

Investigating the effect of the initial concentration of dye on the percentage of dye removal in wastewater treatment containing acid yellow 36

Abstract

Industrial dyes are among the stable materials that cannot be treated from wastewater by conventional methods and have persistent destructive effects on wastewater and environmental waters. Thus, it is crucial to find a suitable way to remove these materials. One of these industrial dyes is acid yellow 36. In the current study, the effect of zero-valent iron nano-adsorbent on the removal of this dye was investigated. To carry out this study, 30 experiments were designed using the experiment design software, and different laboratory conditions were applied using the information obtained from this design. Accordingly, the synthetic wastewater in different concentrations of initial dye was prepared and then the effect of nanoparticulate zero-valent iron on the rate of removal of this substance from the water was investigated. The effect of the initial dye concentration parameter on the dye removal percentage was measured. The results revealed that very high concentrations of the initial dye and low concentrations of the nano-adsorbent reduced the removal efficiency.

Keywords: Wastewater treatment, High concentration of dye, Acid yellow 36, nano-adsorbent

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Introduction

Wastewater factories producing dye contain toxic compounds and high levels of COD, BOD, and TOC. These substances harm aquatic and animal life and cause contamination of the food chain. This wastewater also has an adverse effect on human health. The chemical compounds of this wastewater can cause damage to the eyes, skin, and lungs. These compounds may cause complications such as headache, dizziness, and nausea, and may also contribute to respiratory diseases, muscle weakness, liver diseases, and kidney damage (Escobar, Soto-Salazar, and Toral 2006). In recent years, strict environmental regulations have caused innovative, low-cost, and efficient methods to be investigated for industrial wastewater treatment. Owing to its simplicity and efficiency, the adsorption process has attracted a lot of attention for industrial wastewater treatment. Among the industries that have successfully used the adsorption process, we can refer to olive oil production, slaughterhouse, paper and cellulose products, metalworking, and textile industries.

The surface adsorption unit is bio-friendly since it does not produce pollutants and does not lead to corrosion. Compared to conventional processes, this method requires simple equipment and management, less reaction time; does not require chemicals, and produces less sludge (Holt, Barton, and Mitchell 2005). Data suggest that more than 100000 types of commercial dyes have been identified with an annual consumption of about 700000 tons (Wong et al. 2004). The total consumption of dyes in the global textile industry is more than 10000 tons per year, of which approximately 100 tons per year are discharged into water flows (Sen, Afroze, and Ang 2011). The exact amount of dye discharge into the environment in other industrial processes is not known. However, the dye

discharge into the environment is one of the worries of scientists. Various methods such as adsorption, coagulation, advanced oxidation, and membrane filtration, etc. have been used to remove dye from wastewater (Yagub, Sen, and Ang 2012).

Basic dyes have high brightness intensity and can be observed well even in low concentrations. Complex dyes usually contain chromium, which is carcinogenic. By preventing the penetration of light into the water, dyes may cause disturbances in the process of photosynthesis in water. They may also be toxic to some aquatic animals due to the presence of heavy metals and aromatic compounds. Moreover, dye compounds may cause severe dysfunction in the kidney, reproductive system, liver, brain, and central nervous system. Azo dyes are dangerous for human and aquatic health due to the presence of toxic amines. Reactive dyes are soluble in water, and 5 to 10% of them enter the wastewater outflow during production and cause severe environmental problems. Also, reactive dyes are chemically stable and have little biodegradability (Gupta 2009). There are several methods to treat wastewater containing dyes. Among these technologies, we can refer to adsorption processes, coagulation, electrochemical methods, and aerobic and anaerobic biological methods. Each of these methods has its limitations. However, in line with the development of nanotechnology applications over time, this technology can limit the harmful effects of pollutants on the environment. Nanotechnology can create materials and products that not only allow us to track, refine and clean environmental pollutants but also help us prevent pollution. For example, we can replace dangerous substances with harmless substances by using them. One of these methods is the use of bio-friendly materials that do not produce polluting

materials when decomposed in nature. These advantages are due to better reactivity, higher specific surface, or complexation characteristics of nano-materials. Among the classic treatment methods, nanotechnology can play a key role in preventing pollution.

