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Green synthesis of 2-aryl benzothiazole heterogenous catalyzed by MoO_3 nanorods

Abstract: The synthesis of MoO_3 nanoparticles was done
by the electrochemical method by using tetra butyl ammo-
nium bromide (TBAB) as a stabilizer and structure direct-
ing agent in acetonitrile (ACN):tetrahydrofuran (THF) (4:1)
solvent at a constant current supply of 18 mA/cm². After
heating the nanoparticles to 500°C in a muffle furnace,
MoO_3 nanorods were obtained. These synthesized MoO_3
nanorods were characterized by UV-visible spectroscopy,
Fourier transform infrared (FT-IR) spectroscopy, powder
X-ray diffraction (XRD) and scanning electron microscopy.
The prepared nanorods were used as heterogeneous cata-
lysts for the synthesis of 2-aryl benzothiazole derivatives.
This protocol offers several advantages such as a green
method, simple work-up procedure, recyclability of the
catalyst and excellent product yield in a short reaction
time.

Keywords: 2-aryl benzothiazole; electrochemical method;
heterogeneous catalyst; MoO_3 nanorods.

1 Introduction

2-Aryl benzothiazoles and their derivatives exhibit a wide
range of biological properties which have led to continu-
ous interest in the field of medicinal chemistry. 2-Aryl
benzothiazoles exhibit antimicrobial [1, 2], antibiotic [3],
antiviral [4], antiinflammatory [5], antifungal [6], antitu-
mor [7], [8], anticonvulsant [9] and antiparasitic [10] activ-
ities, are antagonists [11] and are used in the treatment of
Alzheimer disease [11]. They exhibit nanomolar inhibi-
tory activity against human cancer cells [12] and several
enzymes such as aldose's reducates [13], H^+-K^+ ATPase [14],
protease [15] and carbonic anhydrase [16]. Benzothiazoles

also exhibit physiological activities like H37Rv inhibition
[17], elastase inhibition [18] and cytotoxicity towards P_{338}
cells [19].

The synthesis of 2-aryl benzothiazoles involves con-
densation of 2-aminothiophenol with aldehyde, acid chlo-
ride, carboxylic acid, ester, aryl bromide and coupling with
aryl boronic acid. The condensation of 2-aminothiophenol
and aldehyde has been reported by using various catalysts
such as NiO_2 [20], Cu NP [21], CuCl [22], MnO_2/SiO_2 [23] and
ceric ammonium nitrate, etc. [24].

However, most of these procedures of synthesis of
benzothiazoles are associated with some disadvantages
such as tedious reaction, expensive catalyst, multistage
processes and loss of catalyst and the use of hazard-
ous and carcinogenic solvents like nitrobenzene and
dioxane, which are harmful to the environment and also
to humans. Therefore, it is necessary to study the reaction
by some green methods, which is efficient and simple. The
present study involves synthesis of 2-aryl benzothiazoles
by using MoO_3 nanorods, which is efficient, simple and
environmentally benign.

2 Materials and methods

2.1 Materials

Tetra butyl ammonium bromide (TBAB), tetrahydrofuran (THF) and
acetonitrile (ACN) were purchased from Aldrich (India) and S.D. Fine
(India) chemicals and used as such. The sacrificial anode, in the form
of a molybdenum sheet, and a platinum sheet acting as an inert cat-
hode with a thickness of 0.25 mm and purity 99.9%, were purchased
from Alfa Aesar (India). The specially designed electrolysis cell of
volume 30 ml was used.

2.2 Synthesis of catalyst MoO_3 nanorods

Synthesis of molybdenum oxide nanoparticles by the electrochemical
reduction method was originally reported by Reetz et al. [25]. In the
initial experiment we used a molybdenum metal sheet (1 cm×1 cm)
as the anode and a platinum sheet (1 cm×1 cm) as the cathode. These
two electrodes were placed parallel with 1.0 cm distance. The TBAB
0.01 M solution was prepared in ACN/THF (4:1) which also served as
the supporting electrolyte. The electrolysis process was then carried

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out at 18 mA/cm² current density for 2 h. After completion of the electrolysis process, the yellow colored solution obtained was allowed to settle for 1 day. The yellow solid sample was separated from the solution by decantation and washed three to four times with THF. The washed samples were then dried under a vacuum desiccator and stored in air tight containers. The obtained MoO_3 nanocrystals were used as a precursor to prepare MoO_3 nanorods. The dried samples of MoO_3 nanocrystals were placed in a silica crucible, which was then put into the muffle furnace at 500°C for 2 h. After natural cooling down to room temperature, bright pale yellowish crystals of MoO_3 nanorods were obtained.

