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Nanocomposite as a highly efficient adsorbent for the rapid adsorption of dye extracted from an aqueous solution

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Abstract

Nickel ferrite nano composite was prepared by urea assisted auto combustion technique. Introduce nickel ferrite nano composite into the surface of copper pod fruit activated carbon provides a large surface area that is used for malachite green dye adsorption. Malachite green adsorption was studied utilising Nickel ferrite nano composite activated carbon in batch adsorption experiments. X-ray diffraction and a scanning electron microscope were used to examine the product. Contact time, pH, and adsorbent dose were all investigated. The results revealed that, increasing the contact duration and starting pH of the solution boosted the dye's adsorption capability. The adsorption isotherms, kinetics of the nanocomposite were found to be in good agreement with the Langmuir equation, the pseudo second order kinetic equation, respectively. The developed Nickel ferrite nanocomposite might be used as a possible adsorbent for the removal of malachite green dye from wastewater treatment in this case.

Introduction

Textile industry is one of the most environmental pollutants, due to the presence of organic toxic compounds known as dyes [1, 2]. The presence of dyes in water limits light penetration, preventing aquatic flora from performing photosynthesis [3, 4].The malachite green dye removal from wastewater is a significant environmental issues, that has initiated substantial research efforts [5, 6]. The severe condemnation to malachite green dye may have serious side effects on the nervous system, reproductive system, liver, kidney and brain. Malachite green is a well-known textile dye and with a wide variety of applications. It has certain applications in the medical field as well [7, 8]. It is highly toxic to flora and fauna. It induces risk of cancer and many other diseases.

The term nanotechnology refers to the study and use of structures between 1nm and 100nm in size [9, 10]. The main features of nanomaterials are high reactivity, high adsorption, large specific surface and desorption capacity [11, 12]. The usage of nanoparticles in environmental applications has expanded as a result of these characteristics [13, 14]. Various nano-adsorbents, for example chitosan/silk fibroin/ hydroxyapatite nanocomposite[15], magnetic Y-Fe2O3/SiO2 nanocomposite[16], chitosan-Zno nanocomposite[17], magnetic starch-g- polyvinyl alcohol nanocomposite[18], monodispersed mesoporous silica nanoparticles[19], zinc oxide nanocomposite[20] to remove various colours from wastewater has been analysed. The adsorption process has been used to successfully remove colour from wastewater [21]. The extent of adsorption based on the area of the surface and the porosity of the adsorbent. A good adsorbent possess larger surface area and takes lesser time for effective adsorption. Adsorption is a technique for removing colour molecules from aqueous solutions. plays an important role from environmental point of view. Methods for removing dye that are commonly used from aqueous solutions are co-precipitation, flocculation, reverse osmosis. Ion exchange, adsorption, electro deposition and filtration. Among them, adsorption method is considered to be more convenient and efficient.

In the present study, $NiFe_2O_4$ nanocomposite as a nano adsorbent for eliminating malachite green from aqueous solution was investigated.

2. EXPERIMENTAL

2.1. Preparation of the Nickel ferrite nanocomposite

The outer skin of the copper pod fruit was peeled off first, followed by the removal of the inner fleshy layer. To eliminate any dirt or sands, the peel was rinsed with regular tap water. The material was washed and sun dried for two to three days to remove any remaining moisture. Sulphuric acid (1:1) was used to carbonise the dry materials. To remove remaining acid from the pores of the carbon particles, the charred material was filtered and rinsed with a lot of water. For 30 minutes, the filtered material was held in a muffle furnace at 600 degrees Celsius. The carbonised material was finely crushed and sieved with 53 μm of particle size.

NiFe2O4/CFAC composite was created using an auto combustion technique. 1 mole of Ni (NO3)2.6H2O and 2 moles of Fe (NO3)3.9H2O were dissolved in 50 mL of distilled water for this synthesis. 50% aqueous solutions of urea, 2 g of activated carbon were added to the aforementioned solution, which was then heated to 150^{0}C for 1 hour with constant stirring using a magnetic stirrer. The combustion process was aided by the addition of urea as a fuel. The dried gel burned in a self propagating oxidation when ignited in room temperature air, releasing a huge amount of gases and loose powder.

Adsorption Experiments

The $NiFe_2O_4$ nanocomposite materials using a batch mode technique, the adsorption of malachite green dye at room temperature was investigated. In this technique, the adsorption studies were investigated by mixing different amounts of $NiFe_2O_4$ nanocomposite to remove the potential of the malachite green dye in 50ml of the coloured solution. The filtrate was analysed on the spectrophotometer at the wavelength of the malachite green dye which is 517nm.

