Sonochemical synthesis, characterization and photodegradation of organic pollutant over Nd_2O_3 nanostructures prepared via a new simple route

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Abstract: For the first time, a new simple route of synthesizing Nd_2O_3 nanostructures has been developed with applying the sonochemical process. As a novel precipitator, 2,2-dimethyl-1,3-propanediamine was applied in the presence of $\text{Nd}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$ to prepare neodymium oxide. In order to control the shape, size and photocatalytic activity of neodymium oxide products, the type of capping agents have been altered. The synthesized nanostructured neodymium oxide has been characterized with the aid of DRS, FT-IR, XRD, TEM, FESEM and EDX. It was demonstrated that shape, size and photocatalytic activity of the sonochemically fabricated neodymium oxide were under the influence of the type of capping agent. The photocatalytic decomposition of eosin Y pollutant has been performed to compare the photocatalytic efficiencies of neodymium oxide nano and bulk structures under ultraviolet illumination.

Keywords: Neodymium oxide; Ultrasonic method; Nanostructure; Electron microscopy; Photocatalytic activity.

1. Introduction

...Recently, the production of nanosized structures has been attracted growing interest due to their several technological usages [1-6]. There has been growing interest in study on neodymium oxide (Nd_2O_3) as a notable rare

earth compound owing to its usages in catalysts, lasers, UV absorbent, sensors and protective coatings [7-11]. To the present time, several ways have been reported to produce neodymium oxide such as precipitation, combustion, sol-gel, thermal decomposition and hydrogen plasma-metal reaction [11-19]. Ultrasonic irradiation as a striking tool has been utilized to produce the materials with a controlled shape and grain size [20-26]. Since characteristics of materials are under the influence of shape and grain size, the production of materials with a controlled shape and grain size has been become an especially substantial research field [27-32].

The goal of the present study is introduction a new simple route of synthesizing Nd_2O_3 nanostructures with applying the sonochemical process. As a novel precipitator, 2,2-dimethyl-1,3-propanediamine was applied in the presence of $\text{Nd}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$ to prepare neodymium oxide. In order to control the shape, size and photocatalytic activity of neodymium oxide products, the type of capping agents have been altered. Also, the photocatalytic destruction of eosin Y pollutant has been performed to compare the photocatalytic efficiencies of neodymium oxide structures under ultraviolet illumination.

2. Experimental

2.1. Materials and characterization

$\text{Nd}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$, 4,4'-methylenedianiline, methanol, liquor NH_3 solution, polyvinylpyrrolidone 40000 (PVP 40000), 2,2-dimethyl-1,3-propanediamine, ethylenediaminetetraacetic acid disodium salt (Titrplex III) and 2-hydroxy-1-naphthaldehyde with reagent grade were obtained from Merck Co. Schiff base structure was obtained similar to former method [11]. The shape and grain size of Nd_2O_3 nanostructures were determined with field emission scanning electron microscope (FESEM, MIRA3 FEG-SEM) and transmission electron microscopy (TEM, JEM-2100). The production was done with an ultrasonic generator (MPI Ultrasonics; Switzerland). GC-2550TG (Teif Gostar Faraz Company, Iran) were used for all chemical analyses. DRS spectrum of the as-formed Nd_2O_3 was acquired on a UV-vis spectrophotometer (Shimadzu, UV-2550, Japan). FT-IR spectrum of Nd_2O_3 was recorded

from KBr pellets on a Magna-IR, spectrometer 550 Nicolet. A Philips XL30 microscope was applied to examine the chemical composition of the as-formed Nd_2O_3 . XRD patterns of the as-produced powders were acquired on a diffractometer of Philips Company with Ni-filtered Cu Ka radiation.

2.2. Preparation of neodymium oxide products

Neodymium oxide samples were produced with a facile sonochemical process. First, the solution comprising 150 mg of $\text{Nd}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$ and stoichiometric quantity of PVP in distilled water was prepared under magnetic stirring. Next, the pH of obtained mixture was made 11 through drop-wise addition of 2,2-dimethyl-1,3-propanediamine solution under ultrasonic waves (for 1/4 h at power of 60 W/m^2). The obtained precipitate was collected, washed out (with distilled water and methanol), air-dried and afterwards calcined at 650°C for 120 min (sample 3). In [Table 1](#) the production conditions of neodymium oxide structures were summarized. For investigating the role of ultrasound irradiation on the shape and size of neodymium oxide, one sample was formed without sonication. For examining the role of novel precipitator, 2,2-dimethyl-1,3-propanediamine, and employing of capping agent on the shape and size of neodymium oxide, two samples were produced in absence of the 2,2-dimethyl-1,3-propanediamine and capping agent.

