



AN EFFICIENT AND REUSABLE HETEROGENEOUS NANOCATALYST: CuO-Co₃O₄@NiO CORE SHELL FOR THE RAPID ONE-POT SYNTHESIS OF PYRANO [2,3-d] PYRIMIDINES

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ABSTRACT

The catalytic activity of CuO-Co₃O₄@NiO core shell as an efficient and reusable catalyst was studied for the synthesis of pyrano[2,3-d] pyrimidine. The core shell catalyst was developed by the impregnation method using aqueous solutions of copper and cobalt nitrates. The structural and morphological properties of synthesized core shell CuO-Co₃O₄@NiO have been determined by characterization techniques such as Fourier-transform infrared spectroscopy (FT-IR), X-ray diffraction analysis (XRD) and scanning electron microscopy (SEM).

KEYWORDS: pyrano [2,3-d] pyrimidinones, NiO nanoplates, CuO-Co₃O₄, Coprecipitation method, XRD, SEM

INTRODUCTION

Recently, in the Nanotechnology field the development of advanced core-shell materials is proposed. Due to enormous application this class of nanostructure has received considerable attention. It has uses in physicsⁱ⁻ⁱⁱⁱ, chemistry^{iv-vi}, and biological area^{vii-ix} because of the collective properties and function of the core and shell. Core shell nanoparticles consist of various types of inorganic nanoparticles like metal oxides.

Metal oxide nanoparticles have drawn large attention as they possess distinctive chemical, electronic, mechanical, magnetic and optical properties which are significantly unlike from those of analogous bulk ones. Transition metal oxides show an expansive structural variety due to changeable oxidation states so being measured as potential materials for many applications. Nanoscale transition metal oxides are acquiring unbroken significance than their bulk equivalents. Nanoparticles expose unique properties because of their small size and high surface area. Owing to chemical stability, novel optical, electronic, magnetic, thermal and mechanical properties, nickel oxide (NiO) is remarkable transition metal oxide nanoparticles. In view of all the mentioned properties NiO material has potential application in catalyst, battery electrodes, gas sensors, electrochromic material etc. Various methods have been employed to synthesize metal oxides like solvothermal, hydrothermal, chemical bath deposition, chemical precipitation, microwave assisted, electrophoretic deposition and sonochemical with different morphologies. From all said methods co-precipitation is an easy and cost-effective method for synthesizing nanoparticles that can be made in a variety of

sizes^{xiii}. The core shell formation with NiO leading to modification of their properties and made desirable for many applications^x. Co₃O₄ and CuO are the promising materials in formation of core shell nanostructure^{xi-xii}.

Multicomponent reactions (MCRs) have been recognized as a very important in the fields, such as synthetic organic chemistry, medicinal chemistry and combinatorial chemistry^{xiv-xv}. Moreover, employing one-pot MCRs generate products of one-step and extensively minimize waste of reagents, solvents, and adsorbents.

Heterocyclic motifs, pyrano[2,3-d] pyrimidines have an extensive range of applications in the field of drug discovery which exhibit anti-cancer, anti-microbial, anti-oxidant and anti-tumor activities^{xvi-xix}. Seeing the importance of such compounds, foremost research attention has been given to the synthesis of such heterocyclic compounds. Therefore, many approaches have been reported for synthesis of pyrano[2,3-d] pyrimidine scaffolds using different catalytic systems^{xx-xxiii}. These conventional synthesis methods strive from such drawbacks as low yields, long reaction times, harsh reaction conditions, tedious work-up procedures include hazardous solvents, and lack of generality of catalyst. Therefore, necessity to develop an efficient procedure for the synthesis of pyrano[2,3-d] pyrimidine scaffolds is of significant concern.

In the present work, we report a promising strategy for the synthesis of pyrano[2,3-d] pyrimidine using an efficient and reusable heterogeneous nanocatalyst CuO-Co₃O₄@NiO core shell. To improve the performance of Nickel Oxide, we have described a simple method to synthesize CuO-Co₃O₄@NiO core shell Nanoplates. Structure determination of synthesizing material was characterized by Fourier-transform infrared spectroscopy (FT-IR), X-ray diffraction (XRD) and scanning electron microscopy (SEM).

