Research Article

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Green synthesis and characterization of hexaferrite strontium-perovskite strontium photocatalyst nanocomposites

<https://doi.org/10.1515/mgmc-2020-0004>

Received November 02, 2019; accepted March 07, 2020.

Abstract: This study presents a preparation of $\text{SrFe}_{12}\text{O}_{19}$ – SrTiO_3 nanocomposite synthesis via the green auto-combustion method. At first, $\text{SrFe}_{12}\text{O}_{19}$ nanoparticles were synthesized as a core and then, SrTiO_3 nanoparticles were prepared as a shell for it to manufacture $\text{SrFe}_{12}\text{O}_{19}$ – SrTiO_3 nanocomposite. A novel sol-gel auto-combustion green synthesis method has been used with lemon juice as a capping agent. The prepared $\text{SrFe}_{12}\text{O}_{19}$ – SrTiO_3 nanocomposites were characterized by using several techniques to characterize their structural, morphological and magnetic properties. The crystal structures of the nanocomposite were investigated via X-ray diffraction (XRD). The morphology of $\text{SrFe}_{12}\text{O}_{19}$ – SrTiO_3 nanocomposite was studied by using a scanning electron microscope (SEM). The elemental composition of the materials was analyzed by an energy-dispersive X-ray (EDX). Magnetic properties and hysteresis loop of nanopowder were characterized via vibrating sample magnetometer (VSM) in the room temperature. Fourier transform infrared spectroscopy (FTIR) spectra of the samples showed the molecular bands of nanoparticles. Also, the photocatalytic behavior of nanocomposites has been checked by the degradation of azo dyes under irradiation of ultraviolet light.

Keywords: nanocomposite autocombustion; $\text{SrFe}_{12}\text{O}_{19}$; SrTiO_3 ; photocatalysts

1 Introduction

Research for green synthesis about nanomaterials by using natural biomaterials such as plants, flowers, and microorganisms is a new branch of nanotechnology known as green synthesis. Green synthesis of nanoparticles has many benefits such as cost-effectiveness, reduction of pollution as well as being eco-friendly (Zhu et al., 2018; Zinatloo-Ajabshir and Salavati-Niasari, 2015). The $\text{SrFe}_{12}\text{O}_{19}$ – SrTiO_3 nanocomposite has been proposed by green synthesis as a novel material. The natural plants that can extract biological capping agents have been green tea (Nadagouda et al., 2010), eucalyptus (Madhavi et al., 2013) and lemon juices. Lemon juice as a rich source of Citric and Ascorbic acid (vitamin C) was used to synthesize nanocomposites and nanoparticles (Ahmadian-Fard-Fini et al., 2020). In this study, the $\text{SrFe}_{12}\text{O}_{19}$ – SrTiO_3 nanocomposite was prepared by using lemon juice. The strontium ferrite, have been synthesized by different techniques such as sonochemistry (Palomino et al., 2016), hydrothermal method (Meng et al., 2016; Xia et al., 2013), co-precipitation (Ariaee et al., 2017; Auwal et al., 2016), sol-gel method (Wang et al., 2009a, 2009b) and sol-gel auto-combustion (Almessiere et al., 2018; Yang et al., 2009). Sol-gel auto-combustion method for synthesis of metals and alloys was proposed at a low temperature which is required for reaction, and the combustion does not need any external energy supply (Hua et al., 2011; Mir et al., 2012; Nabyouni and Ghanbari, 2018; Salavati-Niasari et al., 2010). Traditional reactions for synthesis $\text{SrFe}_{12}\text{O}_{19}$ nanoparticles require a high calcining temperature (1200–1300°C), though the sol-gel auto-combustion method produces homogeneous nanoparticles at much lower calcination temperatures (Jacobo and Bercoff, 2013). The sol-gel auto-combustion synthesis has four steps. Firstly, formation of complexes in the solution, secondly, evaporation the water of the solution and gel formation thirdly, auto-combustion by heated and at the end, obtaining the nanoparticles (Deganello et al., 2009; Mali and Ataie, 2004).