2.3. Photocatalytic studies

For comparing the photocatalytic efficiencies of neodymium oxide structures under ultraviolet illumination, the photocatalytic decomposition of eosin Y pollutant has been performed. For this objective, the reaction suspension involving 60 mg of the as-produced neodymium oxide structures and 1.5 mg of the eosin Y pollutant in the glass reactor has been utilized. The resulting suspension was subjected to the ultraviolet illumination (125 W mercury lamp) after aerating (within 1/2 h in darkness) for attaining the adsorption–desorption equilibrium. The eosin Y pollutant destruction efficiency has been estimated as follow:

$$D.P.(t) = \frac{A_0 - A_t}{A_0} \times 100 \quad (1)$$

where A_0 and A_t are the UV-visible absorbance value of eosin Y pollutant solution before and after destruction.

3. Results and discussion

This article introduces a new simple route of synthesizing Nd_2O_3 nanostructures with applying the sonochemical process. Bis-(2-hydroxy-1-naphthaldehyde)- 4,4'-methylenedianiline, PVP and Titriplex have been applied for evaluating the role of the type of the capping agent on morphology and particle size of neodymium oxide. The FESEM micrographs in Fig. 1a-f demonstrate formation of irregular plate-like microstructures/non-uniform nanobundles, less uniform micro/nanobundles and uniform spherical neodymium oxide nanostructures with the aid of Schiff base structure (Fig. 1a and b), Titriplex (Fig. 1c and d) and PVP (Fig. 1e and f). It seems that the primary nuclei (coated with hydroxyl groups) may adsorb utilized capping agents on their surfaces. The utilized capping agents with the three various steric hindrance mechanisms may inhibit the extra aggregation. In Scheme 1, the possible mechanism for the preparation of the several shapes of neodymium oxide with the aid of different capping agents is schematically demonstrated. Based on the FESEM micrographs of the neodymium oxide samples prepared with the aid of different capping agents (Fig. 1a-f), it is suggested that PVP has a great impact on the sonochemically preparation of uniform spherical neodymium oxide nanostructures. PVP may be formed hydrogen bonds with primary nuclei surface hydroxyls owing to the presence of oxygen atom in its high C=O groups. Since primary nuclei surface coated with great OH groups as well as PVP has a long chain with high C=O groups, PVP may tightly entwine the produced nuclei surface, and hereupon may play more favorable role in control the growth of formed nanoparticles (Scheme 1). But neodymium oxide structures synthesized with the aid of Titriplex and Schiff base structure are irregular and non-uniform. Hence, the use of PVP is favorable to form uniform spherical neodymium oxide nanostructures.

The FESEM micrograph in Fig. 2a illustrates formation of irregular micro/nanobundles with the aid of sonication in absence of the capping agent (samples 4). By comparing the FESEM micrographs of neodymium oxide sample synthesized in absence of the capping agent (Fig. 2a) and the FESEM micrographs of neodymium oxide samples produced with the aid of different capping agents (Fig. 1a-f), it is found that the PVP can play a notable role in control the growth of produced nanoparticles.

Fig. 2b and c depict FESEM micrographs of neodymium oxide obtained without sonication. According to these images, irregular microstructures/bulk structures have been produced without sonication (samples 5). By comparing the FESEM micrographs of neodymium oxide sample formed with magnetic stirring for 1/2 h utilizing 2,2-dimethyl-1,3-propanediamine and PVP (Fig. 2d and e) and the FESEM micrographs of neodymium oxide sample produced with the aid of 2,2-dimethyl-1,3-propanediamine, sonication and PVP (Fig. 1e and f), it can be seen that the utilizing of ultrasound irradiation can play a remarkable role in control the growth and production of uniform spherical neodymium oxide nanostructures. Scheme 2 demonstrates schematic diagram of preparation of neodymium oxide nano and bulk structures. The role of utilizing of ultrasonic irradiation on the shape and particle size of neodymium oxide is clearly illustrated in Scheme 2. Ultrasonic irradiation as a striking tool has been utilized to produce the materials with a controlled shape and grain size [33].

