One-step synthesis of rod-on-plate like 1D/2D-NiMoO$_4$/BiOI nanocomposite for an efficient visible light driven photocatalyst for pollutant degradation

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Abstract
Visible light active 1D/2D-NiMoO$_4$/BiOI nanocomposite photocatalyst has been constructed by single step solvothermal method. Various compositions of NiMoO$_4$/BiOI nanocomposites are prepared by loading different amounts of nickel molybdate (NiMoO$_4$) (1, 2, 3 wt%) to the bismuth oxy iodide (BiOI) and investigated by XRD, FTIR, SEM, EDAX, TEM, UV–vis DRS, and PL analysis. Among the as-prepared photocatalysts, 1 wt% NiMoO$_4$ incorporated BiOI (NMBI-1) showed superior photocatalytic activity with a rate constant of 0.0442 min$^{-1}$ for methylene blue degradation. While the bandgap values of pure BiOI and NiMoO$_4$ are 1.94 and 2.43 eV, respectively, the optimized NMBI-1 exhibited a lower bandgap energy of 1.64 eV, and showed about 2 and 3.7 times higher photodegradation ability than the pure NiMoO$_4$ and BiOI, respectively, towards MB removal under visible light. The NMBI-1 nanocomposite photocatalyst is stable even after four cycles, indicating an excellent photostability and recyclability. Charge carriers on the interface of NiMoO$_4$ and BiOI easily transferred via the newly formed heterojunction, thereby increasing the photocatalytic performance. Photochemically formed $h^+$ and $\text{OH}$ are found to be the major species in the MB removal under visible light illumination. Therefore, the 1D/2D-NiMoO$_4$/BiOI nanocomposite photocatalyst materials may be considered for the wastewater remediation processes.

Keywords NiMoO$_4$/BiOI · Nanocomposite · Photocatalyst · Visible light · Advanced oxidation process · Degradation

Introduction

Environmental pollution is considered as a major crisis that creates global damage, owing to the development of industries and urbanization. Reusing water from the industrial effluent has to be considered as a most needful measure to compensate the increasing water scarcity (Abdelkader et al. 2019). Various industries, like textile, printing, paper, cosmetics, and pharmaceuticals, use large amount of dyes to increase the quality of the products, and their discharged effluents contain vast amount of toxic and hazardous organic pollutants. These dyes even at low concentration can pose harmful health effects on aquatic life and human beings. Hence, it is a dire need to eliminate these harmful contaminants from the wastewater prior to reaching the environment (Malathi et al. 2018a,b,c; Koe et al. 2020; Mansouri et al. 2019). Various wastewater remediation methods, such as adsorption, precipitation, sonolysis, reverse osmosis, and photo-Fenton process, are operative, but their high cost and creation of secondary pollutants limits their practical application in large scale (Hu et al. 2021; Tran et al. 2020; Hu et al. 2018; Louhichi et al. 2019). A much more challenging task for practical application is to imply a green method to eliminate toxic pollutants. In this regard, advanced oxidation process (AOP) with a semiconductor photocatalyst is considered
as an eco-friendly process to degrade the pollutant without producing any secondary pollutants and also being a cost-effective method (Khatri et al. 2018). For the environmental remediation, TiO₂ is a commonly used photocatalyst with advantageous properties like non-toxicity, high stability, and cheap, but its wide bandgap energy (3.2 eV) makes it unfavorable for the visible light absorption (Zhang et al. 2018; Li et al. 2020). To resolve this, it is essential to develop a visible light active photocatalyst with low bandgap energy. A wide range of photocatalysts, such as WO₃ (Senthil et al. 2019a), gC₃N₄ (Priya et al. 2020a), ZnO (Zhang et al. 2019), Bi₂WO₆ (Ju et al. 2014), BiYO₃ (Hou et al. 2019), Bi₂S₃ (Xu et al. 2019), AgVO₃ (Bavani et al. 2021b), MoS₂ (Senthil et al. 2019b), and FeOOH (Malathi et al. 2018a), were prepared and employed for wastewater remediation. Presently, bismuth-based semiconductor photocatalysts are widely preferred as visible light active photocatalysts. Among them, bismuth oxyhalide (BiOX, X = F, Cl, Br, I) photocatalysts have received extensive attention from researchers due to their inexpensiveness over other photocatalysts and unique layered structure that governs the migration of charge carriers (e⁻/h⁺) (Chang et al. 2018; Malathi et al. 2018b; Xu et al. 2020; Alzamly et al. 2019). Specifically, bismuth oxyiodide (BiOI) is one such effective photocatalyst with simple preparation, more economical, stability and has lower bandgap energy (1.8–2.0 eV) which facilitates high absorption in visible region. However, its higher photodegradation efficiency is restricted owing to the rapid rejoining of photoproduced e⁻-h⁺ pairs as reported earlier (Hu et al. 2020). To address this problem, various strategic methods have been employed, (i) morphology tailored BiOI, (ii) coupling with a solid mediator (metal or non-metal), and (iii) coupling with different semiconductor materials. The formation of heterojunction with various semiconductors has been considered as an effective strategic method to promote the separation of charge carriers (e⁻-h⁺), which increases the photodegradation ability of BiOI. On this basis, in this study, nickel molybate (NiMoO₄) has been coupled with BiOI to form NiMoO₄/BiOI nanocomposite, owing to its low bandgap energy (~2.2 eV). To the best of our knowledge, no study has been reported earlier for the degradation of organic dye in the visible light irradiation of NiMoO₄/BiOI photocatalyst.

