



A HIGHLY ACTIVE Cu-Cu₂O-SiO₂ NANOCOMPOSITE FOR SYNTHESIS OF α , β -UNSATURATED COMPOUNDS

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ABSTRACT :

A study of the Knoevenagel condensation of 4-Methoxybenzaldehyde with an active methylene compounds, in aqueous medium is reported. This synthesis approach led these reactions to proceed faster, more cleanly and in higher yields. Thus, an efficient procedure for the Knoevenagel condensation of 4-Methoxybenzaldehyde with an active methylene compounds using the Cu-Cu₂O-SiO₂ as nanocomposite in aqueous medium and very mild conditions has been developed.

KEYWORDS : pharmaceutical industry, characterization and catalytic activity.

1 INTRODUCTION

The Knoevenagel condensation is one of known C-C coupling reactions in Chemistry. In the last couple of years its application ranged from pharmaceutical industry [1], to polymers and even the application of alternative solvents, such as ionic liquids [2], have been reported. However, most of these methods have drawbacks like harsh reaction conditions, low yield, long reaction time and the use of organic solvents which causes environmental waste and pollution. Thus, the development of an alternative method, more particularly with the application of novel, simple, efficient, cost-effective, high-yielding, and green methodologies is highly desirable. Aqueous medium reactions, as well as Cu-Cu₂O-SiO₂ as catalyst reactions, offer the above advantages, and the reactions are complete within minutes. Moreover, the work-up is very simple and does not require complicated purification procedure.

In the proposed work, synthesis, characterization and catalytic activity of a catalytic system, Cu-Cu₂O dispersed on SiO₂, is reported. It is observed that a combination of Cu-Cu₂O-SiO₂ shows enhanced catalytic activity due to well dispersion of catalytic centres. With this aim, a series of Cu-Cu₂O-SiO₂ nanocomposites, having different concentrations of copper, has been synthesized and studied its catalytic activity for the Knoevenagel condensation at room temperature.

2 EXPERIMENTAL DETAILS

All chemicals used were of AR grade. For the synthesis of Cu-Cu₂O-SiO₂ nanocomposites, the different chemical such as copper acetate, sodium dodecyl sulphate as a capping agents, hydrazine hydrate as a reducing agent, commercial silica were used. The 4-Methoxybenzaldehyde and different active methylene compounds were used for Knoevenagel condensation.

2.1 Preparation of Cu-Cu₂O-SiO₂ nanocomposites.

Cu-Cu₂O-SiO₂ nanocomposites were synthesized by chemical reduction followed by impregnation method. The copper nanoparticles were synthesised by using chemical reduction method. 5 mL (1x10⁻² M) copper acetate solution and 5 mL (1x10⁻² M) sodium dodecyl sulphate were mixed together. The mixture was

stirred at 60 °C for 30 min. 3 mL hydrazine hydrate solution was added drop by drop with constant stirring in oil bath keeping the temperature at 60 °C. The dark coloured slurry/residue was obtained. The content was centrifuged, washed with distilled water, ethanol and dried.

For making composite, the copper nanoparticles were dispersed into 100 mg silica powder with 5 mL distilled water. The resulting mixture was stirred for 2-3 hours at room temperature. In the nanocomposites, the amount of copper was varied from 5 wt %, 25 wt % and 50 wt%. The obtained residue was centrifuged, washed with water and dried. The product was used as a catalyst for Knoevenagel condensation.

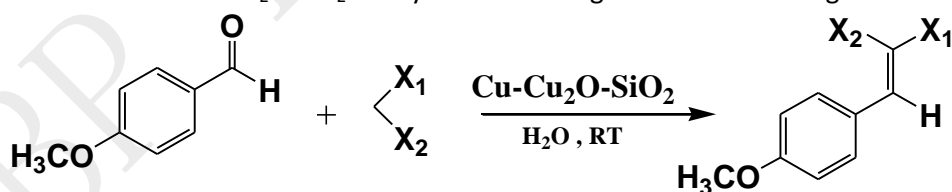
2.2 Characterization of Cu-Cu₂O-SiO₂ nanocomposites

X-ray diffractometer (Philips model PW-1710) was used to identify the structural properties of the samples using Cu K α radiation. Energy-dispersive spectroscopy technique (JSM-JEOL 6360) was used for the elemental analysis of the Cu-Cu₂O-SiO₂ nanocomposites. Particle morphology was measured using a transmission electron microscope (TEM) (Philips, CM200, operating voltages 20–200 kV). The UV-visible (UV-visible) spectra of the powders were recorded using a (JASCO model V-670) spectrophotometer equipped with an integrating sphere accessory. Barium sulphate was used as reference for the reflectance spectra. Fourier transform Infra-red (FT-IR) spectra of the catalysts were recorded in a Perkin-Elmer spectrometer using KBr pellets. The photoluminescence (PL) measurements of the samples were carried out by using Spectrofluorimeter (JASCO FP-750).

