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EFFICIENT DYE REMOVAL BY NANO COMPOSITE HYDROGELS THROUGH A FENTON-LIKE REACTION

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Abstract. *This study investigates the utilization of nano-composite hydrogels for the removal of methyl violet from aqueous solutions, leveraging a Fenton-like reaction mechanism.*

The Fe_2S_3 *nano-composite hydrogel demonstrated exceptional efficiency in dye removal, attributed to the synergistic effects of the hydrogel matrix and the catalytic activity of embedded* Fe_2S_3 *nano-particles. This process generates hydroxyl radicals under mild conditions, leading to the effective breakdown of various industrial dyes. The kinetics of dye removal, the reusability of the nano-composite, and the influence of operational parameters such as different amounts of nano-composite, pH,* $H_2O_2(35\%)$, *temperature, and dye concentration were systematically explored. The findings underscore the potential of* Fe_2S_3 *nano-composite hydrogel as a promising, environmentally friendly solution for wastewater treatment and dye removal.*

Keywords: *methyl violet, nano-composite,* Fe_2S_3 *nano-particles.*

ЭФФЕКТИВНОЕ УДАЛЕНИЕ КРАСИТЕЛЯ НАНОКОМПОЗИТНЫМИ ГИДРОГЕЛЯМИ С ПОМОЩЬЮ РЕАКЦИИ ФЕНТОНА

Аннотация. *В этом исследовании изучается использование нанокомпозитных гидрогелей для удаления метилового фиолетового из водных растворов с использованием механизма реакции Фентона. Нанокомпозитный гидрогель продемонстрировал исключительную эффективность в удалении красителя, что объясняется синергетическим эффектом матрицы гидрогеля и каталитической активностью внедренных наночастиц. Этот процесс генерирует гидроксильные радикалы в мягких условиях, что приводит к эффективному расщеплению различных промышленных красителей. Были систематически исследованы кинетика удаления красителя,* *возможность повторного использования нанокомпозита и влияние рабочих параметров, таких как различные количества нанокомпозита, pH, температура и концентрация красителя. Результаты подчеркивают потенциал нанокомпозитного гидрогеля как многообещающего, экологически чистого решения для очистки сточных вод и удаления красителя.*

Ключевые слова: *метиловый фиолетовый, нанокомпозит, наночастицы.*

Introduction

The synthesized composite is capable of easy and fast separation from aqueous environments along with contaminants absorbed in an external magnetic field.[1] The strong composite hydrogels can be expected to widen the practical applications for pollutant removal from wastewater.[2] Desorption of dyes from the dye loaded nano-composite hydrogel was simply done in ethanol. The results indicate that the prepared magnetic nano-composite hydrogel is an efficient adsorbent with high adsorption capacity for the aforementioned dyes.[3] Dyes can be classified into several groups such as acid, basic, direct, and reactive in the dyeing, printing, sizing, and other industries, 280,000 tons of all kinds of dyes is discharged together with large volumes of wastewater. All these effluents are major waste products creating environmental pollution [3,4] Fenton process has been widely used to degrade various pollutants that directly or indirectly affect the water quality, and the introduction of metal oxide as a heterogeneous catalyst effectively enhances the degradation process.[4] Dye removal from wastewater is of prominence due to its hostile effects on human health and the environment.[5] The complex structure of the dye molecule is responsible for its difficulty in removal,[6] Currently, colors are frequently used in virtually all manufacturing sectors and as a matter of fact are inseparable elements of human daily life. Even though the importance of dyes/colors to civilization is evident, the dye-polluted waters from the textile and allied industries are becoming a major source of environmental contaminations.[1–3] Untreated effluents from these industries make the water bodies become colored and specifically distort the natural growth activity of aquatic life by blocking sunlight and stopping the re-oxygenation capacity of water.[3–5] The HC assisted hydrogel nanocomposite adsorption shows the decolorization of 65 % at the optimized operating conditions such as, pH 7.62, 0.5g clay loaded nanocomposite hydrogel, and 25g of hydrogels loading in adsorption column.[7]

The development of new heterogeneous catalysts with stable catalytic activity in a wide pH range to prevent polluting precipitation plays a vital role in large-scale wastewater treatment.[8] Catalyst to be a suitable candidate for the removal of pollutants in wastewaters by means of the Fenton heterogeneous reaction.[9] Montmorillonite cooperated with acrylamide and acrylic acid via polymerization, hydrogen-bond, amidation and electrostatic interactions to form the three-dimensional reticular-structured hydrogel with the free entrance for macromolecules.[9]