The amount of dye adsorbent were evaluated by

$$q_e = \frac{(C_0 - C_e)V}{M} \qquad (1)$$

Where, q_e is the equilibrium adsorption capacity(mgg^{-1}), V is the volume of malachite green solution (L), M is the dry weight of the adsorbent(g), C_0 is the initial concentration of malachite green dye in the solution(mg.L^{-1}), C_e is the final or equilibrium concentration of malachite green dye in the solution(mg.L^{-1}).

Characterization

Scanning electron microscopy (SEM) images were taken with Zeiss Fe - SEM attached with EDX Unit (Energy Dispersive X-ray Analyses), with accelerating voltage 30 K. X-ray diffractio (XRD) pattern was recorded with PANalytical X'Pert Pro Powder X' Celerator Diffractometer (Cu K_α, 0.154 nm) between 10 and 80 ° 2θ with a step size of 0.01 °/sec.

Results and Discussion

Effect of nanocomposite dosage

Various amounts of NiFe2O4 nanocomposite from 0.05 - 1.0g were added to 50ml malachite green solution (50mg/L) to examine the influence of adsorbent dose [22, 23]. Figure 1 depicts NiFe2O4 nanocomposite dosage effect on malachite green uptake. Because of the more availability of adsorption sites, increasing the amount of NiFe2O4 nanocomposite from 0.05g -0.5g enhances malachite green dye adsorption effectiveness from 70% to 88 percent. The ideal nanocomposite dosage was determined to be 0.5g.

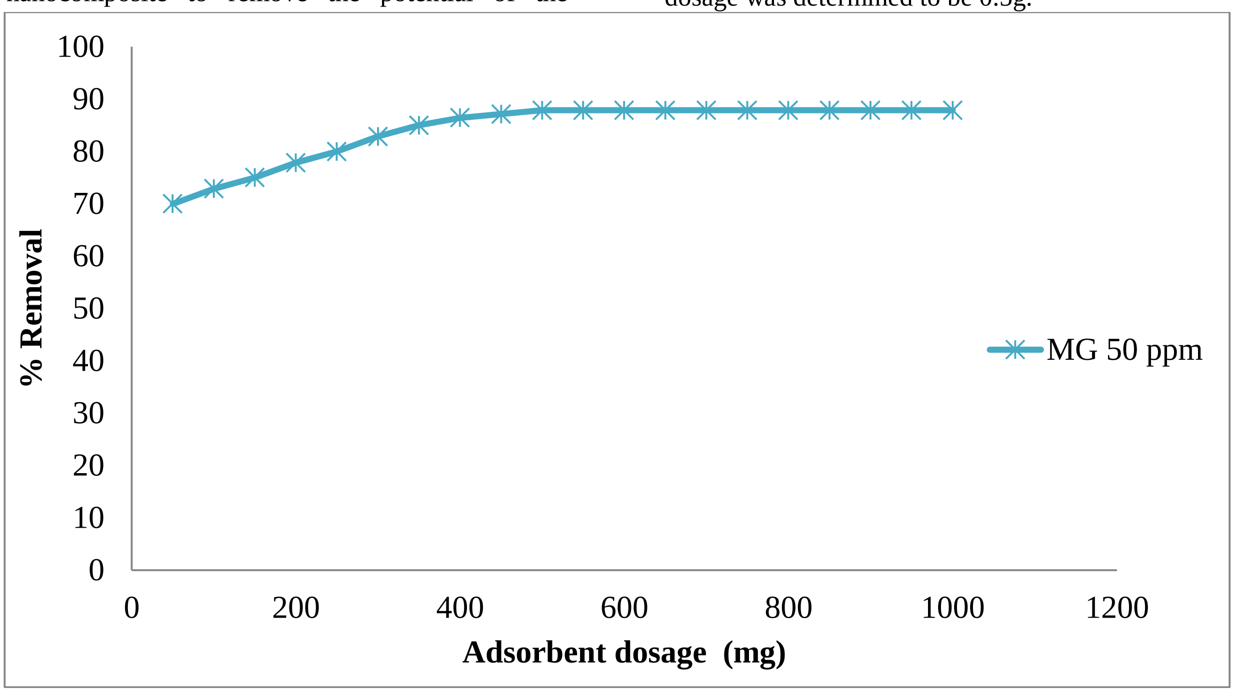

Figure 1: Effect of nanocomposite dosage for malachite green dye adsoprtion

pH effect

The impact of pH on the malachite green dye molecule's adsorption effectiveness was investigated. The studies were conducted with 50 mg/L dye solution concentration, a 60-minute adsorption duration, and 30°C temperature. Figure depicts pH effect. 2 .A malachite green dye solution with a pH range of 2 to 12 was created to test the influence of pH. When comparing dye removal percentages for various pH values, pH

