Study of Self and Cross Coupling Reaction of Amines to Imines Using MCM-41 and Al-20-MCM-41 Catalysts

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Abstract : ***The oxidative coupling reactions of amines to imines with MCM-41 and Al-20-MCM-41 catalysts were studied with different reaction conditions like presence of solvent, absence of solvent, solvent nature, presence of air and excess air. The MCM-41 and Al-MCM-41 catalysts were prepared and characterized by different analytical techniques. Polar solvent nitrobenzene was found to be effective facilitating the reaction by avoiding the reactants/ products stable adsorption over sites and their bulk and pore diffusion. The presence of excess air also promoted the reaction. The self coupling reaction was observed to be faster with Al-20-MCM-41 than MCM-41, and the cross coupling reactions with Al-20-MCM-41 was found to be slightly slower than MCM-41.***

IndexTerms - MCM-41, Al-20-MCM-41, Amines, Imines, Oxidative coupling

I. INTRODUCTION

The condensation of carbonyl compounds with primary amines to produce the corresponding imines was first discovered in 1864 by Hugo Schiff. Hence, imines are often referred to as Schiff bases or azomethines [1]. Imines are very important class of compounds in chemistry as well as in biology that have widely been utilized as intermediates in the synthesis of nitrogen heterocycles, fine chemicals, and pharmaceuticals [2]. Significant progress has been made in recent years, including the direct synthesis of imines through oxidative self-condensation of primary and secondary amines [3]. Many procedures have been introduced for the preparation of imines in the literature among recent methods or techniques for the preparation of imines, the use of ionic liquids [4], infrared [5], microwave [6], and ultrasound [7] irradiation can be mentioned. However, the main problem which affects the yield of the products originates in the existence of equilibrium conditions between the reactants and the corresponding imines, along with water, as a byproduct of the reaction. To overcome this problem, various dehydrating agents such as P_2O_5/SiO_2 [8], $MgSO_4$-$Mg(ClO_4)_2$ [9], fuming $TiCl_4$ [10] or aromatic solvents forming azeotropic mixtures with water at high temperatures have been used.

In recent years, catalytic oxidative coupling (self and cross) of amines to imines using a suitable catalyst and atmospheric oxygen as oxidant has received much importance as greener route for synthesis of imines. Owing to the benefits of heterogeneous catalysts, amine coupling reactions have been attempted using solid catalysts like bulk copper [11] and gold powder [12] as well as with supported precious metals like gold nanoparticles [13] and ruthenium [14]. Such methodologies often suffer from complicated procedures, moisture sensitive catalysts or reagents, large quantities of toxic aromatic solvents, huge amounts of costly dehydrating agents or catalysts, high reaction temperatures, and long reaction times. Therefore, the development of new environment friendly procedures for the synthesis of imines is a very important subject in modern organic synthesis.

On the other hand, ordered mesoporous materials are used for fine chemical synthesis as heterogeneous solid catalysts. In 1992, researchers at the Mobil Corporation made a major discovery of the M41S family of silicate/aluminosilicate mesoporous molecular sieves with exceptionally large uniform pore structures. The keen interest of this work is to study the catalytic properties of MCM-41 and Al grafted MCM-41 acidic materials for oxidative coupling of amines. The interesting feature of the MCM-41 material is that, in spite of amorphous nature of silica, it possesses an ordered structure with uniform mesopores arranged into a hexagonal lattice. MCM-41 materials are popular to be used as a support material for development of heterogeneous catalysts. The Al grafted MCM-41 (Al-MCM-41) have been extensively studied as catalyst for numerous acid catalyzed reactions like esterification [15, 16], acetalization [17], alkylation [18,19]. Herein, we report an effective method for self and cross coupling of amines to imines by MCM-41 and Al-20-MCM-41.

II. EXPERIMENTAL WORK

- **Materials**

Sodium silicate, Cetyl Trimethyl Ammonium Bromide (CTAB; 98%), Sodium hydroxide (NaOH; >97%), Aluminium isopropoxide (97%), Nitrobenzene (98%), Concentrated HCl (35%), Aniline (99%), Acetic acid (98%) and Dichloromethane (99%) were purchased from S.D. Fine Chemicals, India. The Benzyl amine (99%) was purchased from Spectrochem. All the chemicals were used without any further purification.

