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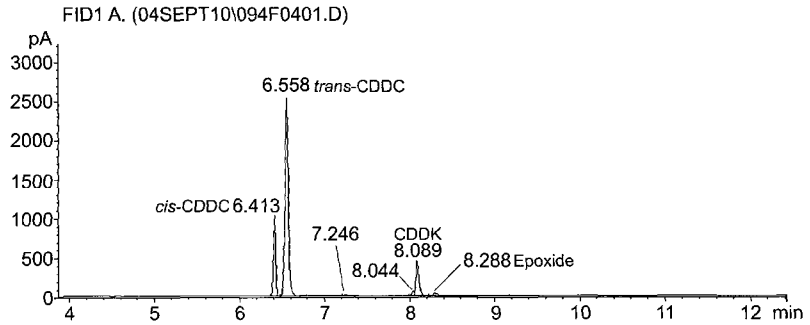
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(54) **Title**: NITROUS OXIDE-CONTAINING IONIC LIQUIDS AS CHEMICAL REAGENTS

FIG. 1



(57) **Abstract**: The invention relates to the use of an N_2O-containing ionic liquid as a reagent in a chemical reaction, for example as an oxidising agent.

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Nitrous oxide-containing ionic liquids as chemical reagents

The invention relates to the use of an N_2O-containing ionic liquid as a reagent in a chemical reaction, for example as an oxidising agent. The invention also relates to a reaction process in which ionic liquids are used to absorb nitrous oxide (hereinafter referred to as N_2O) from a mixture of by-products produced during the reaction process. More particularly, the invention relates to a process for the synthesis of adipic acid using nitric acid which employs an ionic liquid to absorb N_2O from a mixture of by-products produced during the synthesis.

It is known that N_2O can be used as an oxidising agent. For example, the oxidation of an olefinic compound to an aldehyde or a ketone by means of N_2O is described in GB 649,680 or the equivalent U.S. Pat. No. 2,636,898. Both documents quite generally disclose that the oxidation can in principle be effected in the presence of a suitable oxidation catalyst.

G. L. Panov et al., "Non-Catalytic Liquid Phase Oxidation of Alkenes with Nitrous Oxide. 1. Oxidation of Cyclohexene to Cyclohexanone", React. Kinet. Catal. Lett. Vol. 76, No. 2 (2002) p. 401-405; and K. A. Dubkov et al., "Non-Catalytic Liquid Phase Oxidation of Alkenes with Nitrous Oxide. 2. Oxidation of Cyclopentene to Cyclopentanone", React. Kinet. Catal. Lett. Vol. 77, No. 1 (2002) p. 197-205 likewise describe oxidations of olefinic compounds with N_2O. "Liquid Phase Oxidation of Alkenes with Nitrous Oxide to Carbonyl Compounds" by E. V. Starokon et al. in Adv. Synth. Catal. 2004, 346, 268-274 also includes a mechanistic study of the oxidation of alkenes with N_2O in the liquid phase.

The synthesis of carbonyl compounds from alkenes with N_2O is also described in various international patent applications. For instance, WO 03/078370 discloses a process for preparing carbonyl compounds from aliphatic alkenes with N_2O. The reaction is carried out at temperatures in the range from 20 to 350°C and pressures of from 0.01 to 100 atm. WO 03/078374 discloses a corresponding process for preparing cyclohexanone. According to WO 03/078372, cyclic ketones having from 4 to 5 carbon atoms are prepared. According to WO 03/078375, cyclic ketones are prepared under

these process conditions from cyclic alkenes having from 7 to 20 carbon atoms. WO 03/078371 discloses a process for preparing substituted ketones from substituted alkenes. WO 04/000777 discloses a process for reacting di- and polyalkenes with N_2O to give the corresponding carbonyl compounds.

A more recent study of the use of N_2O as an oxidising agent can be found in V.N. Parmon et al "Nitrous oxide in oxidation chemistry and catalysis: application and production", Catalysis Today, 100 (2005), 115-131.

Various preparation processes for N_2O are known in the art. For example, WO 98/25698 discloses a process for preparing N_2O by catalytic partial oxidation of NH_3 with oxygen. According to WO 98/25698, a catalyst composed of manganese oxide, bismuth oxide and aluminium oxide is used, which leads to N_2O with high selectivity. A similar catalyst system is also described in detail in a scientific study (Noskov et al., Chem. Eng. J. 91 (2003) 235-242). U.S. Pat. No. 5,849,257 likewise discloses a process for preparing N_2O by oxidation of ammonia. The oxidation takes place in the presence of a copper-manganese oxide catalyst. WO 00/01654 discloses a process in which N_2O is prepared by reducing a gas stream comprising NO_x and ammonia.

N_2O is also obtained as a by-product in various chemical processes, especially in oxidations with nitric acid. For example, in industry, the synthesis of adipic acid is generally carried out via the nitric acid oxidation of cyclohexanol, cyclohexanone or a mixture of the two (commonly referred to as ketone-alcohol oil or KA oil). N_2O is the major by-product in the synthesis, along with other nitrogen oxides, carbon dioxide, and some lower molecular mass dicarboxylic acids. Some by-products arising from impurities in the KA oil are also present.

Other examples of processes in which N_2O is obtained as a by-product are the oxidation of cyclododecanone and/or cyclododecanol with nitric acid to give dodecanedicarboxylic acid and the partial oxidation of NH_3 to NO.

The formation of N_2O in these processes presents a number of problems for industry. For example, as the recovery and purification processes are generally not cost effective,

the usual practice is to abate the N_2O as waste gas and no commercial value is derived from it. This has consequences because N_2O is a strong greenhouse gas (at least 100 times the strength of CO_2) and industry is coming under increasing pressure to reduce the emission of greenhouse gases into the atmosphere. Therefore, it would be advantageous if N_2O produced in industrial processes could be captured and used in an economical and efficient way, for example as an oxidising agent in a subsequent chemical reaction, rather than simply being abated as a waste gas.

US 2008/0274032 describes a process for purifying and concentrating N_2O containing off-gases obtained from various chemical processes. However, the process requires a number of successive absorption and desorption steps and uses a combination of organic solvents and water, to produce the N_2O solutions. Thus, the recovery of the purified N_2O requires extensive and expensive downstream refining steps. Furthermore, it is not contemplated that the N_2O solutions obtained by the processes can be used directly in a further reaction process.

The inventors have found that the use of an ionic liquid enables N_2O produced in industrial processes to be readily and selectively absorbed and thus captured for later use, so avoiding unfavourable abatement of gaseous N_2O into the atmosphere. The N_2O-containing ionic liquid thus obtained has particularly advantageous properties such as thermal stability and low vapour pressure which enables the N_2O to be recovered relatively easily, if desired. Ionic liquids are also good solvents for a range of other substrates, and this enables the N_2O-containing ionic liquids obtained to be used directly as oxidising agents in further chemical processes.