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A type of ferrites is spinel ferrites (Ahmadian-Fard-Fini et al., 2018), like M-type ferrite. M-type ferrite is an attractive magnetic material that has large saturation magnetization and high coercivity (Lahijani et al., 2018). Therefore it can find wide industrial applications in electronic components, magnetic memories, magnets, and sensors (Valenzuela, 2012). The strontium ferrite ($\text{SrFe}_{12}\text{O}_{19}$) is an M-type hexagonal ferrite (Hedayati et al., 2016, 2017a; Wohlfarth and Buschow, 1982) with large saturation magnetization and high coercivity. Also, it can be widely used for electronic components, high-density recording media, magnets, sensors, and microwave devices (Fang et al., 2000; Garcia-Cerda et al., 2004).

The dielectric properties of strontium ferrite could be improved via the concatenation of perovskite strontium (SrTiO_3). Perovskite-type has a general formula as ABO_3 . The A is a trivalent rare-earth and B is a 3d transition metal (Eskandari et al., 2019; Salavati-Niasari and Davar, 2006). Perovskites are usually used in environmentally friendly catalytic systems (Thornton et al., 1982). In this research, perovskite strontium has been synthesized using the sol-gel auto-combustion method.

In recent years, heterogeneous photocatalysis was developed as several forms, photodegradation of organizational pollutant have been recently the most investigated. SrTiO_3 is cost-effective and its inert photostability compared to other semiconductor photocatalysts was considered higher than photocatalysts effect of other semiconductor (Gaya and Abdullah, 2008).

The present paper seeks to offer a viable heterogeneous photocatalytic degradation alternative for the degradation of organic pollutions in wastewater by using $\text{SrFe}_{12}\text{O}_{19}$ - SrTiO_3 nanocomposite. To acquire the desired photodegradation efficiency, combining diverse techniques and approaches might be essential. In this regard, adding magnetic properties needs to be established because by applying an external magnetic field, nanoparticles can be controlled and separated from the solution (Dong et al., 2015). The nanocomposite of $\text{SrFe}_{12}\text{O}_{19}$ - SrTiO_3 has been synthesized using combustion methodologies. It is thus worth carrying out a study of synthesizing the products of $\text{SrFe}_{12}\text{O}_{19}$ with doping SrTiO_3 .

2 Experimental

2.1 Materials

All the chemical materials that have been used in this experiment, have a very high purity and have

been produced by Merck company, included iron nitrate monohydrate ($\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$), strontium nitrate ($\text{Sr}(\text{NO}_3)_2$) (Garcia-Cerda et al., 2004; Salavati-Niasari, 2004), ammonia (NH_3) (Auwal et al., 2016; Salavati-Niasari, 2005a; Salavati-Niasari and Amiri, 2005), citric acid ($\text{C}_6\text{H}_8\text{O}_7$) (Deganello et al., 2009), titanium isopropoxide ($\text{C}_{12}\text{H}_{28}\text{O}_4\text{Ti}$), ethanol ($\text{C}_2\text{H}_5\text{OH}$), and other chemicals materials were used without further purification. In order to synthesize $\text{SrFe}_{12}\text{O}_{19}$ nanoparticles, deionized and distilled water used. The sample was prepared via green synthesis using juice of fresh lemon. Pieces of fresh lemon in lemon juice were washed and squeezed, and then the lemon juice was filtered.

2.2 Preparation of $\text{SrFe}_{12}\text{O}_{19}$ nanoparticles

$\text{SrFe}_{12}\text{O}_{19}$ nanoparticle was prepared by green synthesis using the sol-gel auto combustion method. First, 100 mL of lemon juice was heated at 50-100°C for 15 min and then solution was filtered to get the lemon extract. The starting reagents that used were stoichiometric amounts of 2.3 g of $\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ and 0.2 g $\text{Sr}(\text{NO}_3)_2$ (molar ratio of Fe/Sr:12/2) were separately dissolved in 20 mL of deionized water at room temperature to form a clear hydrous solution (Garcia-Cerda et al., 2004; Mohandes et al., 2010, 2014; Shabanian et al., 2014). The two above mentioned solutions were mixed together and then continuously were stirred using a magnetic stirrer. After 15 min, 15 mL lemon juice extract was added to the mixture (Almessiere et al., 2018). After stirring for 20 min, 5 mL NH_3 was added drop wise in the pioneer solution until it became neutral (pH~7), as the solution was getting more and more viscous during heating until the water vaporized (Ariaee et al., 2017; Yousefi et al., 2011). The temperature was gradually increased to 150°C to remove the water remnant and a brownish solution was formed. Condensation reaction occurs between adjoining metal nitrates and citric acid. Its conclusion continued until the resulting solution known as a sol. The resultant sol on the hot heated stirrer was heated at 50-100°C under constant stirring until the water of solution was evaporated making a viscous liquid called gel. Then, the gel auto-ignited suddenly and finally evaporated releasing black ash and the exhaust of CO_2 , N_2 , and H_2O gases. The $\text{SrFe}_{12}\text{O}_{19}$ powder was washed with deionized water and then the collected powder was dried in the oven at 80°C for 48 h. The resulting nanoparticles were calcined at 850°C for 120 min to obtain single-phase $\text{SrFe}_{12}\text{O}_{19}$.

