ alkyl optionally interrupted by one or more oxygen and/or sulfur atoms and/or one or more substituted or unsubstituted imino groups, $C_6 - C_{12}$ aryl, $C_5 - C_{12}$ cycloalkyl or a five- to six-membered heterocycle possessing oxygen, nitrogen and/or sulfur atoms, or two of them jointly form

30 an unsaturated, saturated or aromatic ring optionally interrupted by one or more oxygen and/or sulfur atoms and/or one or more substituted or unsubstituted imino groups, wherein said residues can each be substituted by functional groups, aryl, alkyl, aryloxy, alkyloxy, halogen, hetero atoms and/or heterocycles.

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R^1 , R^2 , R^3 , R^4 , R^5 and R^6 can additionally represent hydrogen.

Moreover, R^7 can stand for $C_1 - C_{18}$ alkyloyl (alkylcarbonyl), $C_1 - C_{18}$ - alkyloxycarbonyl, $C_5 - C_{12}$ cycloalkylcarbonyl or $C_6 - C_{12}$

40 aryloyl (arylcabonyl), wherein said residues can be substituted by functional groups, aryl, alkyl, aryloxy, alkyloxy, halogen, hetero atoms and/or heterocycles.

Therein

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- C₁ - C₁₈ alkyl optionally substituted by functional groups, aryl, alkyl, aryloxy, alkyloxy, halogen, hetero atoms and/or heterocycles stands by way of example for methyl, ethyl, propyl, isopropyl, n-butyl, sec-butyl, tert-butyl, pentyl, hexyl, heptyl, 5 octyl, 2-ethylhexyl, 2,4,4-trimethylpentyl, decyl, dodecyl, tetradecyl, heptadecyl, octadecyl, 1,1-dimethylpropyl, 1,1-dimethylbutyl, 1,1,3,3-tetramethylbutyl, benzyl, 1-phenylethyl, 2-phenylethyl, α,α -dimethylbenzyl, benzhydryl, p-tolylmethyl, 1-(p-butylphenyl)ethyl, p-chlorobenzyl, 10 2,4-dichlorobenzyl, p-methoxybenzyl, m-ethoxybenzyl, 2-cyanoethyl, 2-cyanopropyl, 2-methoxycarbonylethyl, 2-ethoxycarbonylethyl, 2-butoxycarbonylpropyl, 1,2-di-(methoxycarbonyl)ethyl, 2-methoxyethyl, 2-ethoxyethyl, 2-butoxyethyl, diethoxymethyl, diethoxyethyl, 1,3-dioxolan-2-yl, 15 1,3-dioxan-2-yl, 2-methyl-1,3-dioxolan-2-yl, 4-methyl-1,3-dioxolan-2-yl, 2-isopropoxyethyl, 2-butoxypropyl, 2-octyloxyethyl, chloromethyl, 2-chloroethyl, trichloromethyl, trifluoromethyl, 1,1-dimethyl-2-chloroethyl, 2-methoxyisopropyl, 2-ethoxyethyl, butylthiomethyl, 2-dodecylthioethyl, 20 2-phenylthioethyl, 2,2,2-trifluoroethyl, 2-hydroxyethyl, 2-hydroxypropyl, 3-hydroxypropyl, 4-hydroxybutyl, 6-hydroxyhexyl, 2-aminoethyl, 2-aminopropyl, 3-aminopropyl, 4-aminobutyl, 6-aminoethyl, 2-methylaminoethyl, 2-methylaminopropyl, 3-methylaminopropyl, 4-methylaminobutyl, 6-methylaminoethyl, 25 2-dimethylaminoethyl, 2-dimethylaminopropyl, 3-dimethylaminopropyl, 4-dimethylaminobutyl, 6-dimethylaminoethyl, 2-hydroxy-2,2-dimethylethyl, 2-phenoxyethyl, 2-phenoxypropyl, 3-phenoxypropyl, 4-phenoxybutyl, 6-phenoxyhexyl, 2-methoxyethyl, 2-methoxypropyl, 3-methoxypropyl, 30 4-methoxybutyl, 6-methoxyhexyl, 2-ethoxyethyl, 2-ethoxypropyl, 3-ethoxypropyl, 4-ethoxybutyl or 6-ethoxyhexyl and,

- C₂ - C₁₈ alkyl optionally interrupted by one or more oxygen and/or sulfur atoms and/or one or more substituted or unsubstituted 35 imino groups stands by way of example for 5-hydroxy-3-oxapentyl, 8-hydroxy-3,6-dioxaoctyl, 11-hydroxy-3,6,9-trioxaundecyl, 7-hydroxy-4-oxa-heptyl, 11-hydroxy-4,8-dioxaundecyl, 15-hydroxy-4,8,12-trioxapentadecyl, 9-hydroxy-5-oxa-nonyl, 14-hydroxy-5,10-oxatetradecyl, 5-methoxy-3-oxapentyl, 40 8-methoxy-3,6-dioxaoctyl, 11-methoxy-3,6,9-trioxaundecyl, 7-methoxy-4-oxaheptyl, 11-methoxy-4,8-dioxaundecyl, 15-methoxy-4,8,12-trioxapentadecyl, 9-methoxy-5-oxanonyl, 14-methoxy-5,10-oxatetradecyl, 5-ethoxy-3-oxapentyl, 8-ethoxy-3,6-dioxaoctyl, 11-ethoxy-3,6,9-trioxaundecyl, 45 7-ethoxy-4-oxa-heptyl, 11-ethoxy-4,8-dioxaundecyl,

15-ethoxy-4,8,12-trioxapentadecyl, 9-ethoxy-5-oxa-nonyl or
14-ethoxy-5,10-oxatetradecyl.