2.3 Characterization of MoO_3 nanorods

The prepared MoO_3 nanorods were characterized by UV-visible, Fourier transform infrared (FT-IR) spectroscopy, X-ray diffraction (XRD), transmission electron microscopy (TEM) and scanning electron microscopy (SEM), energy dispersive spectrophotometer (EDS) techniques. The UV-visible spectrum was recorded on a spectrophotometer (JASCO 503) with a quartz cuvette using ACN/THF (4:1) as the reference solvent. The IR spectra were recorded on an FT-IR spectrophotometer (JASCO FT-IR/4100) Japan using dry KBr as the standard reference in the range of 400–4000 cm⁻¹. The X-ray powder diffraction patterns of MoO_3 nanorods were recorded on a Bruker 8D advanced X-ray diffractometer using CuKα radiation of wavelength=1.54056 Å. To study the morphology and elemental composition, MoO_3 nanorods were examined using SEM and an energy dispersive spectrophotometer. The SEM analysis was carried out with JEOL; JSM-6330 LA operated at 20.0 kV and 1.0000 nA. The shape, size and morphology were calculated by TEM analysis which was carried out with the Philips model CM200 operated at 200 kV.

2.4 Synthesis of 2-aryl benzothiazole

A mixture of 2-aminothiophenol (1 mmol), aromatic aldehyde (1 mmol) and MoO_3 nanorods (100 mg) was stirred at 80°C for 2 h to obtain a crude product (3a-m, Scheme 1). The progress of reaction was monitored by thin layer chromatography (TLC). After completion of the reaction, the crude product was dissolved by adding ethanol and the MoO_3 nanorods were separated by centrifuging, followed by decantation. MoO_3 nanorods were dried in vacuum desiccators and the crude product recrystallized in ethanol. The recrystallized product analysis by ^{1}H NMR and ^{13}C NMR spectra was recorded on a Bruker AVIII HD-300 MHz FT-NMR spectrometer with $CDCl_3$ as a solvent. The chemical shift values were recorded as δ (ppm units) relative to tetramethylsilane (Me_4Si) as an internal standard.
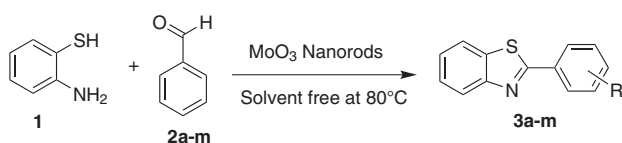
Scheme 1: Synthesis of 2-aryl benzothiazole.

2.5 Spectral data of selected compound

2.5.1 3a) 2-Aryl benzothiazole MP=110–112°C: FTIR (KBr, cm⁻¹): 3062, 1590, 1556, 1510, 1435, 1245, 960, 766 cm⁻¹

^{1}H NMR (400.13 MHz, $CDCl_3$, δ ppm): 7.34 (t, 1H, CH of Ar), 7.88(d, 2H, CH of Ar), 8.06(d, 1H CH of Ar), 8.07(d, 1H, CH of Ar), 8.09(d, 1H, CH of Ar)

^{13}C NMR (100.61 MHz, $CDCl_3$, δ, ppm): 121.89(CH of Ar), 121.91(CH of Ar), 125.20(CH of Ar), 125.90(CH of Ar), 127.51(2CH of Ar), 128.80(CH of Ar), 129.32(2CH of Ar), 133.50(C of Ar), 135.80, 154.42), 166.60, MS (ESI): m/z (%) 212 [M+H]⁺

2.5.2 3b) 2(4-Bromo-aryl) benzothiazole MP=132°C: FTIR (KBr, cm⁻¹): 3056, 1582, 1545, 1505, 1474, 1247, 969, 854, 751 cm⁻¹

