Synthesis and characterization of the $\text{NiFe}_2\text{O}_4@\text{TEOS-TPS}@Ag$ nanocomposite and investigation of its antibacterial activity

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Abstract

In this study, the NiFe_2O_4 was embedded in (3–mercaptopropyl) trimethoxysilane (TPS) and tetraethyl orthosilicate (TEOS) using the sol–gel method. These compounds were used as the support of Ag nanoparticles (Ag NPs). The $\text{NiFe}_2\text{O}_4@\text{TEOS-TPS@Ag}$ nanocomposites were obtained with the development of bonding between the silver atoms of Ag NPs and the sulfur atoms of TPS molecule. Field emission scanning electron microscopy (FE–SEM), transmission electron microscopy (TEM), X–ray diffraction (XRD) and Fourier transform infrared spectroscopy (FT–IR) were used for the characterization of the Ag nanocomposites. Also, the magnetic properties of these nanocomposites were studied by using a vibrating sample magnetometer (VSM) technique. The disk diffusion, minimum inhibition concentration (MIC) and minimum bactericidal concentrations (MBC) tests were used for the investigation of the antibacterial effect of this nanocomposite against bacterial strains. The synthesized nanocomposite presented high reusability and good antibacterial activity against gram–positive and gram–negative bacteria. Remarkably, this nanocomposite could be easily removed from the disinfected media by magnetic decantation.

Keywords: Silver nanocomposite; Antibacterial activity; So–gel; Recyclability

1. Introduction

Nanotechnology science has been quickly growing in the last decade. More than 1300 referenced products are dispersed in various groups such as solar energy absorption, chemical catalysis, health, electronics, toys, etc. [1-4]. Because of the antimicrobial properties of silver nanoparticles (Ag NPs), these nanoparticles are classified among consumer products with the most abundant nanomaterial and hence, they can be used as alternative disinfectant agents.

One of the most important problems in using of Ag NPs is the release of Ag ions in the environment and the resulting disruption in the ecosystem. The released Ag ions values in solution is relative inversely to the size of Ag NPs [5, 6] and also surface coating [7, 8]. Therefore, different studies have been carried out to address this issue using various stabilizing agents with large size, such as surfactants, dodecanethiol, sodium citrate, aminosilanes and polymers, to ensure the stable dispersion of Ag NPs in liquid solutions [9]. To achieve the favorable stabilizing agents, some core/shell nanostructures were designed. The universal spinel ferrite of Fe_3O_4 , CoFe_2O_4 , MnFe_2O_4 and NiFe_2O_4 are used as the core of nanostructure [10-14]. Because of the corrosion rate decreases in nano alloy ferrites (XFe_2O_4), therefore, they can be more suitable than Fe_3O_4 for industrial application i.e. economically and efficiently [15, 16]. Some polymers such as casein, dextrin, polyvinylpyrrolidone (PVP) [5, 17], polyethylene (PE) [18], poly(vinylchloride) (PVC) [19] and poly-triallylamine [20] have been examined as the shell of them. This procedure has such advantages as the convenient immobilization and separation of them through the magnetite field from media [21, 22].

Also, reusability is one of the greatest challenges in employing nanoparticle materials for antimicrobial and practical applications. Confidently, by decreasing Ag ions release from Ag NPs in solution, the recyclability or reusability of them can be increased. The increment in reusability without the loss of antibacterial activity suggests that nanoparticles have good

stability and therefore, they can be used as a recyclable antibacterial. Some studies have been done on the recyclability of various nanomagnetic particles [21, 23-26]. Ag nanoparticles, as a kind of heterogeneous, recyclable and moisture stable catalyst, have been used for the synthesis of β -enaminones and β -enamino esters [27]. Zhang and Altangerel have shown that the Ag/Fe₃O₄ nanocomposites not only have a strong antibacterial activity, but also a magnetically recyclable property and therefore, they can be used as novel reusable antibacterial materials [10, 28]. Also, Ag-CuFe₂O₄ magnetic material, as a recyclable nanocomposite, exhibits excellent antibacterial efficiency against four different bacteria [29]. The disinfection activity of Ag/TiO₂ nanofiber membrane has no obvious decrease after the continuous five times recycle [30].

