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Computation of adsorption parameters for the removal of dye from wastewater by microwave assisted sawdust: Theoretical and experimental analysis

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ABSTRACT

In this research, the microwave assistance has been employed for the preparation of novel material from agro/natural bio-waste i.e. sawdust, for the effective removal of methylene blue (MB) dye from aqueous solution. The characterization of the newly prepared microwave assisted sawdust (MASD) material was performed by using FTIR, SEM and XRD analyses. In order to obtain the maximum removal of MB dye from wastewater, the adsorption experimental parameters such as initial dye concentration, contact time, solution pH and adsorbent dosage were optimized by trial and error approach. The obtained experimental results were applied to the different theoretical models to predict the system behaviour. The optimum conditions for the maximum removal MB dye from aqueous solution for an initial MB dye concentration of 25 mg/L was calculated as: adsorbent dose of 3 g/L, contact time of 90 min, solution pH of 7.0 and at the temperature of 30 °C. Freundlich and pseudo-second order models was best obeyed with the studied experimental data. Langmuir maximum monolayer adsorption capacity of MASD for MB dye removal was calculated as 58.14 mg of MB dye/g of MASD. Adsorption diffusion model stated that the present adsorption system was controlled by intraparticle diffusion model. The obtained results proposed that, novel MASD was considered to be an effective and low-cost adsorbent material for the removal of dye from wastewater.

1. Introduction

Nowadays, environmental pollution has become an emerging threat because of its persistent effect on the ecosystem. They are mainly due to the negative consequences of the growth of mankind, society and technology. Wastewater generation is one of the great concerns worldwide because of limited water resources and increasing demand for safe water (Khataee et al., 2013). The dyes are well-known water pollutants, which gives anaesthetic or repelling look and also various health problems. They are usually characterized as high chemical oxygen demand and low biochemical oxygen demand which spoils the environment enormously (Dhanapal and Subramanian, 2014). Particularly among various dyes classification, methylene blue (MB) ($C_{16}H_{18}N_3SCl$, C. I. No. 52015) dye is a popular water-soluble cationic dye. These dye molecules were widely found in industrial wastewater which includes colouring paper, dyeing, cottons, wools, silk, leather, textiles and coating of paper stock (Kant et al., 2014). Like most of other dyes, it tends to poses a long term health hazard such as heartbeat increase, vomiting, shock, cyanosis, jaundice, quadriplegia, tissue necrosis in humans, gastritis, mental confusion and methemoglobinemia (Kumar et al., 2014a). Even small amounts of dyes will colour the water body because of their synthetic origin and complex chemical structure (Ghaedi and Mosallanejad, 2014). The dyes in water body are dark enough to weaken the permeability of sunlight and restrict photochemical and biological activities of aquatic life (Goscianska et al., 2014). These dyes have the capability to endanger the aquatic life and environment. On other side, they degrade into compounds which have toxic, mutagenic or carcinogenic effects on living organism (Zhang et al., 2014). Hence, the removal of MB dye from water/wastewater is highly important as an environmental concern. In recent years, various techniques were employed to remove the dye molecules from wastewater (Kumar et al., 2014b). The conventional physicochemical methods for dye removal include advanced oxidation process (Karatas et al., 2012), coagulation (Lia et al., 2016), chemical

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precipitation (Silva et al., 2014), flocculation (Kono and Kusumoto, 2015), flotation (Zodi et al., 2013), photocatalysis (Kant et al., 2014) and membrane separation (Lin et al., 2016). However, these methods are restricted particularly due to the poor breakdown of complex aromatic structure, higher operational cost, technical complexity, by-product generation and incompatibility in removal of MB dye (Argun et al., 2014). In contrast, adsorption process seems to be one of the most competitive methods because they have distinct special features such as high adsorption properties, low cost, low energy requirement and simple operations (Ahmed and Gasser, 2012). Several adsorbents such as yolk shell (Zheng et al., 2014), silica gel (Perullini et al., 2014), chitosan (Maity and Ray, 2014), clay (Lia et al., 2016), polymer (Dhanapal and Subramanian, 2014), zeolite (Yurekli, 2016), sawdust (Politi and Sidiras, 2012), activated carbon (Ghaedi and Mosallanejad, 2014), industrial biowaste (Guzel et al., 2014), peel (Argun et al., 2014), plant (Kant et al., 2014), algae (Khataee et al., 2013) were synthesized and utilized for adsorption process. The removal of dye from wastewater by adsorbent is frequently depends on the different properties such as surface area, functional atom or group, reusability and non-toxicity. Synthesis and modification of the adsorbent material using the microwave radiations has received considerable attention because which increases the affinity of adsorbent to adhere more solute from aqueous solution. Microwave radiation poses both electrical and magnetic properties. Generally, the adsorbents are exposed to the microwave radiation the molecules are tending to vibrate by induced or permanent dipoles (Moradi, 2014). The intensity of vibration is determined by the amount of microwave energy absorbed by the adsorbent material. This intensity of vibration results in enhancing the size, shape and polarizability of the molecules, as well as, extent of intermolecular bonding of the adsorbent materials.