In the present work, we have constructed NiMoO₄ on BiOI composite by using single step solvothermal method. The photocatalytic behavior of the photocatalysts is analyzed against the degradation of methylene blue (MB). The results indicated the superior photocatalytic, photo recyclability, and stability characteristics of 1D/2D-NiMoO₄/BiOI composite. It is believed that the developed composite photocatalyst could be a promising material to employ in the remediation of wastewater.

Materials and methods

Materials

Nickel nitrate hexahydrate (Ni(NO₃)₂.6H₂O), sodium molybdate dihydrate (Na₂MoO₄.2H₂O), ethylene glycol, and isopropyl alcohol were bought from Sigma-Aldrich, Bengaluru, India. Bismuth nitrate pentahydrate (Bi(NO₃)₃.5H₂O) potassium iodide (KI) and Triton X-100 were procured from Qualigens, Mumbai, India. Ammonium oxalate, benzoquinone, methylene blue, and ammonia solution (NH₃) were purchased from SDFLC, Mumbai, India. All these chemicals were used without further purification.

Preparation of NiMoO₄ nanorods

NiMoO₄ nanorods were prepared by hydrothermal method. In this method, 2.5 mmol of Ni(NO₃)₂.6H₂O and NaMoO₄ were dissolved in 60 mL of deionized (DI) water with constant stirring for 30 min. After stirring, the above mixture is transferred into a Teflon autoclave and heated at 180 °C for 24 h. Then, the precipitate was filtered, dried at 60 °C for 3 h and annealed at 400 °C for 4 h (Thiagarajan et al. 2020).

Preparation of 1D/2D-NiMoO₄/BiOI nanocomposite

The NiMoO₄/BiOI nanocomposite photocatalyst was fabricated using simple single step solvothermal method. Herein, 5 mmol of Bi(NO₃)₃.5H₂O dissolved in 30 mL of ethylene glycol was added to 5 mmol of KI in 30 mL water with constant stirring for 30 min. Afterwards, varying amounts of NiMoO₄ (1, 2, 3 wt%) were added to the above mixture followed by 30 min of stirring. Then, the mixture was transferred into a Teflon-lined autoclave, and the reaction was executed at 160 °C (20 h). The obtained precipitates were washed with ethanol and water several times and dried at 80 °C for 4 h. The as-prepared NiMoO₄/BiOI nanocomposite with 1, 2, and 3 wt% of NiMoO₄ were indicated as NMBI-1, NMBI-2, and NMBI-3, respectively. The pure BiOI was prepared in the same way but without NiMoO₄. Figure 1 shows the schematic representation of the synthesis of 1D/2D-NiMoO₄/BiOI nanocomposite (Senthil et al. 2021).

Material characterization

The crystal phase formation of the photocatalyst was investigated by powder X-ray diffraction (Rigaku Mini Flex II, UK, with Cu Kα radiation λ = 0.1542 nm) and Fourier transform infrared spectra was acquired in a JASCO-4600 FTIR spectrometer, Japan. The photoluminescence (PL) and UV–vis diffuse reflectance spectra (UV–vis DRS) were, respectively,
studied with Jobin Yvon Fluorolog-3–11 spectrofluorometer, Japan, and JASCO-V670 spectrophotometer, Japan. The morphology of the samples was investigated by transmission electron microscopy (TEM) JEOL-6330 TEM, USA.