If two radicals form a ring these radicals may jointly stand for
5 1,3-propylene, 1,4-butylene, 2-oxa-1,3-propylene,
1-oxa-1,3-propylene, 2-oxa-1,3-propylene, 1-oxa-1,3-propenylene,
1-aza-1,3-propenylene, 1-(C₁-C₄ alkyl)-1-aza-1,3-propenylene,
1,4-buta-1,3-dienylene, 1-aza-1,4-buta-1,3-dienylene or
2-aza-1,4-buta-1,3-dienylene.

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The number of oxygen and/or sulfur atoms and/or imino groups is
not limited. In general there are no more than 5 in the radical,
preferably no more than 4 and very particularly preferably no
more than 3.

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Furthermore, between two hetero atoms there is usually at least
one carbon atom, preferably at least two.

Substituted and unsubstituted imino groups can be by way of
20 example imino, methylimino, *iso*-propylimino, *n*-butylimino or
tert-butylimino.

Furthermore,

25 functional groups stands for carboxy, carboxamido, hydroxy,
di-(C₁-C₄ alkyl)-amino, C₁-C₄ alkyloxycarbonyl, cyano or C₁-C₄
alkyloxy,

C₆ - C₁₂ aryl optionally substituted by functional groups, aryl,
30 alkyl, aryloxy, alkyloxy, halogen, hetero atoms and/or
heterocycles stands by way of example for phenyl, tolyl, xylyl,
 α -naphthyl, β -naphthyl, 4-diphenyl, chlorophenyl,
dichlorophenyl, trichlorophenyl, difluorophenyl, methylphenyl,
dimethylphenyl, trimethylphenyl, ethylphenyl, diethylphenyl,
35 *iso*-propylphenyl, *tert*-butylphenyl, dodecylphenyl, methoxyphenyl,
dimethoxyphenyl, ethoxyphenyl, hexyloxyphenyl, methyl-naphthyl,
isopropyl-naphthyl, chloro-naphthyl, ethoxy-naphthyl,
2,6-dimethylphenyl, 2,4,6-trimethylphenyl, 2,6-dimethoxyphenyl,
2,6-dichlorophenyl, 4-bromophenyl, 2- or 4-nitrophenyl, 2,4- or
40 2,6-dinitrophenyl, 4-dimethylaminophenyl, 4-acetylphenyl,
methoxyethylphenyl or ethoxymethylphenyl,

C₅ - C₁₂ cycloalkyl optionally substituted by functional groups,
aryl, alkyl, aryloxy, alkyloxy, halogen, hetero atoms and/or
45 heterocycles stands by way of example for cyclopentyl,
cyclohexyl, cyclooctyl, cyclododecyl, methylcyclopentyl,
dimethylcyclopentyl, methylcyclohexyl, dimethylcyclohexyl,

diethylcyclohexyl, butylcyclohexyl, methoxycyclohexyl, dimethoxycyclohexyl, diethoxycyclohexyl, butylthiocyclohexyl, chlorocyclohexyl, dichlorocyclohexyl, dichlorocyclopentyl as well as a saturated or unsaturated bicyclic system such as norbornyl
 5 or norbornenyl for example,

a five- to six-membered heterocycle possessing oxygen, nitrogen and/or sulfur atoms stands by way of example for furyl, thiophenyl, pyrrolyl, pyridyl, indolyl, benzoxazolyl, dioxolyl,
 10 dioxyl, benzimidazolyl, benzthiazolyl, dimethylpyridyl, methylquinolyl, dimethylpyrrolyl, methoxyfuryl, dimethoxypyridyl, difluoropyridyl, methylthiophenyl, isopropylthiophenyl or tert-butylthiophenyl and

15 C₁ to C₄ alkyl stands by way of example for methyl, ethyl, propyl, isopropyl, n-butyl, sec-butyl or tert-butyl.

C₁ - C₁₈ alkyloyl (alkylcarbonyl) can be by way of example acetyl, propionyl, n-butyloyl, sec-butyloyl, tert-butyloyl,
 20 2-ethylhexylcarbonyl, decanoyl, dodecanoyl, chloroacetyl, trichloroacetyl or trifluoroacetyl.

C₁ - C₁₈- alkyloxycarbonyl can be by way of example methyloxycarbonyl, ethyloxycarbonyl, propyloxycarbonyl,
 25 isopropyloxycarbonyl, n-butyloxycarbonyl, sec-butyloxycarbonyl, tert-butyloxycarbonyl, hexyloxycarbonyl, 2-ethylhexyloxycarbonyl or benzyloxycarbonyl.

C₅ - C₁₂ cycloalkylcarbonyl can be by way of example
 30 cyclopentylcarbonyl, cyclohexylcarbonyl or cyclododecylcarbonyl.

C₆ - C₁₂ aryloyl (arylcarbonyl) can be by way of example benzoyl, toluylyl, xylylyl, α-naphthoyl, β-naphthoyl, chlorobenzoyl, dichlorobenzoyl, trichlorobenzoyl or trimethylbenzoyl.

35 R¹, R², R³, R⁴, R⁵ and R⁶ independently of one another are preferably hydrogen, methyl, ethyl, n-butyl, 2-hydroxyethyl, 2-cyanoethyl, 2-(methoxycarbonyl)ethyl, 2-(ethoxycarbonyl)-ethyl, 2-(n-butoxycarbonyl)ethyl, dimethylamino, diethylamino and
 40 chlorine.

