# ABSTRACT

## Background of the present work

Ionic liquids are defined as organic salts that are often liquid below 100 °C and consist entirely of truly ionic species. They possess many fascinating properties like negligible vapour pressure, non-flammability, excellent solvating ability which quite justifiably make them fundamental interest to chemists. With low to quite negligible vapour pressure, they eliminate the threat for the emission of volatile organic compound (VOC)s as compared to the traditional organic solvents. Ionic Liquids (ILs) are made up of two components: cation and anion. The cation part is essentially organic whilst anions can be either organic or inorganic. By properly choosing the cations and anions, fine tuning of the physico-chemical properties of the ILs is possible which further emphasizes their potential. This dual nature along with the presence of two electrically charged nano domains provides them advantage over the conventional organic solvents. These special features enable the ILs to contribute to numerous fields such as in organic reactions as solvent/catalyst, in analytics, separation technology, electrochemistry & engineering etc. and also to some extant processes at industrial level viz. BASIL (Biphasic Acid Scavenging utilising Ionic Liquids), aluminium plating, Difasol, paint additives, hydraulic ionic liquid compressor, batteries and solar cells.

Ionic liquids with specific functional groups covalently tethered into it as part of the anion or cation according to the requirement of a particular purpose are categorized as “Task specific ILs”. The incorporation can suffuse the resulting ionic salt with a capacity to interact with the dissolved solutes in a specific manner. It dramatically enhances the ability of an IL to catalyze a reaction, solubilize particular substrates, improves its physical, chemical, biological properties & stability as well as reusability profile. In recent times, these ionic liquids find applications in various fields such as organic syntheses, catalysis, and separation of specific materials as well as in the construction of nanostructured materials and ion conductive materials etc.

Ionic liquids can be classified based on the number/nature of cation or anion present and also according to its inherent acidity/basicity. Depending on the numbers of the cations present, ILs can be classified as monocationic, dicationic or polycationic ILs. These multicharged ionic liquids (especially dicationic and tricationic ILs) possess a greater range of physical properties than most traditional, singly charged ILs. In

particular, varying the cationic or anionic moieties to produce unsymmetrical dicationic (or dianionic) moieties allows greater variety and control of virtually all IL properties. Consequently, they have been shown to be exceptional high temperature and selective gas chromatographic stationary phases and have been prepared as a new class of high temperature lubricants over the singly charged traditional ILs. Depending on the nature of the anions present, ILs can be categorized in to first generation, second generation and third generation ILs. The development of more air and oxygen stable, hydrophobic anions over the years is the basis for such classification. Depending on the type of anion and cation present or the functionality incorporated into the cation, ionic liquids can be classified as neutral, Brönsted acidic or basic and Lewis acidic or basic.

The attachment of more number of basic cations/anions in multi-charged ILs may influence the basicity, thermal stability, water sensitivity, viscosity, conductivity and solubility of the ILs in various solvents. As compared to the functionalized acidic ILs, the reports related to the basic ILs are quite few. But, they have the ability to replace conventional basic reagents like NaOH, KOH, $K_2CO_3$, $NaHCO_3$, NaOAc etc. in organic reactions including Knoevenagel condensation by acting as reusable basic catalysts. These conventional bases produce excellent results only with stoichiometric amount of bases for any type of base promoted organic reactions. In industrial scale reactions, they release large amount of toxic and corrosive basic waste to the environment. From this point of view, the nature of basic ionic liquids serves its purpose much justifiably and their function to act as both solvent and catalyst make the process much easier to handle. Therefore, it is always an exciting challenge to develop novel Brönsted-type basic catalytic systems that are environment friendly, recyclable and cost effective in nature.

Nitrogen heterocycles are key building blocks used to develop compounds of biological or medicinal interest to chemists. The majority of pharmaceutical products that mimic natural products with biological activity are heterocyclic. A vast number of nitrogen containing heterocyclic building blocks have applications in pharmaceuticals and agrochemical research and drug discovery. They are used to modulate hypertension, angina pectoris, act as $Ca^{2+}$ channel blockers and are anti-diabetic, hepatoprotective and show antitumor properties. Heterocyclic compounds also have a practical use as components in dyes, antioxidants, copolymers, bases, and ligands. Finally, as an applied science, heterocyclic chemistry is an inexhaustible resource of novel compounds.

## Objectives

[1] Exploration of Brønsted/Lewis acidic catalysts for one-pot synthesis of nitrogen heterocycles such as *bis*(indolyl)methanes, 3,4-dihydropyrimidinones, pyrimidines and styrylpyrimidine derivatives under environmentally benign approach.

[2] Development of target oriented Lewis-Brönsted acidic chlorometallate ionic salt systems and exploration of their catalytic activities towards the synthesis of nitrogen heterocycles under solvent free approach.

[3] Synthesis of hybrid composites of NaY and acidic ionic salts in different w/w ratios and investigation of the effects of loading of acidic ionic salts over the zeolite framework.