2.3 Catalytic activity

The catalytic properties of Cu-Cu₂O-SiO₂ system were examined by Knoevenagel condensation. This condensation was conducted between 4-Methoxybenzaldehyde and different substituted active methylene compounds in water as a solvent. In this reaction, the mixture of 4-Methoxybenzaldehyde (1 mmol), active methylene compound (1 mmol), Cu-Cu₂O-SiO₂ (10 mg) catalyst with distilled water was taken in RB flask and stirred continuously at room temperature. The progress of the reaction was monitored by TLC. After completion of reaction, the reaction mixture was treated with ethanol for separating the desired product and catalyst by filtration. The products were recrystallized by ethanol and thereafter the various experimental parameters such as melting points, reaction-time and yield of the products were noted. NMR spectra were taken in CDCl₃ using a Bruker Spectrospin Avance II-300MHz spectrophotometer and Jeol-400MHz spectrophotometer with TMS as an internal standard. The catalyst exhibited a clean reaction profile with excellent yields in a short reaction time. The experimental data of all the products were consistent with the proposed structure.

The general route for Cu-Cu₂O-SiO₂ catalysed Knoevenagel condensation is given below:



3. RESULTS AND DISCUSSION

3.1 X-ray diffraction studies

Fig. 1.1 shows the powder X-ray diffraction patterns of Cu-Cu₂O and Cu-Cu₂O-SiO₂ nanocomposites. All samples show peaks corresponding to well crystallized phase of metallic copper particles [JCPDS card no. 85-1326, 04-0836, 70-3038, 89-2883] with the presence of small intensity peaks for Cu₂O particles [JCPDS

No. 78-2076, 05-0667]. This observation reveals the presence of copper particles with Cu₂O particles due to partial oxidation of surface copper particles [3]. The diffraction peaks with strong intensities appear at $\sim 43.41^\circ$, $\sim 50.36^\circ$, $\sim 74.16^\circ$ are corresponds to (111), (200) and (220) planes of copper particles, respectively. These diffraction peaks corresponds to face-centered cubic structure of elemental copper with the space group of Fm3m [JCPDS No. 85-1326]. The diffraction peaks at $\sim 36.27^\circ$ and $\sim 61.34^\circ$ indicates the presence of Cu₂O, which corresponds to the (110) and (211) plane. In the composites, the broad and diffuse diffraction peak of SiO₂ is observed at $\sim 21.44^\circ$, which is attributed to amorphous silica [4].

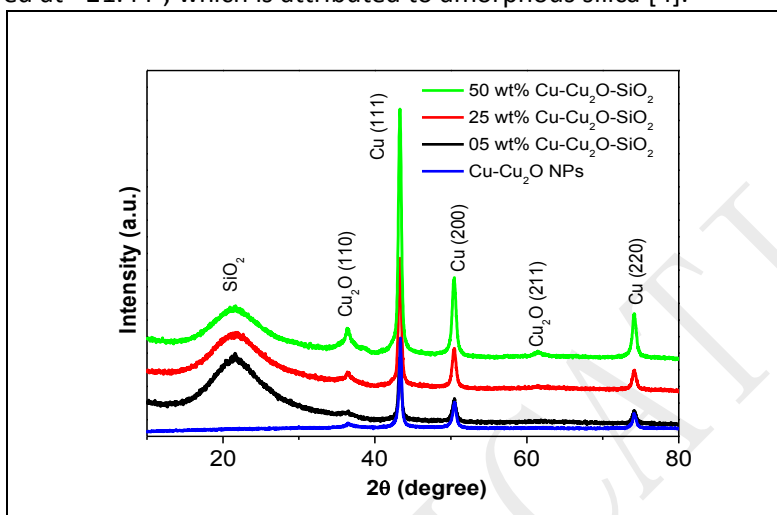


Fig. 1.1: Powder XRD patterns of (a) Cu-Cu₂O nanoparticles, (b) Cu-Cu₂O-SiO₂ (5 wt%), (c) Cu-Cu₂O-SiO₂ (25 wt %), and (d) Cu-Cu₂O-SiO₂ (50 wt %)

3.2 TEM and EDAX studies

Fig. 1.2 (a–b) depicts the transmission electron micrographs of Cu-Cu₂O and Cu-Cu₂O-SiO₂ samples. It is evident from Fig. 1.2(a) that the average particle size of copper nanoparticles is found in the range of 10–15 nm. Fig. 1.2(b) clearly shows the presence of a dispersed phase of Cu-Cu₂O particles in the matrix of SiO₂. The compositions of 5 wt% Cu-Cu₂O-SiO₂, 25 wt% Cu-Cu₂O-SiO₂ and 50 wt% Cu-Cu₂O-SiO₂ samples were determined by using the energy dispersive X-ray analysis (EDAX). Typical EDAX spectrum of 50 wt% Cu-Cu₂O-SiO₂ sample is shown in Fig.1.3. The quantitative analysis of the EDAX spectrum revealed that the relative atomic ratios of Cu and Cu: Si are close to the initial values taken for three nanocomposites samples.