EXPERIMENTAL

MATERIAL

The chemicals used are nickel nitrate (Ni(NO₃)₂.6H₂O (Sigma Aldrich 99.99%), Cobalt nitrate (Co(NO₃)₂.6H₂O) (Sigma Aldrich 99.99%), (Cu(NO₃)₂.3H₂O) copper nitrate (Sigma Aldrich 99.99%), sodium hydroxide (NaOH, Merck 99%) cetyltrimethylammonium bromide (CTAB) (Sigma-Aldrich). Double distilled water (DDW) was used as a solvent in all the experiments. All chemicals for preparation of pyrano[2,3-d] pyrimidines were purchased from Sigma-Aldrich

Preparation of NiO nanoparticles

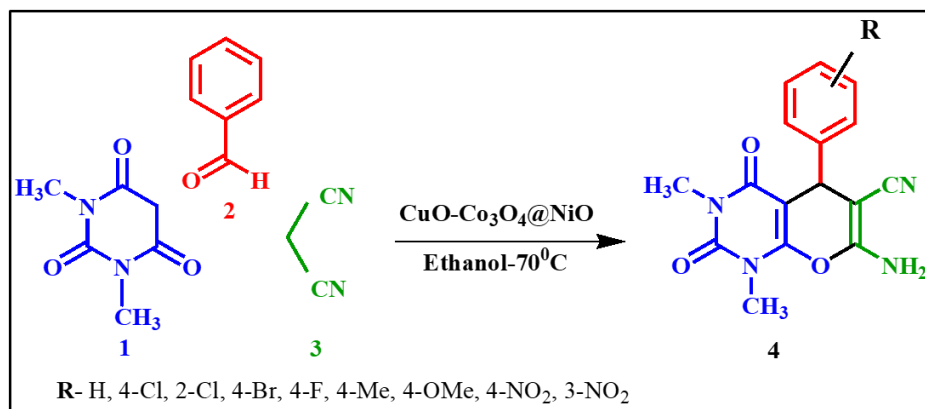
The NiO nanoparticles were synthesized by the coprecipitation method using Ni(NO₃)₂.6H₂O (1M) used as precursor and CTAB as surfactant was dissolved in 100 ml double distilled water. The sodium hydroxide (0.1M) was slowly added drop wise under continuous stirring. The green colored precipitates of Nickel hydroxide were obtained. The mixtures were stirred for 3 h at 80°C the precipitate obtained was filtered and washed with double distilled water. The washed precipitate was dried at 110°C for 12 h. The dried precipitate was calcined at 450°C for 5h. The synthesized NiO was characterized by FT-IR, XRD and SEM techniques.

Preparation of CuO-Co₃O₄@NiO core shell Nanoplates

CuO-Co₃O₄@NiO core shell Nanoplates was obtained an impregnation method. The method involve loading aqueous solution of stoichiometric amount of (Cu(NO₃)₂.3H₂O) copper nitrate and Cobalt nitrate (Co(NO₃)₂ of of.6H₂O) on prepared NiO Nanoplates. The mixture obtained was refluxed at 110°C for 12 h then filtered and washed with double distilled water. The product obtained was dried at 100°C in the oven and calcined at 750°C for 4 h in air. The synthesized CuO-Co₃O₄@NiO catalyst was characterized by FT-IR, XRD and SEM techniques.

General procedure for preparation of pyrano[2,3-d] pyrimidines

A mixture of 1,3 dimethyl barbituric acid (2mmol), aromatic aldehyde (1.5mmol), malononitrile (2mmol) and catalyst CuO-Co₃O₄@NiO (0.5mol) stirred for appropriate time. The progress and completion of reaction was monitored by TLC. After completion of reaction, the mixture was cooled to room temperature. The mixture was poured in cold water. The solid separated was filtered by suction to afford crude product. Pure product was obtained by further crystallization from ethanol to get the desired compound in pure form (Scheme 1.) The structure of all products was confirmed by using physical and ¹HNMR spectroscopic data.



Scheme 1: Synthesis of pyrano[2,3-d] pyrimidines

RESULT AND DISCUSSION

FT-IR spectra of NiO, synthesized CuO-Co₃O₄@NiO was taken in the region of 400-4000 cm⁻¹ and is given in Fig. 1.1a FT-IR spectrum confirming the formation of NiO as it shows stretching frequency at 501.49 is because of Ni-O stretching mode. Fig.1.1b. along with Ni-O stretching frequency for nickel oxide, it also reveals strong band at 432 cm⁻¹ due to vibrations of Cu-O of CuO nanoparticles as well as absorption band at 524cm⁻¹and 648cm⁻¹ which assigned Co-O stretching vibration mode and bridging vibration of O-Co-O respectively of Co₃O₄.