There is a serious risk for drinking water consumers before its treatment as the load of protozoa, fungi, bacteria and viruses should be decreased [31]. Therefore, disinfection is essential to regulator microbial health risks and it has usually been obtained by chlorination or ultraviolet irradiation. Recent studies have indicated that after water disinfection treatment, there are some residual pathogens such as *Pseudomonas aeruginosa* and β -Proteobacteria that are resistant to chlorination or UV disinfection. Hence, these two techniques are not adequate for the complete removal of pathogens from water [32, 33].

Accordingly, with selection of NiFe₂O₄ as nanocomposite core, tetraethyl orthosilicate (TEOS) and (3-mercaptopropyl) trimethoxysilane (TPS) was reacted by using the sol-gel method for TEOS-TPS making with large size that used as a shell of core. Therefore, NiFe₂O₄ was selected as core of nanocomposite. Then, immobilization of Ag NPs on the NiFe₂O₄@TEOS-TPS surface creates NiFe₂O₄@TEOS-TPS@Ag nanocomposite. Some spectroscopic techniques such as field emission scanning of electron microscopy (FE-SEM), transmission electron microscopy (TEM), Fourier transform infrared spectroscopy (FT-IR) and X-ray diffraction (XRD) were applied for the characterization of the as-prepared

nanocomposites. Vibrating sample magnetometer (VSM) method was used for the evaluation of nanocomposite magnetic properties. The antibacterial activity of this nanocomposite against bacterial strains was studied by the disk diffusion, minimum inhibition concentration (MIC) and minimum bactericidal concentration (MBC) methods. These nanocomposites showed an appropriate antibacterial activity against gram-positive and gram-negative bacteria and high recyclability. In addition, the separation of this silver nanocomposite was simply carried out by some magnetic decantation that was essential after water treatment.

2. Experimental details

2.1. Materials and methods

The NaOH, Fe(NO₃)₃, Na(BH₄), Ni(NO₃)₂ and Ag(NO₃), TEOS and TPS were purchased from Merck Co. (Germany). Deionized and doubly distilled water were used as a solvent in this research. The FT-IR spectrum was achieved using a FT-IR Jasco Japan spectrophotometer. A Philips X-ray diffractometer by using Cu K_α radiation ($\lambda^{1/4}$ 0.154 nm) was applied to XRD profiles of the produced samples. The Hitachi Japan S4160 field emission scanning electron microscope was used for FE-SEM images of the nanocomposites. By utilizing of a Philips CM10-HT 100KV microscope, the TEM image scanned for the morphology and size of the as-prepared nanoparticles investigation. The magnetic properties of the as prepared composites were studied by using a vibrating sample magnetometer (VSM) from Meghnatis Daghigh Kavir Company (Iran). Single-point Brunauer-Emmett-Teller (BET; NanoSord, Iran) technique was applied for calculating the surface area of the synthesized nanomaterials.

2.2. Synthesis of NiFe₂O₄

Nickel ferrite nanoparticles were prepared by a citrate gel method using nickel (II) and iron (III) nitrates with a known amount of citrate [34]. At First, a solution containing $\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ and $\text{Ni}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ was prepared, with Fe:Ni molar ratio being kept at 2:1. Then, 0.02 mol of citric acid was added to the solution and by using the hydroxide ammonium solution, the pH value was adjusted to 9.0. This reaction was completed by stirring the mixture at 30 °C for 2 h. The produced mixture was dried in an oven at 100 °C for 24 h. The prepared substance was calcinated at 600 °C for 2 h in argon atmosphere.

2.3. Preparation of TEOS–TPS

For preparing the TPS and TEOS solution, the sol–gel method was employed. Initially, the solution of 51.3% weight of TEOS/absolute ethanol was prepared and stirred to complete mixing. Then, TPS was added to a TEOS/ethanol solution in which the weight percent of TEOS was equal to 5%. Afterwards, a solution of hydrochloric acid (pH: 1) and absolute ethanol, with relative 2/100, was added to the last solution. Magnetic stirring of the hydrolyzed solution was done for 3 h and followed by leaving the solution at room temperature for 24 hours.