Transition metal and nanocarbon-based composites with high activity and stability draw great attention in electro-Fenton system for organic pollutants removal.[10] The dye-water treatment using UF membrane is still a challenge. In the present study, the optimized PAN-ETA ultrafiltration membrane was hydrolyzed and subsequently characterized by SEM, IR, CA, XPS, NMR, mechanic measurement, etc.[11] Fenton technology has been proven an effective way to remove dyes from wastewater a potential hydrogel based on sodium alginate integrated with poly ethyleneimine (PEI) was fabricated and employed for the elimination of methyl blue in aqueous media. The SA/PEI hydrogel demonstrated excellent removal performance for methyl blue, i.e. ~99% of methyl blue could be removed from water within ~30 min using 0.5 g/L SA/PEI hydrogel at 100 mg/L initial concentration. [12] The nanocomposite used is a cross linked network of acrylic acid synthesized inside poly(acrylamide) grafted Guggul gum in the presence of UV-visible respondent bismuth ferrite nanoparticles.[13] A new nanocomposite of kaolin/copper iron oxide ($CuFe_2O_4$) was synthesized and its characteristics were determined using various analyzes such as FTIR, SEM, XRD, BET, VSM, and EDX/Mapping. According to the results, the specific surface areas of kaolin and kaolin/ $CuFe_2O_4$ composite were obtained as 10.023 and 174.78m2/g, respectively, which indicated a significant specific surface area for kaolin/ $CuFe_2O_4$ nanocomposite.[14] The magnetic $CuFe_2O_4$ composite is an effective photo-Fenton catalyst for the degradation of organics in aqueous solution.[15] The as-prepared MIL-88A exhibited excellent photo-Fenton catalytic performance towards rhodamine B and bisphenol A removal under visible light irradiation (LED).[16] Magnetic Chitosan/ Al_2O_3/Fe_3O_4 nanocomposite was prepared and used as an adsorbent to remove acid fuchsin dye from aqueous solution.[17] MMGO nanocomposite is a facile and a promising adsorbent for removing of cationic and anionic dyes from textile and other wastewater by a little change in pH value[18] Cellulose/graphene oxide/Fe_3O_4 composites were prepared by coprecipitating iron salts onto cellulose/GO hydrogels in a basic solution.[19] graphene oxide, fluorinated graphene oxide and interconnected reduced graphene oxide were synthesized and systemically investigated for the removal of two cationic dyes, methylene blue and rhodamine B, from aqueous solution[20] Octahedral and spherical Fe_3O_4 nanoparticles were synthesized and used as heterogeneous Fenton-like catalysts to degrade methylene blue.[21] Beta-cyclo dextrin-based composite fibers have demonstrated potential large-scale applications in dye uptake and wastewater treatment.[22] Provides a green pathway to the fabrication of a stable nanocomposite catalyst with high catalytic performance and reusability for the degradation of organic pollutants[23] The outcomes demonstrate that silver nanoparticles with uniform sizes were homogenously distributed through DAA/Ge hydrogel.[24] The nanocomposites exhibited a photo-Fenton catalytic feature for the degradation of Maxilon C.I. basicdye in aqueous medium using sunlight.[25] The FTIR profile at relevant wavenumbers detected intercalation of aluminum and incorporation of iron.[26] The efficiency of Fenton and Fenton-like processes can be seriously affected by the continuous loss of iron ions and by the formation of solid sludge.[27] In situproduction of Fenton's reagent through bioelectrochemical technology (bioelectro-Fenton) is emergingas a possible strategy to reduce the cost associated with Fenton's reagent.[28] $\alpha\text{-}Fe_2O_3/GA$ was used as a candidate cathode material for treatment of organic wastewater by EF system.[29] Hydrogel-based magnetic nanocomposites loaded with anisotropic Fe_3O_4nano crystals including nanooctahedra, nanorods, and nanoneedles were prepared by synthesizing in situ Fe_3O_4 nanostructures in the matrix of an anionic PNaAMPS hydrogel. Fe_3O_4anisotropic nanostructures that exhibit excellent catalytic performance are rarely used to catalyze Fenton-like reactions because of the inevitable drawbacks resulting from traditional preparation methods[30] magnetic Cu-Fe oxide(CuFeO) was developed as the heterogeneous photo-Fenton catalyst through a facile two-step method.[31]

A magnetic composite material composed of nano-magnetite, heulandite, and cross-linked chitosan was prepared and used as an adsorbent for methylene blue and methyl orange.[32] A magnetite-loaded mesocellular carbonaceous material, $Fe_3O_4/MSU-F-C$, exhibited superior activity as both a Fenton catalyst and an adsorbent for removal of phenol and arsenic, and strong magnetic property rendering it separable by simply applying magnetic field.[33] MnO_2–chitin hybrid was used for the effective removal of methylene blue from liquid solution asmodel for wastewater treatment.[34] Scientists are constantly engaged in finding the advanced technology with high proficiency and low investment.[35] the advanced technology with high proficiency and low investment.[36] The synthesis of porous gelatin/AcA (PGE-AcA) hydrogel and novel porous gelatin-silver/AcA (NPGESNC-AcA) nanocomposite hydrogel, and their ability as effective biosorbents for the removal of Cu^{2+}ions from contaminated water.[37]

