



## Properties and Green Applications Based Review on Highly Efficient Deep Eutectic Solvents



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**D**EEP eutectic solvents (Ionic liquids)(DESSs), a new type of low cost and eco-friendly solvent, have fascinating rising interest in chemistry. To recapitulate the properties and significance of deep eutectic solvents (DESSs), this review focus on characteristics of deep eutectic solvents, as well as their applications in electrochemistry, catalytic activity, biodegradability, bio-catalysis, as aromatic hydrocarbons, extraction and separation. The existing data and references are appraisal to go over the developments of DESSs.

**Keywords:** Deep eutectic solvents, Ionic liquids, Green applications

### Introduction

DES solvents also known as ionic liquid (ILs) with peculiar properties such as less volatile, adaptable viscosity, eco-friendly [1] low vapor pressure [2], low cost, biodegradable [3] high soluble strength [4] low or even non-toxic [5] high purity [6] and have similar effects to green solvents (ionic liquids) [7]. Mostly DES solvents are hydrophobic in nature because they are unstable in H<sub>2</sub>O [8]. Deep eutectic solvents[9], (also called low transition temperature mixture LTTM [10] includes one hydrogen bond donor (HBD) and one hydrogen bond acceptor (HBA) in their composition that are capable for self-association by hydrogen bonding. Usually it is putative that, the hydrogen bonding and Vander Waals contact performs self-association process. There is no purification step is required for DES solvents except the mixing of HBA and HBD

which is firstly reported by[11], also state that the DES solvents have low melting and boiling points than HBD and HBA. The Urea (m.p. 133°C) and choline chloride (m.p. 302°C), (2:1) ratio mixture was firstly used as a DES solvent (<100°C melting point) [12]. Abbott have been reported that the mixing of metal salts (organic) and HBD molecule formed complex type DES solvents by lowering the lattice energy of metal salt, as shown in table [13]. Due to lowering in lattice energy, the melting point of DES solvents are less than reacting components [14]. The chemical reagents, categories and formulas for the formation of DES solvents are discussed in table 1.

Type (I) DES Solvent systems that comprise of metal halides, such as ZnCl<sub>2</sub>, mixed with an organic salt [14]. A variety of metal halides including; SnCl<sub>2</sub>, ZnCl<sub>2</sub> and FeCl<sub>3</sub> are reacted with choline chloride (1:2) ratio respectively to

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Received 8/5/2019; Accepted 9/7/2019

DOI: 10.21608/ejchem.2019.12604.1782

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form mixtures, which have freezing points below 100°C [10]. The freezing mixtures of a type (I) DES system [14] is dependent on the metal species in the system at a given concentration ratio [10]. Considering the  $ZnCl_2$  [12]; choline chloride (ChCl) [17] DES solvent system as an example, at low concentrations of  $ZnCl_2$ , the amount of  $ZnCl_3$  is high, and as the molar ratio of  $ZnCl_2$  increases, the larger  $Zn_2Cl_5$  species becomes more prevalent, and the concentrations of  $ZnCl_3$  decreases [9]. The prevalence of the  $Zn_2Cl_5$  species results in weaker electrostatic forces, which decreases lattice energy of DES solvents resulting in decrease in freezing temperature [9]. However, the range is limited for those anhydrous metal hydrides which have low melting points to form type (I) DES solvents [18].

Type (II) DES solvents substitute anhydrous metallic salt with a hydrated metallic salt (anionic), which are highly efficient [19] and removes problems with moisture sensitivity and the necessity for dryness [15]. Type (II) DES solvents do not require the (IL) synthesis methods in which conjunction with moisture insensitivity potentially enables their use in large scale industrial applications [20].  $CrCl_3 \cdot 6H_2O$  can be mixed with ChCl to form a type (II) DES solvents, but it is not possible to form a DES solvents with anhydrous  $CrCl_3$  even if 6 molar equivalents of  $H_2O$  are added, which indicates the hydrated water are part of the Cr speciation [21]. Type (I and II) DES solvents have not solely interaction through ionic bond, however they have interaction of hydrogen bonding between the metallic salt and quaternary ammonium salt [12]. In contrast, ILs network through ionic interactions, type (I and II) DES solvents cannot be regarded as ILs method [13].