[4] Investigation of the catalytic efficiency of these hybrid composites for the synthesis of nitrogen heterocycles under mild conditions.

[5] Development of $PEG_{6000}$ bridged dicationic ILs and exploration of their catalytic efficiencies towards the transformation of fructose in to 5-hydroxymethyl furfural (HMF).

[6] Synthesis of basic tricationic ILs and exploration of their catalytic activities for synthesis of functionalized alkenes.

## Plan of work

In order to accomplish and fulfill the purpose of objectives, the proposed work has been planned in the following manner:

[1] Exploration of Brönsted/Lewis acidic catalysts for the one-pot synthesis of nitrogen heterocycles such as bis(indolyl)methanes, 3,4-dihydropyrimidinones, pyrimidines and styrylpyrimidine derivatives under environmentally benign approach.

[2] Synthesis of Lewis-Brönsted acidic chlorometallate systems of 1-methyl imidazole and diisopropylamine based ionic liquids and their characterization using FT-IR, $^{1}H$ NMR, $^{13}C$ NMR, Raman, P-XRD, TGA, SEM-EDX, BET, ICP-OES, UV-Vis diffuse reflectance spectroscopy (UV-Vis DRS), UV-Vis spectroscopy and elemental analysis.

[3] Development of hybrid acidic composites of NaY with acidic ionic salts in different w/w ratios (or in percent) and exploration of the structural changes of the zeolite framework with loading of the ionic salt via FT-IR, P-XRD, TGA, BET, SEM-EDX, TEM, Raman and UV-Vis spectroscopy.

[4] Synthesis of $-SO_3H$ functionalized $PEG_{6000}$ bridged dicationic ILs and their characterization using FT-IR, $^1H$ NMR, $^{13}C$ NMR, TGA and UV-Vis spectroscopy.

[5] Development of triethylamine bridged basic tricationic ILs and their characterization using FT-IR, $^1H$ NMR, $^{13}C$ NMR, TGA, UV-Vis spectroscopy and elemental analysis.

[6] Studies on the catalytic activity of novel ionic liquid systems and hybrid acidic composites as reusable homogeneous/heterogeneous catalyst for one pot multicomponent synthesis of pyrimidine heterocycles.

[7] Synthesis of the library of each heterocyclic compound by varying the substrates molecules and their characterization via $^1H$-NMR, $^{13}C$-NMR, FT-IR, and elemental analyzer.

[8] Determination of percentage conversion of fructose to HMF via HPLC analysis.

## Outline of the thesis

The present work explains the development of various Brönsted or Brönsted-Lewis acidic or Brönsted basic ionic liquid systems and also Brönsted acidic hybrid acidic composites; and their characterization and applications for the one-pot synthesis of different nitrogen containing heterocycles and also for Knoevenagel condensation reaction. Entire works have been divided into **seven chapters**.

## Chapter 1A: General review on target-oriented ionic liquid based systems in catalysis

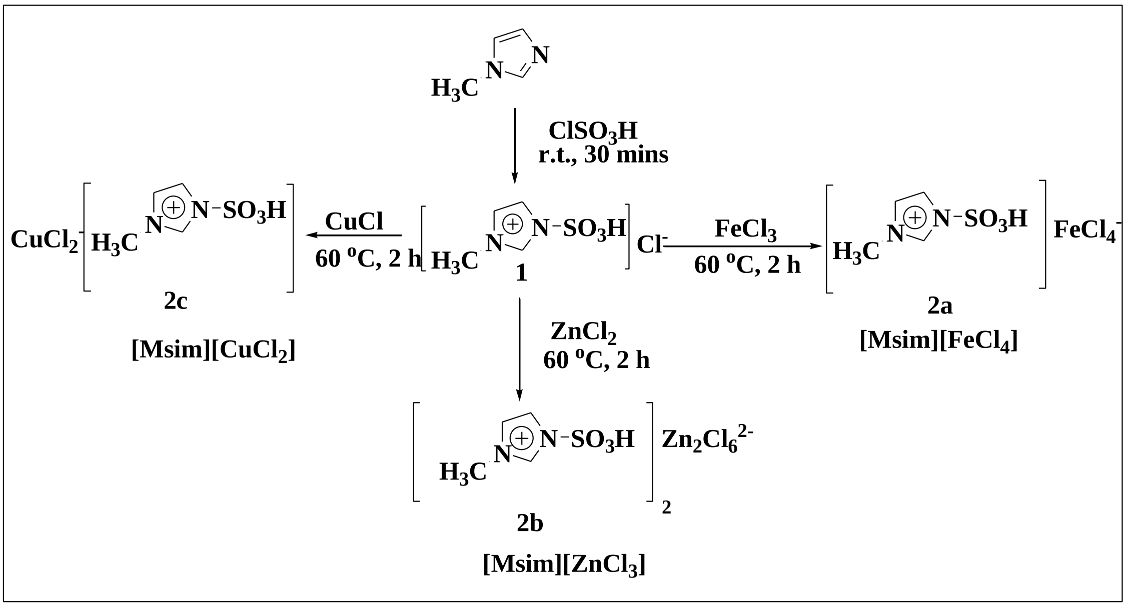
This chapter includes general introduction on target oriented ionic liquids and their classification and applications in catalysis.