The proposed preparation mechanism of neodymium oxide with the aid of ultrasound irradiation utilizing 2,2-dimethyl-1,3-propanediamine can be explained as follows:

where the symbol Δ demonstrates ultrasound irradiation.

It may be proposed that the $\text{OH}^\bullet$ radicals formed with the aid of sonolysis of H_2O may partake in the hydrolysis of the neodymium source and hereupon may play favorable role in sonochemical production of neodymium oxide. Similar offer about the contribution of $\text{OH}^\bullet$ radicals in the production of metal oxides with the aid of sonication has been proposed by Prasad et al. [34].

The FESEM micrographs in [Fig. 2d and e](#) demonstrate formation of non-uniform microstructures/bulk structures with the aid of sonication and PVP in absence of 2,2-dimethyl-1,3-propanediamine (samples 6). 2,2-Dimethyl-1,3-propanediamine as co-capping agent may create high steric hindrance effect and its use may be a remarkable factor in control the growth and production of uniform spherical neodymium oxide nanostructures. Based on the FESEM micrographs of the neodymium oxide samples ([Figs. 1a-f and 2a-e](#)), it can be seen that use of 2,2-dimethyl-1,3-propanediamine, ultrasound irradiation and PVP has a great impact on the preparation of uniform spherical neodymium oxide nanostructures.

The detailed morphological features of neodymium oxide sample produced with the aid of ultrasound irradiation, 2,2-dimethyl-1,3-propanediamine and PVP are given in the TEM micrographs in [Fig. 3a-d](#). Based on the TEM micrographs ([Fig. 3a-d](#)), grain sizes of the neodymium oxide sample are between 15 and 75 nm.

XRD patterns have been recorded for the phase identification of sample produced with the aid of ultrasound irradiation, 2,2-dimethyl-1,3-propanediamine and PVP (sample 3) before and after calcination at 650 °C (Fig. 4a and b). XRD pattern in Fig. 4a demonstrates formation of amorphous structure before calcination. In the case of produced sample after calcination, all reflection lines in Fig. 4b may be well indexed as hexagonal neodymium oxide (JCPDS No. 74-2139). The mean crystalline size obtained with the Scherrer's formula for sample 3 is about 28 nm [35].

The surface of produced neodymium oxide (sample 3) has been evaluated with FT-IR spectrum (Fig. 5). The bands seen around 900, 1388 and 1496 cm^{-1} are assigned to carbonate group [36]. The band corresponding to the stretching vibration of OH group of adsorbed H_2O is seen at 3427 cm^{-1} [31, 37]. The bands assigned to the neodymium oxide are clearly seen at 406 and 666 cm^{-1} [31, 37].

The EDS pattern in Fig. 6 demonstrates the presence of Nd and O elements in chemical composition of the sample produced with the aid of ultrasound irradiation, 2,2-dimethyl-1,3-propanediamine and PVP (sample 3). Based on the structural and morphological information, it can be observed that the use of 2,2-dimethyl-1,3-propanediamine, ultrasound irradiation and PVP is favorable for the preparation of uniform spherical neodymium oxide nanostructures with pure hexagonal phase.

DRS spectrum has been recorded for the identification of optical features of produced neodymium oxide (sample 3). The DRS spectrum has one band nearly 354 nm (Fig. 7a). The energy gap (E_g) as a remarkable factor in the photocatalytic studies has been estimated with the aid of Tauc's formula and DRS information [29, 38]. The E_g of produced neodymium oxide (Fig. 7b) has been obtained with the aid of extrapolation of the plot of $(\alpha h\nu)^2$ against $h\nu$ to the energy axis. The E_g of neodymium oxide produced with the aid of ultrasound irradiation, 2,2-dimethyl-1,3-propanediamine and PVP was estimated to be 3.28 eV. The determined energy gap proves that formed neodymium oxide may be utilized as photocatalyst under ultraviolet illumination.