Type (III) DES solvents includes HBD donor molecules (poly-carboxylic acids, poly-alcohols and poly-amides) which are hydrophobic, biodegradable and easily synthesized [11]. One of the first type (III) DES solvents to be studied

involved urea and ChCl (2:1) ratio respectively, which had freezing point 12°C [11]. Abbott have used phenolic di-carboxylic acids to form DES solvents with ChCl and demonstrated a 2:1 ratio for the eutectic composition as observed for the Urea: ChCl DES system, which indicates that 2 carboxylic acid molecules in complex form with the chloride ion [9]. Mono-carboxylic acids were also tested in the studies by the Abbott group, but found DES solvent formation was not possible in many cases [9]. However freezing point of DES solvents is affected by lattice energy of HBD donor molecule and organic salt [22].

Type (IV) DES solvents use a hydrated metallic salt as a replacement of organic salt that was used for the formation of type (I, II and III). Early investigations into type (IV) DES solvents studied by Abbott group such as  $ZnCl_2$  [12] with HBD donor molecule including; acetamide, 6-hexanediol [23], urea and 1,2-ethanediols [16], and found the eutectic composition was affected by strength, HBD donor molecule and metallic halide species [24]. Abbott has built upon the initial studies with  $ZnCl_2$ , and has demonstrated that a scope of progress metals can be fused into surrounding temperature eutectic blends.  $CrCl_3 \cdot 6H_2O$  has been shown to form a type (IV) DES solvents when complexed with urea, glycerol or ethylene glycol [21]. Also hydrophobic DES solvents include decanoic, lidocaine acid and quaternary ammonium salt (Tetra butyl ammonium chloride ( $N_{7777}$ -Cl), Methyl trioctylammonium chloride ( $N_{8881}$ -Cl), Tetraheptylammonium Chloride ( $N_{7777}$ -Cl), Tetraoctylammonium chloride ( $N_{8888}$ -Cl), Tetraoctylammonium bromide ( $N_{8888}$ -Br) and Methyltrioctylammonium bromide ( $N_{8881}$ -Br) which are used for adsorption metallic ions from water [25, 26]. The other HBA and HBD in DES solvents are; (a) Halogens containing Salts; (b) Hydrogen bond donors; as shown in Fig. 1.

TABLE 1: Composition of DESs

| Type  | Categories                            | General Term's                | Compounds                               | References |
|-------|---------------------------------------|-------------------------------|---|------------|
| (I)   | Organic Salt + Metallic Salt          | $(Cat)^+(X) n(MCl)_x$         | $ZnCl_2$ + Choline chloride             | [14]       |
| (II)  | Hydrated metallic salt + Organic Salt | $(Cat)^+(X).n(MCl)_x.(yH_2O)$ | $CoCl_2 \cdot 6H_2O$ + Choline Chloride | [15]       |
| (III) | HBD donor molecule + metal salt       | $Cat^+X.nRZ$                  | Choline Chloride + urea                 | [11]       |
| (IV)  | HBD donor molecule + metal salt       | $(MCl)^+y (RZ) + MCl + y + 1$ | $ZnCl_2$ + Urea                         | [16]       |

### *Properties of deep eutectic solvents*

The melting point of DES mixture is lower as compared to individual components. The DES solvents can be hydrophilic or hydrophobic depends on the type of extraction. The metal salts (ionic compounds) exhibit high solubility due to high polarity and ionic nature of DES solvents [27]. Decanoic acid is highly hydrophobic compound has ability to donate hydrogen bond and used in hydrophobic DES solvents that are consist of a quaternary ammonium salt and fatty acid. DES freezing point is determined by the interaction strength (Hydrogen bonding) of the HBD with the anion of organic salt, therefore DES, along with urea, derived from choline salt has decreasing order, i.e. ( $F^- > NO_3^- > Cl^- > BF_4^-$ ). Inside the eutectic mixtures NMR spectra confirmed the presence of Hydrogen bonding [11]. The composition and nature of the HBD has great impact on the DES freezing point, like the lowest freezing point is shown by a ChCl urea having 1:2 eutectic molar composition and 67 mol% acid composition. While for dicarboxylic acids like oxalic, succinic and malonic acid where the molar ratio of eutectic (1:1), it can be supposed that anion has interaction with two groups of carboxylic acid, but the clear relation of the freezing point with the components pure melting points could not be obtained. The depression in the freezing point is reliant on the DESs lattice energies, the HBD and anion interaction and the alteration in the entropy arising during liquid formation [12]. In addition, the densities of DES are higher than that of water, comparable to the values varying between 1.1 g cm<sup>-3</sup> and 2.4 cm<sup>-3</sup> of ILs. The density of DES is governed by the molecular organization and the packing of DES, therefore like ILs, the suggested composition of DESs and LMMs are holes and empty vacancies. The decline in densities with increasing temperature may be associated with the molecular faster movement and creation of spaces [28]. In addition, water content also affects the density, as by increasing percentage of water, the density decreases [29]. Furthermore, the density is also affected by the HBDs and organic salt ratio, as decreases by the addition of ChCl to glycerol, by the free volume and hole theory this can be justified [23]. For practical applications viscosity of a material is important. In comparison of molecular solvents most of the DESs and LMMs, at room temperature (> 100 cP), show relatively high values [17]. Like that of density, the free volume and holes of suitable dimensions for the ions or solvent molecules