2.4. Preparation of Ag NPs

The synthesis of silver nanoparticles, which is well known, has been developed by using various methods [35-38]. In this study, silver nanoparticles were synthesized by following a procedure described by Varaprasad [36]. In the typical synthesis of silver nanoparticles, a solution AgNO_3 was added to sodium borohydrate in which the Na:Ag molar ratio reached to 2:1. After 2 h, the synthesized Ag NPs was washed with distilled water several times to remove any excess protecting agent. The final product was dried in an oven at 50 °C for 2 h.

2.5. Synthesis of $\text{NiFe}_2\text{O}_4@\text{TEOS-TPS}$ and $\text{NiFe}_2\text{O}_4@\text{TEOS-TPS}@Ag$ nanocomposites

At first, 4.3 mmol of NiFe_2O_4 was added to 1 mL of TEOS–TPS solution. After that, the mixture was further sonicated for 10 min. Finally, the collected $\text{NiFe}_2\text{O}_4@\text{TEOS-TPS}$ composite was dried in an oven at 60 °C for 6 h.

The $\text{NiFe}_2\text{O}_4@\text{TEOS-TPS}@Ag$ nanocomposite was prepared. In this nanocomposite, 1.0 g of $\text{NiFe}_2\text{O}_4@\text{TEOS-TPS}$ has been dispersed by ultrasonic in AgNO_3 aqueous solution (2 mmol) for 5 min. After this step, a solution of hydrazine, as the reducing agent, was introduced into the reaction vessel. After 1 h, the prepared $\text{NiFe}_2\text{O}_4@\text{TEOS-TPS}@Ag$ nanocomposite was collected by the magnet and washed three times with water and dried in an oven at 60 °C for 6 h.

2.6. Antibacterial tests of the nanocomposite

The Kirby–Bauer disk diffusion procedure, as a standard method, was used to assess the antibacterial activity of the nanocomposites [39]. In the previous study, we have explained this method in details [14]. Briefly, the *Bacillus cereus* (ATCC 14579) and *Staphylococcus aureus* (ATCC 29213) bacteria, for gram positive assessment, and *Salmonella typhimurium* (ATCC 14028) and *Escherichia coli* (ATCC 35218) bacteria, for gram negative assessment, were chosen and suspended in phosphate buffer saline (PBS). The bacterial suspensions turbidity was adjusted to the 0.5 McFarland standard and sterile swabs were dipped into the inoculum tubes. The Ag NPs, NiFe_2O_4 , $\text{NiFe}_2\text{O}_4@\text{TEOS-TPS}$ and $\text{NiFe}_2\text{O}_4@\text{TEOS-TPS}@Ag$ suspensions were prepared by separately dissolving 0.1 mg of the mentioned nanoparticle in 1 mL distilled water. After the sonication of them for 10 min, the standard discs of Ag NPs, NiFe_2O_4 , $\text{NiFe}_2\text{O}_4@\text{TEOS-TPS}$ and $\text{NiFe}_2\text{O}_4@\text{TEOS-TPS}@Ag$ were separately prepared, and distilled water was used as a negative control. At the end, the discs were

utilized to assess the antibacterial activity against four different bacterial strains on Mueller–Hinton agar (Merck, Germany) plates. Impregnated disks were located on the surface of the agar using sterile forceps. Then, these plates were incubated at 37 °C for 24 h to check the antibacterial activity. The antibacterial activities assays were done in triplicate (the zone of inhibition) and measured in millimeter unit.

2.7. Minimum –inhibitory and –bactericidal concentrations (MIC and MBC)

The MIC is the lowest concentration of antimicrobial agents inhibiting 99 % growth of the microorganisms. As explained in the previous section, by putting subculturing bacteria into the sterile nutrient, broth bacterial inocula were provided at 37°C for 24 h. The solutions of bacteria were approximately diluted to 10^6 CFU (colony forming units)/mL. The solutions of $\text{NiFe}_2\text{O}_4@\text{TEOS-TPS@Ag}$ were two fold diluted (1000, 500, 250, 125, 62.5 and 31 $\mu\text{g/mL}$) with PBS. Then, 20 μL from each of the diluted solutions was added to 180 μL of the nutrient broth in tubes containing each of the standardized bacterial suspensions (10^6CFU/mL). All tubes were incubated at 37°C for 24 h. The highest diluted solution with no observable growth was recorded as the MIC. The diluted tubes without growing were plated onto the nutrient agar (100 μL from each tube) and incubated at 37°C for 24 h. This was used for determining the MBC. The MBC value was recorded for the highest dilutions with no observable growth on the nutrient agar.