Moreover, N_2O-containing ionic liquids as oxidising agents have been found to give favourable conversion of reactants to products, and to lead to higher selectively for the desired product than corresponding reactions in the absence of an ionic liquid. Thus, the use of N_2O-containing ionic liquids gives higher yields and higher conversion to the desired reaction products.

The invention provides the use of an N_2O-containing ionic liquid as a reagent in a chemical reaction. The N_2O-containing ionic liquid can be used as a reagent in a number

of different reactions, for example as an oxidising agent, as an epoxidising agent, in oxidative dehydrogenation reactions and as a catalyst.

In one aspect, the invention provides the use of an N_2O-containing ionic liquid as a reagent in a chemical reaction for the purpose of improving the reaction yield and conversion compared to a reaction conducted in the absence of an ionic liquid. In another aspect, the invention provides the use of an N_2O-containing ionic liquid as a reagent in a chemical reaction for the purpose of improving the selectivity of the reaction for the desired product compared to a reaction conducted in the absence of an ionic liquid.

In other aspects, the invention also provides a method corresponding to the use described herein. Thus, the invention provides a method of conducting a chemical reaction, the method comprising contacting one or more reactants with an N_2O-containing ionic liquid.

As used herein, an N_2O-containing ionic liquid describes a composition in which an ionic liquid and N_2O are associated with each other. For example, in one embodiment the N_2O-containing ionic liquid is a solution of N_2O in an ionic liquid. However, the N_2O-containing ionic liquids of the invention are not limited to such physical solvent-solute interactions between the ionic liquid and the N_2O and they also encompass relationships in which there is some chemical interaction between the N_2O and the ionic liquid, for example the formation of a lewis acid/base adduct, or the chemical reaction of the N_2O and the ionic liquid to form N_2O and ionic liquid derivatives which themselves are associated with each other for example the formation of an intermediate peroxide or epoxide compound from reaction of the N_2O.

In one aspect, the N_2O-containing ionic liquid is used as an oxidising agent. In another aspect, the invention provides the use or method described above, wherein the N_2O-containing ionic liquid is obtained via the reaction process described herein.

The N_2O-containing ionic liquid can be used as an oxidising agent in a number of different oxidation reactions. For example, in one aspect, the use or method comprises

oxidising benzene to produce phenol or oxidising cyclohexene to cyclohexanol, cyclohexanone or a mixture of cyclohexanol and cyclohexanone. In another aspect the use or method comprises the oxidative dehydrogenation of an alcohol to a ketone or the oxidative dehydrogenation of butene to 1,3-butadiene.

In one aspect, the N_2O-containing ionic liquid is used as an epoxidising agent. For example, the N_2O-containing ionic liquid is reacted with an olefin to produce an epoxide.

In another aspect, the use of the N_2O-containing ionic liquid, or the method of conducting a chemical reaction, comprises the oxidation of cyclopentene to cyclopentanone.

In yet another aspect, the use of the N_2O-containing ionic liquid, or the method of conducting a chemical reaction, comprises the oxidation of cyclododecene (CDDC) to cyclododecanone (CDDK).

Ionic liquids or low temperature molten salts are known in the art as very low volatility solvents suitable for carrying out a range of chemical processes. For example, the solubility of N_2O in certain ionic liquids has been investigated *("Anion Effects on Gas Solubility in Ionic Liquids", J.Phys.Chem.B 2005, 109, 6366-6374, Brennecke et al.)*

However it has not previously been disclosed that ionic liquids can be employed as selective solvents for absorption of N_2O from a mixture of by-products produced in an oxidation process, particularly an adipic acid synthesis process. Furthermore, the use of an N_2O-containing ionic liquid as a reagent in a chemical reaction has not been investigated previously.

An ionic liquid is a liquid that contains essentially only ions, i.e. molten salts, although some ionic liquids are in a dynamic equilibrium wherein the majority of the liquid is made up of ionic rather than molecular species. In the art, the term "ionic liquid" is used to refer to such salts whose melting point is below 100°C. Such ionic liquids are sometimes also referred to as room temperature ionic liquids (RTIL). Ionic liquids are

typically salts of bulky and asymmetric organic cations. For instance, US 7,157,588 teaches compositions based on N-substituted pyrrolidinones having a pendant ammonium cation separated from the pyrrolidone ring by a variable length alkyl spacer. WO 2006/136529 teaches pyrazolium alkylsulfates and a method for their production. WO 2008/150842 describes a broad class of ionic liquids comprising heterocyclic nitrogen containing cations.

The term "ionic liquid" as used in the context of the invention refers to a salt whose melting point is below about 100°C. Optionally, the ionic liquids used in the invention comprise an organic cation. Organic cations are cations containing at least one carbon atom. Typically, the organic cation contains at least one alkyl group. Conveniently, the ionic liquid comprises an asymmetric organic nitrogen containing cation. In one aspect, the ionic liquids used in the invention comprise an organic anion. Organic anions are anions containing at least one carbon atom. Typically, organic anions are anions containing at least one carbon atom but excluding carbonate anions or bicarbonate anions. In another aspect, the ionic liquids used in the invention comprise an organic cation and an organic anion, wherein the organic cation and anion are as defined above. In yet another aspect, the ionic liquids used in the invention comprise an inorganic anion.

The use and method of the present invention may utilise a single ionic liquid or a mixture of two or more ionic liquids. Typically, one or two, and typically only one ionic liquid is used.

Thus in one embodiment the ionic liquid comprises a cation selected from one or more of 1-alkylpyridinium (N-alkylpyridinium); alkyl- or polyalkyl-pyridinium; alkyl- or polyalkyl-guanidinium (particularly tetraalkylguanidinium); phosphonium (PR_4^+); alkyl- or polyalkyl-phosphonium (particularly tetraalkylphosphonium); imidazolium, alkyl- or polyalkyl-imidazolium (particularly 1,3-dialkylimidazolium); ammonium (NR_4^+), alkyl- or polyalkyl-ammonium (particularly tetraalkylammonium); alkyl- or polyalkyl-pyrazoliuml; alkyl- or polyalkyl-pyrrolidinium (particularly dialkylpyrrolidinium); alkyl- or polyalkyl-piperidinium (particularly 3-methylpiperidinium); alkyl- or polyalkyl-azepanium; alkyl or polyalkyl-azepinium, alkyloxonium, and alkysulfonium. Each R group of the phosphonium and ammonium cations may be independently selected from

hydrogen, hydroxyl, alkyl, alkyl ethers, alkyl esters, alkyl amides, alkyl carboxylic acids, or sulfonate. Examples include N-ethylpyridinium; N-methyl-N-alkylpyrrolidinium such as N-butyl-N-methylpyrrolidinium; N-methyl-N-(butyl-4-sulfonic acid)pyrrolidinium; 1-alkyl-3-alkylimidazolium such as 1-butyl-3-methylimidazolium (bmim) and N-methyl-N'-ethylimidazolium; trimethyl-(2-hydroxyethyl)ammonium; and tetradecyltrihexylphosphonium ([CAS# 258864-54-9], referred to herein as $[P_{66614}]$).