^{1}H NMR (400.13 MHz, $CDCl_3$, δ ppm): 7.38(t, 1H, CH of Ar), 7.48(t, 1H, CH of Ar), 7.60(d, 2H, CH of Ar), 7.88(d, 1H, CH of Ar), 7.90(d, 2H, CH of Ar), 8.06(d, 1H, CH of Ar)

^{13}C NMR (100.61 MHz, $CDCl_3$ δ ppm): 121.68(CH of Ar), 123.34(CH of Ar), 125.43(C-N), 125(CH of Ar), 126.52(CH of Ar), 128.91(2 CH of Ar), 132.56(2 CH of Ar), 135.06, 154.9, 166.69. MS (ESI): m/z (%) 291 [M+H]⁺

2.5.3 3c) 2(4-Chloro-aryl) benzothiazole MP=114–116°C: FTIR (KBr, cm⁻¹): 3056, 1582, 1545, 1505, 1474, 1247, 969, 854, 751 cm⁻¹

^{1}H NMR (400.13 MHz, $CDCl_3$, δ ppm): 7.38(t, 1H, CH of Ar), 7.48(t, 1H, CH of Ar), 7.60(d, 2H, CH of Ar), 7.88(d, 1H, CH of Ar), 7.90(d, 2H, CH of Ar), 8.06(d, 1H, CH of Ar)

^{13}C NMR (100.61 MHz, $CDCl_3$ δ ppm): 121.68(CH of Ar), 123.34(CH of Ar), 125.43(C-N), 125(CH of Ar), 126.52(CH of Ar), 128.91(2 CH of Ar), 132.56(2 CH of Ar), 135.06, 154.9, 166.69. MS (ESI): m/z (%) 246 [M+H]⁺

3 Results and discussion

The UV-visible absorption spectrum recorded for MoO_3 nanoparticles capped with TBAB at 18 mA current density exhibited maximum absorption at 642 nm, as shown in Figure 1, which can be attributed to the surface plasmon
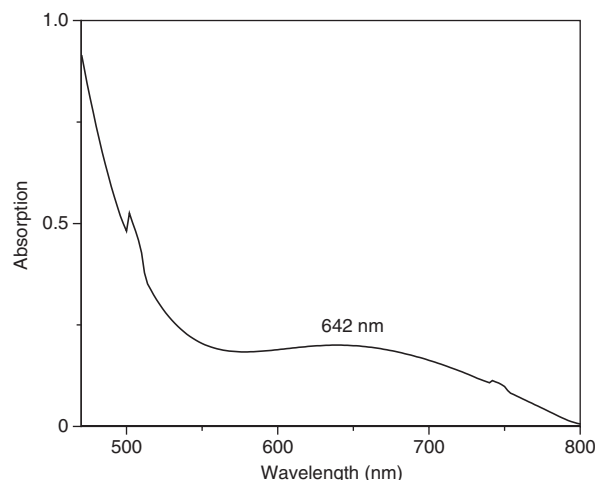

Figure 1: UV-visible Spectrum of MoO_3 nanoparticles capped with 0.1 M tetra butyl ammonium bromide (TBAB) at 18 mA current density.

resonance peak of MoO_3 nanoparticles. A broad peak around 642 nm can be attributed to wide size distribution of nanoparticles formed in the solution. The broadening of the surface plasmon resonance peak was due to the agglomeration of the nanoparticles in the sample and high width of these particles distributed. The particles showed hardly any change in the absorption spectra, even after a month of ageing time, indicating the highly stable nature of particles.

XRD was employed to examine the crystal structure of prepared MoO_3 nanorods. As shown in Figure 2, all the diffraction peaks can be indexed to the orthorhombic lattice system with lattice parameter (a=3.96 Å, b=13.85 Å, c=3.696 Å, JCPDS: 35-0609). The strong diffraction peaks of MoO_3 appear at 23.21, 25.72, 27.31, 33.78, 39.00, 46.31, 49.27, 55.20 and 57.67, which correspond to (110), (040), (021), (111), (060), (061), (002), (112) and (171) planes, respectively. The observed planes at (040) and (060) show very strong peaks of the MoO_3 nanorods indicating the highly anisotropic growth as well as the preferred orientation of the nanorods.