2.3 Preparation of SrTiO_3 nanoparticles

In order to fabricate nanocrystals of perovskite strontium by auto-combustion sol-gel, 0.22 g of $\text{Sr}(\text{NO}_3)_2$ was slowly dissolved in 50 mL of ethanol by a magnetic stirrer. In the next step, 0.3 g of $\text{C}_{12}\text{H}_{28}\text{O}_4\text{Ti}$ added to the above solution. After 10 min, 5 mL of lemon juice was added to the solution at room temperature as a gel agent. A quantity of 5 mL of NH_3 as a pH adjuster in 7 was added to the solution. The solution was heated until applied after self-ignition flaring and burning smoke occurs. Then the gray powder was obtained by the self-combustion sol-gel process. The resulting product was rinsed by deionized water and then centrifuged. The nanoparticles dried in an oven at 80°C for one day, and finally, the resulting powder was calcified at 500°C for 2 h inside the oven.

getting a better homogeneity for 3 h. 15 mL of lemon juice was added to the solution as a capping agent. After stirring for 20 min, the pH value of the solution was adjusted to 7 with adding 7 mL ammonia solution. The green solution was evaporated slowly at 80°C until a little of sol remained as the solution was getting vicious and remained water vaporization. The temperature was increased to 150°C until starting the auto-combustion. The product powder was obtained by filtering and washing the suspension with deionized water. The obtained black powder contained $\text{SrTiO}_3\text{--SrFe}_{12}\text{O}_{19}$ (with weight ratio 1:1) and the nanocomposite placed in a dryer oven in order to dry at 80°C for 48 h. Figure 1 shows the schematic for the experimental setup for nanoparticle and nanocomposite preparation.

2.4 Synthesis of $\text{SrFe}_{12}\text{O}_{19}\text{--SrTiO}_3$ nanocomposites (50/50% w/w)

At first for the production of hexaferrite strontium-perovskite strontium nanocomposite, 0.1 g $\text{SrFe}_{12}\text{O}_{19}$ nanoparticles that were synthesized by using the auto-combustion method was dissolved in 100 mL of ethanol at room temperature. Then, 0.1 g of $\text{Sr}(\text{NO}_3)_2$ and 0.1 g $\text{C}_{12}\text{H}_{28}\text{O}_4\text{Ti}$ were dissolved by a mechanical stirrer on the styrene at room temperature for 3 h. Then the solution was continuously stirred using a mechanical stirrer for

3 Characterization

X-ray diffraction patterns were recorded by using a Philips (Amsterdam, Netherlands) X-ray diffractometer using $\text{CuK}\alpha$ radiation ($\lambda = 1.54 \text{ \AA}$). SEM images and EDX elemental analysis were obtained by using a LEO (Cambridge, UK) instrument (Model 1455VP). Vibration Sampling Magnetometer was used to investigate the magnetic properties and hysteresis loop of synthesized materials. The magnetic measurements were carried out at room temperature using a VSM (MeghnatisKavir Kashan

Figure 1: Schematic of nanoparticle $\text{SrFe}_{12}\text{O}_{19}$ and nanocomposite $\text{SrFe}_{12}\text{O}_{19}\text{--SrTiO}_3$ preparation.

Company, Iran) in an applied magnetic field sweeping between ± 10000 Oe. To identify chemical bonds between the atoms the FTIR by Thermal camera BRUKER model ALPHA (Germany) instrument using KBr pellets was used. The optical properties of the particles from the UV-Vis Shimadzu UV-2600m (China) have been used.