A number of different anions may be employed, including inorganic anions and large organic anions. In one embodiment, the anion of the ionic liquid(s) is selected from one or more of a halide (conveniently chloride, bromide or iodide), nitrate, an alkylsulfonate or alkyl polyalkoxysulfonate, hydrogensulfonate, hexafluorophosphate and tetrafluoroborate, and other anions based on nitrogen, phosphorous, sulphur, boron, silicon, selenium, tellurium, gallium, indium, halogens, and oxoanions of metals. Suitable anions include, but are not limited to tetrafluoroborate (BF_4^-), bis(trifluoromethylsulfonyl)imide (NTf_2^-), hydrogensulfate (HSO_4^-), methylsulfonate, trifluoromethylsulfonate, methoxyethylsulfonate, 2-methoxyethylsulfonate, ethoxyethylsulfonate, 2-ethoxyethylsulfonate, (methoxypropoxy)propylsulfonate, 1-(1-methoxypropoxy)-propylsulfonate, (methoxyethoxy)-ethylsulfonate, 1-(1-methoxyethoxy)-ethylsulfonate, methyl(diethoxy)ethylsulfonate, 1-methyl(diethoxy)ethylsulfonate, toluene-4-sulfonate, trifluoromethylsulfonyl, carboxylate, formate, acetate, dicyanimide, trifluoroacetate, bis(trifluoromethanesulfonyl)imide, $[Ga_2Cl_7]^-$, $[InCl_4]^-$ and $[In_2Cl_7]^-$.

When a mixture of two or more ionic liquids is used, the cation and/or the anion of each of the ionic liquids present in the mixture may be the same or different. In one embodiment, the or each ionic liquid comprises at least one $C_2 - C_6$ alkyl group. The $C_2 - C_6$ alkyl group may be a substituent on either the anion or the cation of the ionic liquid(s). Optionally, the $C_2 - C_6$ alkyl group is a substituent on the cation of the ionic liquid(s).

In one embodiment, the ionic liquid is selected from; 1-n-butyl-3-methylimidazolium$[Ga_2Cl_7]$, 1-n-butyl-3-methylimidazolium$[In_2Cl_7]$, 1-n-butyl-3-methylimidazolium bis(trifluoromethylsulfonyl)imide,

tetradecyltrihexylphosphonium[Ga_2Cl_7] tetradecyltrihexylphosphonium [$InCl_4$] and tetradecyltrihexylphosphonium bis(trifluoromethylsulfonyl)imide.

The invention also provides a reaction process comprising the steps, (a) contacting a reactant with a reagent to produce a product and a mixture of by-products comprising N_2O; and (b) contacting the mixture of by-products with an ionic liquid to absorb the N_2O to produce an N_2O-containing ionic liquid.

The reaction process can be any one in which N_2O is produced. Thus, the reagent can be an oxidising agent, a reducing agent, a catalyst, a nucleophile or an electrophile. In one aspect, the reaction is an oxidation reaction, the reagent is an oxidising agent and the product is an oxidised product.

Thus, N_2O present in a mixture of by-products produced in a reaction process, for example an oxidation process, can be absorbed, for example selectively, into an ionic liquid to form an N_2O-containing ionic liquid. This process therefore enables the N_2O to be recovered and used, rather than it being abated into the atmosphere.

In one aspect, the invention provides an oxidation process as described above, wherein the oxidising agent is a nitrogen containing oxidising agent. For example, the oxidising agent is N_2O or nitric acid. Typically, the oxidising agent is nitric acid.

In the aspect of the invention where the oxidising agent is N_2O, the N_2O present in the mixture of by-products represents the portion of the N_2O used as the oxidising agent which is not consumed during the oxidation reaction. Thus, in this embodiment, the unreacted N_2O can be recovered and reused in another oxidation process, or recycled back into the same oxidation process.

In one aspect, the invention provides an oxidation process comprising steps (a) and (b) as described above, wherein the reactant is selected from cyclohexanol, cyclohexanone or a mixture of cyclohexanol and cyclohexanone. In one embodiment the oxidised product formed in step (a) is adipic acid. In a preferred embodiment, the oxidising agent is nitric acid, the reactant is selected from cyclohexanol, cyclohexanone or a mixture of

cyclohexanol and cyclohexanone and the oxidised product is adipic acid. Thus, the preferred oxidation process of the invention represents the synthesis of adipic acid, in which a mixture of by-products comprising N_2O is produced, the mixture of by-products being contacted with an ionic liquid to absorb the N_2O to produce an N_2O-containing ionic liquid. Thus, in this embodiment, the synthesis of adipic acid is made more economical and environmentally friendly, as the by-product N_2O is recovered for further use and not abated into the atmosphere.

Differences among commercial adipic acid synthesis processes are mainly in the manufacture of the KA oil. In most processes the six carbon atoms of the adipic acid backbone come from benzene. In one process benzene is hydrogenated to cyclohexane and the cyclohexane is oxidised to give the KA oil. In an alternative process, benzene is first oxidised to phenol, the phenol then being hydrogenated to give the KA oil.

Thus, in one aspect of the oxidation process of the invention, the reactant is produced by the oxidation of cyclohexane and the cyclohexane is produced by the hydrogenation of benzene.

In another aspect of the oxidation process of the invention, the reactant is produced by the hydrogenation of phenol and the phenol is produced by the oxidation of benzene.

Adipic acid is a commercially important aliphatic dicarboxylic acid. Its primary application is in the production of nylon 6,6. Thus, in one aspect, the invention provides a process for the manufacture of nylon 6,6 from the adipic acid produced via the oxidation process described above. Therefore, the process of the invention allows for a more economical and environmentally friendly synthesis of nylon, owing to the recovery and re-use of the N_2O produced in synthesis of the intermediate adipic acid.

In one aspect, in addition to N_2O, the mixture of by-products obtained in step (a) of the process of the invention contains one or more components selected from; oxides of carbon (for example, carbon monoxide and carbon dioxide), nitrogen, oxides of nitrogen (for example, NO, NO_2, N_2O_3, N_2O_4 and N_2O_5 – known collectively as NOx) and C_1-C_5 dicarboxylic acids. The N_2O is separated from the other components of the mixture of

by-products owing to the selective absorption of the N_2O into the ionic liquid to form the N_2O-containing ionic liquid. The solubility of NOx in ionic liquids is very low (see J. Phys. Chem. B 2007, 111, 7778-7785) which gives a solubility of 2.5g/Kg of EMIM NTf_2 compared with 50 to 100 g/Kg for N_20. Carbon monoxide and nitrogen are very insoluble in typical ionic liquids (see J. Phys. Chem. B 2005, 109, 6366-6374 in which the authors report undetectable solubility for carbon monoxide in ionic liquids). Carbon Dioxide has a solubility similar to N_2O in Ionic Liquids, but its presence as an inert in the oxidant system is not a problem for the invention.