7 reveals a higher percentage of malachite green removal when compared to other pH values [24, 25]. Reduced adsorption of malachite green dye on NiFe2O4 nanocomposite at acidic pH showed that the adsorbent's surface could acquire a positive charge and is due to the presence of extra hydrogen ions in the acidic medium, resulting in competition between H+ ions and cationic groups

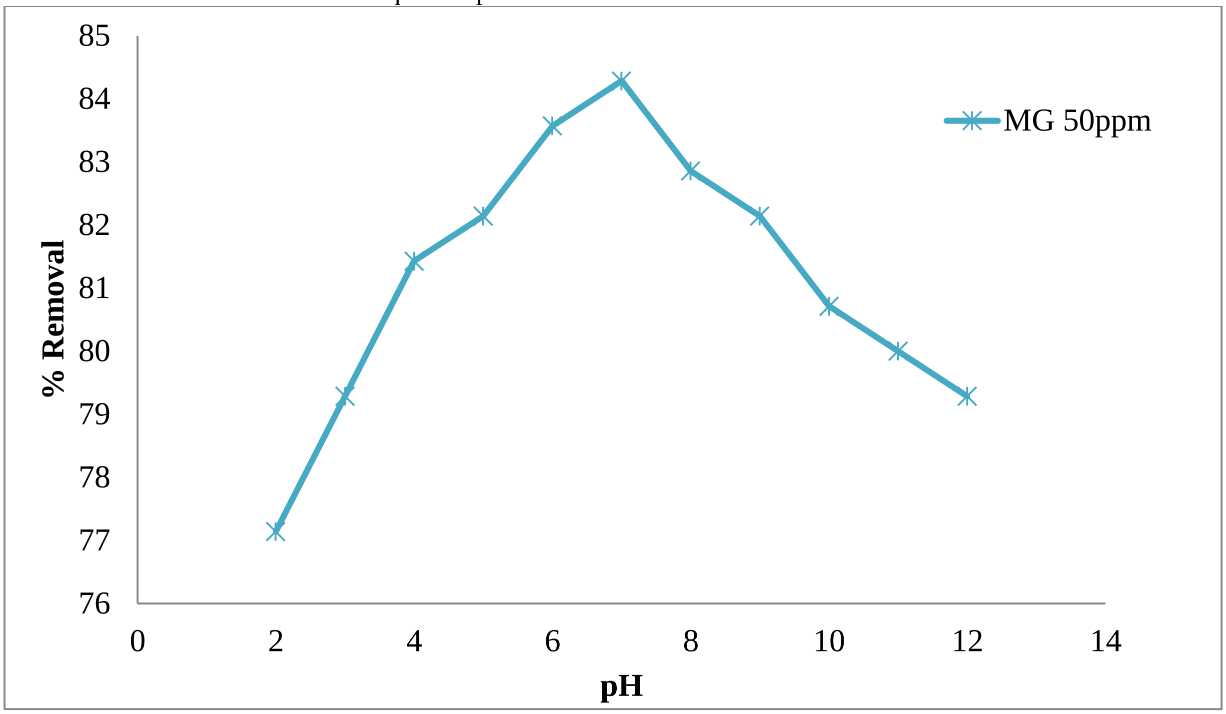

Figure 2: Effect of pH

Effect of contact time and initial dye concentration

Using solutions with an initial concentration of 50 mg/L, the effect of the initial concentration of the malachite green dye molecule on adsorption efficiency and capacity was analysed. When demonstrated in figure 3, the adsorption efficiency and capacity improve as the initial malachite dye concentration increases [26, 27].