The hydrogel is made up of Fe_3O_4 nanoparticles, reduced graphene oxide and polyacrylamide, which is prepared by a two-step chemical synthetic method, and exhibits the outstanding mechanical strength, Photo-Fenton activity, adsorptive property and reversibility.[38] Fenton catalytic oxidation is an efficient and green method to remove pollutants, and the preparation of Fenton catalyst by MOF is a significant task.[39] Oxidation by Fenton-like reactions is proven and economically feasible process for destruction of a variety of hazardous pollutants in wastewater.[40] Magnetic iron particles doped with TiO_2 were synthetized to be used as a photo electro Fenton catalyst, being easily eliminated from the treated solution.[41] Fe-rich biochar with multivalent iron compounds (Fe 0, Fe 0.95 C 0.05, Fe_3O_4, and $FeAl_2O_4$) pyrolyzed from sludge cake conditioned with Fenton's reagent and red mud was utilized as an efficient Fenton catalyst for the degradation of 4-chlorophenol(4-CP).[42] Silver nanoparticles decorated reduced graphene oxide is a well-established nanoparticle for multifunctional applications.[43] Fe-supported bentonite (Fe-B) was successfully fabricated as a low-cost heterogeneous catalyst foradsorption and visible light photo-Fenton degradation of rhodamine B from aqueous solution.[44]

Experimental section

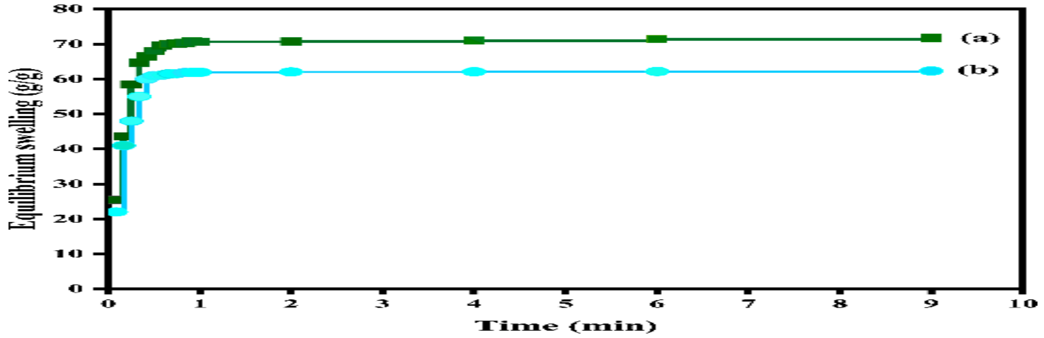
2-1- Materials: Carboxymethylcellulose, N,N-methylenebisacrylamide, ammoniumpersulfate, acrylic acid, sodiumhydroxide, ethanol(96%), H_2O_2 35% were doctor Majalali chemical complex, Iran. $FeCl_3.6H_2O$, $FeSO_4.7H_2O$, thioacetamide (C_2H_5NS), methylviolet ($C_{24}H_{28}N_3Cl$) were Merck, and water.

2-2- Instruments: For dye removal measurement quantity UV (Camspec M350 Double Beam model, England), for functional group identification FTIR (AVATAR model made in Thermo company, America), for thermal stability used TGA (model Perkin Elmer Pyris Diamond TGA/DTA, America), for elements present in the nano-composite hydrogel EDX used, for checking morphology surface SEM (microscopy MIRA III model TESCAN company Czech Republic), for presence of nano-particles in the hydrogel tissue XRD (PW1730 model, PHILIPS company Netherland), for identify the elements XRF (PW1410 model, PHILIPS company Netherland) used, for specification measurement nanoparticles TEM (Zeiss EM10C model whit 80 kV accelerated voltage USA), for porosity amount measurement and representative BET (BELSORP MINI II model BEL Company Japan) and for functional group Raman (P50C0R10 model Teksan company) used.

2-3- Preparation of hydrogel: 1g carb oxy methyl cellulose in 40 mL water, 0.1 g N, N-methylene bis acrylamide in 5 mL water, 0.1 g ammonium per sulfate in 5 mL water and 0.7g NaOH in 6 mL water, were dissolved. Next step, carb oxy methyl cellulose solution in the water bath ($80°C$) and 150 rmp, and N, N-methylene bis acrylamide, 4 mL acrylic acid, 1 mL NaOH (0.1M), ammonium per sulfate were added for 45 min to obtain a hydrogel. The formed hydrogel in ethanol for 12 h and in oven at $50°C$ for 12 h.

2-3- Preparation of the Nanocomposite: 0.1 g carb oxy methyl cellulose in 150 mL water for 3h fully swelling. 0.3g $FeCl_3.6H_2O$ and 0.3g $FeSO_4.7H_2O$ in 15 mL water in this solution added hydrogel for 10 min and washed with water. 0.4g thioacetamide in 15 mL water after added hydrogel to a few min and 1mL NaOH 0.1M. Formed nano-composite in ethyl alcohol for 12h and in oven at $50°C$ for 12h.

2-4- Swelling studies: 0.1g hydrogel and 0.1g nano-composite in 250 mL water for each one, at different times they are swelling.



(Fig 1) Swellings of hydrogel (a) and nano-composite (b)

2-5- Dye removal study: For compare the removal of methylviolet, need to make five solution of methylviolet with concentration of 10 mg/L it will be prepared 50 mL solution of methyl violet.