In one embodiment, the oxidation process of the invention further comprises a step (c) of using the N_2O-containing ionic liquid produced in step (b) as an oxidising agent. Optionally, the use of the N_2O-containing ionic liquid comprises the oxidation of benzene to produce phenol.

In one aspect, the N_2O-containing ionic liquid produced in step (b) is recycled and used as an oxidising agent to oxidise benzene to phenol, said phenol being subsequently hydrogenated to produce the reactant used in step (a) of the process of the invention. Thus, in this aspect, the by-product N_2O is recovered and recycled back into the process.

For example, in the case of the synthesis of adipic acid described above, starting material benzene is oxidised to produce phenol, and the phenol is hydrogenated to produce the KA oil. The KA oil is then contacted with nitric acid, according to the embodiment described above, to produce adipic acid and a mixture of by-products containing N_2O. The mixture of by-products containing N_2O is contacted with an ionic liquid to absorb the N_2O to produce an N_2O-containing ionic liquid. The N_2O-containing ionic liquid thus obtained is then recycled back into the synthesis and used as an oxidising agent in the oxidation of starting material benzene to produce phenol. Thus, the invention greatly increases the economy of the process, as N_2O, which is conventionally considered to be a waste by-product, can now be used as an oxidising agent in the synthesis.

In one aspect, the invention provides an oxidation process described above, further comprising the step of recovering the N_2O from the N_2O-containing ionic liquid by desorption of the N_2O. For example, the N_2O is recovered via thermal desorption or

pressure swing desorption. Conveniently, the N_2O is recovered via thermal desorption. The ionic liquids used in the present invention are suitable for this process owing to their high capacity for the reversible absorption of N_2O. That is, N_2O is readily absorbed in the ionic liquids but it is also readily desorbed by heating or lowering the pressure. Typically, the temperature of the desorption step is at or below 200°C. Preferably, the temperature is at or below 150°C, more preferably at or below 100°C, more preferably, at or below 50°C.

Typical saturation solubilities for the N_2O-containing ionic liquids of the present invention at room temperature are approximately 0.3, 0.4, 0.5, 0.6, 0.7, 0.8 or 0.9 mol% for a Henry's constant of 30. At higher pressure and lower temperature solubilities above 1 mol% may be achieved. More preferably, solubilities above 5 mol%, more preferably above 10 mol %, more preferably above 15 mol% can be achieved.

In certain embodiments the N_2O-containing ionic liquid is obtained from a commercial adipic acid synthesis. Such adipic acid syntheses are described by M.T Musser, Ullmann's Encyclopedia of Chemical Technology, 5th edition, A1, 259, incorporated herein by reference. Adipic acid synthesis results in the production of N_2O as a by-product. Accordingly, contacting the N_2O with an ionic liquid enables an N_2O-containing ionic liquid to be obtained as a useful additional product form the adipic acid synthesis.

In a further embodiment the N_2O can be obtained as a by-product in the off gas from a nitric acid production process. In a still further embodiment the N_2O can be produced as a by-product of a hydroxylamine production process.

The invention is illustrated by the non-limiting embodiments described below, in which the following figures are referred to:

Figure 1 shows the GC analysis of the reaction mixture for the reaction of CDDC with N_2O at 30bar, 200°C for 12 hours, in the absence of an ionic liquid.

Figure 2 shows the GC analysis of the organic layer of the reaction mixture for the reaction of CDDC with N_2O-containing [bmim][NTf_2] ionic liquid, at 30bar, 200°C for 12 hours.

Figure 3 shows the ^1H NMR analysis of the ionic liquid layer of the reaction mixture for the reaction of CDDC with N_2O-containing [bmim][NTf_2] ionic liquid, at 30bar, 200°C for 12 hours.

Figure 4 shows ^1H NMR analysis of the ionic liquid layer of the reaction mixture for the reaction of CDDC with N_2O-containing [P_{66614}][NTf_2] ionic liquid, at 30bar, 200°C for 12hours.

Figure 5 shows a summary of % CDDC conversion for reaction of CDDC with N_2O and various N_2O-containing ionic liquids at 200°C, 45bar for 12 hours.

Figure 6 shows a GC calibration curve for CDDC.

Figure 7 shows a GC calibration curve for CDDK.

Experimental

Materials

Cyclododecene (CDDC) (mixture *cis/trans*) was purchased from sigma-Aldrich. Analysis by ^1H NMR and GC-MS show that the mixture content is 25.5 % *cis* and 71.6 % *trans*. [bmim][NTf_2] was synthesised in the laboratory. [bmim][Ga_2Cl_7] was prepared by reacting [bmim]Cl with $GaCl_3$ (2 eq.). [P_{66614}]Ga_2Cl_7 was made from the corresponding chloride [P_{66614}]Cl using $GaCl_3$ in the laboratory. [P_{66614}]$InCl_4$ was made from the corresponding chloride [P_{66614}]Cl using $InCl_3$ in the laboratory. [P_{66614}]NTf_2 was made in the laboratory from [P_{66614}]Cl. Nitrous oxide was purchased from Air liquide.

Neat reactions

General procedure

A 20 cm^3 autoclave was initially charged with 1 g of cyclododecene (6.01mmol), sealed and flushed with argon. Subsequently, N_2O (10 to 45 bar) was injected to the autoclave and the temperature increased to 200 °C. After 12 h reaction, the autoclave was cooled and decompressed. After dilution in cyclohexane, a sample was analysed by means of quantitative GC (see **Figure 1**). The different results are summarised in Table 1.

Table 1

Pressure N_2O injected (bar) at 20 °C	Temperature (°C)	Maximum pressure in the autoclave	Time (h)	Conversion (%)	CDDK-selectivity (%)
10	200	16	12	8	≥ 99
20	200	38	12	15	98*
30	200	53	12	18	96*
45	200	78	12	28	93*

*formation of epoxide and other products was also observed by GC-MS

Reaction with N_2O-containing ionic liquid

General procedure

A 20 cm^3 autoclave was initially charged with 1 g of cyclododecene (6.01mmol) and 1 g of ionic liquid, sealed and flushed with argon. Subsequently, N_2O (10 to 30 bar) was injected to the autoclave and the temperature increased to 200 °C. After 12 h reaction, the autoclave was cooled and decompressed. A biphasic system was obtained in this case. The organic layer (top layer) was analysed by means of quantitative GC (see **Figure 2**) while the ionic liquid layer was analysed by ^1H NMR (see **Figure 3**). The different results are summarised in Table 2. The conversion of cyclododecene is based on the GC analysis since only a small amount of cyclododecanone was observed in the ionic liquid layer (the real conversion values should be slightly higher then those depicted in Table 2).

