

Indium Modified Mesoporous Zeolite AIMCM-41 as a Heterogeneous Catalyst for the Knoevenagel Condensation Reaction

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The Indium modified mesoporous zeolite AIMCM-41 were synthesized by hydrothermal method and characterized by powder X-ray diffraction (XRD), fourier transform infrared spectroscopy (FT-IR) and scanning electron microscopy with energy dispersive spectroscopy (SEM-EDS) techniques. The Knoevenagel condensation of aldehyde with malononitrile or ethyl cyanoacetate was carried out at reflux condition in ethanol by using heterogeneous In/AIMCM-41 catalyst. This method is fast, efficient, easy work-up and eco-friendly to afford the corresponding Knoevenagel adducts. The catalyst was recovered and reused for several cycles with consistent activity.

Key Words: Knoevenagel condensation, Mesoporous zeolite In/AIMCM-41, Heterogeneous catalyst

Introduction

The Knoevenagel condensation is one of the most useful carbon-carbon bond forming reactions in organic syntheses.¹ There has been extensive interest in Knoevenagel products in recent years as they have very important applications in industry, the products containing nitrile groups have been used in the anionic polymerization and the α,β -unsaturated ester intermediates have been employed in the synthesis of several therapeutic drugs, such as niphendipine and nitrendipine.² In addition to that this reaction has been used widely for the preparation of coumarin derivatives, which are very important intermediates in cosmetics, perfumes and pharmaceuticals industry.³ Many alternative methodologies and reagents were developed for Knoevenagel reaction, such as clays,⁴ layered double hydroxides (LDHs),⁵ hydrotalcites,⁶ piperidine⁷ or amino acids such as glycine, alanine, L-proline⁸ and guanidine.⁹ In addition to these methods, in recent years, various homogenous and heterogeneous catalyst are used, such as TiCl_4 ,¹⁰ ZnCl_2 ,¹¹ MgF_2 ,¹² $\text{CeCl}_3 \cdot 7\text{H}_2\text{O}/\text{NaI}$,¹³ $\text{HClO}_4\text{-SiO}_2$,¹⁴ Ni-SiO_2 ,¹⁵ and $\text{SiO}_2\text{-NH}_4\text{OAc}$.¹⁶ However, many of these methods are plagued by some drawbacks, such as harsh reaction conditions, long reaction times, unsatisfactory yields and tedious experimental procedures. Thus, the development of new reagents with great efficiency, environmentally friendly and convenient procedure, for the Knoevenagel condensation is of great interest.

In recent years, considerable emphasis has been placed on improvement in the environmental impact of industrial chemical processes. It is well recognized that solids can play a significant role in the development of cleaner technologies through their abilities to act as catalyst and influence product selectivity.¹⁷ There have been many successful reports on the indium modified mesoporous Si-MCM-41 for the organic transformation, including benzylation of benzene,¹⁸ acylation of benzene¹⁹ and acylation of aromatic compounds.²⁰

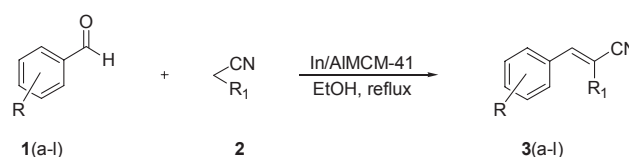
In view of the importance of heterogeneous solid acids as a reusable catalyst in organic synthesis and in continuation of

our ongoing research on zeolite as a solid acid catalyst for organic transformation,²¹⁻²⁵ in this communication, we report a facile method for the Knoevenagel reaction by condensing various aromatic aldehyde and malononitrile at reflux condition in ethanol (Scheme 1).

Experimental Part

Chemicals. All chemicals are purchased from Aldrich and Rankem chemical suppliers and used as received. The uncorrected melting points of compounds were taken in an open capillary in a paraffin bath. ^1H NMR spectra were recorded on an 300 MHz FT-NMR spectrometer in CDCl_3 as a solvent and chemical shifts values are recorded in δ (ppm) relative to tetramethylsilane (Me_4Si) as an internal standard.