movement also has an effect on the viscosity [30]. High viscosity of DESs is related to the presence of massive hydrogen bonding, causing the mobility of free species to be lower. Other forces like van der Waals or electrostatic interactions may also contribute to high viscosities. However, using small quaternary ammonium cations, less viscous materials can also be obtained [31]. The viscosity has also an important relation with water content, temperature and composition [23]. With increase in temperature DESs viscosity show Arrhenius-like behavior i.e. it decreases [32]. The viscosity of different ChCl-glycerol mixtures decreases with increase in ChCl amount showing consistency with observed data, while the opposite effect is shown in case of mixtures with ethylene glycerol, showing the dependency of viscosity on the composition and interactions. Furthermore, the viscosity decreases with increasing water percentage, as water has lower viscosity value than that of DESs [33]. Due to high viscosity, the conductivity of DESs and LMMs is weak (lower than 2mS.cm<sup>-1</sup> at room temperature), as there is a strong relation between viscosity and conductivity. DESs showed an Arrhenius like behavior [34]. As already mentioned, the viscosity is dependent on the composition so therefore the conductivity also depends on it. The conductivity is therefore increases (from 0.74 mS cm<sup>-1</sup>, 1-4 molar ratio of ChCl-glycerol to 1.30 mS cm<sup>-1</sup> 1-2 molar ratio of ChCl-glycerol), due to the availability of more charge carriers, with the addition of ChCl to glycerol successively, as the viscosity decreases. DESs have massive Hydrogen bond network, making them polar in nature [13]. With change of composition and temperature ionic conductivity changes and DESs show low values when viscosity is higher (i.e. 0.1-10 mS cm<sup>-1</sup>). Protic and polar DESs show acidity and basicity depending on their HBDs, so DESs acidic or basic nature is strongly affected by corresponding HBDs [6].

### *Dissolution capabilities of DESs: metal oxides, highly-functionalized molecules, macromolecules and biomass*

DESs with hydrogen bonding ability by donating electron and proton, can cause dissolution of metal oxides [17], highly functionalized molecules, macromolecules and biomass. So, in electrochemistry technology, it provides a novel way to recycle or separate the metals. Solubility of different metal oxides by using ChCl-DESs is shown in Fig. 2.

With change in nature of metal oxide or DESs,

the solubility also changes. Malonic acid based DESs with proton that act as an oxygen acceptor, provides the higher solubility than the other solvents. Hence, it changes the metal centre in synthesized complex.

Later on, dissolution of other highly functionalized molecules and complexes in DESs was investigated. In 2009, Morrison gave the uses of DESs by dissolving it into griseofulvin, danazol and itraconazole, the poor water soluble compounds [35]{Abbott, 2001 #2}. These compounds enhanced the solubility of DESs by 5 to 22000-fold factor. Later on, (Choi) synthesized the DESs naturally by cell metabolism, the so-called NADESs (natural deep eutectic solvents) [36]. NADESs provides the medium for biosynthetic steps or storage of hydrophobic products. Solubility of some natural products like rutin, paclitaxel and ginkgolide B in NADESs was very high when measured [37].

Because of these dissolution properties, DESs has other application in biomass valorization. In 2011, Francisco investigated several DES obtained by the combination of natural and renewable biomaterials. For screening of lignin, starch and cellulose, about 26 mixtures were screened as solvent. For the separation of lignin and cellulose, they can be dissolved in DES, and due to very high solubility of lignin as compared to negligible solubility of cellulose, they can be separated out [33].

#### *Applications of Deep Eutectic Solvents*

DESs in liquid phase have number of advantages. Some of those are being discussed in this section.