For compare the removal five solutions of methyl violet, with concentration of 10mg/L and 50mL were prepared. 0.07g of hydrogel with 40-60 mesh in two solutions, 0.07g of nano-composite with 40-60 mesh in the other two solutions and 2mL of H_2O_2 in the other solution. The equilibrium removal time of the sub-filter dye solution was evaluated by UV-Vis at 582nm.

2-6- Radical formation study: For production of hydroxyl radical, 20 mL of 2H-1-Benzopyran-2-one with concentration 100µM and 0.028g of hydrogel and 0.8mL of H_2O_2 were added for 30min using magnetic stirrer. Another 20mL of 2H-1-Benzopyran-2-one with concentration 100µM and 0.028g of nano-composite and 0.8mL of H_2O_2 were added for 30min using magnetic stirrer.

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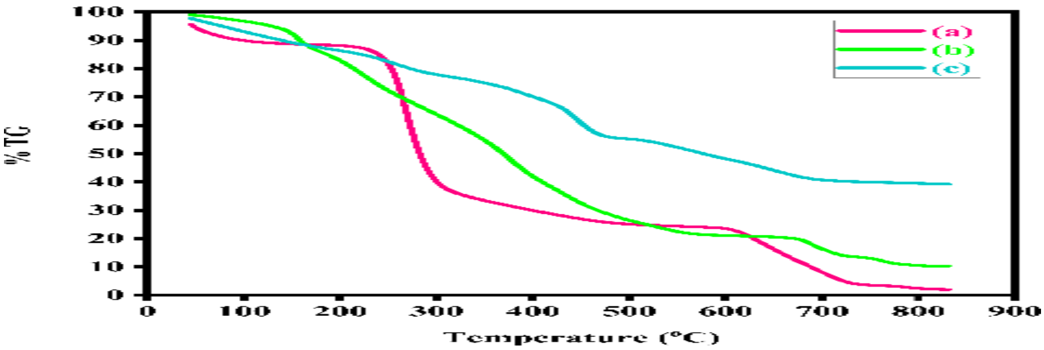
Results and discussions

3-1- Synthesis and Characterization: Swelled of hydrogel by water and then added it to $FeCl_3.6H_2O$ and $FeSO_4.7H_2O$ solution, which will load divalent and trivalent iron ions in hydrogel, added hydrogel to the thioacetmaide solution. Nano-particales of Fe_2S_3 are formed in the hydrogel bed. (Fig 2).

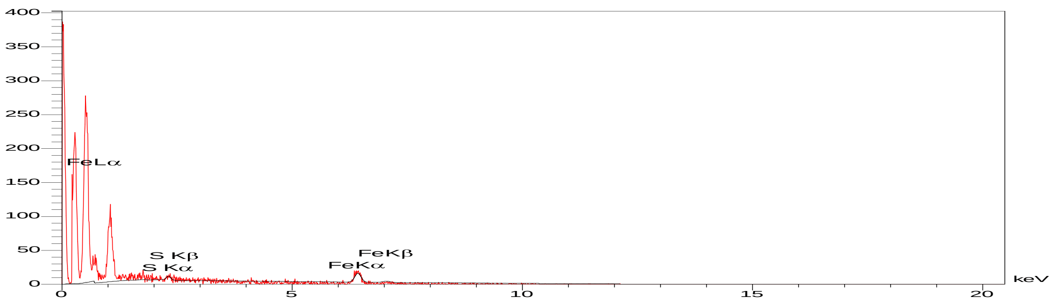
(Fig 2) nano-composite including Fe_2S_3 nanoparticles

3-1-1- Thermal Gravimetric Analysis (TGA): (Fig 3) TGA of (a), (b) and (c). Stability of (c) structure compared to (b) and (a), presence of Fe_2S_3 nano-particles. Stability of (b) structure compared to (a), presence of poly acrylic acid and network formation.



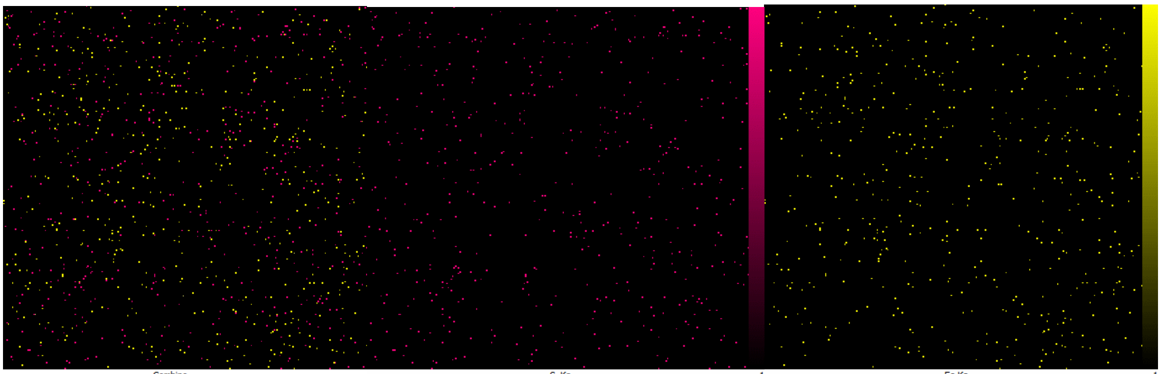
(Fig 3) TGA chart of carb oxy methyl cellulose (a), hydrogel (b) and nano-composite (c)

3-1-2- Energy Dispersive X-ray spectroscopy: Fe and S particles in the nano-composite (Fig 5).



