Enhanced photocatalytic degradation of toxic contaminants using Dy$_2$O$_3$-SiO$_2$ ceramic nanostructured materials fabricated by a new, simple and rapid sonochemical approach

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1. Introduction

Rapid population growth, along with the emergence of various industries, has led to the discharge of effluents containing toxic organic contaminants such as various dyes into the environment [1,2]. Release of effluents containing toxic organic compounds such as erythrosine [3], thymol blue [4], eriochrome black T [5], Acid Red 14 [6], methyl orange [7], malachite green [8], and Rhodamine B [9] can have adverse impacts on the environment and human life, as these organic compounds have poor biodegradability [10–12]. Among the various solutions reported so far, photocatalysis can be beneficial through the direct usage of solar energy to decompose and remove toxic contaminants, including dyes [13–15]. The solar photocatalytic process does not require any additional chemical agents or the usage of any other energy to treat the contaminated water [16–18]. Thus, with the increasing demand for the decomposition and elimination of toxic and unsafe contaminants, the design and development of high-performance nanostructured photocatalysts have become one of the most popular research topics [19–21]. So far, a wide range of nanostructures and nanocomposites have been explored to treat water contaminated with organic compounds [22–24]. Nevertheless, there is still a strong need to design and produce new high-efficiency photocatalytic compounds through reproducible and large-scale approaches.

Dysprosium oxide with the formula Dy$_2$O$_3$ is a compound based on rare earth elements that has special features that are derived from their 4f electrons [25]. It is a basic substance, with exceptional thermal stability, and high insolubility properties [26,27]. This oxide compound crystallizes in three different phases: cubic, hexagonal, and monoclinic.
What is more, dysprosium oxide and compounds based on this oxide have unique features, making their wide use in luminescent compounds [29,30], catalysis [31], MRI contrast agents [32], fuel cells [33], and ceramics [34] possible. Since Dy₂O₃ has a wide energy gap (4.8 eV) [35], efforts have been made to improve its photocatalytic ability by doping it with other compounds, such as zinc oxide, which tunes its energy gap [36]. Up to present, a variety of methods have been reported for the fabrication of dysprosium oxide structures, including precipitation [25], thermal decomposition [37,38], sol–gel process [26], and hydrothermal [39]. The methods employed so far to fabricate nanostructured Dy₂O₃ have drawbacks such as high time and energy consumption, the need for costly precursors, and multiple and sometimes complex steps [26,37,38]. The use of ultrasound waves to fabricate a variety of nanomaterials is an area of interest to many scientists because it has significant benefits [40]. Ultrasonic radiation accelerates the reactions because high temperatures as well as high pressures are fabricated in the reaction medium, which causes the reactions to take place in a short time [41]. In addition, low energy consumption, good ability to tune the dimensions, architecture, and morphology of different compounds, and simplicity are other unique features of the use of sonochemistry, which has made it very popular for the fabrication of nanostructured compounds [42].

In order to eliminate the shortcomings including secondary contamination owing to high dispersion of nanostructured catalysts in the aqueous medium or the impossibility of effective binding of contaminant molecules to larger photocatalyst clusters, the combination of photocatalysts with adsorbents has been considered as a desirable approach [43]. In the nanocomposite formed, the adsorbent component will efficiently adsorb the contaminant molecules and the photocatalyst component with active sites will cause the decomposition of the contaminant molecules. So far, silicon dioxide has been used as a support to improve the performance of titanium dioxide catalyst [44].

Very few reports are available for the fabrication of Dy₂O₃–SiO₂ nanocomposites, which have drawbacks such as high energy consumption as well as a long process [45]. The present study on the fabrication of new photocatalytic nanocomposites (Dy₂O₃–SiO₂) employing a basic agent, tetraethylenepentamine (Tetrene), through a simple, efficient, and quick sonochemical approach. The combination of silicon dioxide with a porous structure with Dy₂O₃ can both form a nanocomposite photocatalyst with a narrower energy gap and enhance the rate of adsorption of pollutant molecules. To the best of the author’s knowledge, no previous experimental research has focused on the efficient production of Dy₂O₃–SiO₂ nanocomposites using ultrasonic waves and Tetrene and the study of its photocatalytic efficiency in the decomposition of several toxic contaminants. The effect of altering the sonication time and ultrasonic power on the architecture, dimensions, and morphology of photocatalytic nanocomposite was explored to select the optimal nanostructure. Furthermore, in order to achieve the best photocatalytic efficiency in the decomposition of each contaminant, the effects of the amount of contaminant as well as the dose of the composite nanostructure were investigated.