R⁷ is preferably methyl, ethyl, n-butyl, 2-hydroxyethyl, 2-cyanoethyl, 2-(methoxycarbonyl)-ethyl, 2-(ethoxycarbonyl)ethyl, 2-(n-butoxycarbonyl)ethyl, acetyl, propionyl, t-butyryl,
 45 methoxycarbonyl, ethoxycarbonyl or n-butoxycarbonyl.

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Particularly preferred pyridinium ions (Ia) are those in which one of the radicals R^1 to R^5 is methyl, ethyl or chlorine, R^7 is acetyl, methyl, ethyl or n-butyl and all others are hydrogen, or R^3 is dimethylamino, R^7 acetyl, methyl, ethyl or n-butyl and all others are hydrogen, or R^7 is acetyl, methyl, ethyl or n-butyl and all others are hydrogen, or R^2 is carboxy or carboxamido, R^7 acetyl, methyl, ethyl or n-butyl and all others are hydrogen, or R^1 and R^2 or R^2 and R^3 are 1,4-buta-1,3-dienylene, R^7 acetyl, methyl, ethyl or n-butyl and all others are hydrogen.

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Particularly preferred pyridazinium ions (Ib) are those in which one of the groups R^1 to R^4 is methyl or ethyl, R^7 is acetyl, methyl, ethyl or n-butyl and all others are hydrogen, or R^7 is acetyl, methyl, ethyl or n-butyl and all others are hydrogen.

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Particularly preferred pyrimidinium ions (Ic) are those in which R^2 to R^4 are hydrogen or methyl, R^7 is acetyl, methyl, ethyl or n-butyl and R^1 is hydrogen, methyl or ethyl, or R^2 and R^4 are methyl, R^3 is hydrogen and R^1 is hydrogen, methyl or ethyl and R^7 is acetyl, methyl, ethyl or n-butyl.

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Particularly preferred pyrazinium ions (Id) are those in which R^1 to R^4 are all methyl and R^7 is acetyl, methyl, ethyl or n-butyl, or R^7 is acetyl, methyl, ethyl or n-butyl and all others are hydrogen.

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Particularly preferred imidazolium ions (Ie) are those in which independently of one another R^1 is selected from methyl, ethyl, n-propyl, n-butyl, n-pentyl, n-octyl, n-decyl, n-dodecyl, 2-hydroxyethyl or 2-cyanoethyl, R^7 is acetyl, methyl, ethyl or n-butyl and R^2 to R^4 independently of one another stand for hydrogen, methyl or ethyl.

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Particularly preferred 1H-pyrazolium ions (If) are those in which independently of one another

R^1 is selected from hydrogen, methyl or ethyl,
 R^2 , R^3 and R^4 from hydrogen or methyl and
 R^7 from acetyl, methyl, ethyl or n-butyl.

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Particularly preferred 3H-pyrazolium ions (Ig) are those in which independently of one another

R^1 is selected from hydrogen, methyl or ethyl,
 R^2 , R^3 and R^4 from hydrogen or methyl and

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R⁷ from acetyl, methyl, ethyl or n-butyl.

Particularly preferred 4H-pyrazolium ions (Ih) are those in which independently of one another

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R¹ to R⁴ are selected from hydrogen or methyl and
R⁷ from acetyl, methyl, ethyl or n-butyl.

Particularly preferred 1-pyrazolinium ions (Ii) are those in
10 which independently of one another

R¹ to R⁶ are selected from hydrogen or methyl and
R⁷ from acetyl, methyl, ethyl or n-butyl.

15 Particularly preferred 2-pyrazolinium ions (Ij) are those in which independently of one another

R¹ is selected from hydrogen, methyl, ethyl or phenyl,
R⁷ from acetyl, methyl, ethyl or n-butyl and

20 R² to R⁶ from hydrogen or methyl.

Particularly preferred 3-pyrazolinium ions (Ik) are those in which independently of one another

R¹ or R² is selected from hydrogen, methyl, ethyl or phenyl,

25 R⁷ from acetyl, methyl, ethyl or n-butyl and
R³ to R⁶ from hydrogen or methyl.

Particularly preferred imidazolinium ions (Il) are those in which independently of one another

30

R¹ or R² is selected from hydrogen, methyl, ethyl, n-butyl or phenyl,

R⁷ from acetyl, methyl, ethyl or n-butyl and

R³ or R⁴ from hydrogen, methyl or ethyl and

35 R⁵ or R⁶ from hydrogen or methyl.

Particularly preferred imidazolinium ions (Im) are those in which independently of one another

40 R¹ or R² is selected from hydrogen, methyl or ethyl,

R⁷ from acetyl, methyl, ethyl or n-butyl and

R³ to R⁶ from hydrogen or methyl.

Particularly preferred imidazolinium ions (In) are those in which
45 independently of one another

R¹, R² or R³ is selected from hydrogen, methyl or ethyl,

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R⁷ from acetyl, methyl, ethyl or n-butyl and
R⁴ to R⁶ from hydrogen or methyl.

Particularly preferred thiazolium ions (Io) or oxazolium ions
5 (Ip) are those in which independently of one another

R¹ is selected from hydrogen, methyl, ethyl or phenyl,
R⁷ from acetyl, methyl, ethyl or n-butyl and
R² or R³ from hydrogen or methyl.

10

Particularly preferred 1,2,4-triazolium ions (Iq) and (Ir) are
those in which independently of one another

R¹ or R² is selected from hydrogen, methyl, ethyl or phenyl,
15 R⁷ from acetyl, methyl, ethyl or n-butyl and
R³ from hydrogen, methyl or phenyl.