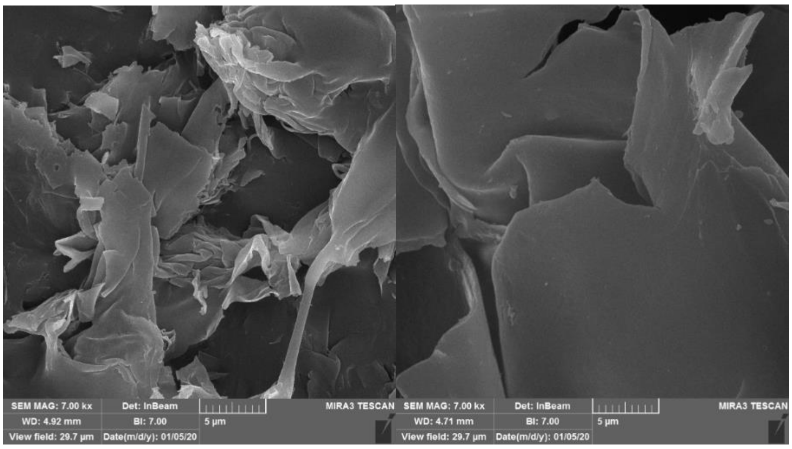
(Fig 5) Elements in nano-composite by EDX

(Fig 6) Presence Fe and S elements and Fe_2S_3 nano-particles in the hydrogel.



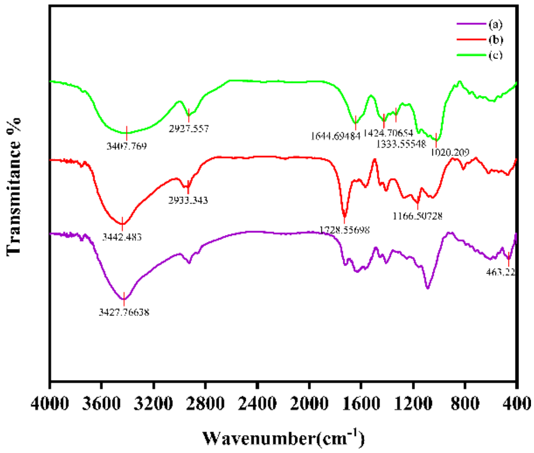
(Fig 6) elements entity in nano-composite by electron microscopy

3-1-3- Scanning Electron Microscopy (SEM): Holes and empty sites in the hydrogel (a), (b), occupied by Fe_2S_3 nano-particles (c), (d), (fig 7).



(Fig 7) SEM image of hydrogel with 20000 nm (a), nano-composite with 20000 nm (b)

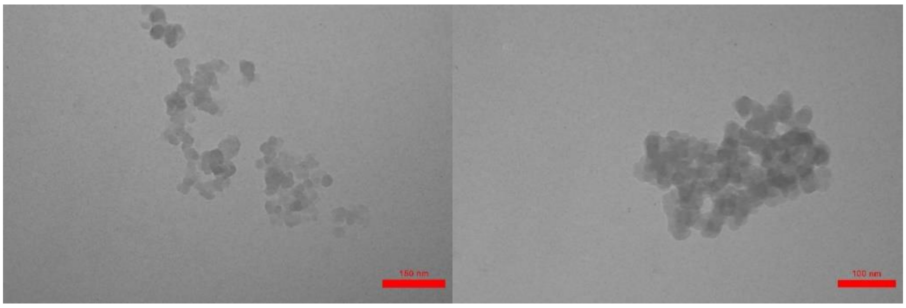
3-1-4- Fourier Transform Infrared spectroscopy (FTIR): Spectrum (a) related to the nano-composite, absorption in the area of $3427.80\ cm^{-1}$ indicates the alcoholic OH group. Absorption in the $463.21\ cm^{-1}$ area shows the presence of Fe_2S_3 group. Spectrum (b) related to the hydrogel, absorption in the area of $3442.62\ cm^{-1}$ indicates the hydroxyl group and absorption in the $2933.08\ cm^{-1}$ area is attributed to the CH stretching vibration. Area $1728.50\ cm^{-1}$ represents the grafting of acrylic acid on the polysaccharide. Spectrum (c) related to the carb oxy methylcellulose, absorption in the $3407.55\ cm^{-1}$ area attributed to the OH stretching vibration and absorption in the $2927.55\ cm^{-1}$ area is attributed to the CH stretching vibration.