Catalyst preparation. AIMCM-41 was prepared by direct hydrothermal method. An aqueous solution of sodium aluminate was added into tetraethylorthosilicate (TEOS) (19.3 gm) containing aqueous solution of cetyltrimethylammonium bromide (CTABr) (7.6 gm) and 10% aqueous tetramethylammonium hydroxide (TMAOH) (17 gm) was added with constant stirring at room temperature for 1 h. then the resulting mixture was treated with 2 N H_2SO_4 to adjust the pH 10 to 10.5. The resultant gel was transferred into autoclavable bottle at 100 °C for 96 h. The solid product was filtered, washed several times with distilled water, dried in air at 373 K and finally, calcined at 540 °C for 6 h. The calcined materials were converted into H-form by ion exchange with aqueous 1 M NH_4Cl solution this procedure was repeated twice followed by calcination at



Scheme 1

550 °C for 6 h. In/AlMCM-41 was obtained by wetness impregnation method with acetonitrile solution of Indium trichloride with respective H-AlMCM-41 evaporating the solvent in a vacuum oven at 120 °C for 8 h.

Catalyst characterization. The X-ray powder diffraction patterns were recorded by using Bruker 8D X-ray diffractometer using CuK α radiation of wavelength = 1.54056 Å. FT-IR spectra were recorded on JASCO FT-IR-4100, Japan. Scanning electron microscope image with energy dispersive X-ray spectroscopy (SEM-EDS) was obtained on JEOL, JSM-6330 LA operated at 20.0 kV 1.0000 nA.

General procedure for the Knoevenagel condensation. A mixture of an aldehyde (10 mmol), malononitrile or ethyl cyanoacetate (12 mmol), In/AlMCM-41 (0.1 gm) and ethanol (10 mL) was refluxed up to completion of reaction. The progress of the reaction was monitored by thin layer chromatography, using petroleum ether/ethyl acetate (7:3) as a solvent system. After completion of the reaction, In/AlMCM-41 was filtered and the filtrate was concentrated under reduced pressure, the solid product obtained was crystallized from ethanol to afford the pure product

Representative data of selective compound.

3f: IR (KBr, cm⁻¹) 3110, 2850, 2230, 1600, 1550, 1460, 1370, 1280 cm⁻¹. ¹H NMR (300 MHz, δ in ppm) 3.90 (s, 3H), 7.00 (d, J = 8.1 Hz, 2H), 7.68 (s, 1H), 7.95 (d, J = 8.1 Hz, 2H).

Results and Discussion

XRD analysis. X-ray powder diffraction patterns of AlMCM-41 and In/AlMCM-41 are shown in Figure 1. An intense peak representing the (100) diffraction is observed and is in good agreement with reported patterns of mesoporous zeolite AlMCM-41.²⁶ Peaks corresponding to (110), (200) and (210) reflections are also observed. XRD pattern of In/AlMCM-41 shows the decrease in intensity of peak to (100) reflections and also in case of intensity of (110), (200) and (210) in the 2 θ range 3.5 - 7.0, indicating that the long range order of AlMCM-41 has decreased after the modification, but fundamentally the mesostructure of the AlMCM-41 materials is still maintained. This suggests that structural integrity of the mesoporous AlMCM-41 still intact after post-synthesis modification with InCl₃.

FT-IR analysis. FT-IR spectra of AlMCM-41 and In/AlMCM-41 are shown in Figure 2. The peak appeared at 1627 cm⁻¹ due to the bending mode of vibrations of adsorbed OH group. The peak around 1082 cm⁻¹ is attributed to the asymmetric stretching of Si-O-Si groups. The symmetric stretching modes of Si-O-Si groups are observed at around 803 cm⁻¹, while the absorption band at around 455 cm⁻¹ corresponds to the bending vibration of Si-O-Si or Al-O-Si groups which is typical characteristic of AlMCM-41.

SEM-EDS analysis. The surface morphology of AlMCM-41 and In/AlMCM-41 was investigated by SEM with different magnification and the micrographs are presented in Figure 3. Figure 3a and 3b shows the well agglomeration of particles and which was irregular in shape. Figure 4 shows the EDS spectra for In/AlMCM-41 the presence of indium 4.35 mass % were estimated.

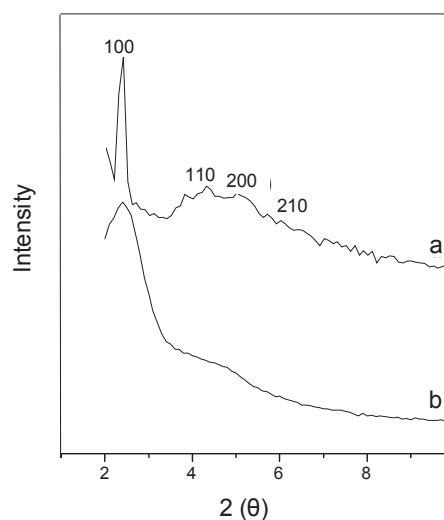


Figure 1. XRD patterns of AlMCM-41 (a), In/AlMCM-41 (b).