2.8. Recyclability of the $\text{NiFe}_2\text{O}_4@\text{TEOS-TPS@Ag}$ nanocomposite

The $\text{NiFe}_2\text{O}_4@\text{TEOS-TPS@Ag}$ nanocomposite (20.0 mg) was incubated with both *Bacillus cereus* and *Escherichia coli* bacteria suspensions (5 mL) in a conical tube at 37 °C for 120 min, with 200 rpm. After 24 h of incubation, the tube was located in a magnetic separation stand at room temperature for 10 min. The nanocomposites were attracted to the

wall of the tube via the magnetic force. After removing the supernatant from the tube, 0.1 mL of the supernatant was diluted properly and plated onto the agar plates. Each viable bacterium formed into a bacterial colony was counted after being incubated at 37 °C for 24 h. The recycled magnetite nanocomposites were incubated with a fresh sample of 5 mL of the suspension in the tube under the same conditions. The methods described above were repeated by employing the same procedures five more times. In each cycle, the magnetic nanocomposites were collected only by exposure to the external magnetic field without washing with any solvents or water.

3. Results and discussion

3.1. XRD analysis

The XRD profiles of $\text{NiFe}_2\text{O}_4@\text{Ag}$, $\text{NiFe}_2\text{O}_4@\text{TEOS-TPS}$ and $\text{NiFe}_2\text{O}_4@\text{TEOS-TPS}@\text{Ag}$ nanocomposites have been plotted in Fig. 1. In Fig. 1 (a), the four characteristic peaks at 38.5°, 44.5°, 64.5° and 78.1°; and six peaks at 30.3°, 35.65°, 43.26°, 53.61°, 57.16° and 62.74° are assigned to Ag NPs and NiFe_2O_4 , respectively. The (hkl) planes of the Ag NPs in (111), (200), (220) and (311) indices showed that the silver arrangement at the surface of the nanomagnetite was face-centered cubic (*fcc*) [40]. For NiFe_2O_4 , the (hkl) planes of (220), (311), (400), (422), (511) and (440) were consistent with the previous studies [41, 42]. As regarding, the TEOS-TPS has only a wide peak at 22° [43, 44]; therefore Figs 1. (a) & (c) exhibit the same XRD patterns of NiFe_2O_4 and Ag NPs. As for characteristic peaks of Ag NPs in Figs 1. (a) & (c), the *fcc* symmetry structure of Ag NPs was maintained in the synthesis procedure of $\text{NiFe}_2\text{O}_4@\text{TEOS-TPS}@\text{Ag}$ nanocomposite. There was agreement between the visible diffraction peaks of NiFe_2O_4 and the characteristic diffraction of spinel NiFe_2O_4 standard data, as shown in JCPDS 44-1485. The sharp peaks in NiFe_2O_4 pattern indicated that

high crystalline NiFe₂O₄ had been formed and its coating with TEOS–TPS had no effect on the spinel structure of the NiFe₂O₄ magnetic core.

By using of the Scherrer equation, the average crystalline size of NiFe₂O₄@TEOS–TPS@Ag nanocomposite was obtained 42 nm.

$$D = K\lambda / \beta \cos\theta \quad (1)$$

where ‘D’, ‘λ’, ‘β’ and ‘θ’ are the average crystalline size, X–ray source wavelength (0.1541 nm), the full width half maximum (FWHM) and the Bragg angle, respectively; and ‘K’= 1.

Fig. 1. The XRD pattern of as–synthesized nanocomposites.

3.2. FE–SEM analysis

The FE–SEM was used to determine the morphology of nanomaterials. As shown in Fig. 2, it could be concluded that uncoated NiFe₂O₄ and NiFe₂O₄@TEOS–TPS nanoparticles had a agglomerated cloudy and spongy porous bubble structure, respectively, which was the characteristic of citrate–gel synthesis [45]. The FE–SEM micrograph of NiFe₂O₄@TEOS–TPS@Ag nanocomposites showed the distribution of them with few agglomerates containing the well sphere–like nanostructures. This could be due to the coating of TEOS–TPS on the surface of NiFe₂O₄ nanoparticles. The histogram profile of the decorated Ag NPs on the synthesized nanocomposite has been plotted in Fig. 3; the averaged diameter size of the spherical Ag nanoparticles on the surface of the TEOS–TPS matrix was obtained to be 36 nm.