(Fig 8) FTIR of nano-composite (a), hydrogel (b) and carb oxy methyl cellulose (c)

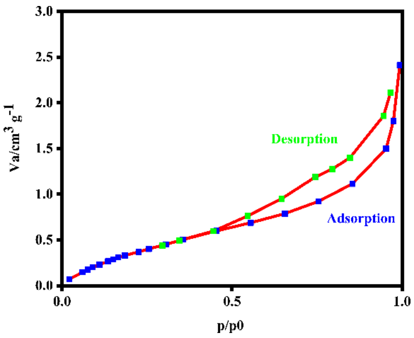
3-1-5- X-ray fluorescence spectroscopy (XRF): 25.753 % Of iron with oxidation number (+3). Sulfur oxidation number (-2), which indicates the successful synthesis of Fe_2S_3 nano-particales in the hydrogel bed.

3-1-6- Transmission Electron Microscopy (TEM): (Fig 10) TEM images of nano-composite in the different sizes.



(Fig 10) TEM images of nano-composite at 100 and 150 nm

3-1-7- Brunauer Emmett Teller (BET): At the beginning of the isothermal curve of nitrogen absorption by nano-composite, which corresponds to a small relative pressure of (p/p_0 = 0-0.4), the pores are saturated with nitrogen gas. The more this part is in the prepared sample, it indicates the number of micro-holes in the nano-composite. When the relative pressure of the gas is (p/p0 = 0.3-0.5), the surface of the cavities are covered with multi-layer of nitrogen gas molecules. With a further increase in the relative pressure of gas (p/p0 > 0.5), the saturation of nano-composite cavities by nitrogen gas begins (Fig 11).

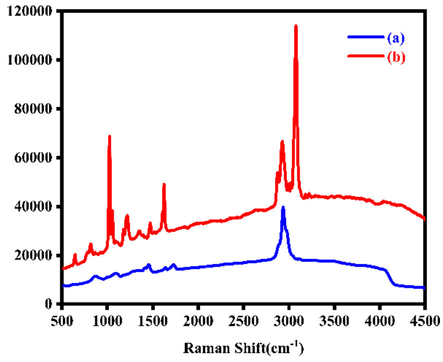


N_2 adsorption/desorption isotherm and pore size distribution of nano-composite (Fig 11)

Physical characteristics such as the total volume of holes, average diameter of holes and volume of absorbed gas to produce a layer on the surface of nano-composite are listed in (Table 1). In addition to measuring these physical properties, this test shows the amount of empty spaces in the nano-composite. Table 1 Physical properties of nano-composite

sample	Volume of adsorbed gas for a layer on the surface	Mean pore diameter	Total pore volume(p/p0=0.990)
nanocomposite	2.4101 cm^3 g^{-1}	7.9391 nm	0.0035728 cm^3 g^{-1}

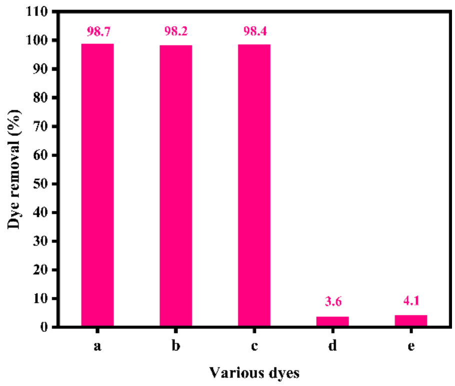
3-1-8- Raman spectroscopy (RS): The spectra related to hydrogel (a) peak 1446.489 related to CH_2, peak 2936.579 is related to stretch CH. The spectra related to nano-composite (b) peak 1094.036 is related to COH, peak 1226.933 is related to COC, peak 1472.854 is related to CH_2, peak 2928.251 is related to stretching CH, peak 3072.119 is related to stretching OH, (Fig 12).



(Fig 12) Raman spectrum of hydrogel (a) and nano-composite (b)

3-2-Deferment dyes removal: 50mL of methyl violet, crystal violet, malachitegreen, methyl orange and tartrazine with 10mL/g and pH=6. 2mL of H_2O_2, 0.07g of nano-composite.

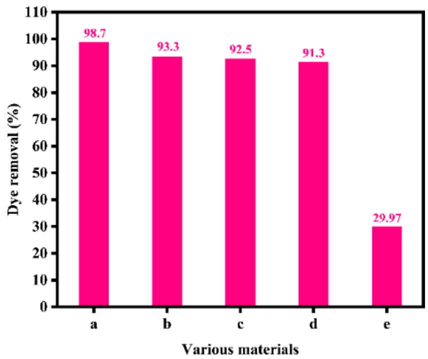
The removal efficiency of cationic dyes higher than anionic dyes. Which hydrogel contains carboxylate anionic groups.