**Photocatalytic degradation experiment**

The photocatalytic degradation ability of the as-prepared photocatalysts was examined via the degradation of methylene blue (MB) dye under visible light irradiation, using 250 W tungsten lamp (Philips, Type-7748XHP, 24 V), which emit light of wavelengths 370 to 1200 nm with maximum intensity around 650 nm was used as light source. In this experiment, 75 mg of photocatalyst was added to 75 mL of MB ($2 \times 10^{-4}$ M) dye solution. Prior to visible light irradiation, the solution was stirred under dark for 45 min for sorption equilibrium. Under irradiation of visible light, 5 mL of aliquots were drawn at regular time intervals, and after separating the photocatalyst by centrifugation, the concentration of MB was evaluated from the absorption at its $\lambda_{\text{max}} = 664$ nm (spectrophotometrically).

**Photoelectrochemical studies**

The photoelectrochemical properties of the as-prepared photocatalysts were examined using electrochemical workstation in three electrode configuration (Pt electrode as counter electrode, Ag/AgCl electrode as reference electrode, and the photocatalyst-coated FTO plate as working electrode). 0.1 M $\text{Na}_2\text{SO}_4$ was used as the electrolyte. The working electrode was prepared by doctor-blade method (10 $\mu$L of Triton X-100 and 20 $\mu$L of water were ground with 5 mg of photocatalyst, and the slurry of the mixture was coated over the conducting surface of FTO plate ($0.5 \times 0.5$ cm$^2$) followed by drying at 80 °C for 6 h).

**Results and discussion**

**Structural and optical properties**

The crystal structure and phase purity of the fabricated photocatalysts were confirmed by X-ray diffraction studies. The XRD patterns of the pure BiOI, pure NiMoO$_4$, and NiMoO$_4$/BiOI nanocomposites are presented in Fig. 2a. The diffraction pattern of NiMoO$_4$ (Fig. 2a) unveils monoclinic phase structure, and the diffraction peaks at 17.2°, 23.8°, 25.5°, 26.9°, 28.9°, 32.6°, 34.3°, 37.1°, 39.2°, 40.9°, 42.9°, 47.6°, 52.6°, 54.4°, and 63.1° are well correlating with JCPDS No. 45–0142 (He et al. 2014). The tetragonal phase structure of the BiOI shows diffraction peaks at 18.9°, 24.7°, 29.4°, 31.4°, 33.4°, 37.2°, 39.2°, 45.3°, 51.4°, 55.2°, and 60.1° well matching with JCPDS No. 10–0445 (Bavani et al. 2021b). The NiMoO$_4$/BiOI nanocomposites show decrease in the peak intensity of BiOI on adding NiMoO$_4$. But, no characteristic peaks of NiMoO$_4$ are noticed due to its low content in the nanocomposite. Crystallite size of BiOI, NiMoO$_4$ and NMBI-1, calculated using Scherrer formula, are found to be 9.7, 3.1, and 4.2 nm respectively (Table 1). Figure 2b displays the FT-IR spectra of bare BiOI, bare NiMoO$_4$, and NiMoO$_4$/BiOI nanocomposite photocatalysts. In Fig. 2b, the peaks observed at 478 and 597 cm$^{-1}$ are due to Bi-O and I-O bonds, and the broad band at 3476 and 1628 cm$^{-1}$ corresponds to the stretching and bending vibration modes of the O–H bond for the water molecules adsorbed on the surface (Bavani et al. 2021b). For NiMoO$_4$, the band located at 471 cm$^{-1}$ is associated with Mo–O–Mo bond, whereas
the peaks present at 863 and 1092 cm\(^{-1}\) are the asymmetric and symmetric stretching vibrations of the Mo=O linkage. The band due to Mo–O–Ni appeared at 722 cm\(^{-1}\), and the bending and stretching vibrations of O–H are placed at 1616 and 3416 cm\(^{-1}\) (Mengting et al. 2020). It is noticed that the peaks of both NiMoO\(_4\) and BiOI are seen in NiMoO\(_4\)/BiOI nanocomposites, and the peak intensities of NiMoO\(_4\) seem to be increasing with the increasing amounts of NiMoO\(_4\) in BiOI, thus clearly showing formation of the NiMoO\(_4\)/BiOI nanocomposite between BiOI and NiMoO\(_4\).