Fig. 2. The FE–SEM images of as–synthesized nanocomposites.

Fig. 3. The size distribution of Ag NPs in the as–synthesized nanocomposite.

3.3 TEM Analysis

TEM observation of the $\text{NiFe}_2\text{O}_4@\text{TEOS-TPS@Ag}$ composite was carried out to explore the morphological and structural landscapes of these nanocomposites. It can be concluding from Fig. 4 that the surface of NiFe_2O_4 nanoparticles was decorated with TEOS-TPS and Ag NPs. The averaged particles size of decorated nanocomposite was estimated 46.5 nm.

Fig. 4. The TEM image of $\text{NiFe}_2\text{O}_4@\text{TEOS-TPS@Ag}$ nanocomposites.

3.4. FT-IR spectra analysis

In Fig. 5, the FT-IR spectra of $\text{NiFe}_2\text{O}_4@\text{TEOS-TPS}$ and $\text{NiFe}_2\text{O}_4@\text{TEOS-TPS@Ag}$ nanocomposites in the range of 2500 to 400 cm^{-1} at room temperature have been scanned. The FT-IR spectrum of NiFe_2O_4 has not been shown; this can be seen in the reference [14]. The main absorption bands at around 453 and 579 cm^{-1} were assigned to the intrinsic stretching vibrations of Fe ions in octahedral and tetrahedral of spinel structure sites. The peak at 579 cm^{-1} overlaid with characteristic peak at 595 cm^{-1} that observed in both spectra. The assignment of the different peaks of TEOS-TPS at around 595 cm^{-1} (C-S), 1153 and 949 cm^{-1} (Si-O-C bond) [46] could be observed in Fig. 5. The strong peak at 1096 cm^{-1} was assigned to the asymmetric stretching vibration of Si-O-Si [47, 48]. However, as could be observed in this Figure, the FT-IR spectrum of $\text{NiFe}_2\text{O}_4@\text{TEOS-TPS@Ag}$ nanocomposite exhibited all characteristic peaks of TEOS-TPS, in addition to the Fe-O stretching vibrations [41, 42]. The C-O stretching vibration of carbonyl group was assigned to the strong peak at 1650 cm^{-1} . In comparison with Figs. 5 (a) & (b), the reducing of peaks at around 595 showed that this new nanocomposite was formed. The reason for this was that silver had been linked with sulfur.

Fig. 5. The FT-IR spectra of NiFe₂O₄@TEOS-TPS (a) and NiFe₂O₄@TEOS-TPS@Ag (b).

3.5. The VSM results

The magnetic properties of all synthesized nanocomposites were studied by VSM at room temperature. The VSM magnetization curves of the NiFe₂O₄ nanoparticles, NiFe₂O₄@TEOS-TPS and NiFe₂O₄@TEOS-TPS@Ag nanocomposites are exhibited in Fig. 6. The saturation magnetization (M_s), remnant magnetization (M_r) and the coercivity (H_c) of these synthesized materials were determined from the hysteresis loops measurements, as presented in Table 1. Regarding this data, the values of M_s , M_r and H_c for NiFe₂O₄@TEOS-TPS nanocomposite (Fig. 6 b) were less than those gained for the pure NiFe₂O₄. Also, the decrease in the magnetic nature of the naked ferrite was noticed for the three-component NiFe₂O₄@TEOS-TPS@Ag nanocomposite (Fig. 6 c). The decrease in the magnetic property of the produced new nanocomposite was due to the TEOS-TPS and Ag NPs layers that acted as the magnetic dead layers. Thus, more decrease in the magnetic nature of NiFe₂O₄@TEOS-TPS@Ag could be predictable in comparison of NiFe₂O₄@TEOS-TPS. The slight increase in the coercivity (H_c) value for NiFe₂O₄@TEOS-TPS@Ag could be attributed to the anisotropy of the surface coating [39, 49].

Fig. 6. The VSM profiles of as-synthesized nanocomposites.