Table 2

Solvent	Pressure N_2O injected (bar) at 20 °C	Temperature (°C)	Maximum pressure in the autoclave	Time (h)	Conversion (%)	CDDK-selectivity (%)
[bmim][NTf_2]	10	200	15	12	4	≥ 99
[bmim][NTf_2]	20	200	35	12	10	≥ 99
[bmim][NTf_2]	30	200	50	12	16	≥ 99
[bmim][NTf_2]	45	200	75	12	24	98

[bmim][Ga_2Cl_7]	30	200	50	12	16	≥ 99
[bmim][In_2Cl_7]	30	200	47	12	4	≥ 99

Further reactions were carried out using phosphonium ionic liquids in an analogous manner to the reactions carried out above for [bmim] ionic liquids. The results are shown in Table 3 below and **Figure 4** (NMR analysis).

Table 3

Solvent	Pressure (bar)	Temperature (°C)	Maximum pressure in the autoclave	Time (h)	Conversion (%) (^{1}H NMR)	CDDK-selectivity (%)
[P_{66614}][NTf_2]	30	200	47	12	40	
[P_{66614}] [NTf_2]	45	200	74	12	40	98
[P_{66614}] [Ga_2Cl_7]	30	200	50	12	Black viscous solution *	
[P_{66614}] [Ga_2Cl_7]	30	200	50	3	*	
[P_{66614}] [Ga_2Cl_7]	30	20	30	3	*	
[P_{66614}] [Ga_2Cl_7]	0	200	0	3	*	
[P_{66614}][InCl4]	30	200	50	12	35	
[P_{66614}][InCl4]	45	200	75	12	50	90

*1H NMR shows that no CDDC is left in the solution however no formation of CDDK is observed

GC method:

Instrument: Agilent 6890N GC

Column: HP-5 (5% phenyl)-methylsiloxane

Oven program

Initial temperature: 40 °C

Ramps: rate (°C/min)	final temp.	final time (min)
15	200	0.00
50	320	2.00

GC calibration curves are shown in **Figures 6** and **7**.

NMR measurements were carried out on a Bruker Avance DPX, 300 Mhz instrument.

Claims

1. Use of an N_2O-containing ionic liquid as a reagent in a chemical reaction.

2. Use according to claim 1, wherein the N_2O-containing ionic liquid is used as an oxidising agent.

3. Use according to claim 1 or 2, wherein the N_2O-containing ionic liquid is obtained via a reaction process comprising the steps:

   (a) contacting a reactant with a reagent to produce a product and a mixture of by-products comprising N_2O; and
   (b) contacting the mixture of by-products with an ionic liquid to absorb the N_2O to produce an N_2O-containing ionic liquid.

4. Use according to claim 3, wherein the reaction is an oxidation reaction, the reagent is an oxidising agent and the product is an oxidised product.

5. Use according to claim 4, wherein the oxidising agent is nitric acid.

6. Use according to claim 4 or 5, wherein the reactant is selected from cyclohexanol, cyclohexanone or a mixture of cyclohexanol and cyclohexanone and the oxidised product is adipic acid.

7. Use according to any one of claims 3 to 6, wherein the reactant is produced by the hydrogenation of phenol.

8. Use according to claim 7, wherein the phenol is produced by the oxidation of benzene.

9. Use according to any one of claims 1 to 8, wherein the use comprises oxidising benzene to produce phenol.

10. Use according to any one of claims 1 to 8, where in the use comprises the oxidative dehydrogenation of an alcohol to a ketone.

11. Use according to any one of claims 1 to 8, wherein the use comprises the oxidative dehydrogenation of butene to 1,3-butadiene.

12. Use according to any one of claims 1 to 8, wherein the use comprises the oxidation of cyclohexene to cyclohexanol, cyclohexanone or a mixture of cyclohexanol and cyclohexanone.

13. Use according to any one of claims 1 to 8, wherein the use comprises the oxidation of cyclododecene to cyclododecanone.

14. Use according to any one of claims 1 to 13, wherein the N_2O-containing ionic liquid comprises an imidazolium cation.

15. Use according to any one of claims 1 to 13, wherein the N_2O-containing ionic liquid comprises an N-methyl-N'-butylimidazolium cation.

16. Use according to any one of claims 1 to 13, wherein the N_2O-containing ionic liquid comprises a phosphonium cation.

17. Use according to any one of claims 1 to 13, wherein the N_2O-containing ionic liquid comprises a tetradecyltrihexylphosphonium cation.

18. A reaction process comprising the steps;

(a) contacting a reactant with a reagent to produce a product and a mixture of by-products comprising N_2O; and

(b) contacting the mixture of by-products with an ionic liquid to absorb the N_2O to produce an N_2O-containing ionic liquid.

19. The reaction process according to claim 18, wherein the reaction is an oxidation reaction, the reagent is an oxidising agent and the product is an oxidised product.

20. The reaction process according to claim 19, wherein the oxidising agent is nitric acid.

21. The reaction process according to claim 20, wherein the reactant is selected from cyclohexanol, cyclohexanone or a mixture of cyclohexanol and cyclohexanone and the oxidised product is adipic acid.

22. The reaction process according to claim 21, wherein the reactant is produced by the hydrogenation of phenol.

23. The reaction process according to claim 22, wherein the phenol is produced by the oxidation of benzene.

24. The reaction process according to any one of claims 18 to 23, further comprising step (c) of using the N_2O-containing ionic liquid produced in step (b) as a reagent in a chemical reaction.

25. The reaction process according to claim 24, comprising using the N_2O-containing ionic liquid produced in step (b) as an oxidising agent

26. The reaction process according to claim 25, wherein the use of the N_2O-containing ionic liquid comprises the oxidation of benzene to produce phenol, the phenol being used in the process of claim 22.

27. The reaction process according to any one of claims 1 to 6, wherein the N_2O is recovered from the N_2O-containing ionic liquid via desorption.