TEM analysis clearly provides the insights of the morphology and crystalline structure of the photocatalysts. Figure 3a–c shows the TEM and HR-TEM images of the pure BiOI, pure NiMoO\(_4\), and the optimized NMBI-1 nanocomposites. While Fig. 3a displays the nanoplate-like structure of the 2D-BiOI, the nanorod-like morphology is present in 1D-NiMoO\(_4\) (Fig. 3b). In the case of optimized NMBI-1 nanocomposite, the NiMoO\(_4\) nanorods are irregularly arranged on the surface of the BiOI nanoplate, which confirms the formation of the 1D/2D-NiMoO\(_4\)/BiOI nanocomposite (Fig. 3c). Figure 3d–e shows the high magnification TEM (HR-TEM) image and SAED pattern of NMBI-1 nanocomposite. The lattice fringe values of 0.253 and 0.295 nm corresponds to (001) and (102) planes of NiMoO\(_4\) and BiOI, respectively. Figure 4a–c shows the particle size distribution plot of the pure NiMoO\(_4\), pure BiOI, and NMBI-1 wherein the particle size decreases with the addition of NiMoO\(_4\) on BiOI. From Fig. 4c, it is clear that the NMBI nanocomposite has small particle size, and it is expected to show higher photocatalytic activity than pure BiOI and NiMoO\(_4\) owing to the fact that the decreasing particle size will increase the active sites for the degradation. Further, the energy-dispersive X-ray spectrum (EDAX) reveals the presence of Bi, Ni, Mo, I, and O elements only in the NMBI-1 nanocomposite (Fig. 5a). The elemental mapping images of the optimized NMBI-1, displayed in Fig. 5b, clearly confirm the presence of Bi, Ni, I, Mo, and O elements in the composite. Thus, the EDAX further confirms the formation of pure NiMoO\(_4\)/BiOI composite.

The optical characteristics of the photocatalysts were investigated by UV–visible diffuse reflectance spectroscopy (UV-DRS) and photoluminescence (PL) analyses. Figure 6a displays the UV–vis DRS of the as-prepared photocatalysts. The bandgap energy \(E_g\) of the photocatalysts were calculated using Kubelka–Munk function (Eq. (1)) (Priya et al. 2018a):

\[
\alpha h\nu = A(h\nu - E_g)^{n/2}
\]

where \(\alpha\), \(h\), \(\nu\), \(A\) and \(n\) are the absorption coefficient, Planck’s constant, frequency of light, and proportionality constant, respectively. From Fig. 6b, the \(E_g\) values were calculated and are found to be 1.94, 2.43, 1.64, 1.78, and 1.85 eV, respectively, for pure BiOI, pure NiMoO\(_4\), NMBI-1, NMBI-2, and NMBI-3 nanocomposite photocatalysts. The \(E_g\) values of different NiMoO\(_4\)/BiOI nanocomposites are noted to be comparatively lower than those of BiOI and NiMoO\(_4\). The lower \(E_g\) values of NiMoO\(_4\)/BiOI nanocomposite indicate
high absorption in the visible region as well as higher photocatalytic activity by producing high number of photogenerated $e^-/h^+$. Photoluminescence (PL) spectrum discloses the transfer and separation ability of the photoexcited charge carriers on the surface of the semiconductor. Figure 7 shows the PL spectra of pure BiOI, pure NiMoO$_4$, and various NiMoO$_4$/BiOI nanocomposites obtained at an excitation wavelength of 320 nm. As seen in Fig. 7, the NiMoO$_4$/BiOI nanocomposite photocatalysts exhibit relatively lower PL emission intensities compared to pure BiOI and NiMoO$_4$. This pointed out that the NiMoO$_4$/BiOI nanocomposites possess less recombination of charge carriers, by virtue of rapid charge transfer and separation. Similarly, the higher PL emission peak intensity means greater reconnection of the charge carriers. The observed PL intensity order of NMBI-1 > NMBI-2 > NMBI-3 > BiOI > NiMoO$_4$ reveals that the 1 wt % NiMoO$_4$ incorporation in the BiOI is optimum for better photocatalytic degradation performance.