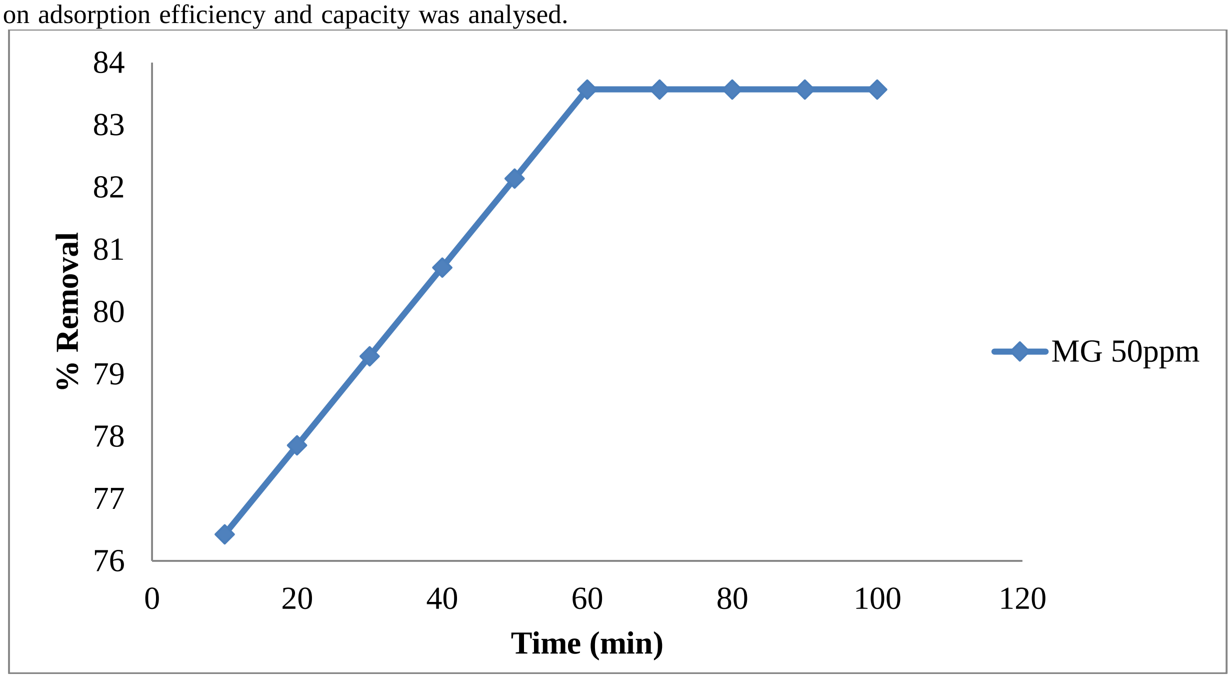

Figure 3: Effect of time

Adsorption isotherm

Langmuir isotherm

The Langmuir adsorption isotherm model, assumes homogeneous adsorption energies on the surface and no adsorbate transmigration in the structure's plane. Each adsorption location is comparable to the others, and each location can only adsorp one type.

Langmuir equation is

$$\frac{C_e}{q_e} = \frac{1}{Q_0 b} + \frac{C_e}{Q_0} \quad (2)$$

The Langmuir isotherm's essential requirements may be derived in terms of a dimensionless separation factor.

$$R_L = \frac{1}{1 + bC_0}$$

The adsorption of malachite green dye onto nanocomposite is favourable because the RL is between 0 and 1.

The Langmuir isotherm constant value, as given in table 1, shows the adsorption capacity Q_0 = 83 mg/g.