(Fig 13) Removal (%) of methylviolet (a), crystalviolet (b), malachite green (c), methylorange (d) and tartrazine (e)

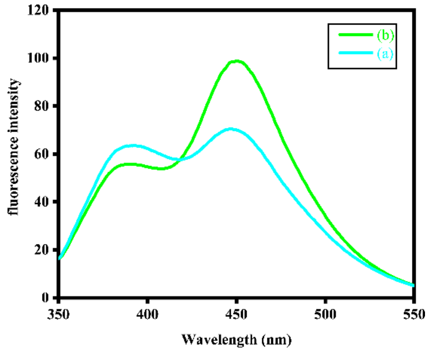
3-2- Dye removal Mechanism: Removal (%) of methyl violet by nano-composite different factors subordinate parable amounts is of H_2O_2, nano-compostie, time, temperature, concentration and pH. $\text{Removal}(\%) = \frac{C_0 - C_t}{C_0} \text{ x } 100$

Effect of H_2O_2: (Fig 14) Removal (%) by nano-composite and H_2O_2 (a), only nano-composite (b), hydrogel and H_2O_2 (c), only hydrogel (d), and only H_2O_2 (e). 0.07g of nano-composite and hydrogel, 50mL methylviolet with 10mg/L and pH = 6, 25^{o}C and 35min

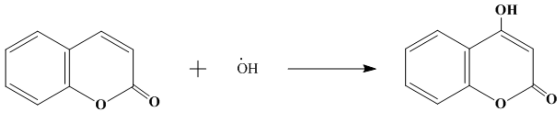


Removal (%) of methyl violet by parameters (Fig 14)

3-2-1- Confirm hydroxyl radical formation: 2H-1-Benzopyran-2-one used to for measure hydroxy radical. 4-Hydroxy-2H-1-Benzopyran-2-one product by reaction of 2H-1-Benzopyran-2-one with hydroxyl radical. Nano-composite has increased radical production. In this process used 0.028g of hydrogel, 20mL of 2H-1-Benzopyran-2-one with 100 µM, 0.8mL of H_2O_2, 25^{o}C, 30 min (a) and nano-composite with the same conditions (b) (Fig 15).

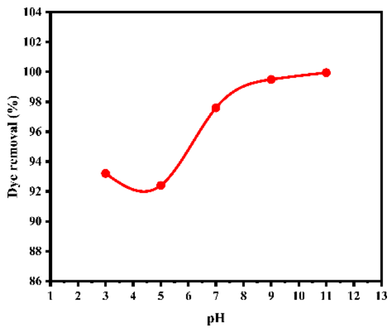


Fluorescence spectra related to 2H-1-Benzopyran-2-one solution. Hydrogel (a) and nano-composite (b) (Fig 15)



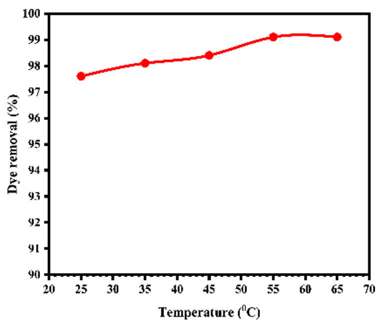
2H-1-Benzopyran-2-one Hydroxyl radical 4-Hydroxy-2H-1-Benzopyran-2-one

3-3- Effect of pHs: The pH increases, methylviolet removal (%) increaseing. In 3, 5, 7, 9, 11 pHs, 0.07g of nano-composite, 50mL of methylviolet with 10mg/L, 2.0mL of H_2O_2, 25°C.



Removal (%) of methylviolet in different pHs (Fig 16)

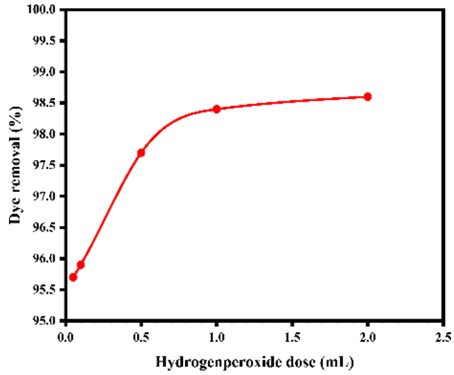
3-4- Effect of temperatures: Temperature increases, methylviolet removal (%) increasing because the collisions between the dye and nano-composite molecules increase. In 25, 35, 45, 55, 65 °C, 0.07g of nano-composite, 50mL with pH=6 and 10mg/L of methylviolet, 2.0mL of H_2O_2.



Removal (%) of methylviolet in different temperatures (Fig 17)

3-5- Effect of hydrogen per oxide doses: Hydrogenperoxide increases with methylviolet removal (%) in initials increasing after reaches a constant value. 0.05, 0.1, 0.5, 1 and 2mL of H_2O_2, 0.07g of nano-composite, 50mL with pH=6 and 10mg/L of methylviolet and 25°C.

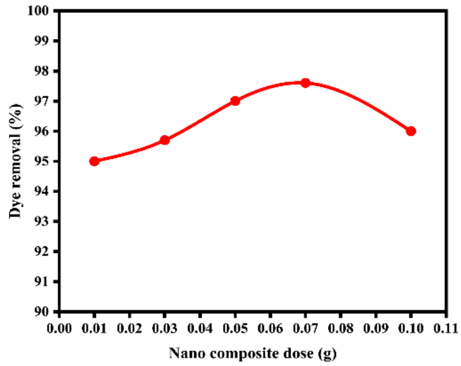
When 2 mL of H_2O_2 was used, the maximum methylviolet removal was obtained in the shortest time.