The role of the use of ultrasonic irradiation as well as type of capping agent on the photocatalytic efficiency of neodymium oxide has been investigated with the aid of monitoring the destruction of eosin Y pollutant under ultraviolet illumination. Figs. 8 and 9 present comparison of photocatalytic behaviors of neodymium oxide structures (samples 1, 2, 3 and 5). No eosin Y contaminant was almost decomposed after 80 min in absence of neodymium oxide structures (samples 1, 2, 3 and 5) or UV illumination. By considering the experimental results, it can be found that the share of self-decomposition was negligible. By comparing the photocatalytic performances of neodymium oxide structures (Figs. 8 and 9), it is clear that the photocatalytic efficiency of the neodymium oxide prepared with the aid of ultrasound irradiation and PVP is greater than that of the other neodymium oxide structures. From the photocatalytic calculations, the eosin Y pollutant decomposition were about 72.4% by sample 1, about 84.2% by sample 2, about 91.7% by sample 3 and about 54.3% by sample 5 after 80 min UV illumination. By comparing the FESEM micrographs of neodymium oxide structures (Figs. 1 and 2b and c), it can be observed that the use of ultrasound irradiation as well as PVP is favorable for the preparation of uniform spherical neodymium oxide nanostructures with fine grain size. The offered mechanism of the decomposition of eosin Y pollutant can be summarized as:

It seems that use of ultrasound irradiation and PVP has a great impact on the preparation of uniform spherical neodymium oxide nanostructures with the best photocatalytic performance. It is suggested that use of ultrasound irradiation and PVP may cause enhance in the ratio of surface area to volume, attainable active sites on neodymium oxide surface as well as transition quantity of interfacial charge carrier with diminishing grain size of neodymium oxide, and hereupon causing the best catalytic performance [39]. Based on the photocatalytic investigations, it can be observed that the use of ultrasound irradiation and PVP is favorable for the preparation of neodymium oxide nanostructures with the best photocatalytic performance.

4. Conclusions

A new simple route of synthesizing Nd_2O_3 nanostructures was developed with applying the sonochemical process for the first time. As a novel precipitator, 2,2-dimethyl-1,3-propanediamine was applied in the presence of $\text{Nd}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$ to prepare neodymium oxide. For controlling the shape, size and photocatalytic activity of neodymium oxide products, the type of capping agents have been altered. It was demonstrated that shape, size and photocatalytic activity of the sonochemically fabricated neodymium oxide were under the influence of the type of capping agent. The photocatalytic and morphological investigations demonstrate that use of ultrasound irradiation and PVP has a great impact on the preparation of uniform spherical neodymium oxide nanostructures with the best photocatalytic performance. The results of photocatalytic studies reveal that the as-produced neodymium oxide nanostructures may be employed as striking and advantageous photocatalyst under ultraviolet illumination.

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References

- [1] F. Beshkar, S. Zinatloo-Ajabshir, M. Salavati-Niasari, Simple morphology-controlled fabrication of nickel chromite nanostructures via a novel route, *Chemical Engineering Journal*, 279 (2015) 605-614.
- [2] S. Zinatloo-Ajabshir, M. Salavati-Niasari, Synthesis of pure nanocrystalline ZrO_2 via a simple sonochemical-assisted route, *Journal of Industrial and Engineering Chemistry*, 20 (2014) 3313-3319.
- [3] M.S. Morassaei, S. Zinatloo-Ajabshir, M. Salavati-Niasari, Simple salt-assisted combustion synthesis of $\text{Nd}_2\text{Sn}_2\text{O}_7\text{--SnO}_2$ nanocomposites with different amino acids as fuel: an efficient photocatalyst for the degradation of methyl orange dye, *Journal of Materials Science: Materials in Electronics*, 27 (2016) 11698-11706.
- [4] S. Zinatloo-Ajabshir, M. Salavati-Niasari, M. Hamadian, Praseodymium oxide nanostructures: novel solvent-less preparation, characterization and investigation of their optical and photocatalytic properties, *RSC Advances*, 5 (2015) 33792-33800.
- [5] F. Razi, S. Zinatloo-Ajabshir, M. Salavati-Niasari, Preparation, characterization and photocatalytic properties of $\text{Ag}_2\text{ZnI}_4/\text{AgI}$ nanocomposites via a new simple hydrothermal approach, *Journal of Molecular Liquids*, (2016).
- [6] S. Zinatloo-Ajabshir, M. Salavati-Niasari, Novel poly(ethyleneglycol)-assisted synthesis of praseodymium oxide nanostructures via a facile precipitation route, *Ceramics International*, 41 (2015) 567-575.
- [7] R.B. Yu, K.H. Yu, W. Wei, X.X. Xu, X.M. Qiu, S. Liu, W. Huang, G. Tang, H. Ford, B. Peng, Nd_2O_3 Nanoparticles Modified with a Silane-Coupling Agent as a Liquid Laser Medium, *Advanced Materials*, 19 (2007) 838-842.
- [8] C.R. Michel, A.H. Martínez-Preciado, N.L.L. Contreras, Gas sensing properties of Nd_2O_3 nanostructured microspheres, *Sensors and Actuators B: Chemical*, 184 (2013) 8-14.
- [9] M. Zawadzki, L. Kpiński, Synthesis and characterization of neodymium oxide nanoparticles, *Journal of Alloys and Compounds*, 380 (2004) 255-259.