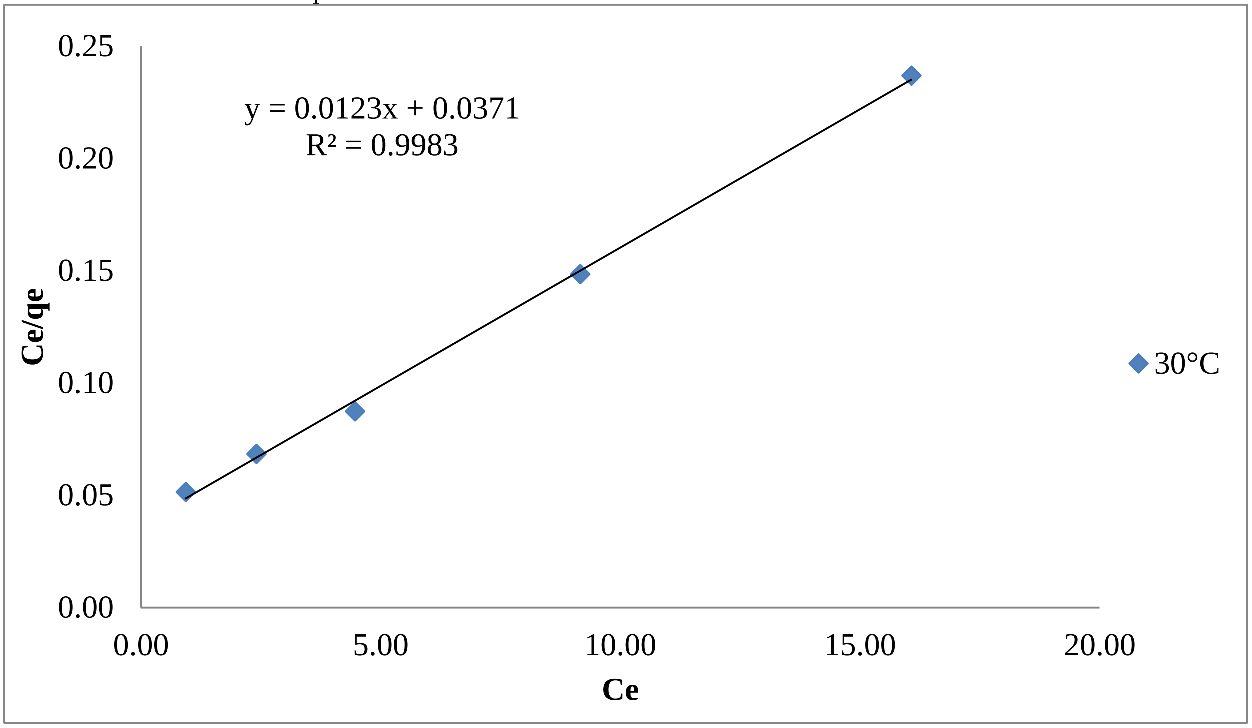

Figure 5: Langmuir isotherm for malachite green dye adsoprtion

Freundlich isotherm

The Freundlich isotherm model is

$$\log q_e = \log k_f + \left(\frac{1}{n}\right)\log C_e$$

(3)

As seen in table 1, the Freundlich isotherm has a correlation coefficient (R2) of 0.934, whereas the Langmuir isotherm has an R2 of 0.998. A higher k f value suggests a greater affinity for the adsorbate [28]. The 1/n values are in the 2.155 range, indicating good adsorption. The correlation coefficient values, on the other hand, imply that the experimental data does not match the Freundlich model [29].

According to the correlation coefficient (R2) of the linearized form of both equations, the Langmuir model suited the experimental equilibrium adsorption data better than the Freundlich model. The creation of a monolayer covering of dye molecules on the outer surface of $NiFe_2O_4$ nanocomposite was clearly denoted by this result, which demonstrated the homogenous nature of the sample surface.

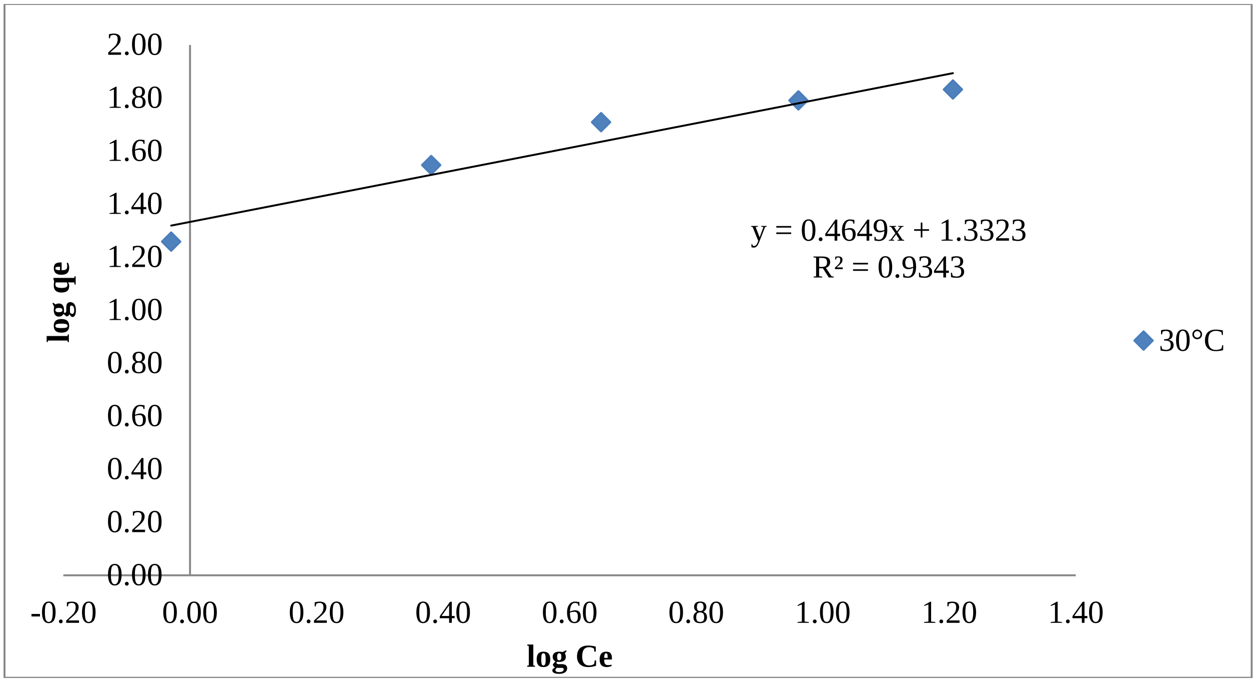

Figure 6: Freundlich isotherm for malachite green dye

Table 1: The isotherm parameter for the adsorption of malachite green by $NiFe_2O_4$ nanocomposite