In the present research, the microwave assisted saw dust (MASD) was synthesized for the purpose to remove the methylene blue (MB) dye molecules from aqueous environment. The effectiveness of the adsorbent material was identified by its characterization studies namely Fourier transform infrared spectroscopy (FTIR), Scanning electron microscope (SEM) and X-Ray diffraction (XRD) analyses. The adsorption influencing parameters such as initial MB dye concentration, solution pH, adsorbent dosage and contact time were optimized. The evaluated data from these studies were used to discuss about the different adsorption isotherm, kinetic and mechanism models. Also the performance of the newly prepared adsorbent was compared with the other adsorbents for the removal of MB dye from aqueous solution.

2. Materials and methods

2.1. Collection and preparation of precursor for adsorbent preparation

Agricultural waste biomass, saw dust, was used as a precursor for the preparation of adsorbent material for the removal of MB dye from aqueous solution. The saw dust was collected from wooden furniture works (Kelambakkam, Tamilnadu, India). The collected sawdust was initially washed with deionized water several times to remove the dust particles and other impurities. After that, this saw dust was dried in hot air oven (Industrial and Laboratory Tools Corporation, Chennai) at the temperature of 80 °C and then the dried sawdust was grinded to fine powder. After grinding, saw dust was sieved to obtain the fine powder to use for the preparation of adsorbent. This prepared material is referred as raw sawdust. This ensuring material was further proceeding to pyrolysis treatment. Before that, the powdered raw sawdust was dried at 125 °C for 6 h using hot air oven (Industrial and Laboratory Tools Corporation, Chennai) with the inner dimension of 455 mm (W) × 605 mm (H) × 455 mm (D).

2.2. Microwave assisted pyrolysis of sawdust

Pyrolysis of sawdust was carried out in a microwave cavity oven (Panasonic-NN-CT254B, India). The heating area of the oven is 46.1 cm × 28.9 cm × 37.7 cm and this has a maximum output power of 800 W. In a typical experiment, 100 g of dried sawdust was taken in the two-neck round bottom quartz flask and this was placed inside the microwave cavity. Appropriate holes were made in the oven such that the flask can be connected for nitrogen supply and condenser set-up. The outlet of the first condenser was connected to the second and subsequently to the third to condense most of the volatiles escapes during pyrolysis process. Water was used as the coolant in the condensers. Before the start of experiments, the flask containing raw sawdust was purged with nitrogen for about 10 min to create an oxygen free environment, and further continued till the completion of pyrolysis reaction. Since microwave heating assists in fast pyrolysis, a sufficient time of 10 min was kept to achieve complete pyrolysis (conducted based on preliminary experiments). Due to rapid microwave heating, continuous monitoring of temperature was not possible; however, the observed temperature at the end of the pyrolysis reaction was in the range of 400–500 °C. At the end of experiments, most of the liquid products (bio-oil) remained in the round bottomed flask connected to the bottom of first condenser, and only few drops oils were present in the second condenser set-up. All the bio-oil were collected in a single tight sealed Teflon coated container, and analyzed further. The obtained solid bio char referred as microwave assisted sawdust (MASD) in the quartz flask was allowed to cool and then weighed. The non-condensable gases were left into the atmosphere. This prepared MASD was utilized as an effective adsorbent for the present adsorption studies.

2.3. Preparation of methylene blue dye solutions

In this present adsorption study, methylene blue (MB) dye was used as an adsorbate. MB dye is a cationic dye which has a molecular formula of $C_{16}H_{18}N_3ClS{\cdot}3H_2O$ and molecular weight of 373.90 g/mol. A stock solution of 1000 mg/L of MB dye solution was prepared by dissolving required amount of MB dye into the double distilled water. Since different concentrations of MB dye solution were required for adsorption studies namely 25–150 mg/L. The required concentrations of MB dye solutions were attained by diluting the stock solution with double distilled water. The pH of each working solutions were adjusted to the required value by using 0.1 M NaOH or 0.1N HCl before mixing the adsorbent.

2.4. Chemicals and apparatus

The MB dye was purchased from E. Merck Chemicals, India. The required pH of the different concentration of MB dye solution was maintained by using 0.1N HCl and 0.1N NaOH. pH meter (HI 98107; Hanna Equipment Private Limited, Mumbai, India) was used to measure the pH of aqueous solution. A double beam UV visible spectrophotometer (Model V630, JASCO Analytical Instruments, Japan) was used to find out λ_{max} and to measure the concentration of MB dye in the supernatant solution before and after the adsorption process. The presence of several important functional groups on the surface of the MASD was identified by using FTIR spectrometer (Perkin Elmer FTIRC 100566, UK). The crystalline phase of MASD was determined by using X-Ray diffraction technique. The surface morphology of MASD was analyzed by using Scanning electron microscopy (Leo Gemini 1530 model) at an accelerating voltage of 5 kV.