## Chapter 1B: Literature on halometallate ionic salts and ionic liquid catalyzed synthesis of *bis*(indolyl)methanes

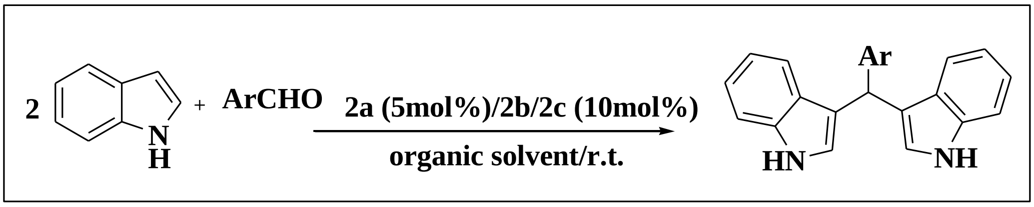
This chapter includes up to date literature on halometallate ionic salt systems and ionic liquid mediated/catalyzed synthesis of *bis*(indolyl)methanes. It also emphasizes the pharmaceutical importances of *bis*(indolyl)methanes.

## Chapter 1C: Design of Brönsted-Lewis acidic solid catalytic systems of 3-methyl-1-sulfonic acid imidazolium transition metal chlorides and evaluation of their catalytic performances in preparation of *bis*(indolyl)methanes

In this chapter, three new solid Brönsted-Lewis acidic catalysts of 3-methyl-1-sulfonic acid imidazolium metal chlorides ([Msim][X], where X = $FeCl_4$, $CuCl_2$, $Zn_2Cl_6^{2-}$) (**Scheme 1**) were prepared and characterized via FT-IR, $^1$H NMR, $^{13}$C NMR, Raman, TGA, SEM-EDX, BET, AAS, UV-Vis spectroscopy and elemental analysis. The catalytic efficiencies of these chlorometallate systems were explored for the synthesis of *bis*(indolyl)methane derivatives (**Scheme 2**) under ambient condition. All the synthesized products were characterized via FT-IR, $^1$H NMR, $^{13}$C NMR and melting point determination.



**Scheme 1**: Synthesis of 3-methyl-1-sulfonic acid imidazolium metal chlorides



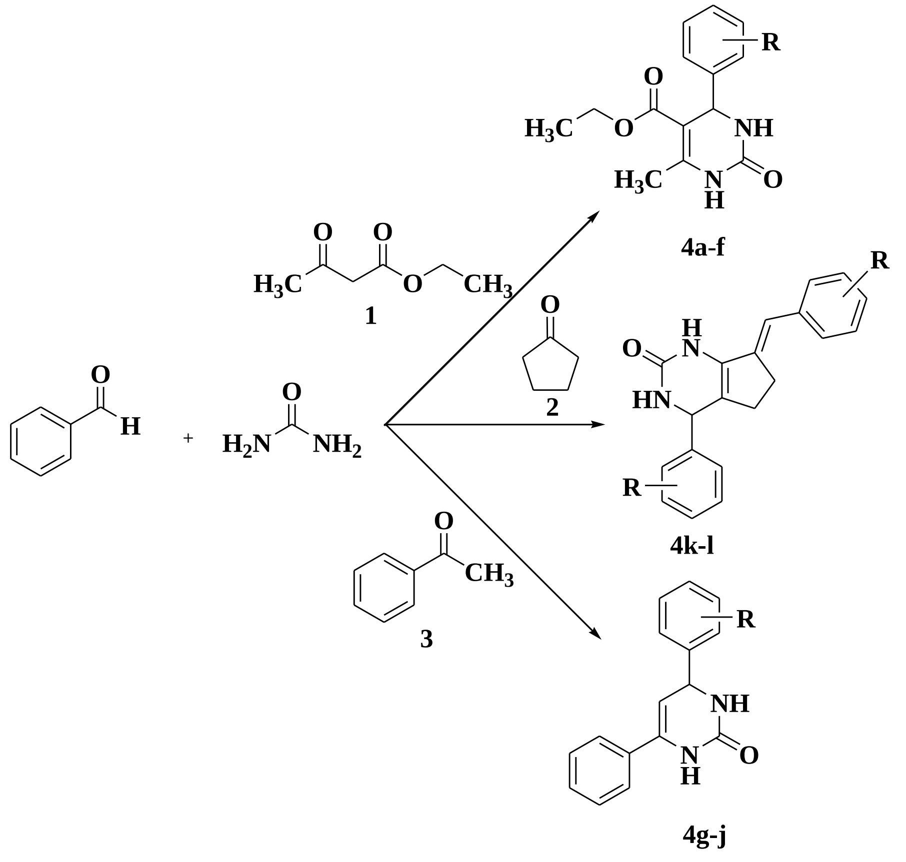
**Scheme 2**: Synthesis of bis(indolyl)methane derivatives