Table 1 The magnetic parameters of as-prepared nanocomposites.

3.6. Antibacterial activity

As can be observed from the data in Table 2 and figure 7, the immobilization of Ag nanoparticles onto the TEOS–TPS matrix of the nanocomposite could retain their antibacterial activity. Of course, it was predictable that the cytotoxic effect of the immobilized Ag NPs on mammalian cells would be less than that of free silver nanoparticles because of the slow release of silver ions from the TEOS–TPS matrix.

Fig. 7. The inhibition Zone of 1: Distilled water, 2: NiFe_2O_4 , 3: NiFe_2O_4 @TPS–TEOS and 4: NiFe_2O_4 @TPS–TEOS@Ag against tested bacteria.

Table 2 The inhibition Zone (mm) of Blank disk and as–prepared of nanocomposites against tested bacteria.

3.7. MIC and MBC results

The MICs and MBCs values of NiFe_2O_4 @TEOS–TPS@Ag nanocomposite against the tested bacteria are listed in Table 3. The as-synthesized nanocomposite showed MICs values from 5.40 to 21.50 mg/mL against gram–positive (*S. aureus*, *B. cereus*) bacteria and 5.40 to 10.80 mg/mL against gram–negative (*S. typhimurium*, *E. coli*) bacteria. The values of determined MBCs were in a range of 10 to 43 mg/mL for the nanocomposite powder. The MBC/MIC ratio values were ≤ 4 , showing that NiFe_2O_4 @TEOS–TPS@Ag nanocomposite had a bactericidal effect against the mentioned bacterial strains [50, 51].

Table 3 The MIC and MBC parameters of as–prepared of Ag nanocomposites.

3.8. Recyclability

The recyclable antibacterial activity of $\text{NiFe}_2\text{O}_4@\text{TEOS-TPS}$ coated with Ag NPs was obtained. It was found that the bacterial killing efficiency was not changed after contact with the same magnetic nanoparticles through five cycles for $\text{NiFe}_2\text{O}_4@\text{TEOS-TPS@Ag}$. The bactericidal efficiency of the $\text{NiFe}_2\text{O}_4@\text{TEOS-TPS@Ag}$ nanocomposite remained around 100% for both *S. aureus* and *E. coli* of the first three cycles. The antibacterial activity was reduced by 10 % for both bacterial strains after 5 repeated usages. Sureshkumar *et.al* [52] and Pinto *coworkers* [53] have been reported that the decrease in the antimicrobial activity was due to two effects: escape of Ag NPs during incubation in bacterial solution and/or the active Ag surface being covered by proteins and nucleic acids released from the killed bacterial cells.

3.9. The BET results

The surface area of the prepared nanomaterials was evaluated by using single-point Brunauer–Emmett–Teller (BET; NanoSord, Iran) method. The surface area of the NiFe_2O_4 , $\text{NiFe}_2\text{O}_4@\text{TEOS-TPS}$ and $\text{NiFe}_2\text{O}_4@\text{TEOS-TPS@Ag}$ was gained to be 74.2, 27.9 and 26.7 m^2/g , respectively. By increasing the particle size of as-synthesized nanocomposites, the BET was reduced due to pores size on the surface of nanocomposite [54]. This showed the available surface of these nanocomposites was decreased with increasing their particle size.

4. Conclusion

The sol–gel method was used for the synthesis of the TEOS–TPS matrix that covered NiFe_2O_4 core for the formation of $\text{NiFe}_2\text{O}_4@\text{TEOS-TPS}$ nanocomposite. By coating the $\text{NiFe}_2\text{O}_4@\text{TEOS-TPS}$ with the silver nanoparticles, $\text{NiFe}_2\text{O}_4@\text{TEOS-TPS@Ag}$ nanocomposite was prepared. Some spectroscopic methods such as FT–IR, XRD, FE–SEM and TEM proved the formation of the three components of $\text{NiFe}_2\text{O}_4@\text{TEOS-TPS@Ag}$ nanocomposite. The VSM method was applied for evaluating the magnetic properties of these