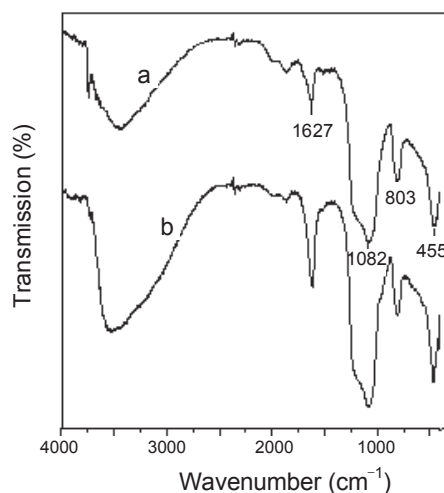


Figure 2. FT-IR spectrum of AlMCM-41 (a), In/AlMCM-41 (b).

To optimize the reaction conditions, 4-chlorobenzaldehyde and malononitrile were selected as a model reaction in the presence of varying amounts of catalyst (Table 1). The reaction could proceed efficiently with 0.1 gm of In/AlMCM-41 catalyst and gave excellent product yield (Table 1, entry 4). Furthermore, we have increased amount of In/AlMCM-41 catalyst (0.15 and 0.2 gm), results does not show any variation in time and yield (Table 1, entries 5 and 6). However, only moderate yield obtained when 0.01 gm and 0.05 gm of In/AlMCM-41 was employed (Table 1, entries 2 and 3). In the absence of catalyst, no product was found (Table 1, entry 1).

On the basis of the optimization dosage of the catalyst, studies focused on the effect of different solvents, such as dimethylformamide (DMF), dichloromethane (DCM), methanol (MeOH), acetonitrile (MeCN) and ethanol (EtOH) and the results were given in Table 1. The results showed that moderate yields of the desired product in DMF, DCM, MeOH and MeCN (Table 2, entries 1, 2, 3 and 4). Moreover, when the reaction is carried out in ethanol, it gave excellent product yield (95%)

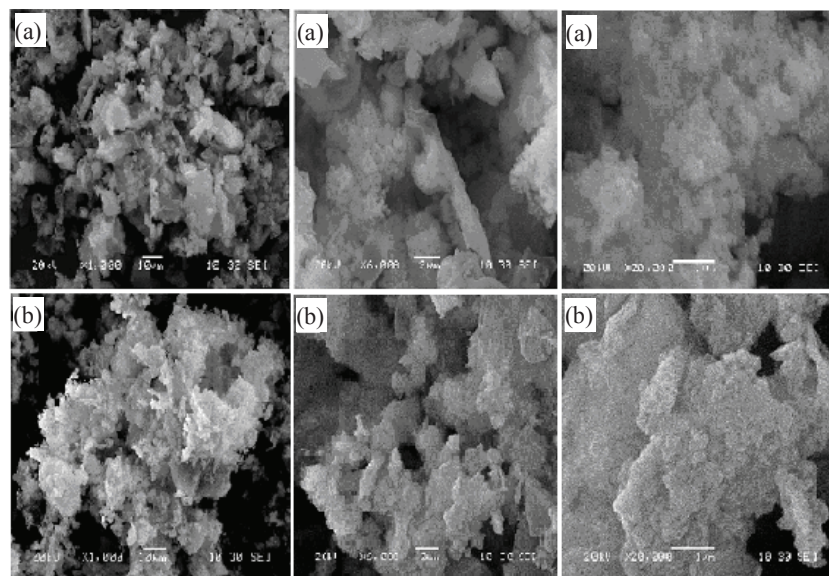


Figure 3. SEM micrograph of (a) AIMCM-41; (b) In/AIMCM-41.

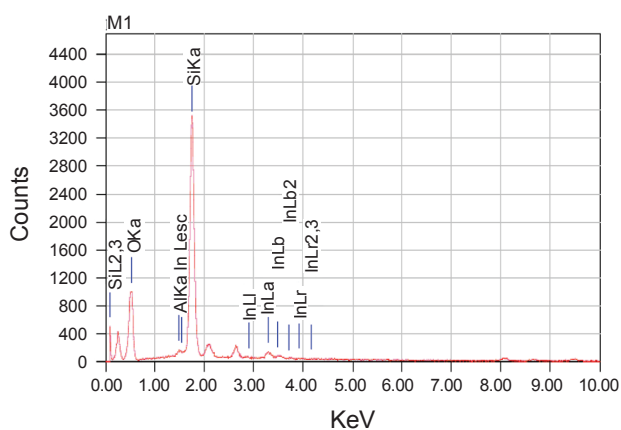


Figure 4. EDS spectrum of In/AIMCM-41.