## Chapter 2A: Review on zeolite supported ionic liquids in organic synthesis with special emphasis on preparation of 3, 4-dihydropyrimidinone derivatives via Biginelli reaction

This chapter includes up to date literature on use of zeolite support for development of immobilized ionic liquids. It also includes the literature on use of heterogenized ionic liquid catalysts for synthesis of 3,4-dihydropyrimidinone derivatives via Biginelli reaction.

## Chapter 2B: A study on structural changes of 1, 3-disulfoimidazolium trifluoroacetate ionic liquid/NaY zeolite composites and their catalytic uses for three component synthesis of 3, 4-dihydropyrimidinones

- In this chapter, we aimed to synthesize functionalized hybrid material of ionic liquids using NaY zeolite as suitable choice of support. For this purpose, six acidic composites of Y-zeolite with 1, 3-disulfoimidazolium trifluoroacetate [Dsim][$CF_3COO$] ionic liquid (IL) were prepared by mixing [Dsim][$CF_3COO$] ionic liquid with NaY zeolite powder in six different percentage ratios (weight/weight) expressed as 3%, 5%, 10%, 20%, 50% and 80% in methanol.
- . The structural changes of modified framework of zeolite were analyzed by FT-IR, Power XRD, SEM-EDX, TEM, TGA and BET techniques. The acidity of each IL composite is determined from Hammett function and evaluated as heterogeneous catalyst for three-component preparation of Biginelli 3,4-dihydropyrimidinones under solvent-free method at 60°C as well as using mechanochemical energy under mild condition (**Scheme 3**).



**Method: r.t. grinding or heating at 60 $^{o}$C at neat condition using 3mg of the catalyst**

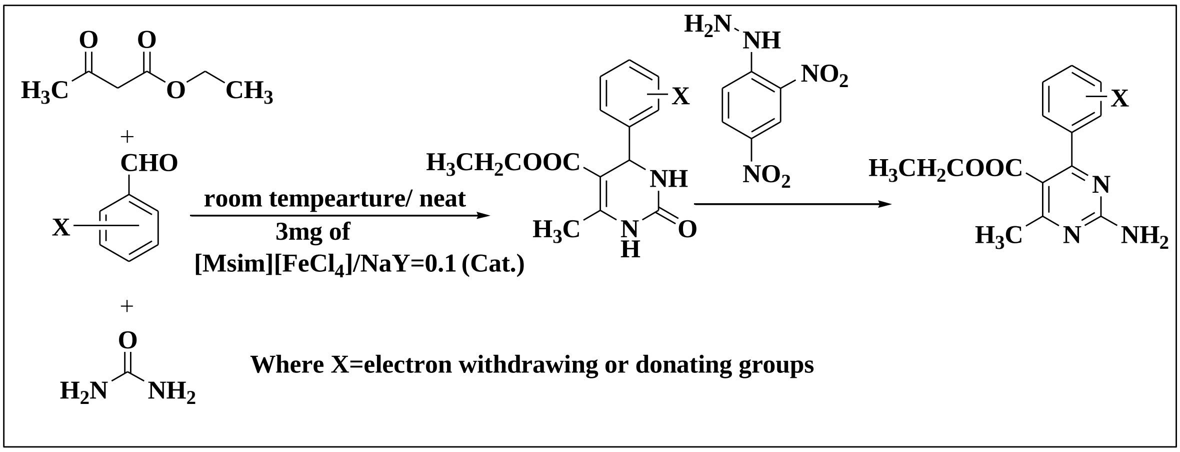
**Scheme 3**: Synthesis of 3, 4-dihydropyrimidinone derivatives

## Chapter 3A: Literature on strategies for conversion of 3, 4-dihydropyrimidinones to pyrimidines

This chapter includes the different possible routes developed for conversion of Biginelli 3, 4-dihydropyrimidinones to pyrimidine derivatives till date.