- **Synthesis of mesoporous material**

- ***Procedure for Preparation of MCM-41:***

CTAB (3.64 g) was dissolved in distilled water (50 mL) followed by addition of NaOH (11 g diluted in 50 ml water). The entire mixture was stirred for 20 min to get clear solution. To the resulting solution, Acetic acid (3 ml diluted in 50 ml water) was added in drop wise fashion till pH in the range of 8-9 was obtained. Then formed gel was allowed to react for 1 hour under stirring action at room temperature. The solid mass was then filtered, washed with distilled water and dried at 80 ^{0}C for 12 hours in oven, followed by calcination at 550 ^{0}C for 6 hours in static air to remove all the surfactant[20].

- ***Procedure for Preparation of Al-20-MCM-41:***

For the synthesis of Aluminium (Al) grafted MCM-41 sample (Al-20-MCM-41) ,1 gram MCM-41 was added to the 50 ml toluene and stirred at least for 15 minutes. Then, 0.17 gram aluminium iso-propoxide was dissolved in 50 ml toluene and added to previous

toluene solution containing MCM-41. Both solution are mixed and stirred at room temperature for 24 hours. The solid product was formed that is filtered out, dried at 80 ^{0}C for 12 hours and calcined at 550 ^{0}C for 3 hours to get Al-20-MCM-41[20].

- **Procedure for oxidative coupling of amine to imine with MCM-41 and Al-20-MCM-41**

The amine was taken in a 50 mL reaction tube of reaction station (12 Place Heated Carousel Reaction Station, RR99030, Radleys Discovery Technologies, UK) along with the catalyst activated at 180 ^{0}C for 1 hour. The reaction was carried out in solvent free or in presence of solvent at desired temperature under stirring action for required reaction time. The reactions were performed in closed condition as well as under continuous air purging to provide excess oxygen for the reaction. After the reaction, the reaction mixture was cooled and diluted with dichloromethane. The reaction mixture was analyzed by gas chromatography (Agilent 7890A) having a HP-5 (60 m) capillary column with a programmed oven temperature from 50 to 280 ^{0}C, 0.5 cm^3/min. flow rate of N_2 as carrier gas and FID detector. The products formed in the reactions were characterized by GC–MS analysis and the data were matched with those reported in the literature. GC–MS analysis was carried out using gas chromatograph mass spectrometer (Agilent 5975C GC/MSD with 7890A GC system) having HP-5 capillary column of 60 m length and 250 µm diameter with a programmed oven temperature from 50 to 280 ^{0}C, at 1 mL min^{-1} flow rate of He as carrier gas and ion source at 230 ^{0}C.

III. Result and Discussion

Catalyst characterization was done by X-Ray Diffraction, Thermo Gravimetric Analysis (TGA) and BET surface area.

- **X-Ray Diffraction (XRD) of MCM-41 and Al-20-MCM**

From figure 1 it can be seen the intensity of Al-20-MCM-41 is lower than MCM-41 which shows loading of Al on MCM-41. The one (100) peak obtained between 2.5 to 3° C. The peck of calcined MCM-41 shows removal of organic surfactant template and condensation of silanol groups in the pore walls. In low 2-theta region of 1.5°-8° which shows characteristics of long range hexagonal MCM-41 and Al-20-MCM-41mesoporous phase.

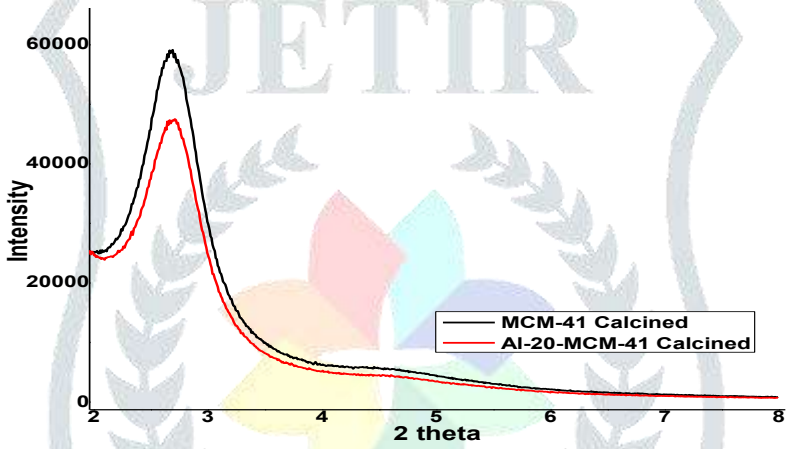


Fig. 1: XRD Patterns of MCM-41 and Al-20-MCM-41

- **Thermo Gravimetric Analysis (TGA) of MCM-41**

Figure 2 shows TGA profile of calcined and uncalcined MCM-41. The first weight loss was observed between 0 to 150°C. Decomposition of residual surfactant and water loss occur at temperature range between 330 - 550°C. After 550°C no loss was measured. So the calcination of MCM-41 was done at 550°C and from figure we say that surfactant was removed completely at this temperature.