Particularly preferred 1,2,3-triazolium ions (Is) and (It) are
those in which independently of one another

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R¹ is selected from hydrogen, methyl or ethyl,
R⁷ from acetyl, methyl, ethyl or n-butyl and
R² or R³ from hydrogen or methyl, or
R² and R³ are 1,4-buta-1,3-dienylene and all others are hydrogen.

25

Particularly preferred pyrrolidinium ions (Iu) are those in which
independently of one another

R¹ and R⁷ are selected from acetyl, methyl, ethyl or n-butyl and
R², R³, R⁴ and R⁵ stand for hydrogen.

30

Particularly preferred ammonium ions (Iv) are those in which
independently of one another

R⁷ is selected from acetyl, methyl, ethyl or n-butyl and
35 R¹, R², and R³ from methyl, ethyl, n-butyl, 2-hydroxyethyl, benzyl
or phenyl.

Particularly preferred phosphonium ions (Iw) are those in which
independently of one another

40 R⁷ is selected from acetyl, methyl, ethyl or n-butyl and
R¹, R², and R³ from phenyl, phenoxy, ethoxy and n-butoxy.

Among these the ammonium, phosphonium, pyridinium and imidazolium
ions are preferred.

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Very particularly preferred as cations are

- 1,2-dimethylpyridinium, 1-methyl-2-ethylpyridinium,
 1-methyl-2-ethyl-6-methylpyridinium, N-methylpyridinium,
 1-butyl-2-methylpyridinium, 1-butyl-2-ethylpyridinium,
 5 1-butyl-2-ethyl-6-methylpyridinium, N-butylpyridinium,
 1-butyl-4-methylpyridinium, 1,3-dimethylimidazolium,
 1,2,3-trimethylimidazolium, 1-n-butyl-3-methylimidazolium,
 1,3,4,5-tetramethylimidazolium, 1,3,4-trimethylimidazolium,
 2,3-dimethylimidazolium, 1-butyl-2,3-dimethylimidazolium,
 10 3,4-dimethylimidazolium, 2-ethyl-3,4-dimethylimidazolium,
 3-methyl-2-ethylimidazol, 3-butyl-1-methylimidazolium,
 3-butyl-1-ethylimidazolium, 3-butyl-1,2-dimethylimidazolium,
 1,3-di-n-Butylimidazolium, 3-butyl-1,4,5-trimethylimidazolium,
 3-butyl-1,4-dimethylimidazolium, 3-butyl-2-methylimidazolium,
 15 1,3-dibutyl-2-methylimidazolium, 3-butyl-4-methylimidazolium,
 3-butyl-2-ethyl-4-methylimidazolium and
 3-butyl-2-ethylimidazolium, 1-methyl-3-octylimidazolium and
 1-decyl-3-methylimidazolium.
- 20 Particularly preferred are 1-butyl-4-methylpyridinium,
 1-n-butyl-3-methylimidazolium and 1-n-butyl-3-ethylimidazolium,

For the anions, all anions are conceivable in principle.

- 25 Preferred anions are halides, F^- , Cl^- , Br^- , I^- , acetate CH_3COO^- ,
 trifluoroacetate CF_3COO^- , triflate $CF_3SO_3^-$, sulfate SO_4^{2-} ,
 hydrogensulfate HSO_4^- , methylsulfate $CH_3OSO_3^-$, ethylsulfate
 $C_2H_5OSO_3^-$, sulfite SO_3^{2-} , hydrogensulfite HSO_3^- , chloroaluminates
 $AlCl_4^-$, $Al_2Cl_7^-$, $Al_3Cl_{10}^-$, tetrabromoaluminate $AlBr_4^-$, nitrite NO_2^- ,
 30 nitrate NO_3^- , chlorocuprate $CuCl_2^-$, phosphate PO_4^{3-} ,
 hydrogenphosphate HPO_4^{2-} , dihydrogenphosphate $H_2PO_4^-$, carbonate
 CO_3^{2-} and hydrogencarbonate HCO_3^- .

Particularly preferred tetrafluoroborate BF_4^- , hexafluorophosphate

- 35 PF_6^- , bis(trifluoromethylsulfonyl)imide $(CF_3SO_2)_2N^-$ and tosylate
 $p-CH_3C_6H_4SO_3^-$.

Ionic liquids which are very particularly preferred are those
 whose salts exhibit an $E_T(30)$ value of > 20 , preferably of > 30 ,

- 40 particularly preferably of > 40 . The $E_T(30)$ value is a measure of
 polarity and is described by C. Reichardt in Reichardt,
 Christian, Solvent Effects in Organic Chemistry, Weinheim: VCH,
 1979 - XI, (Monographs in Modern Chemistry 3), ISBN
 3-527-25793-4, page 241.

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The change in separation factor brought about by the entrainer can be determined by a number of methods, preferably by headspace analysis as published by Hachenberg and Schmidt in Verfahrenstechnik, 8(1974), 12, pages 343-347. In determining the effect of the entrainer on the mixture to be separated (the feed) calculation is generally done on an entrainer-free basis, that is to say that although the concentration of the entrainer in the liquid mixture is noted it is not taken into account in the percentage statement of the concentrations of the target components.

Suitable ionic liquids are those which at a total concentration in the liquid of 5 to 90 mol%, preferably 10 to 70 mol%, result in a change in the separation factor of the target components relative to one another different from one. This change can be determined in the described headspace analysis.