### 2. Experimental

#### 2.1. Materials and characterization

All reagents employed in this experimental study, including dysprosium (III) nitrate, tetraethylenepentamine (Tetrene), and Si (OC₂H₅)₄ (TEOS), were of analytical purity and were all purchased from Merck. A diffractometer of Philips Company was employed to record the X-ray diffraction (XRD) outcome of the prepared nanocomposite photocatalyst. Morphological studies and chemical composition analysis of the produced nanocomposite samples were performed by a field emission scanning electron microscopy (MIRA3 FEG-SEM) coupled with energy-dispersive X-ray spectroscopy (EDS). A UV-visible spectrophotometer (Shimadzu, UV-2550, Japan) was employed to examine the optical absorption feature of the fabricated Dy₂O₃–SiO₂ nanocomposite. The morphology and structure of the fabricated nanocatalyst were examined in more detail with a transmission electron microscopy (TEM, FEI F20). Fourier Transform Infrared Spectroscopy (FTIR) investigation was performed with a Magna-IR, spectrometer 550 Nicolet.

#### 2.2. Preparation of binary Dy₂O₃–SiO₂ nanophotocatalyst

A simple, efficient, and quick sonochemical approach was employed to produce binary Dy₂O₃–SiO₂ nanophotocatalyst. First, 1 mmol of TEOS was dissolved in ethanol, and then it was added dropwise to a solution containing 1 mmol of dysprosium nitrate dissolved in ethanol. Then the pH of the resulting mixture was tuned to about 10 with the help of a new alkaline agent (Tetrene), and it was irradiated with the ultrasonic probe at 400 W for 10 min. The resulting precipitate was then dried after...
washing several times with ethanol. Binary Dy$_2$O$_3$-SiO$_2$ nanophotocatalyst (sample 5) was fabricated by calcination of the residual mass at 1000 °C within 8 h (see Scheme 1). The effect of change in the sonication time and ultrasonic power on the architecture, dimensions, and morphology of binary Dy$_2$O$_3$-SiO$_2$ nanophotocatalyst was explored (see Table 1).

2.3. Photocatalytic performance of binary Dy$_2$O$_3$-SiO$_2$ nanocatalyst

The photocatalytic performance of the binary Dy$_2$O$_3$-SiO$_2$ nanophotocatalyst was tested for photodecomposition of several contaminants, including erythrosine, thymol blue, eriochrome black T, Acid Red 14, methyl orange, malachite green, and Rhodamine B. In each test, a certain amount of the binary Dy$_2$O$_3$-SiO$_2$ nanophotocatalyst was dispersed in 50 ml of a solution comprising a specified quantity of the target contaminant. Then the resulting suspension was stirred in the darkness for half an hour to establish adsorption–desorption equilibrium [18]. The light source (400 W mercury lamp) was then switched on, and the suspension irradiated [46]. The efficiency of the sonochemically prepared Dy$_2$O$_3$-SiO$_2$ nanophotocatalyst was evaluated and reported with the efficiency = (A$_0$ / A$_t$) × 100 [18]. A$_0$ and A$_t$ signify the absorbance of each contaminant before and after light irradiation [18].
3. Results and discussion