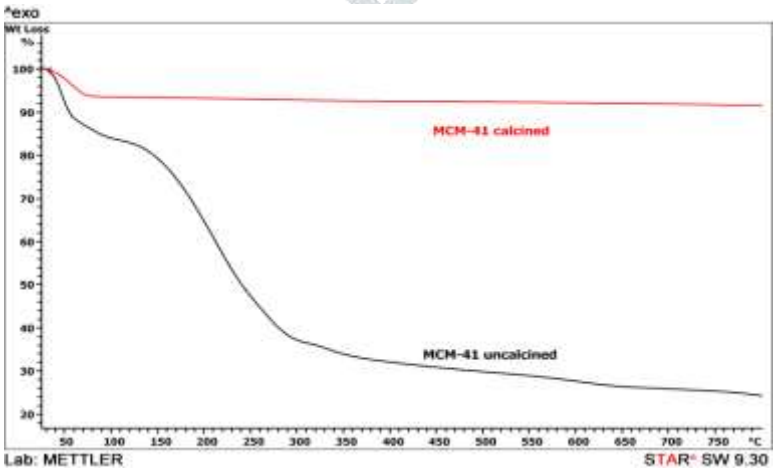


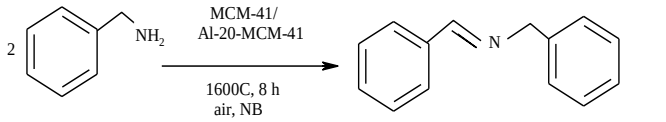
Fig. 2: TGA of MCM-41Catalyst

➢ **BET Surface Area**

Surface area of samples is measured by BET method. After the calcination, surface area of calcined MCM-41 is obtained 1290 m^2/g and for Al-20-MCM-41 it is 1156 m^2/gm. This shows loading of Al on the surface. Which result in increase in adsorption site for nitrogen molecules.

➢ **Oxidative Self Coupling of Benzyl Amine**

Oxidative self-coupling of Benzyl Amine to imine was carried out with MCM-41 and Al-20-MCM-41 at 160 ^{0}C for 6 hours to evaluate their catalytic activity for amine coupling reaction (Scheme 1). The MCM-41 (without Al) sample showed significant activity for self-coupling of Benzyl Amine giving 78% conversion of amine to imine with 100% selectivity (Table 1). The conversion of amine increased to 82% with Al-20-MCM-41. At 8 h Conversion increased to 92% for MCM-41 and 100% for Al-20-MCM-41. Liu et al [21] proposed that during oxidative coupling of Benzylic Amines in water under reflux condition, the amines are activated by water molecules by hydrogen bonding through amino group and thus amines react with oxygen to form an imine intermediate via peroxide complexes; the imine intermediates finally react with free amines to give the imine products.



Benzylamine E-N-benzylidene-1-phenylmethanamine

Scheme 1: Oxidative Self Coupling of Benzyl Amine With MCM-41 and Al-20- MCM-41

Table 1: Activity of MCM-41 and Al-20-MCM-41 for Benzyl Amine Self Coupling Reaction in Solvent, Solvent Free Condition and in Presence of Polar Solvent and Effect of Excess Air

Reaction in solvent free (SF)/in nitrobenzene (NB)	Reaction in closed vessel(CV) / in excess air(AIR)	Catalyst	Conv. of amine (wt.%)
SF	CV	MCM-41	60
SF	CV	Al-20-MCM-41	55.7
SF	AIR	MCM-41	57
SF	AIR	Al-20-MCM-41	62
NB	CV	MCM-41	58
NB	CV	Al-20-MCM-41	65
NB	AIR	MCM-41	78
NB	AIR	Al-20-MCM-41	82

Solvent free: 9.33 mmol Benzyl Amine, 50 mg Catalyst, 160 ^{0}C, 8 hours.
With solvent: 9.33 mmol Benzyl Amine, 0.46 ml NB, 50 mg catalyst, 160 ^{0}C, 6 hours.