Table 1. Effect of catalyst amount in the synthesis of 2-(4-chlorobenzylidene) malononitrile^a

Entry	Catalyst (gm)	Time (min)	Yield (%) ^b
1	None	25	-
2	0.01	25	62
3	0.05	25	79
4	0.1	25	95
5	0.15	25	95
6	0.2	25	95

^aReaction condition: 4-chlorobenzaldehyde (10 mmol) and malononitrile (12 mmol) at reflux condition. ^bIsolated yields.

within 25 min (Table 2, entry 5). This indicates that reaction in ethanol produce the best results with respect to product yield and time.

Using the optimized conditions, the reaction of different carbonyl compound with malononitrile or ethylcyanoacetate

Table 2. Effect of various solvent in the synthesis of 2-(4-chlorobenzylidene) malononitrile^a

Entry	Solvent	Time (min)	Yield (%) ^b
1	DMF	35	35
2	DCM	40	52
3	MeOH	25	73
4	MeCN	25	79
5	EtOH	25	95

^aReaction condition: 4-chlorobenzaldehyde (10 mmol), malononitrile (12 mmol) and 0.1 gm of In/AIMCM-41 catalyst at reflux condition. ^bIsolated yield.

Table 3. Knoevenagel condensation of different carbonyl compound with malononitrile or ethyl cyanoacetate in the presence of In/AIMCM-41 catalyst

Compound	R	R ¹	Time (min)	Yield (%) ^a	mp (°C)	
					Found	Reported
3a	H	CN	25	95	84 - 85	84
3b	4-CH ₃	CN	30	91	128 - 129	129
3c	4-NO ₂	CN	45	89	159 - 160	160
3d	4-OH	CN	30	90	188 - 189	188
3e	4-Cl	CN	25	95	161 - 162	162
3f	4-OMe	CN	40	88	115 - 116	116
3g	H	COOEt	100	87	49 - 50	50
3h	4-CH ₃	COOEt	110	82	90 - 91	91
3i	4-NO ₂	COOEt	150	79	169 - 170	169
3j	4-OH	COOEt	130	85	170 - 171	171
3k	4-Cl	COOEt	120	87	90 - 91	91
3l	4-OMe	COOEt	145	78	79 - 80	80

^aYield refer to isolated products, which were characterized by comparing IR, ¹H-NMR, mass spectral data and melting points with those reported in literature.¹²

Table 4. Reusability of In/AlMCM-41 catalyst in the synthesis of 2-(4-chlorobenzylidene) malononitrile^a

Entry	Run	Yield (%) ^b
1	1 st	95
2	2 nd	95
3	3 rd	94
4	4 th	93

^aReaction condition: 4-chlorobenzaldehyde (10 mmol), malononitrile (12 mmol) were carried out at reflux condition in ethanol. ^bIsolated yield.

Table 5. Comparisons of results of other reported procedures with the present method

Entry	Catalyst	Reaction condition	Time	Yield (%)	Reference
1	In/AlMCM-41	EtOH/reflux	25 min	95	present
2	Ni-SiO ₂	toluene/reflux	15 h	100	15
3	SiO ₂ -NH ₄ OAc	DCM/60 °C	7 h	87	16
4	MgF ₂	EtOH/rt	2.5 h	93	12
5	Guanidine	DCM/rt	4 h	89.8	9

gave the corresponding products in high to excellent yields (Table 3). We found that aromatic as well as heteroaromatic aldehydes containing different functional groups at different position worked well and did not show much difference in the yield of products (Table 3, entries 3a-3l).

Finally, we turned our attention towards the recovery and reusability of catalyst. The catalyst was recovered by simple filtration, washed with *n*-hexane and dried at 120 °C for 2 h and reused. The efficiency of the recovered catalyst was verified with the same model reaction. From Table 4, the results demonstrate that there is no any apparent loss of activity of the catalyst after every use.

In order to show the merits of In/AlMCM-41 in comparison with other reported catalysts, we summarized some of the results for the preparation of 2-benzylidene malononitrile in Table 5, which shows that In/AlMCM-41 is a more efficient catalyst to those previously reported.

Conclusion

In conclusion, we have developed an efficient, convenient and clean method for the Knoevenagel condensation using cheap, uncomplicated handling and reusable In/AlMCM-41 catalyst. The notable merits offered by this methodology are mild reaction conditions, simple procedure, cleaner reactions, short reaction time and excellent yield of products.

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