#### *Organic Synthesis*

It is really crucial to choose a solvent in organic synthesis with particular properties. Solvents are often huge source of waste, so the non-toxic or non-hazardous DESs are of great importance as an alternative, which are used for other different purposes i.e. catalysts and reactants, e.g., organic synthesis in ChCl-Urea (1:2), for epoxide and carbonyl reduction or for bromination, Perkin reaction, mixture of ChCl-urea was used as a solvent [27]. The reaction procedures are outlined. Usually the drastic conditions i.e. high temperature, strong acid or the environmentally toxic solvent are required for the synthesis of shown products. By using the DESs as solvent, we can control these drastic conditions and can carry out reactions at lower temperature in less

time and can enhance eco-friendliness [38].

#### *Electrochemistry*

In few last years, DESs have been used for a number of applications in electrochemistry. The most studied application of metal deposition by incorporating metal ion in solution. Eutectic solvents with high conductivity with respect to non-aqueous solvents and also have high solubility of metal ions even in absence of water are of great importance [39]. DESs have also been used in electro polishing, where they are used to reduce roughness of surface of metal by controlled dissolution, so in this way it enhances the optical reflectivity of metal surface. ChCl-ethylene glycol mixture has been used for electro polishing of stainless steel. Eutectic mixture of ChCl-urea has been used to solubilize the metal oxides for the metal extraction [31]. Solubilization of metal oxides can only be carried out by acidic or basic solutions while they cannot be solubilized by molecular solvents. But an exception is made by ChCl-urea, which can solubilize a number of oxides such as nickel oxide, zinc oxide or cuprous oxide. For the purpose to complex a variety of metals, different ligands such as oxalate, urea and thiourea can be used as a DESs component. But for biphasic extraction, these mixtures cannot be used and are totally miscible with water [33]. In electro polishing as well as in electro deposition, DESs have been used as an electrolyte mainly. In this respect, ChCl-urea DESs have been used in electro deposition of metals in salt form e.g. CdS, ZnS, CuGa, CdSe. Magnesium electro deposition in aqueous medium is difficult due to water sensitivity. So ChCl was mixed with HBDs such as glycerol, urea, ethylene glycol and malonic acid to get efficiency of different DESs for electro deposition of zinc onto several magnesium alloys [40]. DESs with ChCl and ethylene glycol were used as an electrolyte by metals (Zn, Sn, Ag), composites (Zn, Sn, Cu composites), Al<sub>2</sub>O<sub>3</sub>, SiC, CrCo alloys and also for polymers like polypyrrole films during electro deposition [22]. But the instability of DESs is the major drawback which must be addressed before using industrial technology transfer. Further research on stability of ChCl-urea DESs during nucleation of metal result in the formation of gaseous products at anode (chlorine) and cathode (trimethylamine) suggested a partial degradation of DESs.

#### *Catalytic activity and green nature*

The efficiency of organic transformation can be increased by using DESs as alternative