3.1. FESEM studies

In this experimental work, a new alkaline agent, tetraethylenepentamine (Tetrene) was utilized to prepare the binary Dy$_2$O$_3$-SiO$_2$ nanocomposite via a quick sonochemical approach. First, instrumental variables, including tuning sonication time as well as ultrasound power, were tuned to determine the proper conditions for creating a nanostructured product with favorable features in terms of uniformity and particle size (see Figs. 1 and 2). FESEM outcomes for composite samples 1, 2, and 3 fabricated by sonication for 10, 15, and 20 min are displayed in Fig. 1. By sonication for 10 min, sphere-shaped nanoparticles were fabricated that are relatively uniform (Fig. 1a and b). With sonication longer than 10 min, the tendency of the prepared nanoparticles to aggregate enhanced, and irregular micro/nanostructures were formed (Fig. 1c–f). It seems that nanoparticles that have been fabricated in a shorter time owing to their high surface energy can act as initial nuclei and have grown through the Ostwald process, resulting in irregular micro/nanostructures [47,48]. Enhancing the sonication time to 20 min also did not have a positive effect on improving the uniformity of the nanostructures and diminishing the particle size. It led to the creation of irregularly shaped nanostructures. It seems that with the prolongation of sonication, the effect of the Ostwald process has been greater than the mechanical effects of ultrasound waves. As a result, it has enhanced the particle size [48,49]. Therefore, it can be concluded that sonication for 10 min can be proper for the preparation of sphere-shaped Dy$_2$O$_3$-SiO$_2$ nanoparticles.

FESEM outcomes for composite samples 4 and 5 made with 280 and 400 W ultrasonic power are exhibited in Fig. 2. By enhancing the ultrasonic power from 160 W (Fig. 1a and b) to 280 (Fig. 2a and b) and then 400 W (Fig. 2c and d), the accumulation and aggregation of nanoparticles diminishes, the uniformity improves, and the particle size reduces. It can be seen that sphere-shaped composite nanoparticles with excellent uniformity and also tinier particle size are fabricated by tuning the ultrasound power to 400 W. Hence, enhancing the ultrasonic power remarkably affects the uniformity of the composite nanostructure as well as its architecture and particle size. Applying ultrasonic power above 160 W seems to accelerate the collapse of the cavitation bubbles, bringing in a stronger shock wave that hinders nanoparticles from accumulating more effectively [50]. So, the outcomes of morphological studies demonstrate that by proper tuning of sonication time and ultrasonic power (10 min and 400 W), a porous nanocomposite composed of sphere-shaped nanoparticles with a narrow size distribution can be fabricated. This composite nanostructure was selected for further investigation as well as photocatalytic decomposition of various contaminants.

3.2. Formation mechanism of sphere-shaped Dy$_2$O$_3$-SiO$_2$ nanoparticles

Effective help to control the architecture of various nanostructures has been reported to be one of the beneficial applications of ultrasound waves. Desirable and distinctive nanoscale structures with great uniformity can be fabricated by the cavitation fabricated by the application of sonication [50]. According to the hot-spot theory, the conversion of huge structures into tiny particles can be easily facilitated and
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accelerated by creating very high temperatures as well as releasing enormous amounts of energy that occur during the collapse of bubbles [50]. So, as the above outcomes showed, tuning the ultrasonic radiation conditions can be advantageous in controlling the composite nanostructure architecture. Due to the adsorption of ultrasonic waves by water molecules, hydroxyl radical species are fabricated that can play an efficient role in the hydrolysis of dysprosium and silicon precursors and thus have a substantial contribution to the sonochemical fabrication of composite nanophotocatalyst (Dy$_2$O$_3$-SiO$_2$) [51]. The possible mechanism for sonochemical creation of sphere-shaped Dy$_2$O$_3$-SiO$_2$ nanoparticles can be summarized as follows [42,52]:

\[
\begin{align*}
H_2O + \text{ultrasound waves} &\rightarrow H + OH \\
OH + H_2N(CH_2NH)_2CH_2CH_2NH_2 + 2H_2O &\rightarrow H_2N(CH_2CH_2NH)_2CH_2CH_2NH_2^+ + 2OH^- + \text{by products} \\
3OH^- + \text{Dy(NO}_3)_3 &\rightarrow 3NO_3^- + \text{Dy(OH)}_3 \\
\text{Dy(OH)}_3 &\rightarrow \text{Dy}_2O_3 \\
\text{TEOS} + H_2O + OH^- &\rightarrow \text{Si-(OH)}_4 + \text{by-product} \\
2\text{Si-(OH)}_4 &\rightarrow \text{SiO}_2 + \text{by-product} \\
\text{Dy}_2O_3 + \text{SiO}_2 &\rightarrow \text{Dy}_2O_3/\text{SiO}_2 [42,52]
\end{align*}
\]