The IR spectrum (Figure 3) of MoO_3 nanorods shows broad peaks at 3432 cm^{-1} and 1633 cm^{-1} due to the stretching
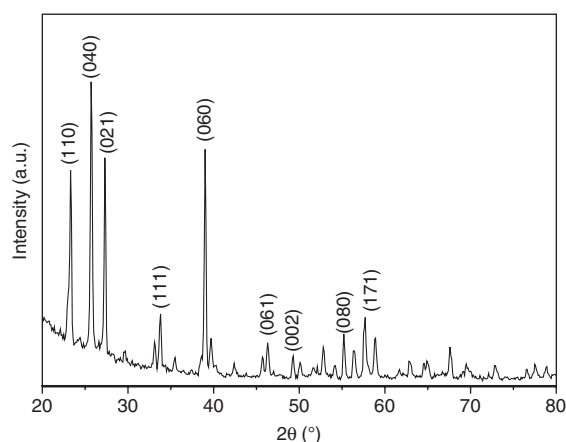

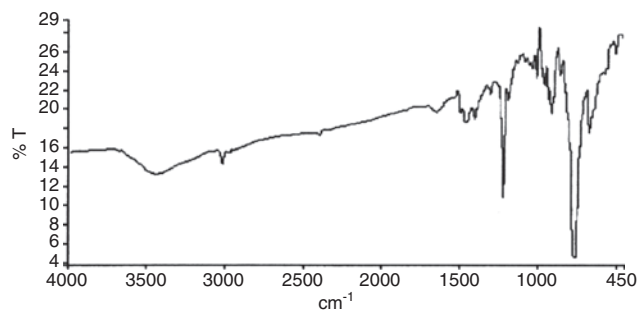**Figure 2:** X-ray diffraction (XRD) pattern of MoO_3 nanorods.

Figure 3: IR Spectrum of MoO_3 nanorods.

and bending vibration of hydroxyl groups adsorbed on the surface. The peak at 1470 cm^{-1} is due to the ammonium ion bending mode of vibration. The C-N linkage in R_4N^+ ion gives a medium band at 1038 cm^{-1} due to C-N stretching vibration. The peak at 949 cm^{-1} is due to the terminal Mo=O bond, which indicates the layered orthorhombic phase [26] and absorption at 848 cm^{-1} and 597 cm^{-1} are of the stretching and bending mode of vibration of Mo-O-Mo. The spectrum also contains distinct peaks at 496 cm^{-1} and 669 cm^{-1}, which correspond to the mixed phase that contain molybdenum and molybdenum oxide.

SEM analysis gives morphology of MoO_3 nanorods (Figure 4) which depicts that most of the rods have a belt shape and a few are cylindrical wires. Energy dispersive spectra were also recorded to determine the chemical composition of MoO_3 nanorods, which show that the nanorods contain 55.02% of molybdenum and 44.98% of oxygen measured in atomic percentage of elements.

We report here a very simple process for the synthesis of 2-aryl benzothiazoles by condensation of 2-aminothiophenol with aromatic aldehyde under solvent free conditions catalyzed by MoO_3 nanorods. In the present work, an attempt was made to optimize the reaction conditions by using 2-aminothiophenol (1 mmol) **1** and 4-bromobenzaldehyde (1 mmol) **2b** as model reaction at different solvents and amounts of catalyst used. In order to investigate the best results in terms of yield and reaction time, we examined the efficiency of different reaction media and the amount of catalyst required. From Table 1, it can be seen that loading of 100 mg of MoO_3 nanorod catalyst was adequate for smooth condensation of 2-aminothiophenol and 4-bromobenzaldehyde under solvent free conditions at 80°C. There was a considerable increase in the yield of product when the amount of catalyst was increased from 50 mg to 100 mg; above 100 mg, no considerable change in reaction time and yield of the product was observed.

The catalyst was recovered by simple work-up using the centrifugation method, washed with ethanol and reused for three successive reactions. The corresponding yield for each cycle is mentioned in Table 2.