➢ ***Effect of Solvent and Excess Air on Catalytic Performance of MCM-41 and Al-20-MCM-41 in Oxidative Self Coupling of Benzyl Amine***

The nitrobenzene might also be reducing the possibility of surface sites blockage (complexation) by removing the adsorbed species (reactant, intermediate and product molecules) by solubilization. In the present study, nitrobenzene was selected as polar solvent due to its high dielectric constant (34.8), high boiling point (205 $^\circ$C) and un-reactive nature, which has already been used as polar solvent in high temperature heterogeneous catalytic reactions [20]. This study reveals that a suitable (greener) high boiling point polar solvent can be explored to promote the efficiency of MCM-41 catalysts for amine coupling reactions. From these studies, it was evident that the presence of polar solvent (nitrobenzene) and excess air in the reaction could promote the catalysts activity. In nitrobenzene, the presence of excess air significantly enhanced the conversion of amine with all the samples showing that the presence of polar solvent and excess air facilitates the reaction. The Al-20-MCM-41 samples showed higher activity than MCM-41 as shown in figure 3.

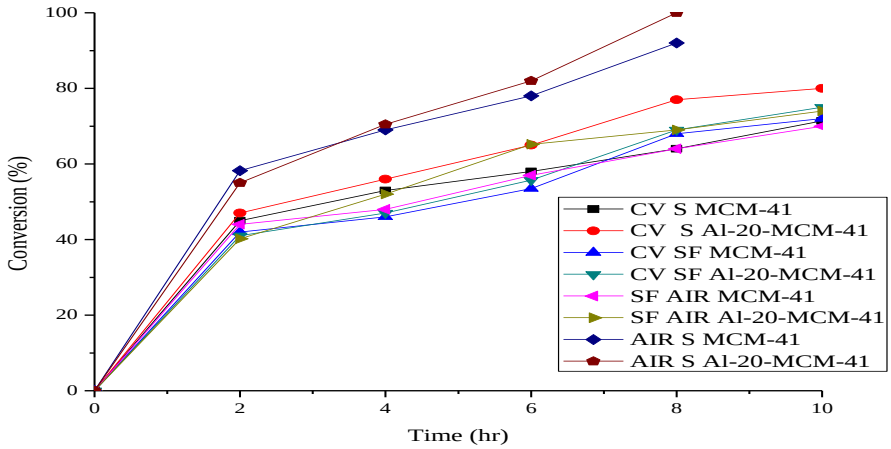
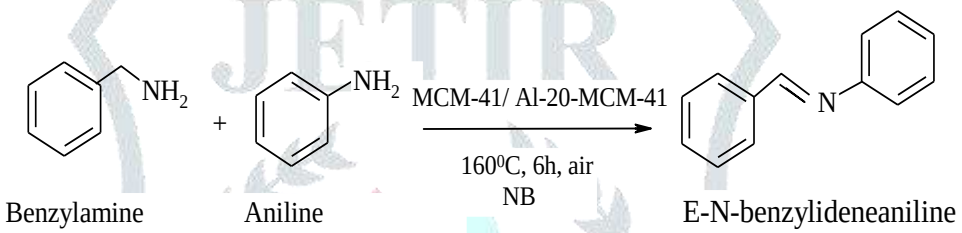


Fig. 3: Conversion of Benzyl Amine Self Coupling with MCM-41 and Al-20-MCM-41 Samples in Nitrobenzene, Solvent Free, Closed Vessel and in Excess Air
(9.33 mmol Benzyl Amine, 50 Mg Catalyst, 0.46 ml NB, Excess Air, 160 ˚C).

➢ **Cross coupling of Benzyl Amine with Aniline using MCM-41 and Al-20-MCM-41**

The catalytic activity of MCM-41 and Al-20-MCM-41 samples was evaluated for cross coupling of benzyl amine with aniline to cross imines (E-N-Benzylideneaniline) under similar reaction conditions (Scheme 2).

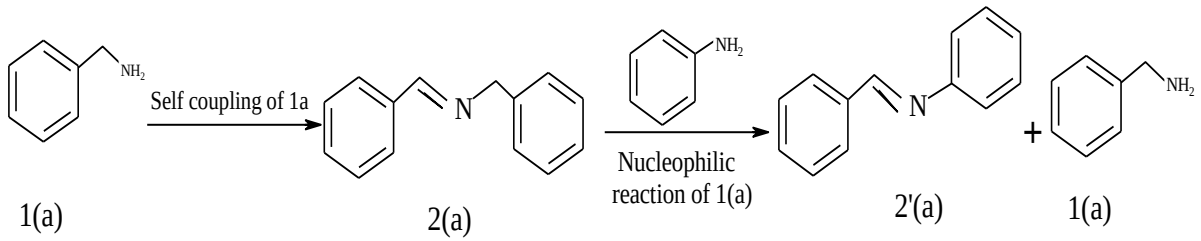


Scheme 2: Oxidative cross coupling of amine to imine with MCM-41 and Al-20- MCM-41