4 Results and discussion

4.1 XRD analysis

The crystalline structure and compound formation of prepared and post sintered samples were studied using X-Ray diffraction in the 2θ range $10-80^\circ$ with step size 0.02° at room temperature (Salavati-Niasari, 2006; Salavati-Niasari and Davar, 2006).

The average crystallite size of the nanocrystals was calculated by Debye-Scherrer formula (Khorsand Zak et al., 2011; Salavati-Niasari, 2006):

$$D = \frac{k\lambda}{\beta \cos \theta} \quad (1)$$

where D is mean crystallite size, θ is the Bragg diffraction angle and β is the width of the observed diffraction peak at its half maximum intensity (FWHM), k is the shape factor (about 0.9), and λ is the X-ray wavelength (0.154 nm) (Khorsand Zak et al., 2011).

The broadening of peaks may be related to strain due to crystal imperfections and distortion. Using the Williamson-Hall method, it is assumed that size and strain broadening are additive components of the total integral breadth of a Bragg peak (Hedayati et al., 2017b; Mousavi-Kamazani et al., 2016; Safardoust-Hojaghan and Salavati-Niasari, 2017). The Williamson-Hall formula is expressed in Eq. 2:

$$\beta \cos \theta = \frac{k\lambda}{D} + 4\varepsilon \sin \theta \quad (2)$$

where ε is a strain of crystal lattice. With the drawing of the $\beta \cos \theta$ diagram in terms of $\sin \theta$ the optimum line equation can find the size of the crystallite and the network strain.

The XRD pattern of the $\text{SrFe}_{12}\text{O}_{19}$ nanoparticles calcinations at 850°C was investigated in Figure 2. The XRD pattern of $\text{SrFe}_{12}\text{O}_{19}$ has shown a pattern of pure hexagonal phase (JCPDS No. 24-1207) with P63/mmc space group that is pure hexaferrite strontium nanoparticles. The mean value of the nano-crystalline of $\text{SrFe}_{12}\text{O}_{19}$ was calculated to be 56 nm using the Debye-Scherrer's formula and 55 nm by the Williamson-Hall method. Also, the strain of the network was equal to 0.000175.

The X-ray diffraction of the SrTiO_3 nanoparticle which calcinated at 500°C , was determined and shown in Figure 3. This shows the cubic phase (JCPDS No. 05-0634) with the Pm3m space group was prepared which is consistent with pure perovskite strontium. The mean value of the nano-crystalline size of SrTiO_3

Figure 2: XRD pattern of the $\text{SrFe}_{12}\text{O}_{19}$ samples prepared at calcination temperature of 850°C .

Figure 3: XRD spectrum of SrTiO₃ nanoparticle that calcinate at 500°C.

was calculated to be 40 nm using the Debye-Scherrer's formula, 49 nm by the Williamson-Hall's formula and the strain of the grid was 0.00075.

The XRD of the composition of the SrFe₁₂O₁₉-SrTiO₃ nanocomposite was also investigated. Figure 4 confirms the presence of both SrFe₁₂O₁₉ and pure perovskite strontium phase. The average crystalline size for SrFe₁₂O₁₉, SrTiO₃ nanoparticles, SrFe₁₂O₁₉-SrTiO₃ nanocomposite, and ϵ were calculated via Debye-Scherrer's formula and Williamson-Hall method and are shown in Table 1.

4.2 FTIR analysis

Figure 5 shows the FTIR spectrum of SrFe₁₂O₁₉ nanoparticles that calcinated at 850°C in the range of 400 to 4000 cm⁻¹. The peak near 3420 cm⁻¹ is due to the stretching modes of the O-H band of the free or adsorbed water (Davar et al., 2010; Salavati-Niasari et al., 2005b). The weak band near 1632 cm⁻¹ is attributed to the H-O-H bending vibration mode. The Peak corresponding to the Fe-O was observed at 593 cm⁻¹ and the peak in 435 cm⁻¹ is indicative of Sr-O.

The FTIR spectrum of SrTiO₃ nanoparticles that calcinated at 500°C is shown in Figure 6. The band at 566 cm⁻¹ was assigned to Ti-O stretching vibration mode and peak in 439 cm⁻¹ indicates Sr-O. The broadband at 3384 cm⁻¹ was assigned to the O-H stretching vibration and the weak band near 1629 cm⁻¹ was assigned to vibration mode of H-O-H bending.