- [10] A. Kosola, J. Päiväsaari, M. Putkonen, L. Niinistö, Neodymium oxide and neodymium aluminate thin films by atomic layer deposition, *Thin Solid Films*, 479 (2005) 152-159.
- [11] S. Mortazavi-Derazkola, S. Zinatloo-Ajabshir, M. Salavati-Niasari, New sodium dodecyl sulfate-assisted preparation of Nd_2O_3 nanostructures via a simple route, *RSC Advances*, 5 (2015) 56666-56676.
- [12] S.V. Chavan, P.U.M. Sastry, A.K. Tyagi, Combustion synthesis of nano-crystalline Nd-doped ceria and Nd_2O_3 and their fractal behavior as studied by small angle X-ray scattering, *Journal of Alloys and Compounds*, 456 (2008) 51-56.
- [13] S. Mortazavi-Derazkola, S. Zinatloo-Ajabshir, M. Salavati-Niasari, Preparation and characterization of Nd_2O_3 nanostructures via a new facile solvent-less route, *Journal of Materials Science: Materials in Electronics*, 26 (2015) 5658-5667.
- [14] L. Kępiński, M. Zawadzki, W. Miśta, Hydrothermal synthesis of precursors of neodymium oxide nanoparticles, *Solid State Sciences*, 6 (2004) 1327-1336.
- [15] Q. Liqin, W. Kaituo, W. Xuehang, W. Wenwei, L. Sen, L. Gengming, Nanocrystalline Nd_2O_3 : Preparation, phase evolution, and kinetics of thermal decomposition of precursor, *Ceramics International*, 40 (2014) 3003-3009.
- [16] T. Liu, Zhang, Shao, Li, Synthesis and Characteristics of Sm_2O_3 and Nd_2O_3 Nanoparticles, *Langmuir*, 19 (2003) 7569-7572.
- [17] R. Yuvakkumar, S.I. Hong, Nd_2O_3 : novel synthesis and characterization, *Journal of Sol-Gel Science and Technology*, 73 (2015) 511-517.
- [18] P. Wu, Z. Zhang, G. Song, Preparation of Nd_2O_3 nanorods in SDBS micelle system, *Journal of Rare Earths*, 32 (2014) 1027-1031.
- [19] X. Qu, J. Dai, J. Tian, X. Huang, Z. Liu, Z. Shen, P. Wang, Syntheses of Nd_2O_3 nanowires through sol-gel process assisted with porous anodic aluminum oxide (AAO) template, *Journal of Alloys and Compounds*, 469 (2009) 332-335.

