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Research paper

Development of cost effective bentonite adsorbent coating for the removal of organic pollutant

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ABSTRACT

The present study deals with the development of an innovative cost effective bentonite adsorbent coating (BAC) and simple mathematical equations are applied to enumerate coating requirement in treating textile effluent. The BAC has been successfully used for the removal of cationic dye from industrial wastewater. It has very good potential to be commercialized and applied by industries innovatively on the existing facilities with simple modifications. By installing bentonite coated fins inside tank, the concentration of dye can be easily reduced up to 90%. The BAC demonstrates good temperature and water resistant efficiency which can be easily coated on many surfaces. The best thickness and surface area of BAC for the optimal adsorption of dye (277.8 mg g^{-1}) was found as 87 μm and 1.12×10^{-2} m^2, respectively. The equilibrium adsorption data were best fitted by the Langmuir isotherm which indicates homogeneous monolayer adsorption. The mathematical formula obtained from isotherm model could be used in the removal and recovery of cationic dye (organic pollutant) in textile industry on large scale.

1. Introduction

Water pollution has become a serious environmental threat around the world owing to rapid industrialization and urbanization (Cui and Shi, 2012; Tianlik et al., 2016). It is caused by the addition of chemical and biological substances either naturally or man-made to the natural water bodies. A number of industries (e.g. textile, food, leather, plastics, cosmetics, etc.) used dyes for colouring their products which produce wastewater containing high concentration of organic content in the form of colouring agents. Among these industries, textile industry is recognized as the most chemically intensive industry in the world and it became the number one polluter in clean water after agriculture (Cude, 2001). Textile industries become the worst offenders of water pollution since these industries use > 2000 types of chemicals and over 7000 types of dyes (Noor Syuhadah et al., 2015). During dyeing processes, the percentage of dye lost in wastewater is found about 50% due to the low levels of dye-fibres fixation (Janet et al., 2015; Sultana et al., 2015).

The carcinogenic and mutagenic characteristic of dyes causes severe damage to aquatic life and human beings (e.g. dysfunction of kidneys, reproductive system, liver, brain and central nervous system, etc.) (Bushra et al., 2014; Nabi et al., 2011). Dyes are harmful to environment because of their chemical structure that is resistant to light, chemicals, oxidizing agents, heat and biologically non-biodegradable and thus it is very difficult to be decolourized once released to water source (Özcan and Özcan, 2004). Removal of colouring substances and metal pollutants from wastewater bodies includes various techniques; adsorption (Ab Kadir et al., 2017; Teh et al., 2016; Zahrim and Hilal, 2013), biological (Babu et al., 2011), precipitation (Zhu et al., 2007), coagulation (Zahrim and Hilal, 2013), filtration (Zahrim and Hilal, 2013), ion-exchange material (Nabi et al., 2010; Nabi et al., 2012) and chemical oxidation (Gonawala and Mehta, 2014) which have been studied by many researchers. Adsorption is one of the preferable method applied in chemical industry as it has been shown to be feasible alternative for the removal and recovery of dyes from wastewater due to its low cost, good efficiency and convenient to operate as compared to other methods (Calvete et al., 2010; Santhi et al., 2009). Adsorption onto activated carbon has been found to be superior and extensively used for removing dyes from wastewater compared to other adsorbent (Kamal et al., 2015; Khan and Khan, 2015; Vega et al., 2005). However, available activated carbons are more expensive (Vijayakumar et al., 2012). Therefore, to generate cost effective technique, clay minerals or bentonite have been increasingly gaining attention as they are cheaper than activated carbons, having high surface area and structural properties as well as chemical and mechanical stability (Azha et al., 2015b). Presently, a few studies on adsorption coating of bentonite especially in treating colour agents have been reported (Blaiszik et al., 2010).

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Bentonite based adsorbent coating layer has been invented for the removal of dye in wastewater (Azha et al., 2015a; Azha et al., 2017). Bentonite based adsorbent is made by the mixing of bentonite, water-based paint and solvent in a specific ratio (0.3: 2.5: 2.0). It can be categorized as an effective adsorbent to be used in adsorption process due to its higher dye removal efficiency (99%) (Hu et al., 2006). Consequently, bentonite adsorbent coating layer (BAC) is utilized as a new concept for the adsorption application and aimed to be economical in textile industries. Thus, bentonite supported adsorbent can be applied in industries that are using cationic dyes in their processing by relying on small modifications of the existing facilities. The present work reports development of bentonite adsorbent coating (BAC) for the removal of cationic dye in wastewater.

2. Experimental

2.1. Materials and methods

Methylene Blue (MB) dye and bentonite clay were purchased from Modern Lab Sdn. Bhd. Malaysia and these were used without further purification. The water-based paint was procured from Sissons Paints Sdn. Bhd. The stock solution of MB (1000 mg L^{-1}) was prepared by dissolving 1 g of MB powder in 1 L distilled water and diluted at different concentrations (100, 200, 300, 400, 500, 600, 700, 800, 900 and 1000 mg L^{-1}). Distilled water was used to prepare all solutions throughout the experiments.