FTIR spectrum of the SrFe₁₂O₁₉-SrTiO₃ nanocomposite is shown in Figure 7. The spectrum shows bands near 3269 cm⁻¹ which are attributed to the stretching modes and O-H bending vibrations of water. In addition, absorption peaks near 1393 cm⁻¹ and 1356 cm⁻¹ refer to Ti-O-Ti vibrations. The main Absorption peaks in 434 cm⁻¹ and 550 cm⁻¹ appertain to the Fe-O bands in SrFe₁₂O₁₉ and the peak of 591 cm⁻¹ belongs to Ti-O in SrTiO₃. The absorption peak at 759 cm⁻¹ belongs to the Ti-O-Sr vibrations in the SrTiO₃. The peak at 1709 cm⁻¹ is the C=O and at 1626 cm⁻¹ is tensile transplants H-O-H. The absorption peak at 1393 cm⁻¹ is C=O and at 1186 cm⁻¹ for the N-H bond, which, if calcined, disappear in the absorption spectrum.

4.3 Morphological analysis

Figure 8 shows the SEM image of SrFe₁₂O₁₉ nanoparticles that synthesized auto-combustion with fresh lemon without calcination. Figure 9 shows the same material with calcinated temperature 850°C for 2 h. According to SEM images, the SrFe₁₂O₁₉ nanoparticles without calcination are agglomerated but when nanoparticles calcinated at 850°C, the particle exhibited needle shape with the average particle size around 40 nm. Figure 10 shows SEM images of the SrTiO₃ nanoparticle synthesis auto-combustion without calcination and Figure 11 shows SEM of SrTiO₃ nanoparticle with calcinated temperature of 500°C. SEM images of the nanoparticles without

Table 1: Crystalline size for XRD patterns.

	D. Scherrer (nm)	D. Williamson-Hall (nm)	ε strain
SrFe ₁₂ O ₁₉ calcination at 850°C	56	55	0.000175
SrTiO ₃ calcination at 500°C	40	49	0.00075
SrFe ₁₂ O ₁₉ -SrTiO ₃	54	59	0.00055

Figure 5: FT-IR spectrum of SrFe₁₂O₁₉ calcinated at 850°C.

Figure 6: FT-IR spectrum of SrTiO₃ calcinated at 500°C.

Figure 7: FT-IR spectrum of nanocomposite SrFe₁₂O₁₉-SrTiO₃.

Figure 8: SEM images of $\text{SrFe}_{12}\text{O}_{19}$ nanoparticle synthesis auto-combustion.

calcination are agglomerated but when nanoparticles calcinated at 500°C , they found Spherical shape with the average particle size around 35 nm. Figure 12 illustrates SEM images of the synthesized $\text{SrFe}_{12}\text{O}_{19}$ - SrTiO_3 nanocomposite. The particles have needle and plane shapes.

4.4 EDX analysis

The EDX analysis of $\text{SrFe}_{12}\text{O}_{19}$ nanoparticles has been shown in Figure 13. The EDX of SrTiO_3 nanoparticle

and $\text{SrFe}_{12}\text{O}_{19}$ - SrTiO_3 nanocomposite is indicated in Figures 14 and 15, respectively. The spectra have verified particles without impurities and a good estimate with stoichiometric amounts of elements in nanoparticles.

4.5 Magnetic properties

Magnetic properties of magnetic materials such as saturation magnetization (M_s), remanence magnetization (M_r) and coercivity (H_c) are determined by the hysteresis loop. The room temperature hysteresis loop of $\text{SrFe}_{12}\text{O}_{19}$

Figure 9: SEM images of $\text{SrFe}_{12}\text{O}_{19}$ nanoparticle synthesis autocombustion that calcinate at 850°C .

was studied via vibration VSM instrument that was shown in Figure 16. The result indicates that the sample exhibit superparamagnetic property. The saturation magnetization of $\text{SrFe}_{12}\text{O}_{19}$ nanoparticles is 13 emu/g. The hysteresis loop of $\text{SrFe}_{12}\text{O}_{19}$ nanoparticles calcined at 850°C is shown in Figure 17. Saturation magnetization around 54 emu/g, remanence magnetization 30 emu/g, and coercivity about 5000 Oe have been achieved. These amounts were confirmed as calcination of both magnetization and coercivity were increased as shown in the hysteresis loop of a ferromagnetic after calcination.