The ionic liquid acting as entrainer is selected so that it has as high a selectivity as possible, it dissolves homogeneously to a concentration of at least 5 mol% in the mixture of substances to be separated, it does not undergo any chemical reaction involving rupture of covalent bonds with either of the components of the mixture of substances to be separated, the components of the bottom product can be separated from the entrainer at low cost by evaporation due to the supply of heat and/or reduction of pressure or rectification or extraction or stripping using inert gas or conversion into a solid phase.

In the rectification column it is not possible to adjust a constant concentration of the ionic fluid over the entire height of the column. On the contrary, in the enriching section directly below the point of addition of the ionic fluid a higher concentration will set in by comparison with the stripping section below the feed inlet. The quantified value of 5 - 90 mol% should be measured directly on the feed plate for the ionic fluid. In this way a suitable concentration would be ensured in the enriching section, that is to say just where the azeotrope is to be broken down.

In order to ensure that the ionic liquid dissolves well in the mixture to be separated the forces of attraction between the molecules of the ionic liquid should be approximately just as great as those between the molecules of the feed. In this case the intermolecular forces in operation are ionic forces,

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dipole-dipole forces, induction forces, dispersion forces and hydrogen bonds, cf. Ullmann's Encyclopedia of Industrial Chemistry (1993), Vol. A24, pp. 438-439. It is possible to adjust these forces in the ionic liquids by varying the cations. In this way solubility properties can be regulated. Thus, for example, by lengthening the chain of the alkyl residue on an alkylmethylimidazolium tetrafluoroborate the water-repelling properties increase and hence miscibility with water decreases. This adjustment of solvation strength is particularly effective in relation to aliphatics, cf. H. Waffenschmidt, Dissertation, RWTH Aachen, 2000. The anion also has an effect on dissolving characteristics. Criteria for estimating the dissolving behavior of an ionic liquid are the dielectric constant of the ionic liquid and of the feed and the polarity of the mixture.

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An embodiment of extractive rectification in a process is illustrated by Figure 1. "2" is the inflow of the entrainer into a countercurrent rectification column. Since in conventional processes the entrainer has a slight but appreciable volatility relative to the top product (stream 7) separative elements "1" must be used for separation between the top product and entrainer. The separative elements "3" and "5" bring about the desired separation between overhead product and bottom product under the action of the entrainer, stream "4" is the inflow of the components to be separated (feed) and stream "6" is bottom product and the entrainer. Separative elements can be by way of example plates or ordered or disordered packings.

The process according to the invention has the advantage that – as mentioned above – the vapor pressure of the pure ionic liquid and hence also its partial pressure in the mixture with the top product is approximately equal to zero. Accordingly, in the process according to the invention the separative elements "1" may be dispensed with.

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The ionic fluid is added preferably in the enriching section close to the top of the column, particularly preferably in the uppermost 3 stages, very particularly preferably in the uppermost stage below the condenser.

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A further advantage of the process according to the invention with ionic liquid as entrainer is that in order to separate the entrainer from the bottom product various separating operations may be used. Advantageous embodiments are:

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Regeneration of the entrainer by simple evaporation.

Since the vapor pressure of the pure entrainer and hence also its partial pressure in the mixture with the bottom product is approximately equal to zero, an evaporation process can be run continuously or discontinuously without further
5 separative elements. Thin film evaporators such as falling-film or rotary evaporators are particularly suitable for continuous evaporation. In discontinuous concentration processes two evaporator stages are run alternately so that regenerated ionic liquid can be fed continuously to the
10 extractive rectification column.

Regeneration of the entrainer by means of a stripping column
Since the vapor pressure of the pure entrainer and hence also its partial pressure in the mixture with the bottom product is equal to zero the entrainer cannot be completely freed of
15 bottom product in the countercurrent process by evaporation alone. In an advantageous embodiment hot gas is conveyed in a stripping column in countercurrent flow relative to a mixture of bottom product and entrainer.

Many ionic liquids are notable for crystallization or glass
20 transition temperatures which are well below 0 °C. In these cases particularly simple, low-cost separation and recirculation of the ionic liquid is possible by precipitation to form a solid phase. The bottom product is then obtained in solid form while the entrainer can be
25 returned as the pure substance to the extractive rectification process. Precipitation can be carried out in accordance with the teachings of cooling crystallization, evaporative crystallization or vacuum crystallization. If the freezing point of the entrainer is above the freezing point
30 of the bottom product in a variant of this method the entrainer is obtained as the solid phase and the bottom product as the liquid phase.

The use of ionic fluids as entrainers in extractive rectification is particularly suitable inter alia for the following
35 applications, e.g. azeotropes: amines/water, THF/water, formic acid/water, alcohols/water, acetone/methanol, acetate/water, acrylate/water or close-boiling mixtures: acetic acid/water, C4 hydrocarbons, C3 hydrocarbons, alkanes/alkenes.

40 For the following reasons the process according to the invention is a substantial improvement over the processes in the literature for conventional extractive rectification.

Ionic liquids are more selective than traditional entrainers.
45 Due to their high selectivity by comparison with conventional extractive rectification they allow a lower mass flow rate of

entrainer to be fed in extractive rectification and/or the number of separation stages in the extractive rectification column to be reduced.

- 5 Due to the extremely low vapor pressure of the entrainer various separation operations can be used to separate the entrainer from the bottom product which by comparison with the second rectification column in conventional extractive rectification afford an advantage in terms of running and capital costs.
- 10 The separative elements "1" in conventional extractive rectification result in separation of the entrainer from the overhead product, but separation is never complete. Discharge of portions of ionic liquid via the vapor phase without the separative elements "1" is not possible due to its extremely
- 15 low volatility.
Capital costs are reduced because the separative elements "1" are not needed.