Prevention of pollution refers to methods that can either reduce polluting sources or eliminate pollutants by effective use of raw materials, energy, water, or other resources (Nano Space Monthly Journal, 2007). Various experiments have been performed to remove organic and mineral pollutants from the water as well as underground water and industrial wastewater using carbon nanotubes. For example, carbon nanotubes have been reported as a super adsorbent for dioxanes. The adsorption energy of dioxanes on nanotubes is three times that of adsorption on activated carbon (Daneshvar, 2016). Extensive laboratory studies indicated that iron nanoparticles can be used for the removal of underground pollutants such as organic chlorine solvents, organic dyes, organic chlorinated pesticides, inorganic compounds of perchlorates, carbon tetrachloride, and hexavalent chromium, and other heavy metals. Researchers have indicated that zero-valent iron in the nano-scale is very suitable for the transformation and detoxification of a large set of common environmental pollutants. These pollutants include methane and chlorinated ethanes, aromatic chlorinated compounds, insecticides, heavy metals, trihalomethanes, and dioxanes (Abadi, 2016). There are various views about the mechanism of removing pollutants by zero iron nanoparticles. A theory that has been extensively accepted by scientists is reduction reactions due to the iron surface (direct reduction), which causes the removal of pollutants by means of the iron element. Also, there are enough observations in the area of pollutant reduction by primary rusted iron products (secondary reducers).

The results of studies suggest that the theory of pollutant reduction at zero iron level is not acceptable, but pollutant removal generally occurs as a result of adsorption/co-precipitation on/with rusty materials. If the oxidized film is

Table 1: Input factors and intervals

row	Factor	Interval
1	rate of iron nanoparticles (mg/L)	9.0-1.0
3	Initial concentration of dye (mg/L)	40-10

Table 2: Design of experiments

Reponses	Factors		Experiment
Percentage of predicted removal	Initial concentration of dye (X_3)	rate of iron nanoparticles (X_1)	
56.76	30	5.0	1
19.70	40	3.0	2
02.88	20	3.0	3
33.81	40	7.0	4
09.93	30	5.0	5

mainly composed of Fe_3O_4 conductors, electrons can transfer from the zero iron surface to the pollutant and reduce the pollutant. Thus, zero iron acts as a source of corroded products to adsorb pollutants and as a generator of Fe^{2+} and H_2 for potential catalytic reduction of pollutants (Noubactep 2008). Another theory regarding the removal of pollutants by iron zero nanoparticles states that iron zero nanoparticles can oxidize organic and inorganic materials in the presence of oxygen (Joo, Feitz, and Waite 2004). Given what was stated above, the present study aims to investigate the effect of the initial concentration of dye on the percentage of dye removal in wastewater treatment containing acidic yellow 36 dye.

Materials and Methods

In this study, the removal of acidic yellow 36 dye with zero-valent nano-iron was investigated. To find out the interactions, and the effect of the effective parameter on the rate of removal, obtaining the optimal conditions and also saving time by reducing the number of experiments (Liu et al., 2012), Design Expert 9 experiment design software was used. By establishing a mathematical and statistical logical relationship and presenting a mathematical model fitted to the test results, this software makes it possible to compare and analyze existing interactions (Liu et al., 2012). In the experiment designed by this software, the dye concentration was considered in the adsorbent (zero valent nano-iron),

The central composite design (CCD) approach, which is a standard approach in response surface methodology (RSM) and is used in most dye removal optimization articles, was used in the design of this experiment. In this case, the number of experiments proposed by the software will be thirty. Thirty experiments including center points and axial points were designed with the CCD approach to show the effects of each operating factor on the response, which was the rate of dye removal in this experiment. Table 1 shows the selection range of factors affecting the experiment, entered into the software as input. Table 2 also includes the design of the experiments and the values predicted by the software.

Reponses	Factors	Experiment
Percentage of predicted removal	Initial concentration of dye (X_3) rate of iron nanoparticles (X_1)	
69.80	30 1.0	6
91.79	30 5.0	7
04.87	20 7.0	8
21.93	30 5.0	9
06.93	30 5.0	10
73.84	20 3.0	11
97.83	50 5.0	12
48.81	40 3.0	13
71.91	10 5.0	14
69.85	40 3.0	15
19.80	20 7.0	16
25.83	40 7.0	17
01.81	40 7.0	18
50.82	30 9.0	19
96.77	40 7.0	20
37.84	20 7.0	21
21.81	30 5.0	22
09.84	30 5.0	23
39.80	40 3.0	24
02.84	20 7.0	25
17.86	20 3.0	26
25.85	20 3.0	27
05.94	30 5.0	28
09.93	30 5.0	29
09.93	30 5.0	30

In all experiments, synthetic wastewater prepared with powdered dye and distilled water was used to examine the ability to remove dye by iron nanoparticles. Also, nanoparticulate zero-valent iron (NZVI) with 85% purity, a particle diameter of 35-45 nm, and a specific surface area of 42-65 m²/g were purchased from Mehreghan Shimi Company. Consumable dye powder with laboratory grade and with a purity of 99.9% was obtained from Alvan Thabet Company (Iran), which has been used in most of the domestic articles on removing dye from this company's products.