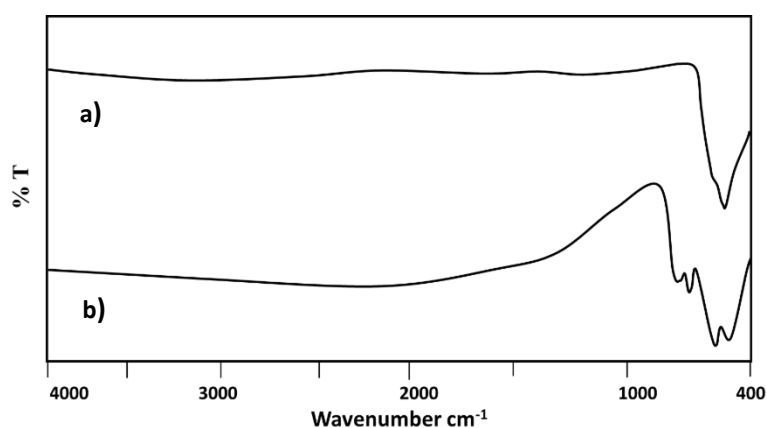


Figure 1.1 FT-IR spectra of a) NiO and b) CuO-Co₃O₄@ NiO core shell Nanoplates

In XRD analysis Fig.1.2 a can be indexed to the standard pattern of the pure cubic phase of NiO (JCPDS No.47-1049). This reveals the diffraction peaks with 2 θ value of 37.26, 43.24,

62.93, 76.34 and 79.20 originate from crystal planes (111), (200), (220), (311) and (222) of NiO. Fig1.2b the diffraction peaks of CuO-Co₃O₄@NiO core shell Nanoplates at 37.26, 62.93, 73.34, 79.20 originate from crystal planes (111), (220), (311) and (222) of NiO (JCPDS No.47-1049). The formation of CuO and Co₃O₄ on the surface NiO of was confirmed by the XRD pattern show peaks at 38.78, 48.84, 53.42, 67.98 of CuO (JCPDS card No. 05-661). The peaks at 36.93, 44.93, 59.39 and 65.33 of Co₃O₄ (JCPDS card No: 74-2120). No extra peak is observed which confirms the purity of product.

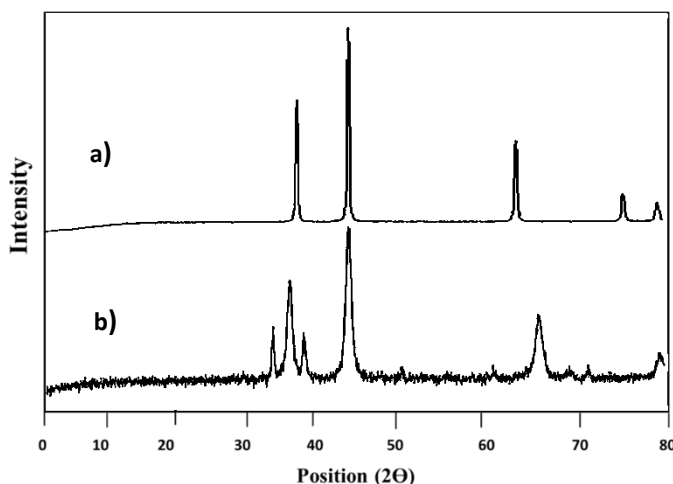


Figure 1.2 XRD Pattern of a) NiO and b) CuO-Co₃O₄@ NiO core shell Nanoplates

To characterize and analyze the morphology, the synthesized material is analyzed by scanning electron microscopy. SEM image of NiO as shown in Fig.1.3a shows cubic shaped nanoparticles with good uniformity and crystallinity. Fig 1.3b revealed shape or morphology of the synthesized CuO-Co₃O₄@NiO. The particles have plate-like morphology and they are aggregated together. In the aggregates, the size of the particles is not uniform.