The process according to the invention is explained below by
20 means of examples.

Example 1

System to be separated: butene-butane

- 25 According to the literature [Gmehling, J, Onken, U and Arlt, W , Vapor-Liquid Equilibrium Data Collection, Dechema Data Series, Vol. I Part 6a, p. 17] the butene-butane system is a close-boiling system. The separation factor which was measured by
- 30 means of gas-liquid chromatography (GLC) at infinite dilution of butane and butene in the ionic liquid octylmethylimidazolium tetrafluoroborate (OMIM - BF₄) at 70 °C is 0.74.

- The calculation of the separation factor as a function of the
- 35 activity coefficient was published by Gmehling and Brehm [Gmehling, J. and Brehm, A. , Grundoperationen (Unit Operations), ISBN 3-13-687401-3, chapter 3].

- Accordingly, the additive interacts more vigorously with butene
- 40 than with butane. The powerful effect exhibited by the ionic liquid OMIM - BF₄ on the phase equilibrium of the binary butene-butane system demonstrates the suitability of OMIM - BF₄ as an entrainer for separating alkanes and alkenes.

Example 2

System to be separated: cyclohexanol-cyclohexanone

- 5 According to the literature [Gmehling, J, Onken, U and Arlt, W , Vapor-Liquid Equilibrium Data Collection, Dechema Data Series, Vol. I Part 2b, p. 403] the cyclohexanol-cyclohexanone system is a close-boiling system.
- 10 The separation factor which was measured by means of gas-liquid chromatography at infinite dilution of cyclohexanol and cyclohexanone in the ionic liquids ethylmethylimidazolium tetrafluoroborate (EMIM-BF₄) and ethylmethylimidazolium hexafluorophosphate (EMIM-PF₆) is 1.66 at 142 °C for EMIM-BF₄ and 15 1.61 at 140.8 °C for EMIM-PF₆. Both ionic liquids bring about an increase in the separation factor of the cyclohexanol - cyclohexanone separation system and are thus suitable as entrainers.

20 Example 3

System to be separated: acetone-methanol

- According to the literature [Gmehling, J, Onken, U and Arlt, W , 25 Vapor-Liquid Equilibrium Data Collection, Dechema Data Series, Vol. I Part 2a, p. 75] the acetone-methanol system forms an azeotrope. The separation factor for a mixture of a ketone and an alcohol, acetone and methanol in this case, was determined by means of GLC in infinite dilution in the ionic liquids EMIM-BF₄, 30 OMIM-BF₄, MMIM-CH₃SO₄, EMIM-(CF₃SO₂)₂N and EMIM-PF₆. These experiments yielded a separation factor of 2.51 at 70 °C for EMIM-BF₄, of 3.15 at 70 °C for OMIM-BF₄, of 1.3 at 70.5 °C for MMIM-CH₃SO₄, of 0.5 at 84.6 °C for EMIM-(CF₃SO₂)₂N and of 0.67 at 70 °C for EMIM-PF₆. From these results it may be seen that it is 35 not just isolated ionic liquids that are suitable as entrainers. On the contrary, many members of this novel class of substances, the ionic liquids, are suitable for use as entrainers.

The process according to the invention is explained below by 40 means of further examples in which headspace analysis is used.

Example 4

- Effect of the ionic liquid 1-ethyl-3-methylimidazolium 45 tetrafluoroborate on the binary homoazeotropic system ethanol-water

Table 1 shows the effect of the additive (entrainer) 1-ethyl-3-methylimidazolium tetrafluoroborate on the binary ethanol-water system at $\vartheta = 70\text{ }^{\circ}\text{C}$ and a molar liquid concentration of the entrainer of 10 mol% and 50 mol%.

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	x_{Ethanol} [mol %]	x_{Water} [mol %]	$\alpha_{\text{Ethanol, Water}}$ binary system without entrainer according to the invention	$\alpha_{\text{Ethanol, Water}}$ ternary system containing 10 mol% of entrainer according to the invention	$\alpha_{\text{Ethanol, Water}}$ ternary system containing 50 mol% of entrainer according to the invention	$\alpha_{\text{Ethanol, Water}}$ ternary system containing 70 mol% of entrainer according to the invention
10	0.10	0.90	7.12	4.64	5.74	6.23
	0.20	0.80	4.45	3.90	5.49	6.11
15	0.30	0.70	2.99	3.25	5.17	6.00
	0.40	0.60	2.37	2.70	4.77	5.86
	0.50	0.50	1.88	2.41	4.57	5.72
	0.60	0.40	1.58	2.12	4.38	5.58
	0.70	0.30	1.34	1.85	4.20	5.25
20	0.80	0.20	1.17	1.68	4.02	4.95
	0.90	0.10	1.06	1.48	3.99	4.90
	0.95	0.05	1.00	1.32	3.56	4.87

Table 1: Separation factor α of the binary, homoazeotropic system ethanol-water at $70\text{ }^{\circ}\text{C}$ using different quantities of the ionic liquid 1-ethyl-3-methylimidazolium tetrafluoroborate

The ethanol-water azeotrope occurs at approximately $x_{\text{Ethanol}} = 0.95$. It is precisely in the range around this that the entrainer has an effect, even at a concentration of 10 mol% in the liquid phase. The fact that in this and in the following examples a higher separation factor is achieved in the peripheral region without entrainer than with entrainer is not disadvantageous since:

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- preliminary concentration can be carried out without entrainer;
- separation factors about > 5 approximately have virtually no influence on operating and capital costs.