Temp. ($0\ ^0C$)	Langmuir isotherm parameters		Freundlich isotherm parameters	
	R^2	0.998	R^2	0.934
30^0C	Q_0	83	n	2.155
	b	0.32	K_f	21.47

Kinetic studies

Pseudo-first-order equation is

$$\log(q_e - q_t) = \log q_e - \frac{k_1 t}{2.303} \quad (7)$$

Kinetic values of malachite green dye adsorption onto $NiFe_2O_4$ nanocomposite were also examined by the pseudo-second-order equation [30]. It is expressed as

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \quad (8)$$

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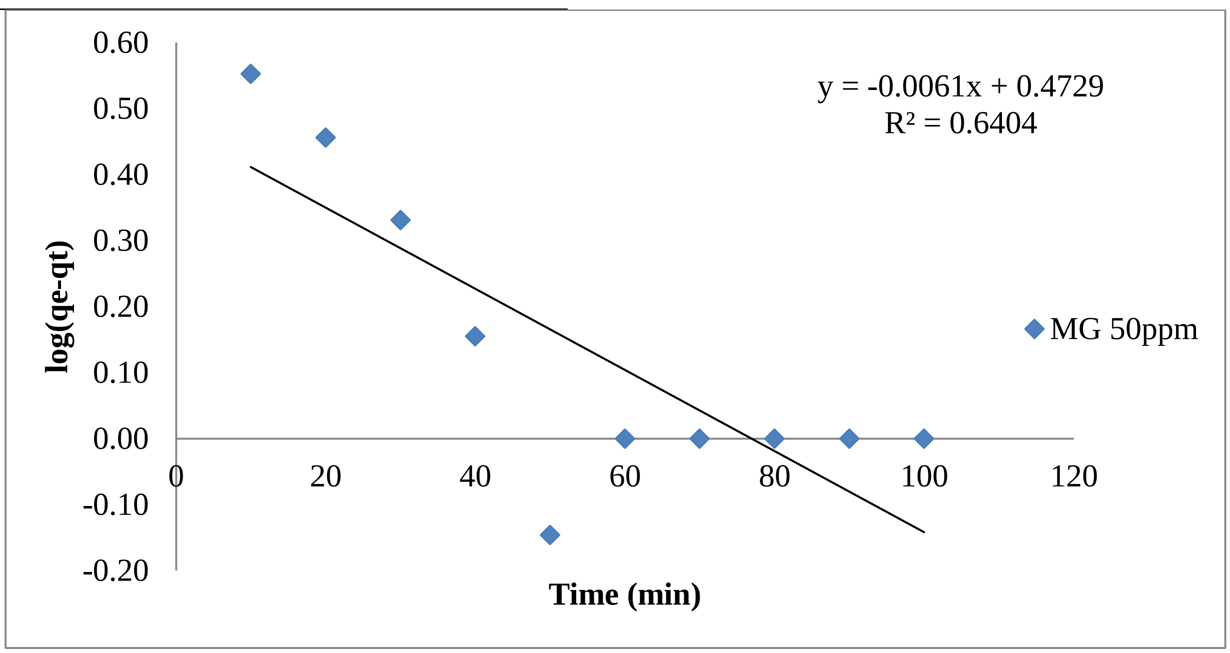