3.3. TEM, EDS, XRD, and FTIR studies

TEM was utilized for the sake of minutely probing the architecture and microstructure of the selected composite nanostructure (Fig. 3). The sonochemically fabricated oxide sample consists of approximately sphere-shaped particles with a particle size in the range of 20 to 60 nm. The elemental composition of the samples fabricated via sonochemistry in three different ultrasonic powers, samples 1, 4, and 5 was determined by EDS. In Fig. 4, only the signals of the elements oxygen, silicon, and dysprosium can be clearly seen, corroborating their presence and the purity of the nanostructures.

As an efficient and exact tool, XRD was employed to evaluate the crystal phase of the selected sample (Fig. 5). The characteristic diffraction lines of cubic Dy$_2$O$_3$ (JCPDS no. 01-074-1985) and tetragonal SiO$_2$ (JCPDS no. 00-047-1300) can be found in Fig. 5, which manifests the fabrication of the binary Dy$_2$O$_3$-SiO$_2$ nanocomposite with poor crystallization. The crystal size of the selected Dy$_2$O$_3$-SiO$_2$ nanostructure was estimated to be about 17.4 nm employing the Scherrer formula [50]. No signal indicative of the impurity was observed in XRD profile, signifying the binary nanocomposite is pure.

The selected sample was also examined by FTIR to further corroborate the fabrication of composite nanophotocatalyst (Dy$_2$O$_3$-SiO$_2$). Signals around 990, 916, and 650 cm$^{-1}$ correspond to Si-O-Si bonds that manifest the creation of the SiO$_2$ phase (see Fig. 6) [53,54]. Characteristic signals of Dy$_2$O$_3$ are observed near 545 and 499 cm$^{-1}$ [31]. The absorption signals at 3603, 3424, and 1632 cm$^{-1}$ demonstrate the physisorbed water molecules [41]. Thus, FTIR findings are in line with XRD and EDS outcomes.

Fig. 3. TEM images of binary Dy$_2$O$_3$-SiO$_2$ nanocomposite (sample 5).
3.4. Optical and textural properties of sphere-shaped Dy$_2$O$_3$-SiO$_2$ nanoparticles

The optical absorption features of the selected composite nanostructure were explored by DRS (see Fig. 7). The binary Dy$_2$O$_3$-SiO$_2$ nanocomposite exhibits an absorption edge at 367 nm. The energy gap of about 3.41 eV for the selected binary nanocomposite was determined employing DRS outcomes and Tauc’s formula [18]. The sonochemically fabricated binary Dy$_2$O$_3$-SiO$_2$ nanocomposite has a narrower energy gap than the pure dysprosium oxide previously reported (4.8 eV) [35]. It can be concluded that the addition of silicon dioxide into Dy$_2$O$_3$ effectively tuned its energy gap, and the prepared binary Dy$_2$O$_3$-SiO$_2$ nanocomposite could possibly manifest improved photocatalytic performance in removing contaminants.

The textural features of the sonochemically fabricated binary Dy$_2$O$_3$-SiO$_2$ nanocomposite were also examined, and the outcomes are presented in Fig. 8 and Table 2. It can be seen that the prepared binary nanocomposite sample is mesoporous in nature. The compounds with the great specific surface area can more efficiently adsorb contaminant molecules and also provide a large number of active sites for the decomposition of contaminant, resulting in excellent photocatalytic efficiency [55]. With a good specific surface area, it can be expected that binary nanocomposites can denote outstanding photocatalytic performance.
3.5. Evaluation of the photocatalytic activity of binary Dy$_2$O$_3$-SiO$_2$ nanocomposite