Removal (%) of methyl violet in different doses of H_2O_2 (Fig 18)

3-6- Effect of nano-composite amount: Nano-composite amount by increases, methylviolet removal (%) increasing. 0.01, 0.03, 0.05, 0.07, 0.1g of nano-composite, 50mL with pH=6 and 10mg/L of methylviolet, 2.0mL of H_2O_2 and 25°C.

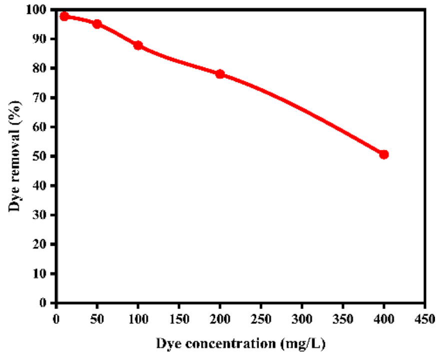
When 0.07g of nano-composite, was used, the maximum methylviolet removal (%).



Removal (%) of methyl violet by different amounts of nano-composite (Fig 19)

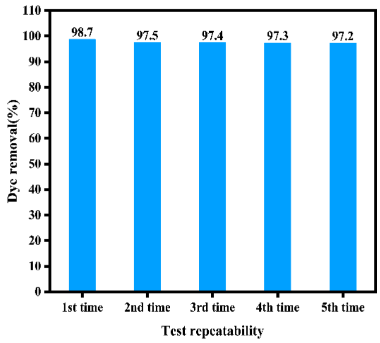
3-7- Effect of concentration: Concentration increases with methylviolet removal (%) decreasing, it is possible to saturate the surface of the nano-composite, and the higher the dye concentration, the longer the time to remove it.

In 10, 50, 100, 200, 400mg/L concentrations of methylviolet, 0.07g of nano-composite, 50mL with pH=6 of methylviolet, 2.0mL of H_2O_2, 25°C.



With different concentrations removal (%) of methylviolet **(Fig 20)**

Repeatability: After several uses, the nanocomposite decreases due to the lack of complete recovery after washing with ethanol and the loss of some nano-composite, as well as due to the lack of complete washing, the amount of removal methylviolet. 0.07g of nanocomposite, 50mL with pH=6 and 10mg/L of methylviolet, 2.0mL of H_2O_2 and 25°C (Fig 21).



Removal (%) of methylviolet by reusability use of nano-composite **(Fig 21)**

Acknowledgement: The article on "Efficient dye removal by Fe_2S_3 nano-composite hydrogel through a Fenton-like reaction" presents a significant advancement in the field of water purification, particularly in the treatment of dye-contaminated wastewater. It highlights the development and application of Fe_2S_3 nano-composite hydrogel that leverage the Fenton-like reaction to degrade dyes effectively. This work is acknowledged for its innovative approach in integrating the catalytic properties of Fe_2S_3 nanoparticles with the versatile matrix of hydrogels, thereby achieving a high efficiency in dye removal under mild conditions. The research provides valuable insights into the kinetics of the dye degradation process, explores the effect of various operational parameters, and demonstrates the composite's reusability, making a noteworthy contribution to the development of sustainable and efficient wastewater treatment technologies.

The study titled "Efficient dye removal by Fe_2S_3 nano-composite hydrogels through a Fenton-like reaction" marks a noteworthy contribution to environmental chemistry and materials

science, particularly in advancing the methods for treating dye-contaminated water. The research underscores the innovative use of Fe_2S_3 nano-composite hydrogel as a catalyst in Fenton-like reaction, offering a novel and efficient approach to degrade various dyes in aqueous solutions.

The authors' exploration into the effects of operational parameters such as different amounts of nano-composite hydrogel, pH, H_2O_2, temperature, and dye concentration were on the removal process, as well as their investigation into the composite's reusability, are commendable for their thoroughness and depth. This work is acknowledged for its potential environmental impact, presenting an eco-friendly solution to a pervasive pollution problem, and contributing valuable insights to the field of water purification technology.

Conclusion

The study on "Efficient dye removal by Fe_2S_3 nano-composite Hydrogels through a Fenton-like reaction" presents a compelling advancement in the field of environmental remediation, particularly in the context of water purification. The introduction of Fe_2S_3 nano-composite hydrogel as a catalyst for a Fenton-like reaction offers a highly effective and environmentally friendly approach for the removal of various dyes in contaminated water. The research conclusively demonstrates that hydrogel not only enhance the catalytic efficiency of the Fenton-like process but also offer advantages in terms of reusability and operational stability under a range of environmental conditions. The successful application of these nano-composite hydrogel in dye removal signifies a potential leap forward in addressing the global challenge of dye pollution in water bodies. The findings underscore the importance of nanotechnology and material science in developing sustainable solutions for environmental protection. Future studies could further optimize the composite material's properties and explore its applicability to a broader spectrum of pollutants, potentially broadening its utility in water treatment technologies. In conclusion, the efficient dye removal capabilities exhibited by Fe_2S_3 nano-composite hydrogel through a Fenton-like reaction highlight a promising avenue for the development of cost-effective, efficient, and green technologies for wastewater treatment, aligning with global efforts towards environmental sustainability and pollution mitigation.

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