- [20] S. Zinatloo-Ajabshir, M. Salavati-Niasari, A Sonochemical-Assisted Synthesis of Pure Nanocrystalline Tetragonal Zirconium Dioxide Using Tetramethylethylenediamine, *International Journal of Applied Ceramic Technology*, 11 (2014) 654-662.
- [21] M. Salavati-Niasari, M. Esmaeili-Zare, A. Sobhani, Synthesis and characterisation of cadmium selenide nanostructures by simple sonochemical method, *IET Micro & Nano Letters*, 7 (2012) 831-834.
- [22] S. Zinatloo-Ajabshir, M. Salavati-Niasari, Facile route to synthesize zirconium dioxide (ZrO_2) nanostructures: Structural, optical and photocatalytic studies, *Journal of Molecular Liquids*, 216 (2016) 545-551.
- [23] M. Jafari, A. Sobhani, M. Salavati-Niasari, Effect of preparation conditions on synthesis of Ag_2Se nanoparticles by simple sonochemical method assisted by thiourea, *Journal of Industrial and Engineering Chemistry*, 20 (2014) 3775-3779.
- [24] M. Esmaeili-Zare, M. Salavati-Niasari, A. Sobhani, Sonochemical synthesis of HgSe nanoparticles: effect of metal salt, reaction time and reductant agent, *Journal of Industrial and Engineering Chemistry*, 20 (2014) 3518-3523.
- [25] M. Salavati-Niasari, M. Esmaeili-Zare, A. Sobhani, Cubic HgSe nanoparticles: sonochemical synthesis and characterisation, *IET Micro & Nano Letters*, 7 (2012) 1300-1304.
- [26] M. Jafari, M. Salavati-Niasari, A. Sobhani, Silver selenide nanoparticles: synthesis, characterisation and effect of preparation conditions under ultrasound radiation, *IET Micro & Nano Letters*, 8 (2013) 508-511.
- [27] S. Moshtaghi, S. Zinatloo-Ajabshir, M. Salavati-Niasari, Preparation and characterization of BaSnO_3 nanostructures via a new simple surfactant-free route, *Journal of Materials Science: Materials in Electronics*, 27 (2016) 425-435.
- [28] S. Zinatloo-Ajabshir, M. Salavati-Niasari, Nanocrystalline Pr_6O_{11} : synthesis, characterization, optical and photocatalytic properties, *New Journal of Chemistry*, 39 (2015) 3948-3955.

- [29] M.S. Morassaei, S. Zinatloo-Ajabshir, M. Salavati-Niasari, New facile synthesis, structural and photocatalytic studies of $\text{NdOCl-Nd}_2\text{Sn}_2\text{O}_7\text{-SnO}_2$ nanocomposites, *Journal of Molecular Liquids*, 220 (2016) 902-909.
- [30] S. Zinatloo-Ajabshir, Z. Salehi, M. Salavati-Niasari, Preparation, characterization and photocatalytic properties of $\text{Pr}_2\text{Ce}_2\text{O}_7$ nanostructures via a facile procedure, *RSC Advances*, 6 (2016) 107785-107792.
- [31] S. Mortazavi-Derazkola, S. Zinatloo-Ajabshir, M. Salavati-Niasari, Novel simple solvent-less preparation, characterization and degradation of the cationic dye over holmium oxide ceramic nanostructures, *Ceramics International*, 41 (2015) 9593-9601.
- [32] S. Zinatloo-Ajabshir, M. Salavati-Niasari, Z. Zinatloo-Ajabshir, $\text{Nd}_2\text{Zr}_2\text{O}_7\text{-Nd}_2\text{O}_3$ nanocomposites: New facile synthesis, characterization and investigation of photocatalytic behaviour, *Materials Letters*, 180 (2016) 27-30.
- [33] V. Misik, N. Miyoshi, P. Riesz, EPR Spin-Trapping Study of the Sonolysis of $\text{H}_2\text{O/D}_2\text{O}$ Mixtures: Probing the Temperatures of Cavitation Regions, *The Journal of Physical Chemistry*, 99 (1995) 3605-3611.
- [34] K. Prasad, D.V. Pinjari, A.B. Pandit, S.T. Mhaske, Synthesis of zirconium dioxide by ultrasound assisted precipitation: Effect of calcination temperature, *Ultrasonics Sonochemistry*, 18 (2011) 1128-1137.
- [35] Z. Salehi, S. Zinatloo-Ajabshir, M. Salavati-Niasari, New simple route to prepare $\text{Dy}_2\text{Ce}_2\text{O}_7$ nanostructures: Structural and photocatalytic studies, *Journal of Molecular Liquids*, 222 (2016) 218-224.
- [36] M. Chandrasekhar, H. Nagabhushana, K.H. Sudheerkumar, N. Dhananjaya, S.C. Sharma, D. Kavyashree, C. Shivakumara, B.M. Nagabhushana, Comparison of structural and luminescence properties of Dy_2O_3 nanopowders synthesized by co-precipitation and green combustion routes, *Materials Research Bulletin*, 55 (2014) 237-245.
- [37] L.M.S. El-Deen, M.S.A. Salhi, M.M. Elkholy, IR and UV spectral studies for rare earths-doped tellurite glasses, *Journal of Alloys and Compounds*, 465 (2008) 333-339.
- [38] S. Zinatloo-Ajabshir, M. Salavati-Niasari, Z. Zinatloo-Ajabshir, Facile size-controlled preparation of highly photocatalytically active praseodymium zirconate nanostructures for degradation and removal of organic pollutants, *Separation and Purification Technology*, 177 (2017) 110-120.