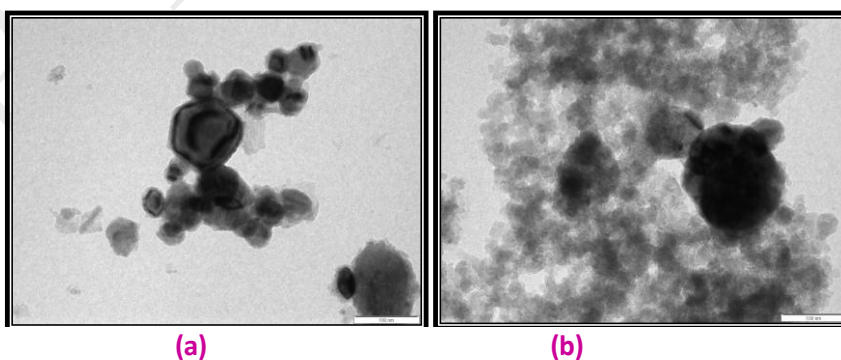


Fig. 1.2: TEM micrographs of (a) Cu-Cu₂O, (b) Cu-Cu₂O-SiO₂ (50 wt%).

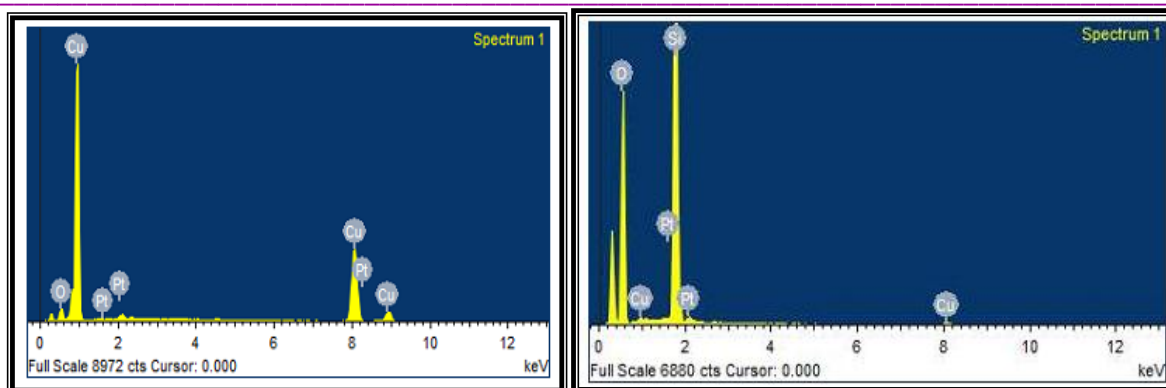


Fig. 1.3: EDAX patterns (a) Cu-Cu₂O nanoparticles and (b) Cu-Cu₂O-SiO₂ (50 wt %).

3.3 Optical absorption properties

Fig. 1.4 shows the UV-visible absorption spectra of the Cu-Cu₂O-SiO₂ nanocomposites in aqueous solution. In all spectra, the surface plasmon resonance (SPR) band is observed at 592 nm for Cu NPs [5]; while the broad absorption edge from 450 to 550 nm is noted for Cu₂O and SiO₂ particles [6].

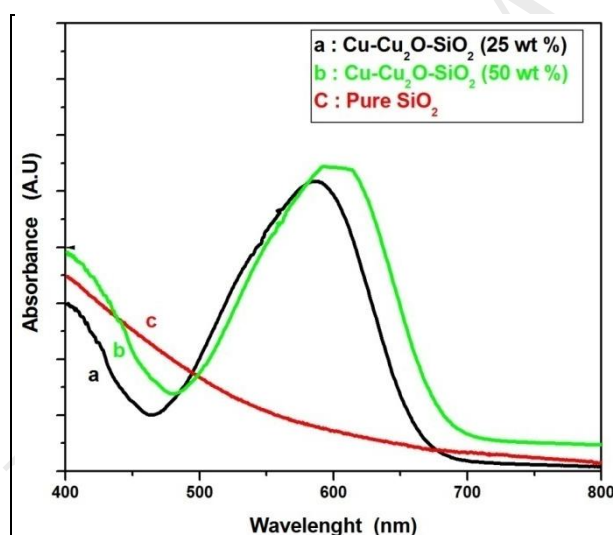


Fig. 1.4: UV-Visible spectra of pure SiO₂ and Cu-Cu₂O-SiO₂.