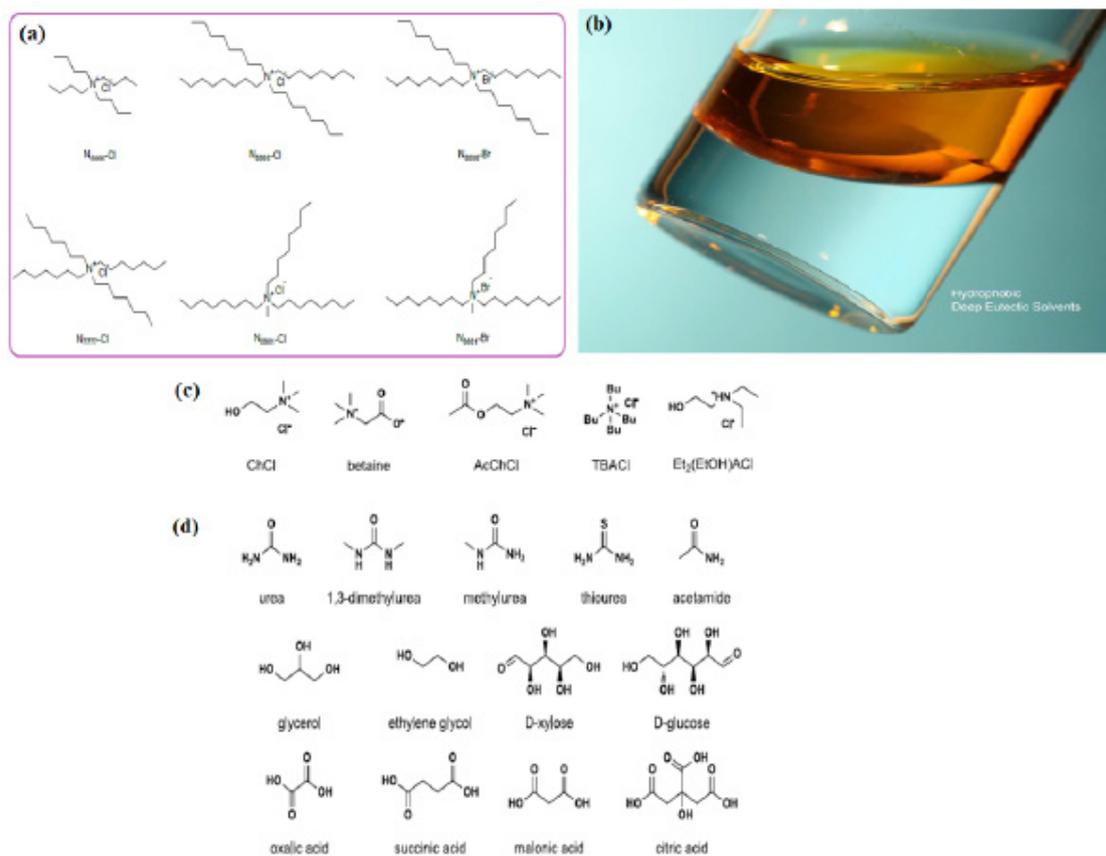


Fig. 1. (a) Quaternary ammonium salts, (b) Hydrophobic DES solvents (c) Structure of some halogen containing salts (d) Hydrogen bond donor molecules

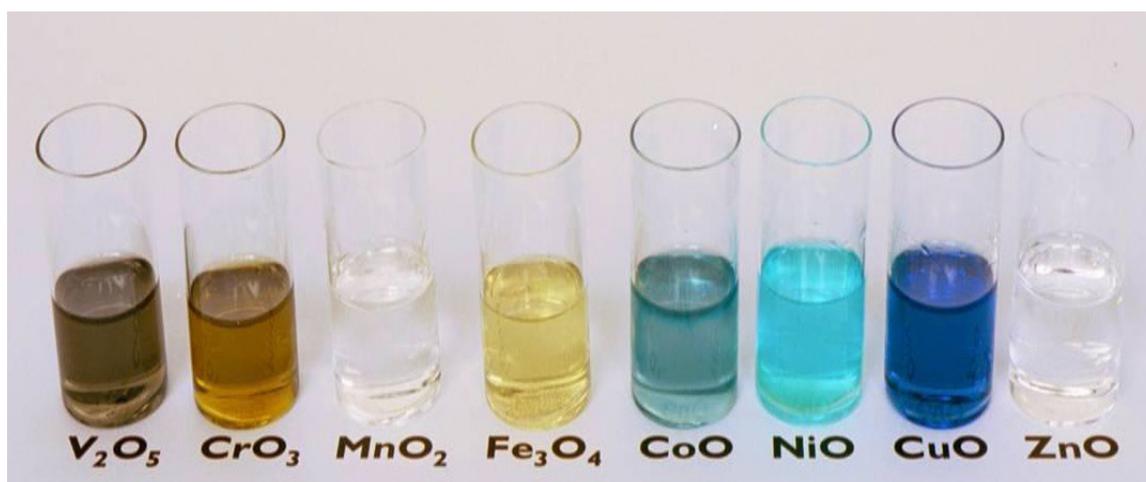


Fig. 2. Wide range of solutes show high solubility e.g. metal oxides

to many organic solvents, petroleum-based, in organic synthesis. As DES solvents do not require post-synthesis purification, so their industrial use is more economically viable, green and these properties made them sustainable green and safe. In the area of electroplating DESs are much explored [6]. DESs also show catalytic behavior to those reaction which are catalysed under acidic or basic conditions. In addition, these properties can be tuned, so the solvents of appropriate choice can be obtained by changing their cationic anionic combinations. Because of the earlier mention property DESs of suitable choice with green approach can be designed. Moreover, as ILs, Hydrogen bonding nature of DESs show not only improved catalytic activity as modest but also can be reused and recycled and thus play dual role [13].

#### *Biodegradability and toxicity*

DESs can be synthesized by natural primary metabolites making them more useful as compared to ILs. Because of this synthetic process DESs are much less toxic than ILs. Using two bacteria strains, gram positive and gram negative, and brine shrimp Hayyan and co-workers evaluated the toxicity and cito-toxicity of three phosphonium DESs [5]. As expected the toxicity of DESs towards brine shrimps is dependent on composition, concentration and viscosity. As DESs show toxicity towards bacteria so they can be used as antibacterial agents [41].