nanocomposites, showing that the non-magnetic layers of TEOS–TPS and Ag NPs decreased the natural magnetic ferrite. Of course, this reduction was palpable for layer's TEOS–TPS, as compared with its Ag NPs; and it could be an advantage for removing $\text{NiFe}_2\text{O}_4@\text{TEOS}$ –TPS nanocomposite from media. However, by applying the magnetite field, all as-prepared nanocomposites were simply removed from the media. The new nanocomposites showed the convenient antibacterial activity. Also, the MBC/MIC ratio values were ≤ 4 , indicating that $\text{NiFe}_2\text{O}_4@\text{TEOS}$ –TPS@Ag nanocomposite had a bactericidal effect against the various bacterial strains. The disinfection activity of $\text{NiFe}_2\text{O}_4@\text{TEOS}$ –TPS@Ag nanocomposite had no apparent decrease after five-time recycle reusability. Therefore, this new as-prepared nanocomposite could have potential application in water disinfection and as regarding to specified the corrosion rate decreases in nano nickel ferrite (NiFe_2O_4), this structure can be more suitable than Fe_3O_4 for industrial application i.e. economically and efficiently [15, 16].

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Table 1 The magnetic parameters of as-repared nanocomposites.

	Magnetic material	magnetization, Saturation	Remnant magnetization, M_r (emu/g)	Coercivity, H_c (O _e)
(a)	NiFe ₂ O ₄	64.8±0.1	8.7±0.3	76.0±0.9
(b)	NiFe ₂ O ₄ @TEOS-TPS	62.4±0.3	6.0±0.2	65.9±1.0
(c)	NiFe ₂ O ₄ @TEOS-TPS@Ag	50.2±0.2	5.5±0.2	67.6±1.1

Table 2 The inhibition Zone (mm) of Blank disk and as-prepared of nanocomposites against tested bacteria.

Compounds		Zone of inhibition (mm) average $\pm$ standard deviation			
		<i>S. aureus</i>	<i>B. cereus</i>	<i>E. coli</i>	<i>S. typhimurium</i>
1	Distilled water	6.4 $\pm$ 0.1	6.4 $\pm$ 0.1	6.4 $\pm$ 0.1	6.4 $\pm$ 0.1
2	NiFe ₂ O ₄	6.4 $\pm$ 0.1	6.4 $\pm$ 0.1	6.4 $\pm$ 0.1	6.4 $\pm$ 0.1
3	NiFe ₂ O ₄ @TPS-TEOS	6.4 $\pm$ 0.1	6.4 $\pm$ 0.1	6.4 $\pm$ 0.1	6.4 $\pm$ 0.1
4	NiFe ₂ O ₄ @TPS-TEOS@Ag	10.3 $\pm$ 0.3	10.9 $\pm$ 0.3	10.7 $\pm$ 0.3	11.1 $\pm$ 0.3

Table 3 The MIC and MBC parameters of as-prepared of Ag nanocomposites.

Compounds	NiFe ₂ O ₄ @TEOS-TPS@Ag		
	MIC (mg/mL)	MBC (mg/mL)	MBC/MIC
<i>S. aureus</i>	5.40	10.80	2.00
<i>B. cereus</i>	21.50	42.90	1.99
<i>E. coli</i>	10.80	21.50	1.99
<i>S. typhimurium</i>	5.40	21.50	3.98

Fig. 1. The XRD pattern of as-synthesized nanocomposites.

Fig. 2. The FE-SEM images of as-synthesized nanocomposites.

Fig. 3. The size distribution of Ag NPs in the as-synthesized nanocomposite.

Fig. 4. The TEM image of $\text{NiFe}_2\text{O}_4@\text{TEOS-TPS@Ag}$ nanocomposites.

Fig. 5. The FT-IR spectra of $\text{NiFe}_2\text{O}_4@\text{TEOS-TPS}$ (a) and $\text{NiFe}_2\text{O}_4@\text{TEOS-TPS@Ag}$ (b).

Fig. 6. The VSM profiles of as-synthesized nanocomposites.

Fig. 7. The inhibition Zone of 1: Distilled water, 2: NiFe_2O_4 , 3: $\text{NiFe}_2\text{O}_4@\text{TPS-TEOS}$ and 4: $\text{NiFe}_2\text{O}_4@\text{TPS-TEOS@Ag}$ against tested bacteria.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Synthesize

characterization

Antibacterial Activity