In such experiments, in the first step, standard solutions of the desired dye should be prepared. To obtain the calibration chart, the axes of this chart are the concentration of the standard solutions and the adsorption read by the spectrophotometer, standard solutions with concentrations of 0, 5, 10, 25, and 50 mg/l were made inside a 50 cc balloon. The next step is to read the adsorption of the samples by a spectrophotometer. According to the articles conducted on the removal of acid

yellow 36, the wavelength reported for adsorption of this dye is 545 nm (Wong, Ranjini, and Wan-Nurdiyana 2014).

To control this wavelength, DR 5000 spectrophotometer was used and after placing the dye in the device and adjusting the wavelength in the range of 400-600 nm, the peak of the adsorption chart was observed at 545 nm. Then, the adsorption of the standard solutions was read and recorded in the desired wavelength to draw the calibration chart. All experiments related to dye removal by nanoparticulate zero-valent iron were performed in 100 ml containers that were first filled with 50 ml of distilled water and then iron nanoparticle was added to it. After adding nanoparticles to distilled water, its pH was adjusted, and to increase the efficiency of surface adsorption, increase the contact surface between pollutants and nanoparticles and break the clumps caused by the accumulation of nanoparticles, the prepared solution underwent ultrasonic waves by the ultrasonic device for 10 minutes.

In the next step, 50 ml of dye was prepared at a concentration 2 times the desired concentration and its pH was adjusted. Then, the iron nanoparticle in 50 cc of distilled water that its pH was adjusted and ultrasonicated was placed on the stirrer and the dye solution was added to it. After the reaction at the desired time, the solution was removed from the stirrer, and to complete the reaction, the solution was placed on a magnet so that the nanoparticle was deposited and separated from the solution. Also, to ensure that the separated solution is free of nanoparticles for reading the adsorption by the spectrophotometer, they were passed through nylon syringe tip filters with a pore size of 0.22 μm .

All steps, including the preparation of samples and reagents, as well as the way of analyzing the samples, were performed according to the standard method book (AWWA1999). To

read the adsorption rate by the spectrophotometer, the wavelength of the device was adjusted at 545 nm and the adsorption rate of the samples was recorded. Then, it was placed on the calibration chart and the final concentration was obtained after removal (Wong, Ranjini, and Wan-Nurdiyana 2014).

By comparing the final concentration and the initial concentration, it is possible to find out the rate of dye removal by nanoparticles. The obtained dye removal percentage values were entered into the software to obtain the optimal conditions and obtain the interaction of the effective parameters. The spectrophotometer device used in the experiments is shown in Figure 1.



Figure 1: Spectrophotometer device used in the experiments

Results

Analysis of characteristics

To know the structural characteristics of iron nanoparticles and control the dimensions reported in the purchased nanoparticle catalog, its SEM and TEM images are shown in Figures 2 and 3, respectively.

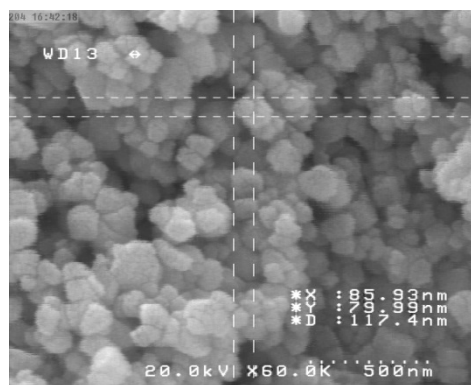


Figure 3: SEM image of iron nanoparticles

As seen, the nanoparticle dimensions are in accordance with the numbers reported in the catalog. It is clearly seen that the nanoparticle dimensions are in the range of 35-45 nm.

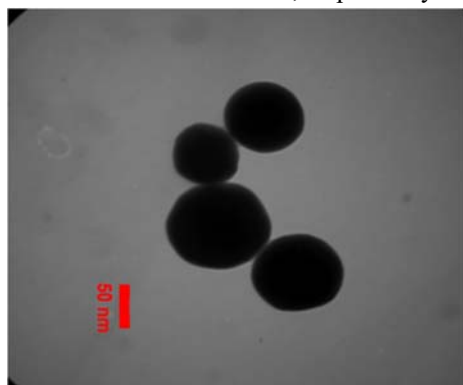


Figure 2: TEM image of iron nanoparticles

Figure 4 shows the XRD spectrum of nanoparticulate zero-valent irons. The main peak shows itself at 44.7° , which indicates zero iron (Kashefialasl et al. 2006).