Figure 8: Pseudo-first order plot

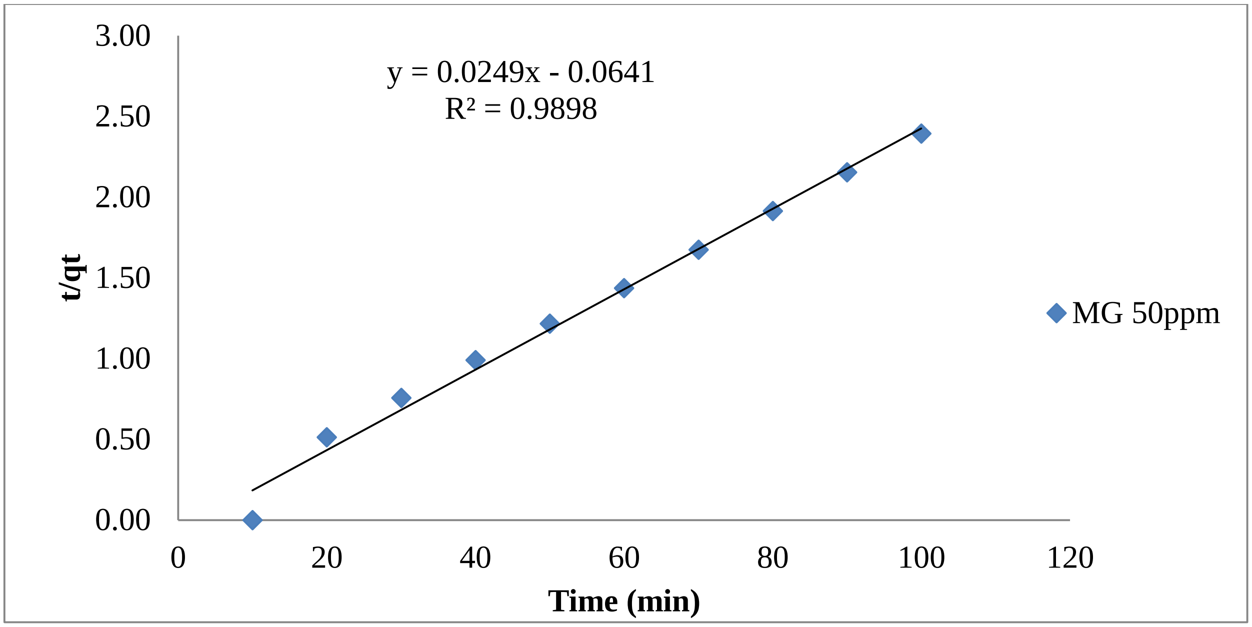

Figure 9: Pseudo- second order plot

Table 2 shows that the q e values predicted by the pseudo-first-order model are lower than the observed value. On the other hand, the q e values computed using the pseudo-second-order model are nearly equal to the experimental value. Table 2 also demonstrates that the pseudo-first-order rate constant's R2 values are relatively low (0.640). However, the pseudo-second-order kinetics correlation value is 0.989, showing that the adsorption of malachite green dye by NiFe2O4 nanocomposite follows the pseudo-second-order kinetic model [31, 32]. Yang et al (2015) and Javadian et al (2015) used a pseudo-second-order kinetic model to control the adsorption of cadmium onto zeolite and a carbon-aluminum composite (2016).

Table 2: The kinetic parameter for the adsorption of malachite green by $NiFe_2O_4$/CFAC

Concentration (mg/L)	**Pseudo-first-order**		**Pseudo-second-order**	
	q_{eexp}	41.79 mg/g	q_{eexp}	41.79mg/g
50	q_{ecal}	2.96 mg/g	q_{ecal}	41.66 mg/g
	k_1	0.013min^{-1}	k_1	0.009min^{-1}
	R^2	0.640	R^2	0.989

X –ray diffraction analysis

XRD analyses are helpful in determining the physical properties of nanocomposite materials. Figure 1 shows the X-ray diffraction patterns of NiFe2O4 nanocomposite. 12. The strong peaks indicate that all ferrites are single phase crystalline. The patterns depict the creation of a cubic spinal crystal structure in a single phase. The large peaks of X-ray diffraction patterns indicate that the produced materials' particles are in the nanoscale range [33]. The nanostructures of the adsorbents are represented by the strong peaks at 2 = 27 and 2 = 29.