## Chapter 3B: Development of heterogenized hybrid catalyst of 1-sulfonic acid-3-methyl imidazolium ferric chloride over NaY zeolite and their utilization in one-pot synthesis of 2-amino-4-arylpyrimidine derivatives: A viable approach

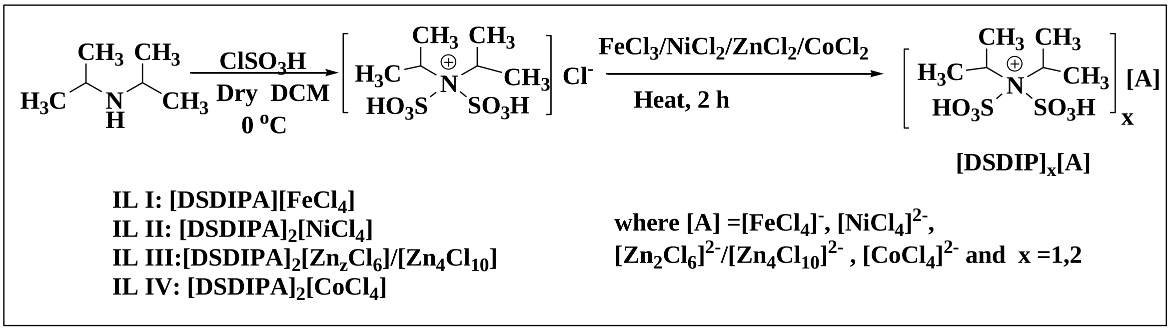
In this chapter, a new series of acidic hybrid material of NaY zeolite were synthesized by modifying the zeolite surface with an acidic ionic salt: 1-sulfonic acid-3-methyl imidazolium ferric chloride ([Msim][$FeCl_4$]) via wet impregnation method. The NaY zeolite powder and [Msim][$FeCl_4$] were mixed in six different weight/weight ratios (such as 0.03, 0.05, 0.1, 0.2, 0.5 & 1) using a few drops of EtOAc. These composites were fully characterized by Powder XRD, FT-IR, Raman, TGA, SEM-EDX, TEM, BET, ICP-OES and Hammett acid strength measurement methods. After observing their structural changes, thermal stability and Hammett acidity, the catalytic activity of the composites were examined for the novel one-pot consecutive transformation of Biginelli 3, 4-dihydropyrimidin-2-(1H)-ones to 2-amino-4-arylpyrimidines (**Scheme 4**).



**Scheme 4**: General route for synthesis of 2-amino-4-arylpyrimidine derivatives

## Chapter 4: Investigation of complex anionic speciation and thermal stability of transition metal chlorides of disulfo-diisopropylammonium based acidic ionic salts and assessment of their catalytic activity in multistep one-pot synthesis of (*2E*)-ethyl 2-(arylideneamino)-6-styrylpyrimidines

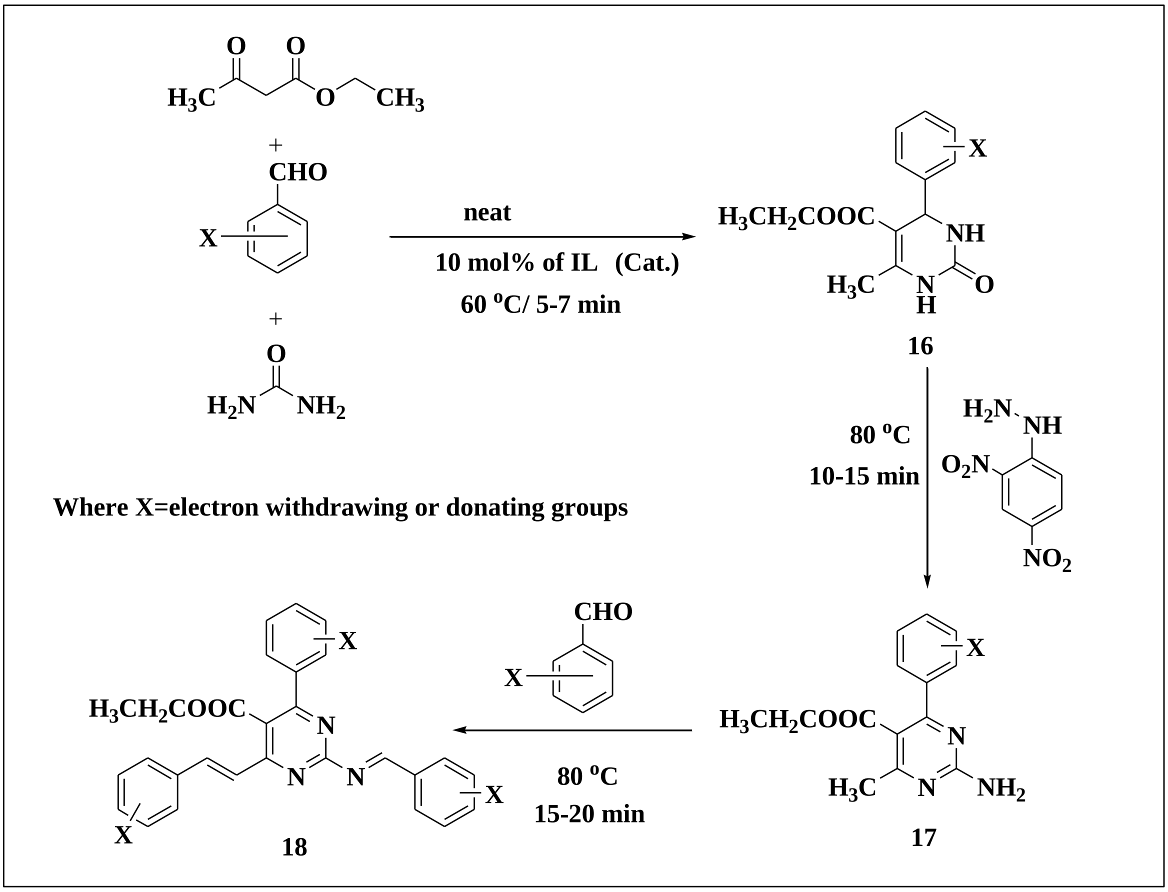
In this chapter, five different chlorometallates of disulfo-diisopropyl-ammonium ionic salt with complex ionic composition ($[DSDIP]_y[A]$; where [A]= $FeCl_x$, $CoCl_x$, $NiCl_x$, $CuCl_x$, $ZnCl_x$; x = 1, 2, 3, 4 and y = 1, 2) were prepared from the 1:1 reaction mixture of disulfo-diisopropylammonium chloride with five transition metal chlorides namely, $FeCl_3$, $CoCl_2$, $NiCl_2$, $CuCl_2$ and $ZnCl_2$ (**Scheme 5**) in an inert atmosphere. The reactions were carried out at 60°C for 2h stirring. The chlorometallate ionic salts were fully characterized via FT-IR, $^1$H NMR, $^{13}$C NMR, Raman, TGA, UV-Vis DRS and UV-Vis spectroscopy. All the synthesized ionic salts were successfully utilized as reusable catalysts for one-pot three-step synthesis of (*2E*)-ethyl 2-(arylideneamino) 6-styrylpyrimidine derivatives starting from three-component Biginelli reaction involving DHPMs as initial product (**Scheme 6**).