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Example 5

Effect of the ionic liquid 1-ethyl-3-methylimidazolium tetrafluoroborate on the binary homoazeotropic system

45 tetrahydrofuran-water

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Table 2 shows the effect of the entrainer 1-ethyl-3-methylimidazolium tetrafluoroborate on the binary tetrahydrofuran (THF)-water system at 70 °C and a molar liquid concentration of the entrainer of 50 mol%.

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	x_{THF} [mol %]	x_{Water} [mol %]	$\alpha_{\text{THF, Water}}$ binary system without entrainer according to the invention	$\alpha_{\text{THF, Water}}$ ternary system containing 50 mol% of entrainer according to the invention
10	0.10	0.90	25.54	18.09
	0.20	0.80	12.38	16.73
	0.30	0.70	7.97	15.37
	0.40	0.60	5.59	14.01
	0.50	0.50	3.87	12.65
15	0.60	0.40	2.56	11.29
	0.70	0.30	1.64	9.93
	0.80	0.20	1.10	8.57
	0.90	0.10	0.79	7.21

20 Table 2: Separation factor α of the homoazeotropic system tetrahydrofuran (THF)-water at 70 °C with and without the ionic liquid 1-ethyl-3-methylimidazolium tetrafluoroborate

The azeotrope at values of x_{THF} between 0.8 and 0.9 is

25 impressively removed.

Example 5a

30 Effect of the ionic liquid 1-ethyl-3-methylimidazolium tetrafluorotriylate on the binary homoazeotropic system tetrahydrofuran-water

Table 2a shows the effect of the entrainer 1-ethyl-3-methylimidazolium tetrafluorotriylate on the binary 35 tetrahydrofuran (THF)-water system at a pressure of 1 bar and a molar liquid concentration of the entrainer of 50 mol%.

	x_{THF} [mol %]	x_{Water} [mol %]	$\alpha_{\text{THF, Water}}$ ternary system containing 50 % of entrainer according to the invention
40	0.2459	0.7541	23.3
	0.3843	0.6157	24.7
	0.5355	0.4645	23.8
45	0.6307	0.3693	22.8

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Table 2a: Separation factor α of the tetrahydrofuran (THF)-water system at 1 bar with the ionic liquid 1-ethyl-3-methylimidazolium tetrafluoroborate. The measured results shown here were not obtained by headspace chromatography but rather by means of an equilibrium apparatus. Here also a distinct increase in the separation factor relative to the binary system (see Table 2) and hence the suitability of the ionic fluid as entrainer may be seen.

10 Example 6

Effect of the ionic liquid 1-ethyl-3-methylimidazolium tetrafluoroborate on the binary homoazeotropic system propanol-water

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Table 3 shows the effect of the entrainer 1-ethyl-3-methylimidazolium tetrafluoroborate on the binary propanol-water system at 85 °C and a molar liquid concentration of the entrainer of 50 mol%.

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x_{Propanol} [Mol %]	x_{Water} [Mol %]	$\alpha_{\text{Propanol, Water}}$ binary system without entrainer according to the invention	$\alpha_{\text{Propanol, Water}}$ ternary system containing 50 mol% of entrainer according to the invention
0.4	0.6	1.10	3.12
0.6	0.4	0.68	2.46

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Table 3: Separation factor α of the homoazeotropic system propanol-water at 85 °C with and without the ionic liquid 1-ethyl-3-methylimidazolium tetrafluoroborate

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Example 7

Effect of the ionic liquid 1-ethyl-3-methylimidazolium tetrafluoroborate on the binary homoazeotropic system isopropanol-water

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Table 4 shows the effect of the entrainer 1-ethyl-3-methylimidazolium tetrafluoroborate on the binary isopropanol-water system at 90 °C and a molar liquid concentration of the entrainer of 50 mol%.

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$x_{\text{Isopropanol}}$ [Mol %]	x_{Water} [Mol %]	$\alpha_{\text{Isopropanol, Water}}$ binary system without entrainer according to the invention	$\alpha_{\text{Isopropanol, Water}}$ ternary system containing 50 mol% of entrainer according to the invention
0.4	0.6	2.09	5.73
0.6	0.4	1.29	4.64

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Table 4: Separation factor α of the homoazeotropic system isopropanol-water at 90 °C with and without the ionic liquid 1-ethyl-3-methylimidazolium tetrafluoroborate

- 5 In Tables 1 to 4 a marked difference is discernible between the binary phase compositions and the ternary phase equilibrium compositions formed after addition of the nonvolatile entrainer according to the invention 1-ethyl-3-methylimidazolium tetrafluoroborate. Due to selective interactions with the polar
- 10 system component, water, the ionic liquid exercises an advantageous effect on the separation factor. Moreover, in the ethanol-water (Table 1) and tetrahydrofuran-water (Table 2) systems it is clearly evident that the effect of the ionic liquid on the vapor-liquid phase equilibrium is so great that the
- 15 azeotropic point has been broken down, that is to say it no longer occurs.

Example 8

- 20 Advantage of the entrainer according to the invention relative to conventional entrainers with reference to the example of the separation of ethanol and water

Table 5 shows for the ethanol-water system the effect of the two

25 entrainers 1-ethyl-3-methylimidazolium tetrafluoroborate and ethanediol on the vapor-liquid phase equilibrium at 70 °C for the entrainer concentration of 50 mol%.