Figure 18 shows the magnetic property of the $\text{SrFe}_{12}\text{O}_{19}$ – SrTiO_3 nanocomposite. Saturation magnetization, remanence magnetization and coercivity about 20 emu/g, 12 emu/g and 4500 Oe were obtained respectively. The magnetic properties of the $\text{SrFe}_{12}\text{O}_{19}$ – SrTiO_3 nanocomposites were affected by the magnetic exchange interactions between the different phases of these nanocomponents. It is clear that the nanocomposite is classified as a hard magnetic material. The magnetization and coercivity are decreased in the composite because of the SrTiO_3 phase.

Figure 10: SEM images of SrTiO_3 nanoparticle synthesis autocombustion.

4.6 Photocatalytic properties

The photocatalytic properties of the $\text{SrFe}_{12}\text{O}_{19}\text{-SrTiO}_3$ nanocomposite were checked via degradation of four azo dyes in the form of an aqueous solution, under irradiation of UV light (Hedayati et al., 2016; Kiani et al., 2019; Nabiyouni and Ghanbari, 2018; Sabet et al., 2014; Salavati-Niasari et al., 2009). The UV-Vis absorption spectra of (a) acid black, (b) acid brown, (c) methyl red, and (d) methyl orange azo dyes in the presence of $\text{SrFe}_{12}\text{O}_{19}\text{-SrTiO}_3$ nanocomposite were shown in Figure 19.

In order to carry out this photocatalytic procedure, 0.5 g of synthesized $\text{SrFe}_{12}\text{O}_{19}\text{-SrTiO}_3$ nanocomposite were placed each in 50 mL solutions of 4 above colored dyes under microwave conditions and laboratory UV light. With passing time, more and more dyes concentration were adsorbed via the nanoparticles catalyst until the absorption peaks (k_{max}) of acid black, acid brown, methyl red and methyl orange decreased and vanished approximately after 60 min. As shown in Figure 20, black acid in 30 min about 95%, brown acid in 40 min about 97%, methyl red in 40 min around 98% and methyl

Figure 11: SEM images of SrTiO_3 nanoparticle synthesis autocombustion that calcinate at 500°C .

orange in 60 min about 95% were degraded. These results indicate good photocatalytic strength of the synthesized nanocomposite. Finally, the magnetic nanocomposite powder can also be extracted by the magnet and removed from the solution. Then, by centrifugation and rinsing it with deionized double distilled water, it is ready for reuse in the next dye. The mechanism of photo-degradation of toxic azo-dyes under ultraviolet irradiation photocatalytic nanocomposite $\text{SrFe}_{12}\text{O}_{19}$ - SrTiO_3 with an indirect bandgap about 3.2 eV is depicted in Figure 21. As it was shown before, organic dyes decompose to CO_2 , H_2O , and other less toxic or nontoxic remaining materials (Gillani et al., 2020;

Hasegawa et al., 2000; Piskunov et al., 2004). Tabel 2 shows some related published works about photocatalytic properties.

5 Conclusion

In this study, $\text{SrFe}_{12}\text{O}_{19}$ - SrTiO_3 nanocomposite was prepared using a green synthesis by auto-combustion sol-gel method using lemon juice extracts. The XRD pattern of the $\text{SrFe}_{12}\text{O}_{19}$ and SrTiO_3 nanoparticles and

Figure 12: SEM images of nanocomposite SrFe₁₂O₁₉-SrTiO₃ synthesis autocombustion.

Figure 13: EDX of $\text{SrFe}_{12}\text{O}_{19}$ calcinated at 850°C . Figure 16: VSM of $\text{SrFe}_{12}\text{O}_{19}$ at room temperature. Figure 14: EDX of SrTiO_3 calcinated at 500°C . Figure 17: VSM of nanoparticle $\text{SrFe}_{12}\text{O}_{19}$ calcinated at 850°C . Figure 15: EDX of nanocomposite $\text{SrFe}_{12}\text{O}_{19}-\text{SrTiO}_3$. Figure 18: VSM of nanocomposite $\text{SrFe}_{12}\text{O}_{19}-\text{SrTiO}_3$.