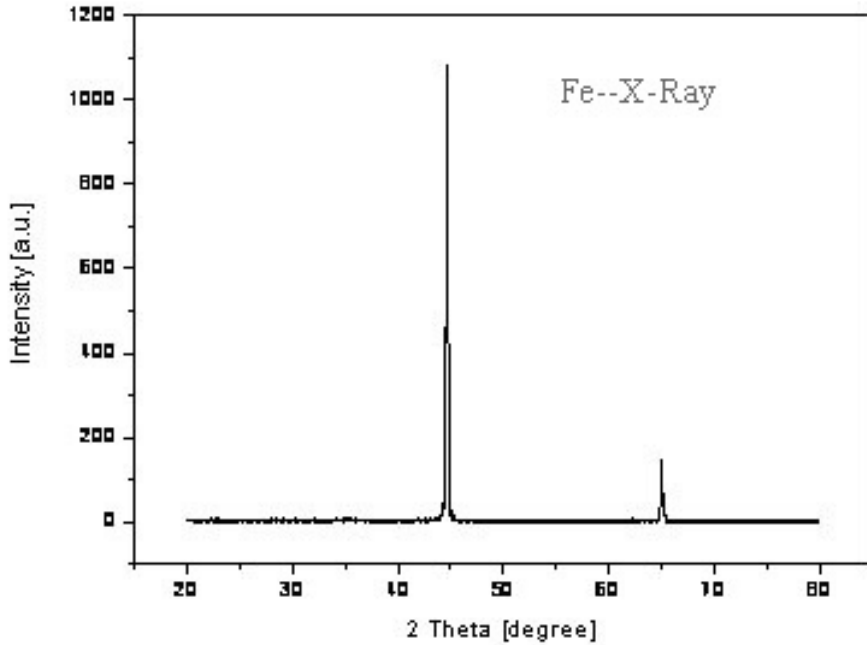


Figure 4: XRD spectrum of nanoparticulate zero-valent iron
Dye removal analysis

Figure 5 shows the rate of base adsorption of specific concentrations of dye.

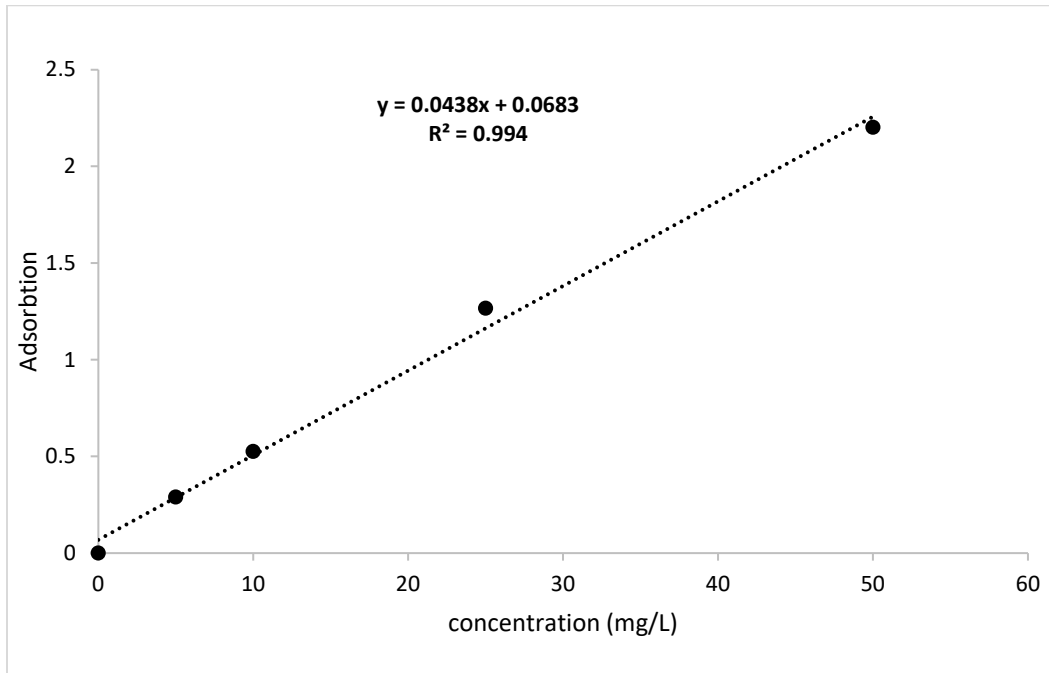


Figure 5: The standard curve of adsorption rate for specific concentrations of acid yellow 36

Conclusion

The present study aims to investigate the effect of the initial concentration of dye on the rate of dye removal in the treatment of wastewater containing acid yellow 36. The results revealed that increasing the concentration of dye from a certain limit greatly reduces the removal efficiency since the number of dye

molecules is more than the available spaces and nanoparticles do not have the ability and capacity to adsorb these molecules. If the number of nanoparticles is low, there will be not enough space (pores) to place and trap dye molecules and the dye removal efficiency will be reduced because the required space has not been provided.

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None.

Conflict of interest

None.

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None.

Ethics statement

None.

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