IL I: [DSDIPA][FeCl$_4$]
IL II: [DSDIPA]$_2$[NiCl$_4$]
IL III:[DSDIPA]$_2$[Zn$_z$Cl$_6$]/[Zn$_4$Cl$_{10}$]
IL IV: [DSDIPA]$_2$[CoCl$_4$]

where [A] =[FeCl$_4$]$^-$, [NiCl$_4$]$^{2-}$,
[Zn$_2$Cl$_6$]$^{2-}$/[Zn$_4$Cl$_{10}$]$^{2-}$ , [CoCl$_4$]$^{2-}$ and x =1,2

**Scheme 5**: Preparation of disulfo-diisopropylammonium chlorometallates



Where X=electron withdrawing or donating groups

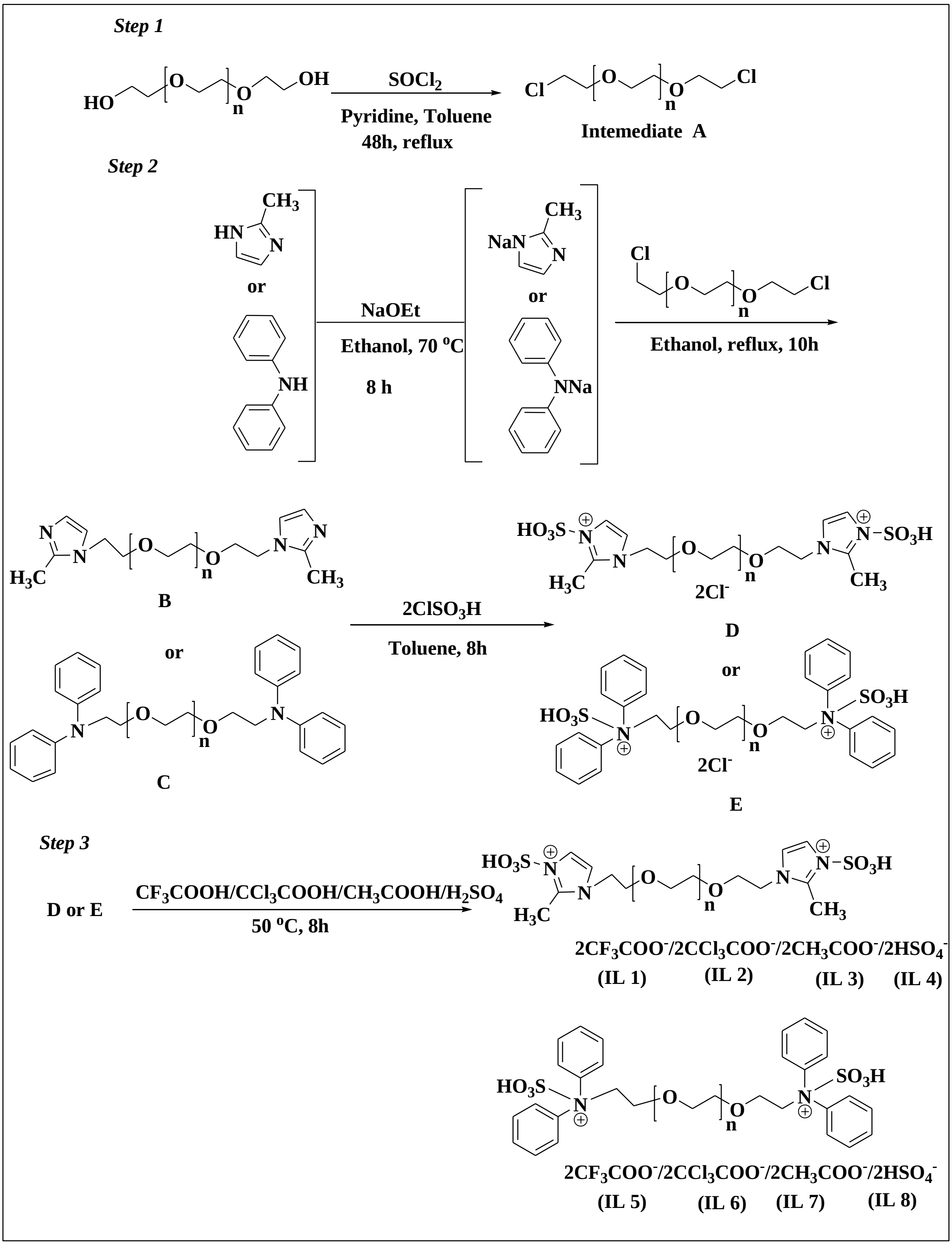
**Scheme 6**: Synthesis of (2*E*)-ethyl 2-(arylideneamino) 6-styrylpyrimidine derivatives