#### *Bio catalysis*

In bio catalysis, DESs has not been utilized extensively, due to denaturing of protein caused by urea with strong hydrogen bond donor [42]. However, Gorke did the testing on catalytical activity hydrolases in DESs [43]. A test reaction of trans-esterification of ethyl valerate in presence of 1-butanol was catalysed by lipase. In few DESs (ChCl-urea, ChCl-glycol or ethyl ammonium chloride glycol) the conversion was comparable to toluene. Further the selectivity and activity of Novozym 435 was tested by Zhao, Novozym 435 is an immobilized *Candida Antarctica* lipase B (CALB), in several DESs [31]. In addition, DESs are used in synthesis of Glycolysis of polyethylene terephthalate [44].

#### *DESs as extracting agent*

DES as an extracting media used in biodiesel synthesis (e.g. rubber seed, sunflower, rapeseed and soy bean oil) as shown in Fig. 3. Such as, Transesterification of alkyl esters requires plants

provided triglyceride oil containing homogenous (e.g. NaOH, KOH) as well as heterogenous catalysts (e.g. immobilized lipases or chitosan for waste valorisation) [45]. Glycerol used in triglyceride oil preparation may cause damage to high pressure injection system due to increase in viscosity. As per specified by American Society for Testing and Materials (ASTM), "end-of-pipe" treatment is needed to achieve the standard biodiesel by removing glycerol [46]. Abbott claimed that the immiscibility of molecules in DES is because of absence of hydrogen bonds with ChCl. Hence, quaternary ammonium salts were tested to remove glycerol from biodiesel. This all effort was made to form an easily removed DES from biodiesel esters due to its immiscibility [16].

#### *DESs as separation media*

For separating phenol from oil, Pang used DES as a supporting media with wide range of polarities as shown in Fig. 4. Phenol with different concentrations was used with oils, such as hexane, toluene or p-xylene. Successful synthesis of DES with phenol (or cresol) was done by quaternary ammonium salts i.e. ChCl, EtNH<sub>3</sub>Cl and Et<sub>3</sub>NHCl. By these novel methods, corrosive acids and alkalis are avoided to be use [12].

A = protic compound, B = aprotic compound

DES as solvent is of great importance because of easy and economic synthesis, renewable precursor and natural non-toxic compounds. Novel researches are being made by using DES in bioactive plant compounds like catechin, terpenoid, phenolic acid etc [15].

#### *Application in aromatic hydrocarbons*

Aromatic hydrocarbon being harmful to human and has been used in preparation of fibers, pesticides, explosives etc for the removal of these harmful aromatic compounds. Found ChCl suitable to form DES for the removal of phenols (or cresol) from oils (toluene, hexane or p-xylene) [47]. ChCl can be recovered by using diethyl ether. Novel methods of separation do not involve alkali, acid or waste water but may involve different quaternary salts of tetra-R ammonium chloride (R=butyl, methyl or propyl), ammonium chloride, ChCl and choline bromide [48]. 99.9% of phenol can be removed by using tetraethyl ammonium chloride/phenol with molar ratio of 0:8:1, and it can be recovered by dibutyl ether or diethyl ether.