FIG. 1

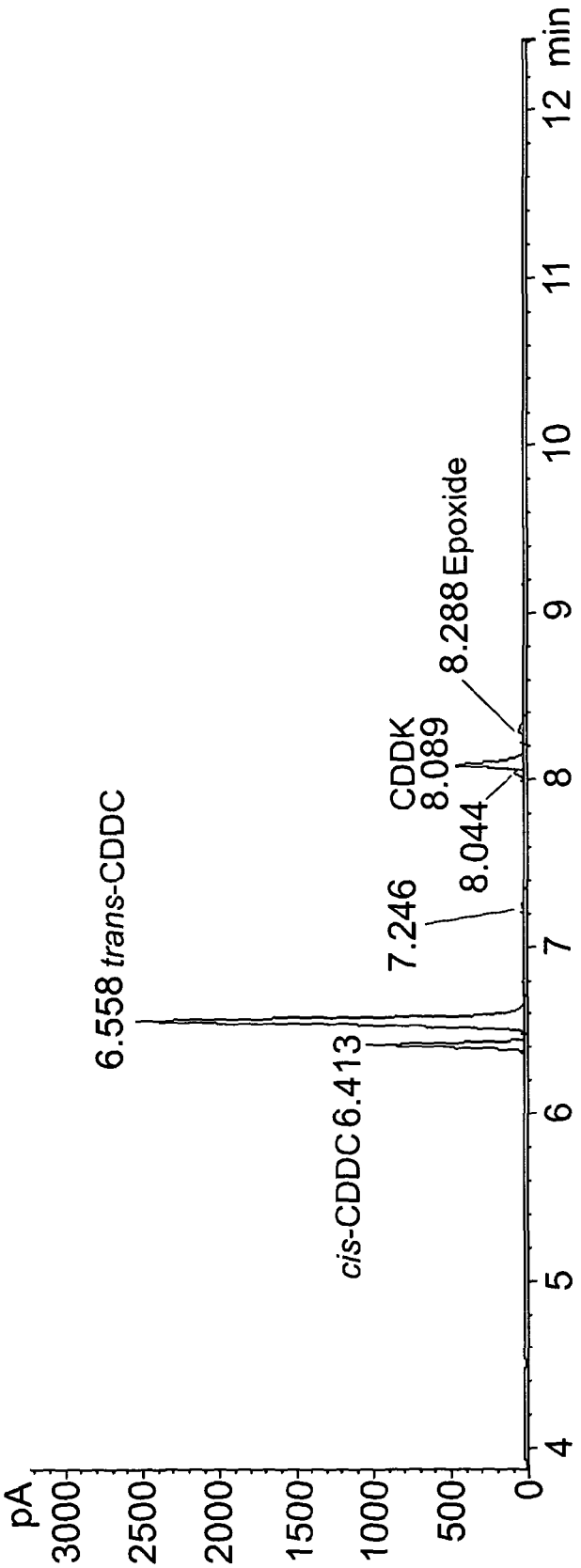

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pA
3000
2500
2000
1500
1000
500
0
4
5
6
7
8
9
10
11
12 min
6.558 trans-CDDC
cis-CDDC 6.413
7.246
8.044
CDDK
8.089
8.288 Epoxide

FIG. 2

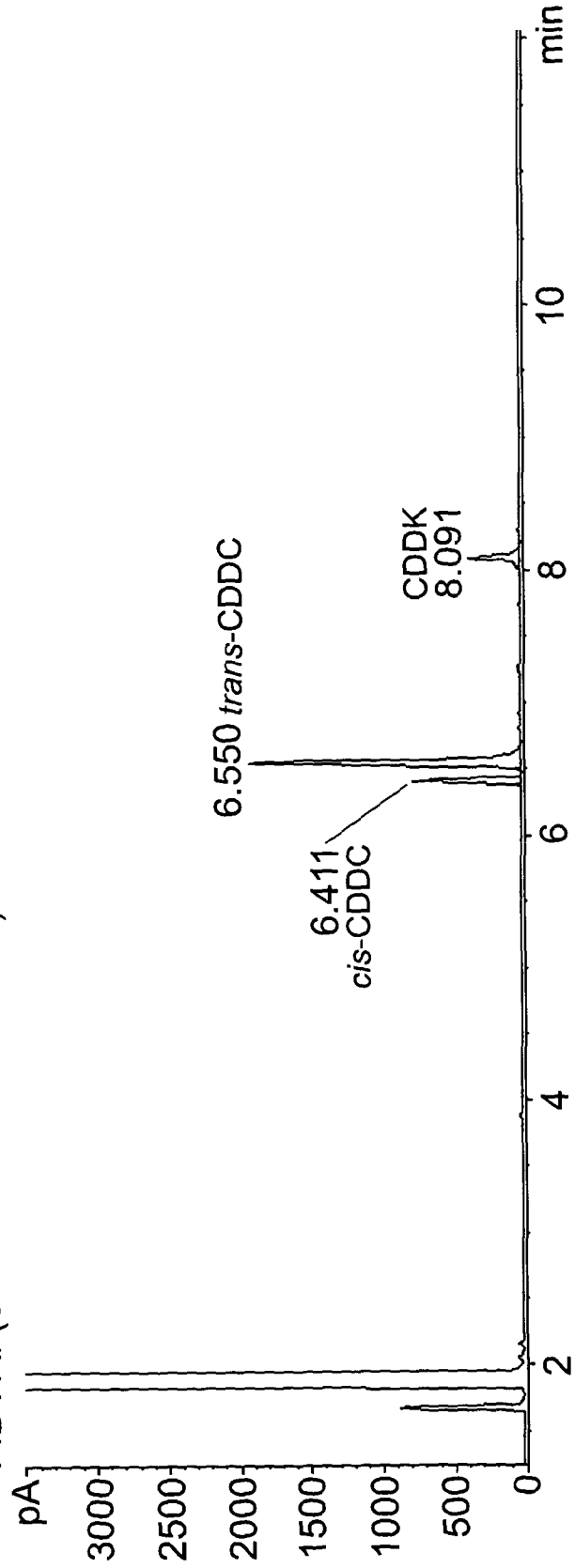

FID1 A. (04SEPT10\091F0101.D)
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2500
2000
1500
1000
500
0
2
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6
8
10
min
6.550 trans-CDDC
6.411
cis-CDDC
CDDK
8.091