Due to the proper energy gap of the selected composite nanostructure, its photocatalytic performance was tested under ultraviolet light for photodecomposition of water contaminant. Several dyes including erythrosine, thymol blue, eriochrome black T, Acid Red 14, methyl orange, malachite green, and Rhodamine B were selected as target contaminants to test the performance of the binary Dy$_2$O$_3$-SiO$_2$ nanocatalyst. In order to achieve the greatest efficiency in photocatalytic decomposition of each contaminant, the impact of variables including contaminant concentration and quantity of Dy$_2$O$_3$-SiO$_2$ nanophotocatalyst was explored (see Figs. 9 and 10). Solutions with different concentrations of 5, 10, and 15 ppm were employed as target contaminants. Various quantities of binary Dy$_2$O$_3$-SiO$_2$ nanophotocatalyst, 0.015 and 0.03 g, were applied for photocatalytic testing. Decomposition of any contaminants was negligible without UV light or without the usage of binary Dy$_2$O$_3$-SiO$_2$ nanocatalyst. Thus, the presence of both factors was necessary to decompose each of the pollutants. It can be seen that the studied variables, the concentration of the contaminant solution and the quantity of Dy$_2$O$_3$-SiO$_2$ nanophotocatalyst, both significantly affect the percentage of decomposition. The effect of these variables for the percentage of decomposition of each contaminant is different from other contaminants. By increasing the quantity of binary Dy$_2$O$_3$-SiO$_2$ nanocomposite from 0.015 g to 0.03 g, in the case of contaminants with a concentration of 5 ppm, the percentage of decomposition of all 4 contaminants was enhanced (Figs. 9a and 10a). It can be observed in the case of contaminant with a concentration of 5 ppm, employing 0.03 g of binary Dy$_2$O$_3$-SiO$_2$ nanocatalyst, 78.75, 71.43, 28.16, and 68.08% of thymol blue, methyl orange, Rhodamine B, and malachite green were decomposed after 120 min of UV exposure (Fig. 10a). In contrast, the percentage of decomposition of Acid Red 14, erythrosine, and eriochrome black T contaminant diminished to 51.04, 86.11, and 75.45 %. For contaminants with a concentration of 10 ppm, by altering the amount of binary Dy$_2$O$_3$-SiO$_2$ nanocatalyst from 0.015 g to 0.03 g, the decomposition percentage of thymol blue, methyl orange, Rhodamine B, and malachite green were decomposed after 120 min of UV exposure (Fig. 10b). In comparison, the percentage of decomposition of Acid Red 14, erythrosine, and eriochrome black T contaminant diminished to 51.04, 86.11, and 75.45 %.
erythrosine, and eriochrome black T contaminant diminished to 25.64, 78.59, and 44.16%. In the case of contaminants with a concentration of 15 ppm, utilizing 0.015 g of binary Dy$_2$O$_3$-SiO$_2$ nanocomposite, 73.97, 32.65, 92.05, 66.19, 29.42, 19.05, and 60% of thymol blue, Acid Red 14, erythrosine, eriochrome black T, methyl orange, Rhodamine B, and malachite green were removed after 120 min of UV exposure. Applying 0.03 g of the composite nanostructure, a lower percentage of decomposition was observed for all contaminants (Figs. 9c and 10c). Based on

![Fig. 9. Photocatalytic degradation of various pollutants with different concentrations of 5 (a), 10 (b), and 15 (c) ppm in the presence of 0.015 g binary Dy$_2$O$_3$-SiO$_2$ nanocomposite (sample 5), under UV light irradiation.](image1)