#### *Application in gas*

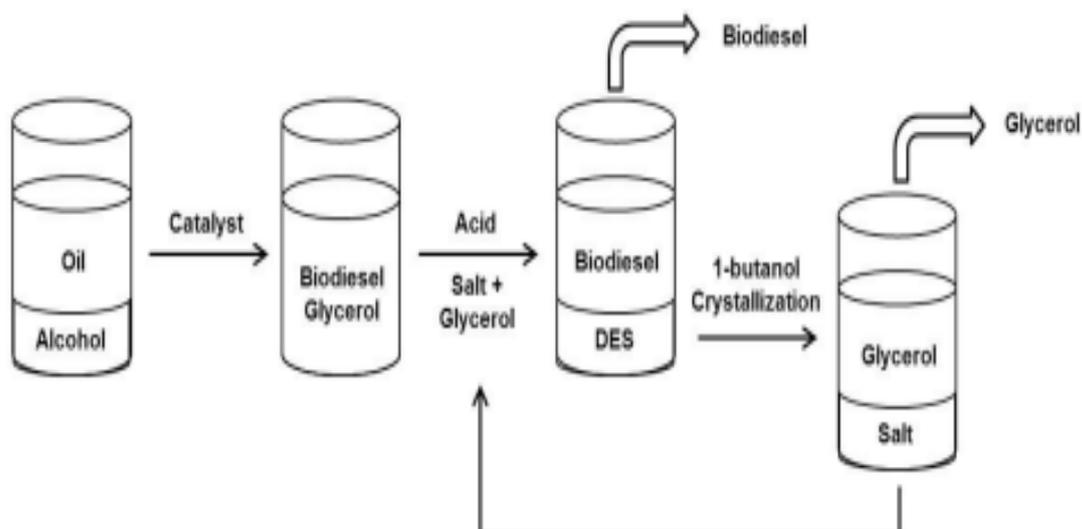


Fig. 3. Schematic diagram for the removal of the glycerol after production of biodiesel

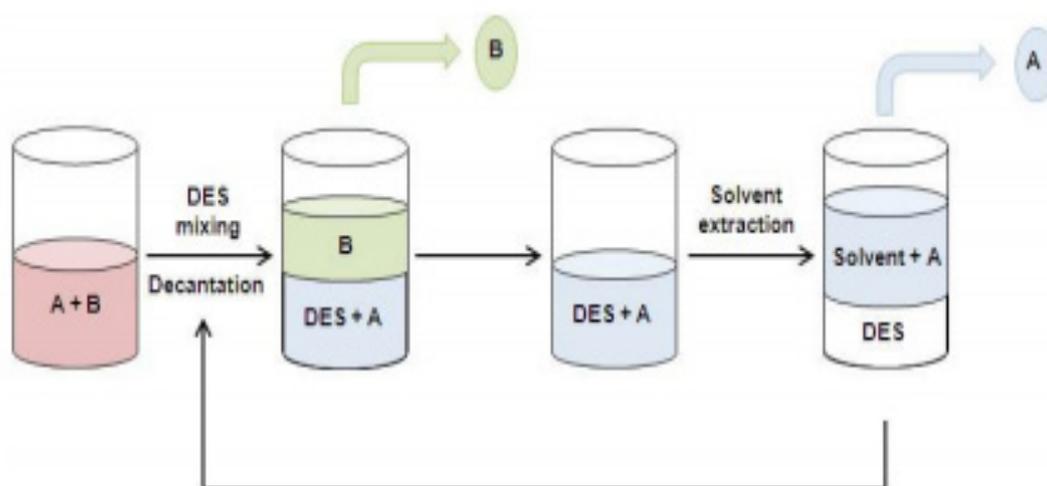


Fig. 4. Schematic representation of separation using DESs

For increasing gas loading by formation of porous nature and unsaturated coordinative centre of metal by using DESs modified materials [49]. DESs demonstration information of porous nature and for depositing the gas in open metal places considering the multipurpose structure-directing part of DESs [50]. Three different DESs which were formed by metals of valences three ( $Y^{3+}$ ,  $Nd^{3+}$ ,  $Sm^{3+}$ ,  $In^{3+}$ ,  $Dy^{3+}$ ,  $Yb^{3+}$  and  $Ho^{3+}$ , 1,4-benzenedicarboxylate and one of more type of DSE. Porous structure and gas depositing characteristics, and thermal stability

was possessed by these metal-organic materials. [Sm (bdc)  $3/2$  (e-urea)] possessed the high thermal stability which was confirmed by using powder X-ray diffraction and gravimeter. It also possesses permanent micro porous property which was checked by pore analyzer to find its adsorption. The data of adsorption of ( $O_2$ ,  $N_2$  and  $CO_2$ ) gases showed that metal organic materials as a new source of depositing gases. To decrease environmental pollution due to  $CO_2$  and  $CH_4$  gases which causes greenhouse effect which is increasing day by day in our environment by the

industries, should be controlled. Therefore, CH<sub>4</sub> and CO<sub>2</sub> depositing ability should be enhanced by reasonable method [51]. Molecular sieves of carbon based DESs, possess CO<sub>2</sub> adsorption ability and selective adsorption ability of CO<sub>2</sub>/CH<sub>4</sub> at low pressure. Then [13] focused on adsorption by ChCl/glycerol DES at low pressure. Then it was discovered that SO<sub>2</sub> solubility increases as we increase ChCl concentration in DESs [52]. SO<sub>2</sub> 0.678g per ChCl/glycerol DES of one gram absorbed at 1atm with 1:1 ratio at 20°C. Another advantage was also that SO<sub>2</sub> can easily store and released as per need for about five cycles. Now a day DESs based carbon monolith are using for depositing CO<sub>2</sub> and separation of gases to play role in decrease of global warming. These DESs based carbon monolith have special structure of continuous micro porous structure, network of carbon and macroporosity due to channels [51]. The two forms of DESs based carbon in powdered and monolith have high selectivity power for CO<sub>2</sub>/CH<sub>4</sub> and N<sub>2</sub>/CO<sub>2</sub>. And DESs based carbon retained their ability either in powder or in monolith form [6].