**Photoelectrochemical performance**

The photoelectrochemical performance conveys the charge transfer and separation efficiency of the $e^-/h^+$ pairs. Figure 8 displays the transient photocurrent response and Nyquist plots for the BiOI, NiMoO$_4$, and the optimized NMBI-1 photocatalysts. It is clear that the optimized NMBI-1 nanocomposite has higher photocurrent response than the pure BiOI and NiMoO$_4$, revealing a higher separation and lower reunion of $e^-/h^+$ pairs (Fig. 8a). The transfer and separation of the charge carriers are further investigated by electrochemical impedance spectroscopy (EIS) (Fig. 8b). From Fig. 8b, it can be seen that the optimized NMBI-1 heterostructure exhibits smaller semicircle diameter than BiOI and NiMoO$_4$, which reflects a lower charge transfer resistance and also presumed to possess less $e^-/h^+$ pair reunion. Hence, the optimized NMBI-1 heterostructure with high separation and reduced recombination of charge carriers is expected to show superior photocatalytic performance.
**Fig. 4** Particle size distribution of pure NiMoO$_4$ (a), BiOI (b), NMBI-1 nanocomposite (c).

**Fig. 5** a EDAX and b elemental mapping images of the NMBI-1 nanocomposite.
The photocatalytic performances of the as-synthesized photocatalysts were explored against the degradation of MB under visible light illumination (Fig. 9a). There was no notable self-degradation of MB observed (data not shown). On the other hand, the NiMoO4/BiOI (NMBI-1, NMBI-2, and NMBI-3) nanocomposites show a significant improvement in the photocatalytic degradation (92, 66, and 46%) than the pure BiOI (41%) and NiMoO4 (25%). As seen in TEM, the BiOI has nano-plate like morphology with average crystallites size of ~10 nm, and in the optimized NMBI-1 nanocomposite, the NiMoO4 nanorods are irregularly arranged on the surface of the BiOI nanoplate with average size of 7 nm. The presence of NiMoO4 nanorods on the surface of the BiOI nanoplate not only reduce the size of BiOI but also create a heterojunction, giving high number of active sites. The NMBI-1 composite displays the maximum photocatalytic activity and may also due to (1) low bandgap that led to the effective absorption in the visible region and (2) the heterojunction between the semiconductors facilitates efficient transfer of e⁻-h⁺ pairs across the interface. However, the photocatalytic activity of the NiMoO4/BiOI composites decreased upon adding > 1 wt% NiMoO4 indicating...
that excessive NiMoO₄ on the surface of the BiOI may create recombination centers.

As observed in Fig. 9b, the photocatalytic degradation of MB over NiMoO₄/BiOI follows the pseudo-first-order kinetics (Eq. (2)) (Priya et al. 2020b; Bavani et al. 2021a):

\[
\ln\left(\frac{C_0}{C}\right) = kt
\]

where \( k \) is the rate constant, \( t \) is the irradiation time (min), and \( C_0 \) and \( C \) are the concentration of MB at initial and different time intervals. The rate constant value for NMBI-1 is found to be 0.0442 min⁻¹ (Fig. 9c), which is about 12 and 5 times higher than those of the pure NiMoO₄ and BiOI, respectively. This represents that there is a formation hetero-junction in NiMoO₄/BiOI nanocomposite, which considerably increases the separation of the \( e^-\cdot h^+ \) pairs.

In the view of practical execution, it is essential to study the influence of catalyst dosage, reusability, and stability of the photocatalyst. Figure 9d shows the effect of NMBI-1 catalyst dosage on the degradation of MB (catalyst amounts of 0.5, 0.1, 1.5, and 0.2 g L⁻¹). An increasing photodegradation performance is noted till 1.0 g L⁻¹ of catalyst, after which a decrease in dye degradation is noted. This is mainly attributed to the formation of turbidity when the dosage of catalyst is higher that led to the scattering of light. As the reusability and stability are the most important factors for large-scale operations, the photocatalyst was collected by centrifugation (at the end of every cycle) and dried at 80 °C for 3 h and then reintroduced in the next cycle. Figure 10a demonstrates the reusability and photostability characteristics of NMBI-1 nanocomposite for four cycles. Further, as shown in Fig. 10b, there is no significant change in the XRD pattern of NMBI-1 before and after recycling tests, thus proving the optimized NMBI-1 composite as a potential material for the remediation of wastewater. These results too supported the stable nature of the synthesized photocatalyst material.