FIG. 3

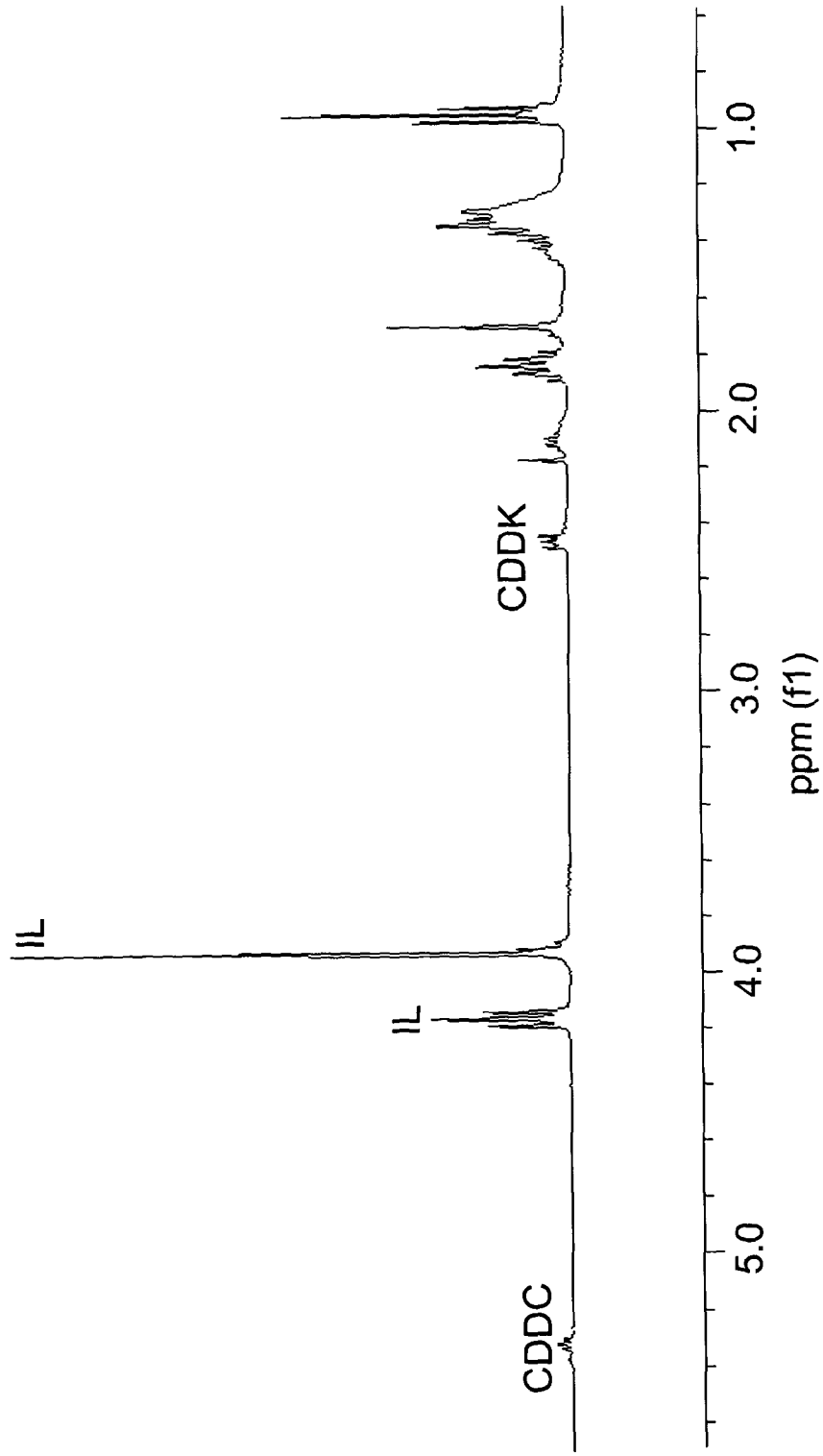


FIG. 4

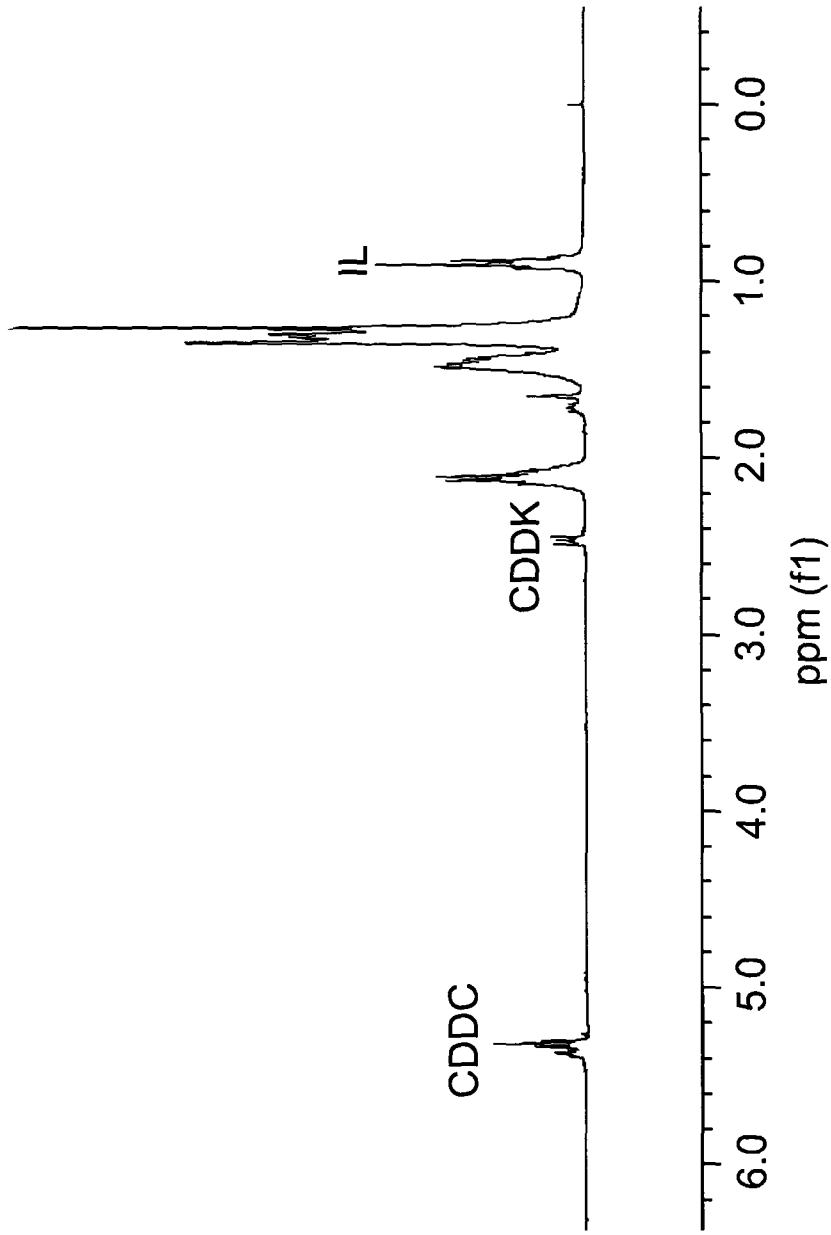


FIG. 5

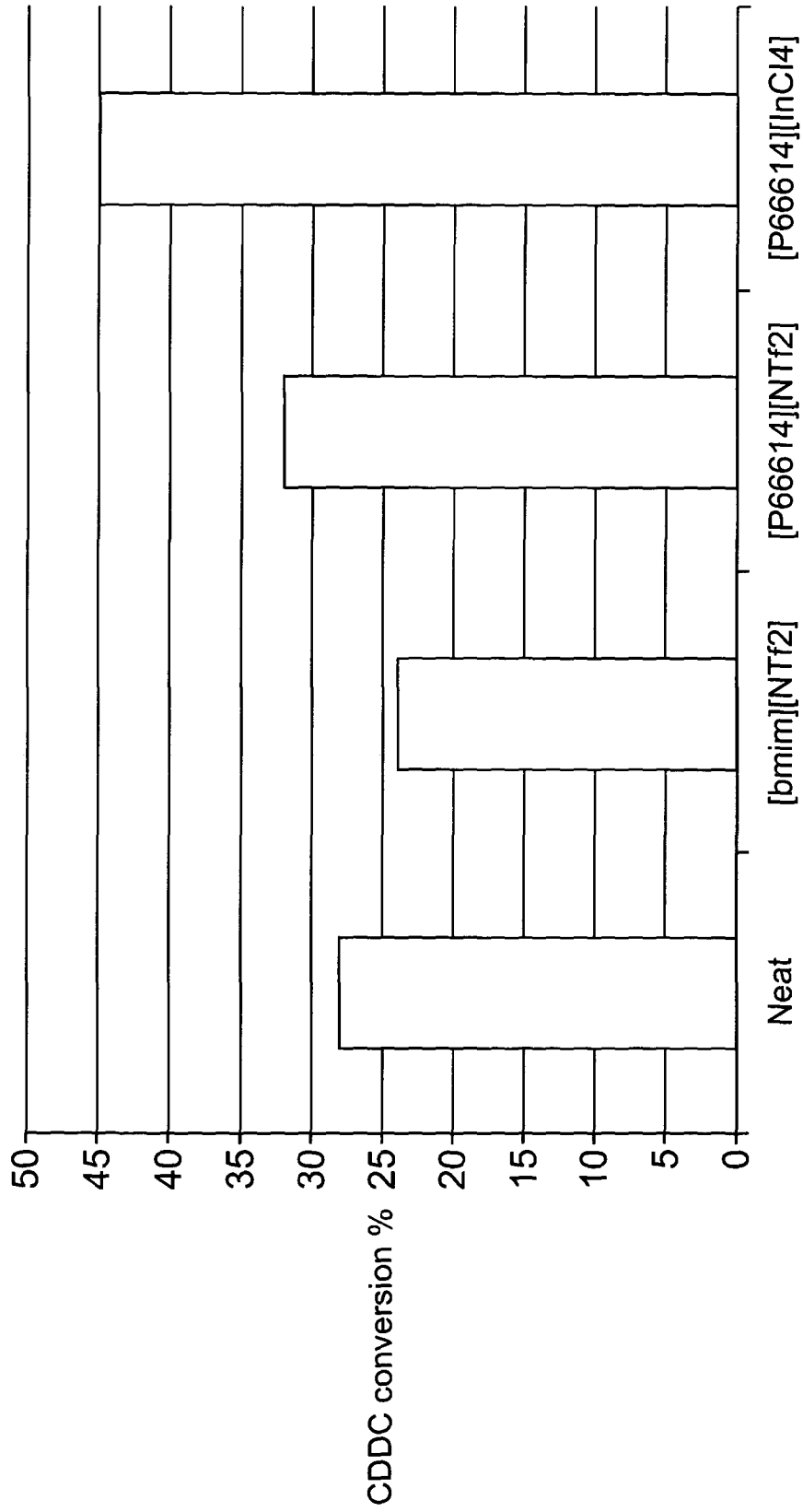

CDDC conversion %
0
5
10
15
20