![Fig. 10. Photocatalytic degradation of various pollutants with different concentrations of 5 (a), 10 (b), and 15 (c) ppm in the presence of 0.03 g of binary Dy$_2$O$_3$-SiO$_2$ nanocomposite (sample 5), under UV light irradiation.](image2)
the above outcomes, it can be concluded that the concentration of 5 ppm of contaminant, as well as the quantity of 0.015 g of Dy$_2$O$_3$-SiO$_2$ nanocatalyst, is the most appropriate conditions to have the highest percentage of degradation of Acid Red 14, erythrosine, and eriochrome black T contaminants (Fig. 9a). In contrast, the highest percentage of decomposition of methyl orange, Rhodamine B, and malachite green occurred under optimal conditions, including a concentration of 5 ppm of contaminant and 0.03 g of Dy$_2$O$_3$-SiO$_2$ nanocatalyst (Fig. 9b). In the case of thymol blue, conditions including 10 ppm of contaminant and 0.03 g of Dy$_2$O$_3$-SiO$_2$ nanocomposite were more proper to achieve the highest percentage of decomposition (Fig. 10a). Under optimized conditions, the binary Dy$_2$O$_3$-SiO$_2$ nanophotocatalyst exhibited superior efficiency toward the decomposition of the studied contaminants, and the highest percentage of erythrosine contaminant (about 92.99) was decomposed. The addition of silicon dioxide into Dy$_2$O$_3$ results in the formation of a binary Dy$_2$O$_3$-SiO$_2$ nanocomposite with a good specific surface area that can be very beneficial for efficient absorption of light as well as enhancing the adsorption of target contaminant molecules. It also tunes its energy gap, which results in more separation of the charge carrier [56,57]. For the above reasons, it seems that sonochemically prepared Dy$_2$O$_3$-SiO$_2$ nanocatalyst manifest superior efficiency in the decomposition of pollutants. Fig. 11a–c exhibit UV–vis absorption spectra of erythrosine, eriochrome black T, and thymol blue with respect to time over the binary Dy$_2$O$_3$-SiO$_2$ nanocomposite, which illustrates that the absorption intensity diminishes as illumination time enhances and; the decomposition of all three contaminant occurs continuously. Since among the studied contaminants, even in optimal conditions, the lowest percentage of decomposition was observed for Rhodamine B contaminant, in order to achieve a greater percentage of degradation, higher quantities of Dy$_2$O$_3$-SiO$_2$ nanophotocatalyst were employed to degrade the solution with a concentration of 5 ppm (see Fig. 12a). With altering the quantity of Dy$_2$O$_3$-SiO$_2$ nanocomposite from 0.03 g to 0.05 g, an increment in Rhodamine B degradation from 28.16 to 65.07% was observed, and the percentage of Rhodamine B degradation almost doubled. A possible reason for the enhancement in Rhodamine B degradation with increasing nanocatalyst dose could be the increment in the number of active sites as well as the improvement in the adsorption of Rhodamine B molecules on the surface of Dy$_2$O$_3$-SiO$_2$ nanocomposite.
However, with a further enhancement in the quantity of Dy$_2$O$_3$-SiO$_2$ nanocomposite to 0.07 g, a decrement in the degradation efficiency of the Rhodamine B was observed, and about 52.82% of the contaminant was degraded. It seems that with the addition in the amount of Dy$_2$O$_3$-SiO$_2$ nanocomposite, owing to the accumulation and precipitation of nanocomposite particles, the light scattering inside the suspension is enhanced, and as a result, the degradation efficiency is diminished [60]. Also, the agglomeration of nanocomposite particles can reduce the number of active photocatalytic sites and be a possible reason for declining the percentage of Rhodamine B decomposition [60]. Thus, the appropriate quantity of Dy$_2$O$_3$-SiO$_2$ nanocomposite for efficient decomposition of Rhodamine B is confirmed, 0.05 g, is confirmed.

Also, to explore the effect of light irradiation time on the enhancement of degradation efficiency, a test was performed in a condition including 0.05 g of Dy$_2$O$_3$-SiO$_2$ nanocomposite and 5 ppm of Rhodamine B for 165 min (see Fig. 12b). It was observed that by prolonging the UV exposure time, the percentage of Rhodamine B degradation could enhance from 54.77 to 61.53%.

The effects of various scavengers upon the photodecomposition of Rhodamine B by binary Dy$_2$O$_3$-SiO$_2$ nanocomposite are illustrated in Fig. 13. Benzoic acid, EDTA, and p-benzoquinone were utilized to quench OH, h$,^+$, and O$_2^-$, correspondingly [18]. Without the presence of a scavenger, about 54.77% of Rhodamine B molecules were decomposed by the binary Dy$_2$O$_3$-SiO$_2$ nanophotocatalyst. The addition of different scavengers, to varying degrees, prevented the photocatalytic decomposition of Rhodamine B molecules. P-benzoquinone had the least inhibitory effect on the decomposition of Rhodamine B molecules, because in its presence, 49.76% of Rhodamine B could be decomposed. The presence of benzoic acid and EDTA diminished the photocatalytic efficiency to 13.92% and 38.19%, correspondingly, signifying that OH radicals are the most active degradative species of Rhodamine B molecules. Of course, holes are also involved in the photocatalytic decomposition of Rhodamine B to a lesser degree than hydroxyl radicals [18].
The mechanism involved in the photodecomposition of Rhodamine B molecules is as follows [18] (see Scheme 2):