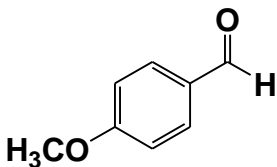
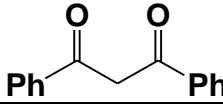
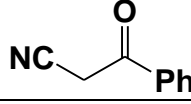
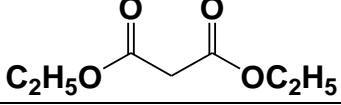
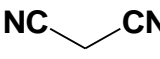
4 CATALYTIC STUDIES

The catalytic activities of Cu-Cu₂O-SiO₂ nanocomposites have been tested towards the Knoevenagel condensation reaction of 4-Methoxybenzaldehyde and different substituted active methylene compounds in water as a solvent. It is observed that all the reactions occurred rapidly and are completed in 3-5 minutes giving excellent yields of the Knoevenagel products.

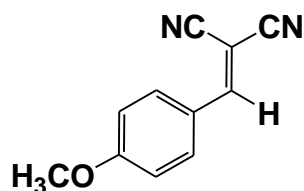
To determine the appropriate composition of the catalysts, we investigated the reaction at different composition of copper nanoparticles such as 5, 25 and 50 wt% supported on SiO₂ matrix. It is noted that 50 wt% copper NPs supported on SiO₂ yields large amount of products than that of other compositions. Therefore, the further catalytic studies are carried out using 50 wt% of Cu-Cu₂O-SiO₂ nanocomposite. The reactants and products formed with their percentage yield as well as melting point, in this condensation, are summarized in Table 1.1.

The yield of the products was in the range of 75-86 %, which reveals that, Cu-Cu₂O-SiO₂ (50 wt %) gave better yield with better selectivity also. Active methylene compounds with strong electron withdrawing groups (-CN) giving better yields in short time as compared to that of others.

Table 1.1: Cu-Cu₂O-SiO₂ (50 wt %) catalysed Knoevenagel condensation of 4-Methoxybenzaldehyde and different substituted active methylene compounds.

Sr. No.	Aldehyde	Different Active Methylene Compounds	Time (min)	Yield (%)	M.P. (°C) Observed
1			5	75	118-120
			4	86	114-116
			3.5	80	112-114
			3	84	118 - 120

5. SPECTRAL DATA OF SELECTED COMPOUNDS



2-(4-Methoxybenzylidene) malononitrile: Solid; M.P.: 118-120°C (Lit⁷. 118°C);

IR (KBr): 3112, 2982, 2359, 2219, 1603, 1558, 1235, 831cm⁻¹;

¹H-NMR (300 MHz, CDCl₃): δ 3.94 (s, 3H), 7.03 (dd, 2H, J = 7.7 & 3.4 Hz), 7.68 (s, 1H), 7.93 (dd, 2H, J = 8.1 & 3.2 Hz).

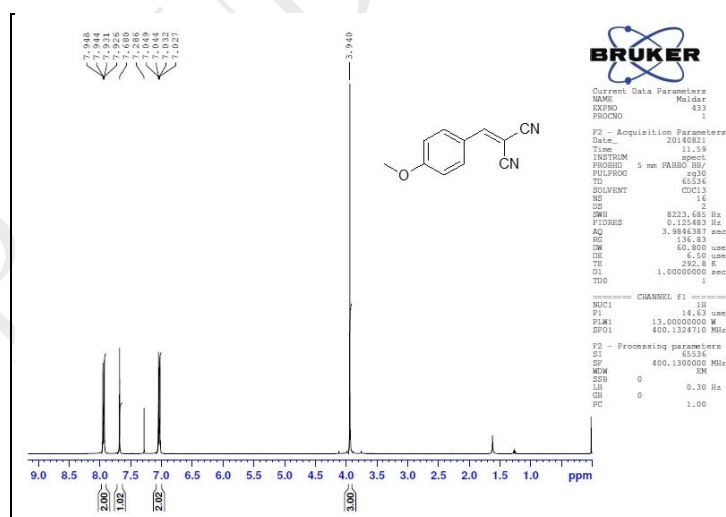


Fig. 1.5: ¹H Spectra of 2-(4-Methoxybenzylidene) malononitrile

6. CONCLUSIONS

Regarding to the Knoevenagel condensation, it was found that a simple, efficient, cost-effective, high-yielding, and green methodology using Cu-Cu₂O-SiO₂ nanocomposite in aqueous medium, at room temperature, achieves higher yields than the other technique. Therefore, the use of this approach in fields

such as synthesis in industry or medicinal and pharmaceutical in order to generate molecules of biological interest using Knoevenagel chemistry is a possibility to be explored.

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