## Chapter 5A: Review on poly(ethyleneglycol) linked dicationic ILs and formation of 5-hydroxymethylfurfural using ionic liquids

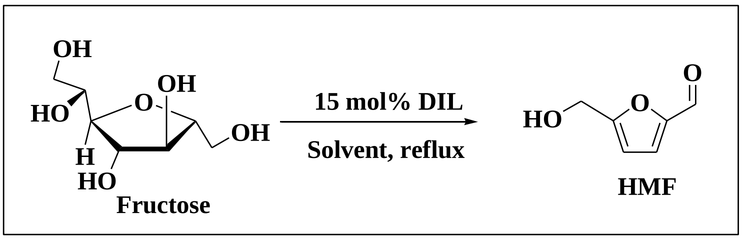
This chapter includes literature on poly(ethyleneglycol) linked dicationic imidazolium/ammonium ionic liquids and their uses in catalysis. It also includes literature review on use of ionic liquids in conversion of biomass to HMF.

## Chapter 5B: Investigation of PEG-6000 bridged -N-$SO_3H$ functionalized geminal dicationic ionic liquids for catalytic conversion of fructose to 5-hydroxymethylfurfural

In this chapter, we have synthesized and investigated a series of PEG-6000 linked dicationic ionic liquids (DILs) with systematic structural variations according to **Scheme 7**. Structural variations investigated include the cations and the accompanying anions. The cations varied were 2-methyl imidazole and diphenylamine and anions studied include trifluroacetate, trichloroacetate, acetate and hydrogen sulfate. Each ionic liquid was carefully characterized by FT-IR, $^1H$ and $^{13}C$ NMR, TGA, DSC and UV-Vis spectroscopy. The Brönsted acidity of the synthesized ILs was determined via the Hammett plot. The catalytic efficiencies of these ILs were explored for the conversion of fructose to 5-hydroxymethyl furfural (HMF) in three different solvents, namely EtOAc, THF and $CH_3CN$ (**Scheme 8**).



**Scheme 7**: Preparation of PEG-6000 bridged dicationic ILs



**Scheme 8**: Conversion of fructose in to HMF in presence of PEG-6000 bridged DILs as catalyst

## Chapter 6A: Literature on imidazolium/pyridinium based basic ionic liquids and their uses in organic reactions

This chapter includes literature on imidazolium and pyridinium based basic ionic liquids and their uses in organic synthesis including Knoevenagel condensation.

## Chapter 6B: Synthesis of triethylamine bridged basic tricationic ionic liquids (TILs) and evaluation of their catalytic efficiencies towards synthesis of functionalized alkenes

In this chapter, we have designed a new series of triethylamine bridged tricationic basic ILs (**TIL**s) containing imidazolium/pyridinium as cations with variation of three anions namely hydroxide, acetate and imidazolide (Im) in the anionic part as represented in **Scheme 9**. The synthesized tricationic basic ILs were characterized via FT-IR, $^1$H NMR, $^{13}$C NMR, TGA and elemental analysis. The relative Brönsted basicities of these TILs were determined from Hammett plot using p-nitrophenol as the acidic indicator. The catalytic activities of these TILs were explored in the Knoevenagel condensation of aliphatic/aromatic aldehydes and ketones with malononitriles (**Scheme 10**).