Under optimization reaction conditions, we obtained 95% yield of 2(4-bromo-aryl) benzothiazole within 40 min. In Table 3, it can be seen that the reaction time and the product yield depend on the substituents introduced on substrates. For instance, the condensation of 2-aminothiophenol having strong electron withdrawing groups (F, Cl, Br, NO_2, OH) in the para position gave the desired product with good yield and a shorter reaction time than meta substituted product and electron donor groups (CH_3, OCH_3).
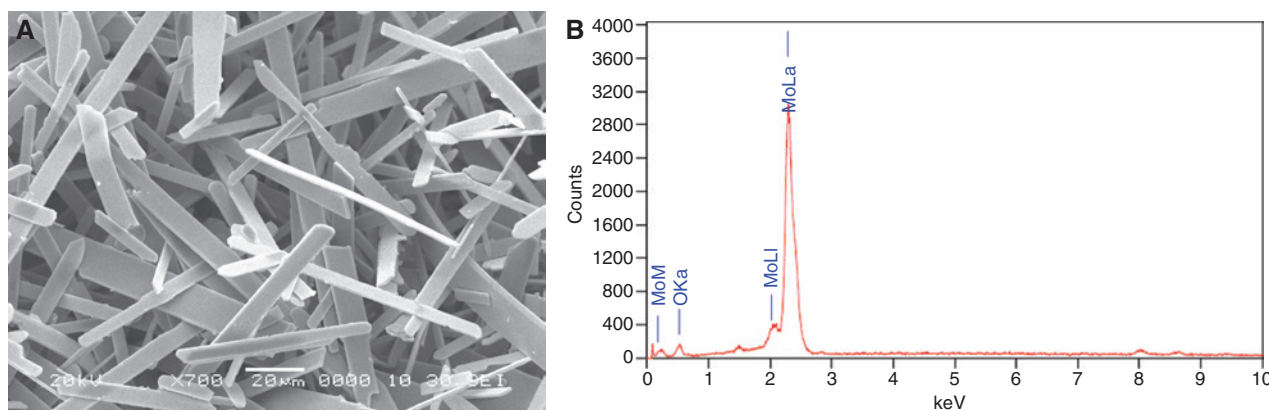
Figure 4: (A) Scanning electron microscopy (SEM) micrograph and (B) energy dispersive X-ray spectroscopy (EDS) of MoO_3 nanorods.

Table 1: Screening of catalyst MoO_3 nanorods amount for the synthesis of 3b.

Entry[a]	Catalyst amount (mg)	Time (min)	Yield[b] (%)
1	00	180	Trace
2	40	160	35
3	60	120	64
4	80	90	78
5	100	45	95
6	120	45	95

[a]Reaction condition: 4-bromobenzaldehyde (1 mmol), 2-amino thiophenol (1 mmol), MoO_3 nanorods.
[b]Isolated yield.

Table 2: Recovery of catalyst MoO_3 nanorods.

Entry[a]	1	2	3	4
No. of recycle	Fresh	I	II	III
Yield[b] (%)	95	94	92	89

[a]Reaction condition: 4-bromobenzaldehyde (1 mmol), 2-amino thiophenol (1 mmol), MoO_3 nanorods.
[b]Isolated yield.

Table 3: Synthesis of 2-aryl benzothiazole derivative using MoO_3 nanorods.

Products[a]	R	Time (min)	Yield[b] (%)	Melting point (°C)	
				Found	Reported
3a	H	70	88	112–114	112–114
3b	4-Br	45	95	131–132	132
3c	4-Cl	50	92	114–116	115–117
3d	4-NO$_2$	50	94	180–182	181–182
3e	4-CH$_3$	100	85	82–84	84–86
3f	4-OCH$_3$	110	86	120–122	120–121
3g	4-OH	60	90	224–227	225–227
3h	4-F	60	80	100–102	101–102
3i	3-NO$_2$	80	87	180–182	181–182
3k	2-OH	90	88	128–129	129–130
3l	2-OCH$_3$	80	90	103–104	103–105
3m	2-Furfural	100	85	100–102	103–104

[a]Reaction condition: 4-bromobenzaldehyde (1 mmol), 2-amino thiophenol (1 mmol), MoO_3 nanorods.
[b]Isolated yield.

4 Conclusion

We developed efficient MoO_3 nanorod catalysts for the synthesis of 2-aryl benzothiazole with a high yield of product in a short reaction time and much less amount of catalyst. This catalyst showed excellent activity during four consecutive runs without appreciable loss of activity. Furthermore, this method is of interest in the context of environmentally greener and safer processes.

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Bionotes

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