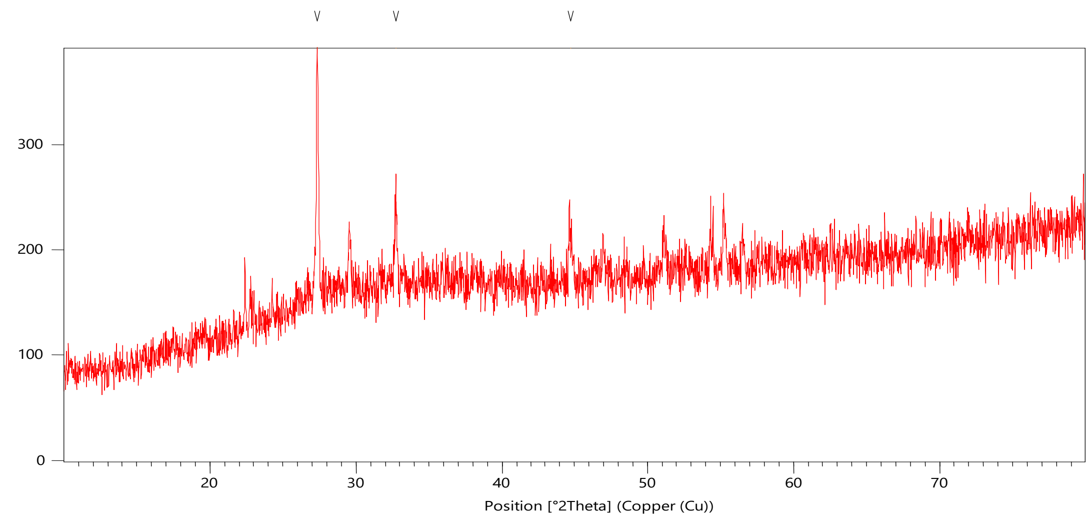

Figure 12: XRD of nickel ferrite nanocomposite

SEM Analysis

The surface morphology of a nickel ferrite nanocomposite was studied using scanning electron microscopy. The agglomerated structure of the produced nanocomposite is visible in SEM images (figure 13) [34, 35]. Clusters are formed by combining nanoparticle micrographs. The particles appeared to be homogeneous grains with a spherical shape, indicating the crystalline structure of nickel ferrite, which is also supported by the XRD profile. Sukhvir singh(2011) [36] reported similar findings. The small ellipsoidal crystals are thought to be the magnetic $NiFe_2O_4$ spinel. The nanocomposite's surface morphology was envisioned. The composite had a diameter range of 10 metres. The surface of the nanocomposite appears to be microporous, with large active groups, which increases its adsorption capability.

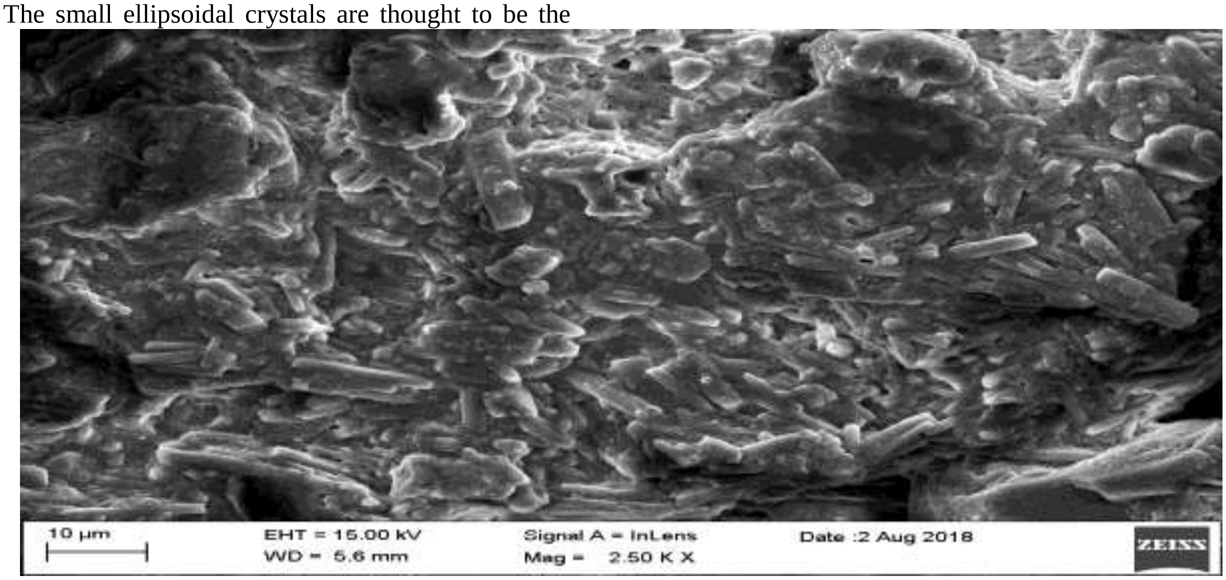

Figure 13: SEM image of nickel ferrite nanocomposite

Conclusion

The produced nickel ferrite nanocomposite was successfully used to eleminate malachite green colour from wastewater by adsorptive removal. From the experimental investigation, the following results were drawn. The pseudo-second-order kinetic model nicely fits and agrees with the kinetic data of adsorption. The Langmuir isotherm was fully suited by the equilibrium experimental data, implying monolayer production on the surface of the nanocomposite made of modified nickel ferrite. The maximum adsorption capacity was 83 mg/g.. However, there is a great deal of need for more research in this field. The following are some of the aims that could be researched in the future.

• Investigating the nickel ferrite nanocomposite's ability to remove various industrial dyes.

• Continuous use of nickel ferrite nanocomposite for industrial wastewater treatment (Fixed bed or fluidized bed studies).

• Adsorption with the nanocomposite removes other dyes from water.

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