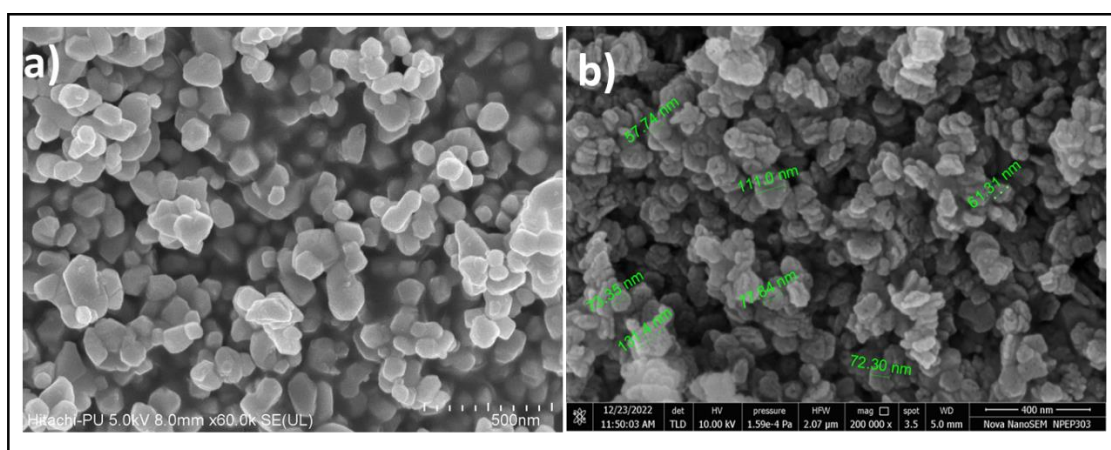


Figure 1.3 SEM images of a) NiO and b) CuO-Co₃O₄@ NiO core shell Nanoplates

The catalytic performance of CuO-Co₃O₄@NiO nanocomposite catalyst was measured by model condensation reaction of 4-methoxy benzaldehyde, 1, 3 dimethyl barbituric acid and malononitrile in ethanol. In order to get maximum conversion and yield of the product, we examined reaction parameters such as the reaction temperature, reaction time and amount of catalyst.

To check the efficacy of CuO-Co₃O₄@NiO, we tried synthesized NiO as a catalyst independently for synthesis of pyrano[2,3-d] pyrimidines using aromatic aldehyde, 1, 3 dimethyl barbituric acid and malononitrile. NiO gave good yield but required more time as compared to modified CuO-Co₃O₄@NiO catalyst Table 1 **entry 3**. To optimize amount of catalyst required for condition we tried various mole equivalent of the catalyst. It was found that when the reaction was carried out with 0.5 mole equivalent the yield was found 96%. Further increased in mole % of catalyst was decreased the % yield due to the adsorption of product over surface area of catalyst, eventually block the active sites of catalyst Table 1 **entry 9**. Effect of temperature shows that maximum yield was found at 70^oC with 96% yield Table 1 **entry 9**.

Table 1. Optimization of reaction conditions for synthesis of pyrano[2,3-d] pyrimidine

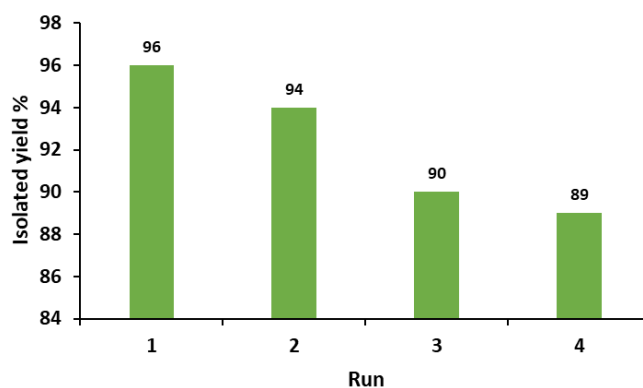
Entry	Catalyst	Mol (%) of Catalyst	Temperature (°C)	Time (Min)	Yield (%)
1	Without catalyst	-	r.t.	180	Reaction incomplete
2	NiO	0.2	r.t.	120	45
3	CuO-Co ₃ O ₄ @NiO	0.2	r.t.	45	60
5	CuO-Co ₃ O ₄ @NiO	0.2	50	30	75
6	CuO-Co ₃ O ₄ @NiO	0.3	50	30	76
8	CuO-Co ₃ O ₄ @NiO	0.4	50	30	80
9	CuO-Co ₃ O ₄ @NiO	0.5	70	10	96
10	CuO-Co ₃ O ₄ @NiO	0.5	Reflux	35	54

After achieving the best reaction conditions, we have checked the applicability of this reaction for synthesis of pyrano[2,3-d] pyrimidines derivatives with series of reaction of ,3 dimethyl barbituric acid (2mmol), malononitrile (2mmol) and a wide range of structurally diverse aldehyde (1.5mmol,) were treated in presence of CuO-Co₃O₄@NiO with optimized reaction condition. Almost in all cases desired product was obtained in good to excellent yield (Table 2).