30	XEthanol [mol %]	XWater [mol %]	α Ethanol, Water binary system without entrainer according to the invention	α Ethanol, Water ternary system containing 50 mol% of ethanediol	α Ethanol, Water ternary system containing 50 mol% of entrainer according to the invention
	0.10	0.90	7.12	4.96	5.74
35	0.20	0.80	4.45	4.37	5.49
	0.30	0.70	2.99	3.77	5.17
	0.40	0.60	2.37	3.45	4.77
	0.50	0.50	1.88	3.14	4.57
	0.60	0.40	1.58	2.82	4.38
40	0.70	0.30	1.34	2.63	4.20
	0.80	0.20	1.17	2.44	4.02
	0.90	0.10	1.06	1.83	3.99
	0.95	0.05	1.00	1.32	3.56

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Table 5: Comparison of the separation factors α in the ethanol-water system at 70 °C for the conventional entrainer ethanediol and the entrainer according to the invention 1-ethyl-3-methylimidazolium tetrafluoroborate

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From Table 5 it emerges that for the same concentration of entrainer the effect on the vapor-liquid phase equilibrium and hence the useful effect is distinctly greater in the case of the ionic liquid, particularly in the azeotropic range.

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What is claimed is:

1. A process for separating liquids or condensable gases in the condensed state comprising:

use of an entrainer which is an ionic liquid and brings about a change in the separation factor of the components to be separated divergent from one;
the ionic liquid being present at a total concentration of 5 to 90 mol%, preferably 10 to 70 mol% in the liquid phase.

2. A method as claimed in claim 1, comprising the separation being carried out by means of extractive rectification in a column wherein:

the low-boiling component or components under the conditions of claim 1 are obtained at the top of the column while all other components are obtained as bottom product together with said entrainer at the bottom of the column,
the liquid mixture at the bottom of the column (bottom product and entrainer) is worked up in such a way that said entrainer can be recovered and the components of the bottom product are obtained as a further fraction,
the column is operated in countercurrent flow,
said entrainer is introduced into the column above the feed of the components to be separated.

3. The method as claimed in claim 2, wherein the separation of said bottom product from said entrainer is carried out by evaporation in evaporators or in rectification columns.

4. The method as claimed in claim 2, wherein the work-up of the mixture of bottom product and entrainer ensues by precipitation of the component which has the higher freezing point.

5. The method as claimed in claim 2, wherein the separation of said bottom product from said entrainer is effected by drying.

6. The method as claimed in claim 2, wherein the separation of said bottom product from said entrainer is effected by extraction.

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7. The method as claimed in claim 2, wherein no separative elements are needed above the point of admission of said entrainer into the extractive rectification system.
- 5 8. The process as claimed in claim 1, wherein the feed is a water-containing system which in addition to water contains
- 10 alcohols having a carbon number between 1 and 12,
 preferably between 1 and 8, particularly preferably
 between 1 and 5,
 organic acids, preferably alkanolic acids,
 ketones,
 furans
- 15 and separation of the water from the other substances is achieved.
9. The process as claimed in claim 1, wherein said feed contains alkanes and alkenes having a carbon number between 3 and 12,
20 preferably between 4 and 10 and separation between alkanes and alkenes is achieved.
10. The process as claimed in claim 1, wherein said feed contains aromatic and aliphatic hydrocarbons and separation between
25 aromatics and aliphatics is achieved.
11. The process as claimed in claim 1, wherein said feed contains ketones and alicyclic compounds and the ketones are separated from the alicyclic components.
- 30 12. The process as claimed in claim 1, wherein said feed contains amides and acids, preferably carboxylic acids, and the amides are separated from the acids.
- 35 13. The process as claimed in claim 1, wherein said feed contains alcohols and alkanes and the alkanes are separated from the alcohols.
- 40 14. The process as claimed in claim 1, wherein said feed contains alcohols and aromatics and the alcohols are separated from the aromatics.
- 45 15. The process as claimed in claim 1, wherein said feed contains ketones and alcohols and the ketones are separated from the alcohols.

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16. The process as claimed in claim 1, wherein said feed contains acetates and ketones and the acetates are separated from the ketones.
- 5 17. The process as claimed in claim 1, wherein said feed contains ethers and alkanes and the ethers are separated from the alkanes.
- 10 18. The process as claimed in claim 1, wherein said feed contains ethers and alkenes and the ethers are separated from the alkenes.
- 15 19. The process as claimed in claim 1, wherein said feed contains sulfides and ketones and the sulfides are separated from the ketones.
- 20 20. The process as claimed in claim 1, wherein said feed contains halogenated hydrocarbons and ketones and the halogenated hydrocarbons are separated from the ketones.
21. The process as claimed in claim 15, wherein said feed contains cyclic ketones and/or cyclic alcohols and these are separated from one another.
- 25 22. The process as claimed in claim 1, wherein the anion of said ionic liquid used as said entrainer is a metallic halide.
- 30 23. The process as claimed in claim 1, wherein said ionic liquid used as said entrainer has an anion such as the nitrate anion or the tetrachloroaluminate anion or the tetrafluoroborate anion or the heptachlorodialuminate anion or the hexafluorophosphate anion or the methylsulfate anion or pure halide anions.
- 35 24. The process as claimed in claim 1, wherein said ionic liquid used as said entrainer has a cation such as the imidazolium cation or the pyridinium cation or the ammonium cation or the phosphonium cation.
- 40 25. The process as claimed in claim 1, wherein mixtures of ionic liquids are used as said entrainer.
- 45 26. A method, wherein the process as claimed in claims 1 and 8 to 25 is carried out and implemented in accordance with claims 2 to 7.

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27. Products which are separated in accordance with claims 1 to 26.

28. The method as claimed in claim 2, wherein the separation of
5 said bottom product from said entrainer is effected by means
of stripping using an inert gas.

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