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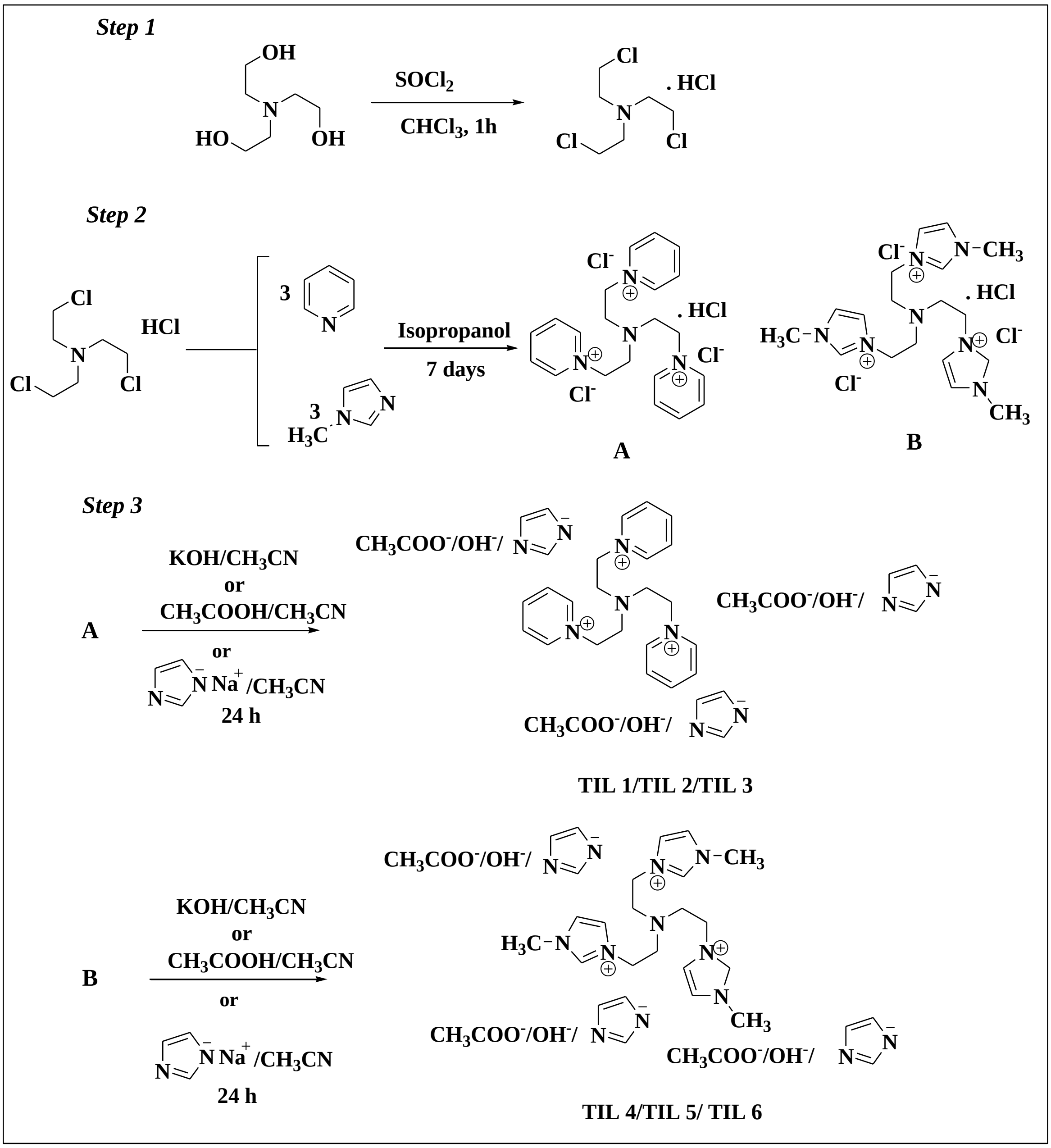
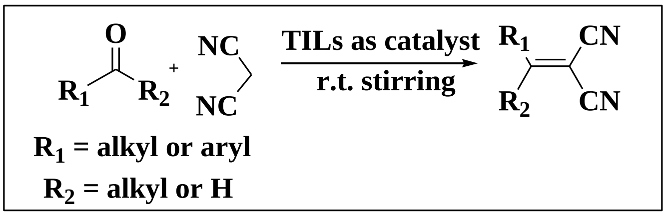


**Scheme 9**: Preparation of tricationic basic ILs



**Scheme 10**: General scheme for synthesis of Knoevenagel condensation reactions

## Chapter 7: Summary and future scopes of the present work

This chapter describes the overall summary of each chapter and future scopes of our present work in different directions.