2.2. Development of bentonite supported adsorbent coating (BAC)

Bentonite supported adsorbent coating (BAC) was prepared by mixing of bentonite, water-based paint and distilled water in 0.3: 2.5: 2.0 ratio. Water-based paint acts as a binder and consists of calcium carbonate, PVA, formalin, ammonia and hydrosol (Azha et al., 2015b). The mixture was stirred continuously using magnetic stirrer at 150 rpm for the homogeneous dispersion of adsorbent. The adsorbent was coated on the stainless steel plate with the help of brush and dried in oven at 343 K for 10 h.

2.3. Instrument

The equilibrium dye concentrations were measured using UV–Vis spectrophotometer (HASH UV–Vis model DR 5000 spectrophotometer) at a wavelength of 664 nm. Since the UV–Vis spectrophotometer gives reading in term of absorbance, thus, the calibration curve was plotted to know the concentration of unknown dye solution.

2.4. Selection of paint and surface for the coating of BAC

In order to determine the type of paint to be used, several factors including the nature of surfaces to be painted, the age of the surfaces and the type of paint that was previously used on the surface were considered (California Paint, 2016). Literally, water based latex paint was suitable to be coated on material surfaces such as wood, concrete, stucco, brick, galvanized metal, vinyl siding, aluminium siding, etc. (California Paint, 2016). The ferrous, steel and zinc are preferably to be coated with the solvent-paint rather than water-based paint. Therefore, it was proven that the water based paint was suitable to be coated on most of the surfaces tested except some metal substrate such as steel and zinc (Grundmeier et al., 2000). The chosen materials for the coating of BAC were steel, stainless steel, aluminium, zinc, acrylic, glass and ceramic tile. These materials were cut into the same size in the form of plate (0.08 m × 0.12 m) of 0.2×10^{-2} m^2 thickness. To select the best material for making fin, a fixed amount (4.8 g) of BAC (0.3:2.5:2.0) was coated on both surfaces of the plate with surface area of 0.07 m × 0.12 m and the plate was dried in oven at 343 K for 10 h. Thereafter dried plate was cooled down at room temperature (298 ± 2 K). Then, the plate of BAC was immersed in 1.5 L MB solution (100 mg L^{-1}) for 24 h. The solution of MB dye was stirred using magnetic stirrer at 300 rpm. The final concentration of MB solution was determined using UV–Vis spectrophotometer.

2.5. The effect of heating on different surfaces

To study the coating strength and crack effect, the BAC was coated on different metal surfaces (steel, stainless steel, aluminium, zinc, acrylic, glass and ceramic tile), and the experiment was performed by coating the substrates with BAC and drying at 343 K for 10 h. It is important for the samples to be completely dried in order to prevent the peeling of paint from the surfaces.

2.6. The effect of temperature

To examine the ability of BAC to stand at various temperatures the effect of temperature was studied. The plates of BAC were immersed into 100 mg L^{-1} MB solution and heated at different temperatures (303, 313, 323, 333 and 343 K) for 10 h using temperature controlled magnetic stirrer.

2.7. The effect of time on coating strength of BAC by immersing in water

In order to observe the performance of BAC to stand in water for several days, the dried coated plates of BAC were immersed in 2 L distilled water for a month. The observation on the adherence of BAC on the substrates has been made and the result was recorded weekly.

2.8. The effect of turbulent flow on coating strength of BAC

The coating strength of BAC was investigated in the presence of turbulent flow of water by stirrer or aerator. The coated plates were immersed in MB solution (100 mg L^{-1}) and stirred using magnetic stirrer at 300 rpm for 24 h to observe peel of coated adsorbent from the surface of metal.

2.9. Peeling off BAC from substrate surface

Peeling method was carried out to find the best way to remove BAC adsorbent from the surface of substrates. In this regard methods including sanding (sand paper), brushing (nylon, soft brush, steel brush), scraping (end of spatula, aluminium, ceramic, knife, plastic scraper) and solvent (thinner, stain remover, $NaHCO_3$ + water, $NaHCO_3$ + hot water, $NaHCO_3$ + vinegar) were applied.

2.10. The effect of thickness and surface area

The experiment related to the thickness and surface area of BAC was conducted by using constant mass of adsorbent (4.8 g). Four plates were coated by varying thickness and surface area of the adsorbent. The stainless steel plates were dried at 70 °C for 10 h. The MB solution of 70 mg L^{-1} was prepared by diluting the stock solution with distilled water in 0.5 L beaker. The BAC adsorbent plates were immersed in the dye solutions for 24 h and stirred at 300 rpm at 303 K. The thickness of paint was measured using Coating thickness gauge (Nicety model CM 8801F) by taking the average thickness due to inconsistency in BAC coating (average of 10 readings) in order to reduce error.

2.11. The effect of cracking by using different thickness of BAC

The crack effect of different adsorbent coating thickness layers were studied by using same amount of adsorbent (each contain 4.8 g adsorbent) on four stainless steel plates. The BAC was coated on the four plates by varying the surface area of adsorbent coating. First plate was coated on front and back side (0.08 × 0.07 m), second plate was coated