Figure 19: UV-Vis absorption spectra of (a) acid black, (b) acid brown, (c) methyl red, and (d) methyl orange in the presence of nanocomposite $\text{SrFe}_{12}\text{O}_{19}\text{-SrTiO}_3$ photocatalyst.

Figure 20: Photo-degradation of (a) acid black, (b) acid brown, (c) methyl red, and (d) methyl orange in the presence of nanocomposite $\text{SrFe}_{12}\text{O}_{19}\text{-SrTiO}_3$.

Figure 21: Photo-catalyst mechanism of $\text{SrFe}_{12}\text{O}_{19}\text{-SrTiO}_3$ in the case of degradation of toxic dye.

$\text{SrFe}_{12}\text{O}_{19}\text{-SrTiO}_3$ nanocomposite have shown a pattern of pure hexaferrite strontium and perovskite strontium phase. The nanocrystalline size and the strain of the network of all particles have been calculated using the

Debye-Scherrer and Williamson-Hall method. The FTIR spectrum of the $\text{SrFe}_{12}\text{O}_{19}$ nanoparticles shows the Fe–O and Sr–O band peaks. FTIR spectrum of SrTiO_3 nanoparticles indicates the band of Ti–O and Sr–O peaks. Also, in the

Table 2: Related published works about photocatalytic properties.

	Nonoparticles	Methods	Average crystal-line size	Photo activity of nano-photo-catalyst		
Our results	$\text{SrFe}_{12}\text{O}_{19}$ – SrTiO_3	Auto-combustion	50 nm	acid black	30 min	95%
				acid brown	40 min	97%
				methyl red	40 min	98%
				methyl orange	60 min	95%
(Hedayat et al., 2016)	CoFe_2O_4 –CdS	precipitation	90 nm	acid black	80 min	
				acid brown	100 min	
				acid blue	120 min	
(Mehdizadeh et al., 2020)	LaFeO_3	sonochemical	67 nm	degrades erythrosine under visible light	90 min	53%
				degrades of erythrosine under UV light	90 min	93.5%
(Monsef et al., 2020)	PrVO_4	sonochemical	25 nm	destruction of eriochrome black T	89.61%	
				decoloration of erythrosine	27.92%	
				methyl violet	8.48%	
(Ahmadi Golsefidi et al., 2016)	Fe_2O_3 – TiO_2	sonochemical	60 nm	methylene blue	81%	

FTIR spectrum of the $\text{SrFe}_{12}\text{O}_{19}$ – SrTiO_3 nanocomposite all peaks of $\text{SrFe}_{12}\text{O}_{19}$ and SrTiO_3 nanoparticles were observed. SEM images of $\text{SrFe}_{12}\text{O}_{19}$ and SrTiO_3 nanoparticles have shown calcination caused reduce agglomeration of particles. Also, all images have an average size under 100 nm and the grain sizes are well estimated with crystallite sizes calculated by XRD patterns. The EDX analysis of nanoparticles and nanocomposites show particles without impurities and with a good estimate, stoichiometric amount of elements in nanoparticles. The hysteresis loop of $\text{SrFe}_{12}\text{O}_{19}$ shows that nanoparticles without calcination is superparamagnetic and calcined at 850°C is ferromagnetic. Also, hysteresis loops of $\text{SrFe}_{12}\text{O}_{19}$ confirmed by calcined as both magnetization and coercivity were increased. Magnetic studies of $\text{SrFe}_{12}\text{O}_{19}$ – SrTiO_3 nanocomposite indicate magnetization and coercivity have decreased in the composite because of the SrTiO_3 shell. The photocatalytic properties of the $\text{SrFe}_{12}\text{O}_{19}$ – SrTiO_3 nanocomposite were investigated under irradiation of UV light. $\text{SrFe}_{12}\text{O}_{19}$ – SrTiO_3 nanocomposite degraded more than 90% of black acid, brown acid, methyl red, and methyl orange in less than 60 min. While the simplicity of this photocatalyst synthesis is one of its possible advantages, it is time-consuming that this can be its disadvantage. The results denoted that $\text{SrFe}_{12}\text{O}_{19}$ – SrTiO_3 nanocomposite has the potential to be applied for improving and removing organic and toxic water pollutants.

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