25
30
35
40
45
50
Neat
[bmim][NTf2]
[P66614][NTf2]
[P66614][InCl4]

FIG. 6

CDDC-GC-Calibration curve

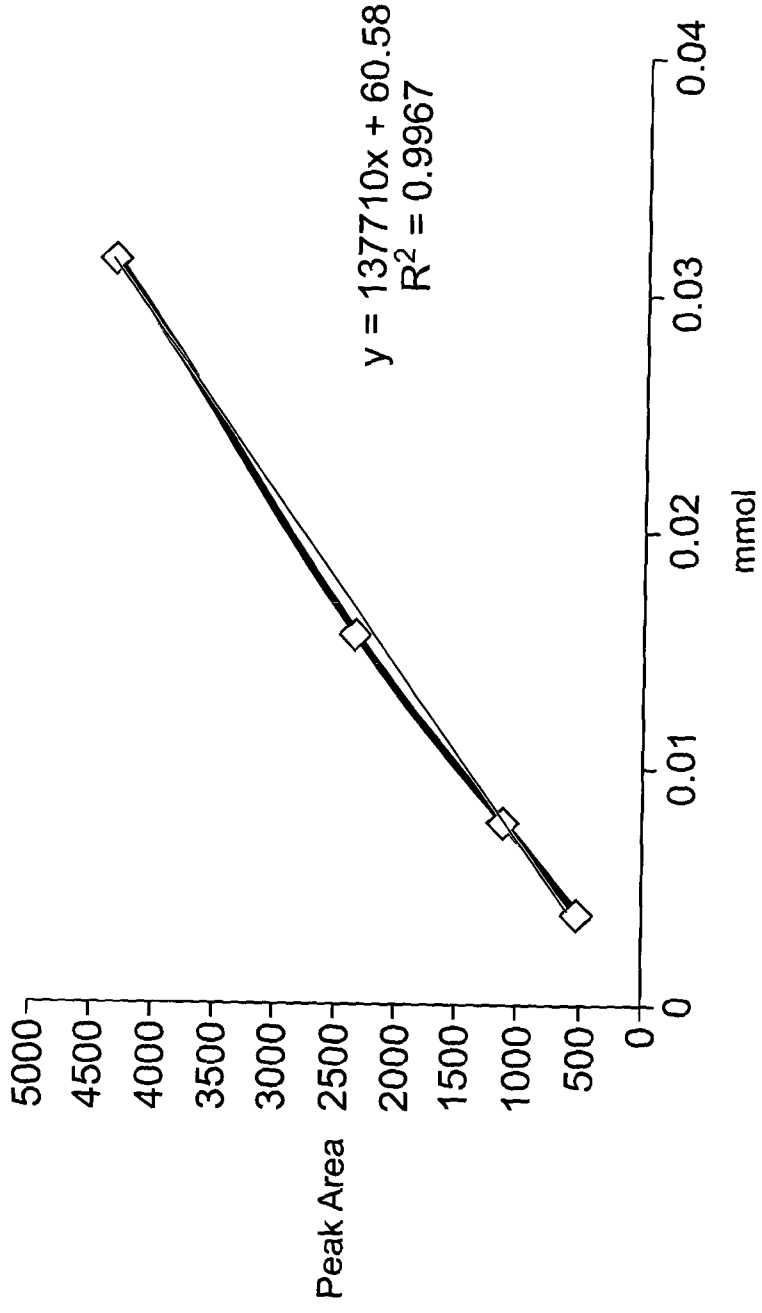


FIG. 7

CDDK-GC-Calibration curve