[39] H. Wang, C. Xie, W. Zhang, S. Cai, Z. Yang, Y. Gui, Comparison of dye degradation efficiency using ZnO powders with various size scales, *Journal of Hazardous Materials*, 141 (2007) 645-652.

Table 1. The production conditions of neodymium oxide structures.

Sample no	Precipitator	Ultrasonic irradiation	Type of capping agent	Figure of FESEM images
1	2,2-Dimethyl-1,3-propanediamine	Yes	Schiff base	1a and b
2	2,2-Dimethyl-1,3-propanediamine	Yes	Titriplex	1c and d
3	2,2-Dimethyl-1,3-propanediamine	Yes	Polyvinylpyrrolidone	1e and f
4	2,2-Dimethyl-1,3-propanediamine	Yes	-	2a
5	2,2-Dimethyl-1,3-propanediamine	No	Polyvinylpyrrolidone	2b and c
6	NH ₄ OH	Yes	Polyvinylpyrrolidone	2d and e

Figure Captions:

Figure 1. FESEM images of neodymium oxide structures prepared with the aid of Schiff base structure (a and b), Titriplex (c and d) and PVP (e and f).

Figure 2. FESEM images of neodymium oxide produced without capping agent (a) and neodymium oxide structures prepared in absence of the sonication (b and c) and 2,2-dimethyl-1,3-propanediamine (d and e).

Figure 3. TEM images of neodymium oxide sample produced with the aid of ultrasound irradiation, 2,2-dimethyl-1,3-propanediamine and PVP (sample 3).

Figure 4. XRD patterns of sample produced with the aid of ultrasound irradiation, 2,2-dimethyl-1,3-propanediamine and PVP (sample 3) before (a) and after (b) calcination.

Figure 5. FT-IR spectrum of produced neodymium oxide (sample 3).

Figure 6. EDS pattern of produced neodymium oxide (sample 3).

Figure 7. DRS spectrum (a), plot to determine the band gap (b) of produced neodymium oxide (sample 3).

Figure 8. Photocatalytic eosin Y pollutant decomposition of neodymium oxide structures produced with and without sonication (samples 3 and 5).

Figure 9. Photocatalytic eosin Y pollutant decomposition of neodymium oxide structures prepared with the aid of Schiff base structure, Titriplex and PVP (samples 1-3).

Scheme 1. Schematic diagram of role of Schiff base structure, Titriplex and PVP on morphology and particle size of neodymium oxide.

Scheme 2. Schematic diagram of preparation of neodymium oxide nanostructures and role of utilizing of ultrasonic irradiation on the shape and particle size of neodymium oxide.

Fig. 1.

**Bis-(2-hydroxy-1-naphthaldehyde)-
4,4'-methylenedianiline**

650 °C
120 min

Irregular plate-like microstructures/
non-uniform nanobundles

Titriplex

650 °C
120 min

Less uniform micro/nanobundles

PVP

650 °C
120 min

Uniform spherical neodymium oxide
nanostructures

Scheme 1.

Fig. 2.

Scheme 2.

Fig. 3.

Fig. 4.

Fig. 5.

Fig. 6.

Fig. 7.

Fig. 8.

Fig. 9.

Used for degradation
of eosin Y pollutant

Neodymium oxide
nanostructures

Ultrasonic irradiation