Table: 2 Conversion of Benzyl Amine And Products (Self And Cross Imine) Selectivity in Cross Coupling of Benzyl Amine (**1a**) and Aniline with MCM-41 and Al-20-MCM-41

Time (hour)	**Reaction in solvent free (SF)/in nitrobenzene (NB)**	**Conversion/selectivity With MCM-41**			**Conversion/selectivity with Al-20-MCM-41**		
		Conv. (%)	Self imine (**2a**)	Cross imine (**2'a**)	Conv. (%)	Self imine (**2a**)	Cross imine (**2'a**)
12	SF	100	41.2	58	100	24.5	75
12	NB	100	20	80	100	16	84

Reaction Condition: 4.66 mmol Benzyl Amine, 5.04 mmol Aniline, 50 Mg Catalyst, 0.46 ml NB, Excess Air, 160 ˚C.



Scheme 3: Formation Of Cross Imine (**2'a**) by Nucleophilic Reaction of Aniline with Self Imine Product (**2a**) Formed by Self Coupling of Benzyl Amine (**1a**).

The results, mentioned in Table 2, show the excellent activity of MCM-41 and Al-20-MCM-41 in cross coupling reactions giving almost complete conversion of 1a in 12 to 24 hours with good selectivity to cross imines. It was found that the cross imine (2'a) formation takes place via nucleophilic reaction of aniline with self imine product (2a) as shown in Scheme 3.

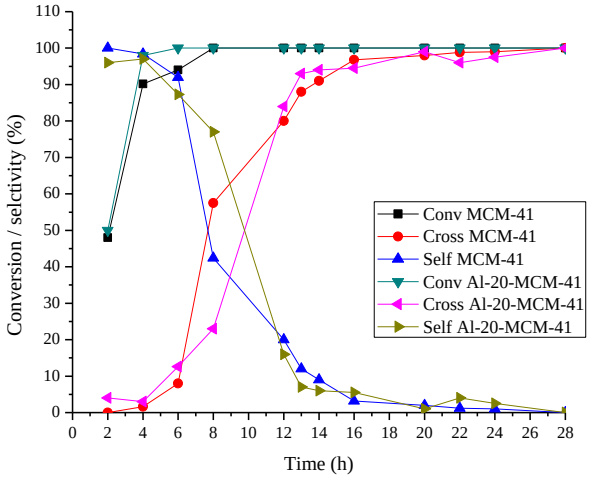


Fig.4: *Reaction of Benzyl Amine*

IV. CONCLUSION

For both self and cross coupling reactions 160^{0}C was optimized as optimum temperature. Self and cross amine coupling reactions are influenced by presence of Al, acidity of catalyst, presence of polar solvent and excess air. Both catalysts Al-20-MCM-41 and MCM-41 shows good activity on oxidative self and cross coupling of amine but somewhat higher conversion was achieved with Al-20-MCM-41 because of presence of acidic site. Self coupling reactions were carried out for four different conditions out of which conclusion is drawn that using Al-20-MCM-41 gave higher conversion when reactions carried out using solvent and excess air then MCM-41 catalyst, closed vessel and without solvent. With the use of Al-20-MCM-41 catalyst, higher conversion was obtained in all cases of self coupling reaction compare to MCM-41 due to higher surface acidic sites for interaction with amino group of Benzylamine. In presence of solvent and excess air in the reaction using both catalysts Al-20-MCM-41 and MCM-41 could promote the catalyst activity as these reactions give higher conversion in all mentioned cases of self coupling reactions. This shows that solvent and excess air facilitates the reaction. The use of solvent with both catalysts MCM-41 and Al-20-MCM-41 during reactions promotes higher conversion compare to non-use of solvent. With excess air higher conversion was obtained with both catalysts then closed vessel.

For cross coupling reaction of Benzylamine, it is concluded that with the use of solvent and excess air with MCM-41 catalyst the higher conversion was obtained in lower time then Al-20-MCM-41 catalyst. It happens because of interaction of aniline molecule with acidic sites. While in case of without solvent and excess air the higher conversion was observed with Al-20-MCM-41 compare to MCM-41 catalyst. With the use of solvent higher selectivity was obtained in lesser time for both catalysts compare to non-use of solvent with both catalysts. The use of solvent nitrobenzene in both catalysts Al-20-MCM-41 and MCM-41 gives higher conversion compare to reactions without solvent because nitrobenzene might be reducing the possibility of surface sites blockage by removing the adsorbed species. Finally, it would be concluded that Al-20-MCM-41 and MCM-41 both are good for self and cross coupling of amines but higher conversion was achieved with the use of Al-20-MCM-41 catalyst.

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