#### *Application in bioactive compounds*

The materials which are concerned and deal with cells, tissues and organisms are bioactive compounds. The environmental friendly DESs solvents used to separate the bioactive compounds from samples of complicated in nature. DESs of alcohol based used for finding antioxidant activity and separation of an bioactive compound and flavonoids [53]. By using various methods of extraction flavonide was extracted by means of seven ChCl/alcohol DESs. The DESChCl/1,4-butanediol of 1:5 molar ratio used for separation of bioactive compounds. The flavonoid solubility increased by application of DESs. Hyaluronic acid was absorb by ClChCl/urea DES-based cotton [54]. The maximum hyaluronic acid absorbed by ClChCl/urea adapted by silica [55]. The adsorption of ferulic acid was adsorbed maximum about 89% by increasing content of silica. On memeber of composite family, herbaartemisiaescopariaeaeall which is a famous medicine in herbaartemisiaescopariae caffeic acid and chlorogenic acid are two vital active agents. These two acids, cholrogenic acid with 9.35mg/g and caffeic acid with 0.31mg/g were extracted from HerbaAetemisiaeScopariae [20]. DESs microextraction is done by using head space, used to extract terpenoids from chamaecyparisobstusa leaves [55]. Regarding as DESs preparation for extraction of bioactive compounds, the mixing of

ChCl with ethylene glycol plays a promising role.

#### *Application in metals*

For comparatively good purification and in industrial process for enhancement or separation electrodeposition is a common method. Nowadays DESs used for metal deposition. Nano wires SmCo films were electrodeposited via ChCl/urea (1:2) [56]. Later samarium cobalt and cobalt/samarium were electrodeposited by ChCl/urea system (1:2) [57]. It was difficult to deposit cobalt and samarium, as deposition of cobalt was occurred by three dimensional growths and by nucleation at low potential, while deposition of samarium by complex process at negative potential. ChCl/urea DES on glass-ITO substrate to use for their best deposition [58]. An Innovative DES used for electrodeposition of Co-Cr alloys, which are brightener, Cr-complexing agent free and decreasing the stress [40]. By ChCl/urea and ChCl/ethylene glycol DES the electrodeposition of copper composite and copper performed by Ryder group [59]. By high efficiency of plating on Cu and Mo electrodes by Ga was reported by Dale [60]. You et al. from ChCl/ethylene glycol DESs deposited Ni alloys at room temperature. electrodeposition of zinc was reported by Pereira and whitehead group from DESs. By ChCl/ethylene glycol DES Silver composite electrodeposition performed [61, 62].

#### *Other Applications*

The applications of DES increases since last few year [63]. Another interesting application is the biomass like chitin, cellulose and lignocellulose solvation. For functional and nanoscale, it is also used as supportable media. It is also used as colloidal assemblies, in DNA/RNA buildings [64] like as functional dyes [65]. DESs is also used as extraction media for example extraction from biodiesel glycerol. For zeolite analogues and ionothermal material preparation DESs are used as organic templates. DESs used for solubilization of drug [35]. In addition, DESs solvents have tremendous applications in Water splitting as an electro-catalyst [66], and also used in the synthesis of biodiesel (renewable energy resource) [67]. Moreover, they are used for bacterial effect to viscose fabric [68] and dyeing of proteinic fabrics [69].

#### **Conclusion**

Instead of using ILs, DESs is proved to cost effective and environmental friendly. These are easily changed as per need by changing nature

of components which make them the most advantageous solvent. Deep eutectic mixtures are more ecological and economical benefit equated to ILs. Certainly, these are prepared with about 100% purity and low cost with 100% economy, these are non-toxic, easily available solvent and non-toxic. Their efficiency is also proved in field of electrochemistry, catalysis and as green solvent. However more work is needed for DESs to use as biocatalyst. Formation of various networks of hydrogen bonding will result in variety of its behavior and reactivity. The greatest primary specific activity of lipase was shown by DESs formed of urea or glycerol when combined with quaternary ammonium salt like choline chloride.

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