\[
\text{Dy}_2\text{O}_3\text{SiO}_2 \; \text{nanophotocatalyst} + \hbar \nu \rightarrow \text{Dy}_2\text{O}_3\text{SiO}_2 \; \text{nano-catalyst}^* + e^- + h^+ \\
2 \text{H}^+ + 2\text{H}_2\text{O} \rightarrow \text{H}_2\text{O}_2 + 2\text{H}^+ \\
\text{H}_2\text{O}_2 \rightarrow 2\text{OH} \\
e^- + \text{O}_2 \rightarrow \text{O}_2^- \\
\text{O}_2^- + 2\text{OH} + \text{H}^+ \rightarrow \text{H}_2\text{O}_2 + \text{O}_2 \\
\text{H}_2\text{O}_2 \rightarrow 2\text{OH} \\
\text{OH} + \text{Rhodamine B molecules} \rightarrow \text{Degradation products} [18]
\]

The reusability of the binary Dy$_2$O$_3$SiO$_2$ nanocomposite (sample 5) was tested for ten cycles in the photodecomposition of Rhodamine B under UV illumination. It was noted that the photocatalytic efficiency diminishes, but was still about 49.5% after the repeated experiments (see Fig. 14).

Table 3 exhibits the photocatalytic efficiency of different compounds for the decomposition of various contaminants under ultraviolet illumination. In this investigation, a new photocatalytic nanocomposite (Dy$_2$O$_3$SiO$_2$) with enhanced catalytic efficiency toward toxic contaminants was efficiently fabricated employing a basic agent, tetraethylammonium (Tetrene), through a simple and quick sonochemical approach. As observed in Table 3, the sonochemically fabricated Dy$_2$O$_3$SiO$_2$ nanocomposite can compete with other compounds as photocatalysts. We can nominate the porous Dy$_2$O$_3$SiO$_2$ nanocomposite as a new kind of high-performance photocatalyst in the field of water remediation and environmental cleaning.

4. Conclusions

In summary, a new photocatalytic nanocomposite (Dy$_2$O$_3$SiO$_2$) with enhanced catalytic efficiency toward toxic contaminants was efficiently fabricated employing a basic agent, tetraethylammonium (Tetrene), through a simple and quick sonochemical approach. The features of the fabricated photocatalytic nanocomposite were examined employing a variety of microscopic and spectroscopic methods. According to the outcomes of morphological studies, it was found that by properly tuning the sonication time and ultrasound power (10 min and 400 W), a porous nanocomposite composed of sphere-shaped nanoparticles with a narrow size distribution can be made. The optimal nanocomposite sample was tested as a nanostructured catalyst for the photodecomposition of several contaminants. The binary Dy$_2$O$_3$SiO$_2$ nanophotocatalyst demonstrated superior efficiency toward the photodecomposition of the studied contaminants, and the highest percentage of erthyrosine contaminant (about 92.99) was decomposed. Optimization studies for the photocatalytic decomposition of each contaminant illustrated that the best performance could be achieved at a specific amount of contaminant and photocatalyst. Trapping experiments illustrated that hydroxyl radicals were more effectively involved in the decomposition process of contaminant molecules by Dy$_2$O$_3$SiO$_2$ nanophotocatalyst. The outcomes of this experimental work demonstrate that the addition of silicon dioxide into Dy$_2$O$_3$ and the sonochemically fabricated porous Dy$_2$O$_3$SiO$_2$ nanocomposite brought a new kind of high-performance photocatalyst in the field of water remediation and environmental cleaning.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Authors are grateful to University of Bonab, the council of Iran National Science Foundation (97017837) and University of Kashan for supporting this work by Grant No (159271/KM).
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