Table 2. Synthesis of pyrano[2,3-d] pyrimidine derivatives under optimized conditions

Entry	Ar	Time (min)	Yield (%)	M P (°C) (Observed)
4a	H	25	91	240-242
4b	4-Cl	15	94	209-211
4c	2-Cl	20	81	244-246
4d	4-Br	25	89	229-230
4e	4-F	15	93	225-227
4f	4-Me	30	90	207-209
4g	4-OMe	10	96	280-282
4h	4-NO ₂	30	87	212-214
4i	3-NO ₂	20	89	205-207

To explore cost effectivity of synthesized catalyst, the separated core shell CuO-Co₃O₄@NiO from the model reaction washed with alcohol and dried in the oven at 110°C for 3h and reused it in next cycles of reaction. This activated catalyst showed insignificant loss of the catalytic activity till 4th reaction cycle which indicate environmental and inexpensive progression Fig.1.4.

**Figure 1.4** Reusability of catalyst in synthesis of pyrano[2,3-d] pyrimidines

CONCLUSION

In conclusion, highly efficient and convenient protocol has been developed for the synthesis of pyrano[2,3-d] pyrimidine. CuO-Co₃O₄@NiO core shell Nanoplates have been effectively synthesized using an impregnation method. By this method get an opportunity to synthesize nanoparticles with controlled morphology. Characterization of the precursors and the oxides by various analytical techniques FT-IR and XRD indicate the formation of core-shell nanoparticles. The SEM images of CuO-Co₃O₄@NiO show core-shell morphology.

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SPECTRAL DATA OF PREPARED COMPOUNDS:

7-Amino-5-(2-chlorophenyl)-1,3-dimethyl-2,4-di-oxo-1,3,4,5-tetrahydro-2H-pyrano-[2,3-d]- pyrimi-dine- 6-carbonitrile (4c)

¹H NMR (400 MHz, DMSO-d₆): 3.28 (3H, s, NCH₃), 3.30 (3H, s, NCH₃), 4.49 (1H, s, CH), 7.52–7.53 (4H, m, ArH and NH₂), 8.10 (2H, t, ArH)

7-Amino-5-(4-fourophenyl)-1,3-dimethyl-2,4-di-oxo-1,3,4,5-tetrahydro-2H-pyrano-[2,3-d]- pyrimi-dine-6-carbonitrile (4d)

¹H NMR (400 MHz, DMSO-d₆): 3.11(s, 3H, CH₃), 3.35 (s, 3H, CH₃), 4.32 (s,1H, CH), 7.09–7.15 (m, 3H, ArH, NH₂), 7.28–7.37 (m, 2H,H-Ar)

7-Amino-5-(4-methoxyphenyl)-1,3-dimethyl-2,4-di-oxo-1,3,4,5-tetrahydro-2H-pyrano-[2,3-d]- pyrimi-dine-6-carbonitrile (4g)

¹H NMR (400 MHz, DMSO-d₆): 3.29 (3H, s, NCH₃), 3.34 (3H, s, NCH₃),3.60 (3H, s, OCH₃), 4.42 (1H, s, CH), 7.49–8.19 (6H, m, ArH and NH₂)

7-Amino-5-(4-nitrophenyl)-1,3-dimethyl-2,4-di-oxo-1,3,4,5-tetrahydro-2H-pyrano-[2,3-d]- pyrimi-dine-6-carbonitrile (4h)

¹H NMR (400 MHz, DMSO-d₆): 3.07(s, 3H, CH₃), 3.28 (s, 3H, CH₃), 4.54 (s,1H, CH), 7.48–7.56 (m, 4H, ArH, NH₂), 8.16–8.19 (m, 2H, ArH)

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