Besides the stability, major active species in the photocatalytic degradation of MB over the NMBI-1 composite was studied through radical trapping experiments. Various radical trapping agents, namely, benzoquinone (BQ, 1 mM), ammonium oxalate (AO, 1 mM), and isopropyl alcohol (IPA, 1 mM), were used to suppress the \( \cdot O_2^- \), \( h^+ \), and \( \cdot OH \) radicals, respectively (Priya et al. 2018b). As in Fig. 10c, no notable effect in photodegradation was observed on using BQ as radical scavengers which indicates that the \( \cdot O_2^- \) is not an active species in the degradation of MB. Meanwhile, the degradation efficiency was found to decrease considerably on adding AO and IPA, revealing the active role of \( \cdot OH \) and \( h^+ \) in the degradation of MB.

**Photocatalytic degradation mechanism**

The conduction band (CB) and valence band (VB) potentials of the photocatalysts were calculated using the following Eqs. (3) and (4) (Senthil et al. 2021).
$E_{VB} = X - E_e + 0.5E_g$  

(3) 

$E_{CB} = E_{VB} - E_g$  

(4) 

where $E_{VB}$ and $E_{CB}$ are the valence band and conduction band potentials, respectively, while $E_g$, $E_e$, and $X$ are band-gap energy value, energy of free electrons (4.5 eV), and electronegativity of the photocatalyst, respectively. The
The electronegativity of the pure BiOI and pure NiMoO₄ is 5.936 and 6.176 eV, respectively. The $E_{CB}$ and $E_{VB}$ values of BiOI nanoplate, calculated using the above equations, are found to be 0.471 and 2.40 eV, respectively, and those of NiMoO₄ nanorods are 0.461 and 2.89 eV, respectively.

Both BiOI and NiMoO₄ are got excited under visible light illumination and produce holes and electrons on the CB and VB correspondingly. The $e^-$ on the CB level of NiMoO₄ moves towards the corresponding level of BiOI, and similarly the $h^+$ on the VB level of the NiMoO₄ migrates to the respective level of the BiOI. Thus, photoproduced $e^-$ and $h^+$ are effectively separated and easily transferred in the fabricated interface of the 1D/2D-NiMoO₄/BiOI nanocomposite, thereby reducing the rapid rejoining of the $e^-/h^+$ pairs to increase the photocatalytic degradation activity. On the basis of the obtained results, the possible charge transfer mechanism for the degradation of MB using 1D/2D-NiMoO₄/BiOI nanocomposite under visible light irradiation is depicted in Fig. 11. The results are found to disclose the fabricated 1D/2D-NiMoO₄/BiOI nanocomposite photocatalyst as a potential material to be used for wastewater treatment applications.

Conclusions

Low-cost and visible light active 1D/2D-NiMoO₄/BiOI nanocomposite was fabricated by single step solvothermal synthesis method. The 1D/2D-NiMoO₄/BiOI nanocomposite has showed excellent efficiency towards photocatalytic degradation of MB. Herein, the 1 wt% NiMoO₄ incorporated BiOI (NMBI-1) photocatalyst showed the highest photodegradation efficiency among the various NiMoO₄/BiOI composites and pure NiMoO₄ and pure BiOI. The photoelectrochemical and PL properties displayed by the optimized NMBI-1 nanocomposite revealed a lower recombination of $e^-/h^+$ pairs. NiMoO₄/BiOI composites exhibited an excellent photostability and reusability properties. Radical quenching studies indicate that $h^+$ and 'OH play a major role in the degradation of MB under visible light irradiation. Moreover, the formation of heterojunction in the 1D/2D-NiMoO₄/BiOI nanocomposite assists to promote the transfer of charge carriers through their interfaces, thereby reducing their recombination, consequently giving increased photocatalytic degradation efficiency. On the basis of the above results, the 1D/2D-NiMoO₄/BiOI nanoparticle photocatalyst can be considered as a potential material for the remediation of wastewater.

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Author contribution All authors contributed to the study conception and design. Material preparation, data collection, analysis, and the first draft of the manuscript were done by Thirungrunam Bavani. Characterization, interpretation of data, and validation are conducted by Vasudevan Vinesh and Bernarudshaw Neppollan. Supervision, validation, and review by Jagannathan Madhavan. Analysis, interpretation, and review by Seperumal Murugesan. Funds, review, and editing by Manickam Selvaraj. All authors read and approved the final manuscript.

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Data availability All data related to this manuscript is incorporated in the manuscript.

Declarations

Ethics approval Not applicable.

Consent to participate All authors have approved the final version of the manuscript and have given their consent for publication.

Competing interests The authors declare no competing interests.

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