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Treatment of Tire Industry Wastewater through Adsorption Process using Waste Tire Rubber

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ABSTRACT

Attempts to use waster rubber powder as an adsorbent of pollutants in wastewater treatment applications is an environmentally friendly, efficient and novel method, especially in the tire industry wastewater treatment process. This study evaluated the efficiency of waste tire rubber powder in adsorbing the tire industry wastewater. The rubber and The wastewater were prepared from Kavir Qom Co. and Artawheel Tire Co., respectively. Comparison of UV-vis spectrophotometer results of the nontreated wastewater with the wastewater data after adsorption under various thermal and temporal conditions indicated that the tire powder adsorbent has the necessary efficiency for treating the tire industry wastewater. Examination of data with pseudo-first- and second-order kinetic models also confirmed the adsorbent's efficiency and showed that the second-order kinetic model had a good correspondence with the obtained results.

GRAPHICAL ABSTRACT

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Introduction

Around 1.5 billion tires are produced annually, with 1000 million becoming worn out. In 2030, it is predicted that the number of waste rubber will reach 1200 million tires [1]. Unique geometric shapes and impermeable tires have made tiresretain water for a long time in them, thereby becoming a habitat for mosquitos and many pests [2]. The simplest method for discarding waste tires is incineration, which is very harmful. Burning tires leads to the emission of toxic gases containing harmful and dangerous compounds for living creatures [2]. Artificial tires are made of styrene monomers and butadiene. With the incineration of tires, various benzene and carcinogenic compounds are released alongside black fume, impairing vision and dirtying colored surfaces. Accumulated waste tire causes health, environmental and economic risks by contaminating air, water and soil. The use of tires as fuel causes the generation of soot/fume and air pollution. This usage as fuel is not commercially economical because of its high price and low quality [3].

Waste rubber and wastewater from factories are both environmental problems [4]. Attempts to use waster rubber powder as an adsorbent of pollutants in factories' wastewater is an environmentally friendly, efficient and novel method [5-8]. Dan Vanichacol *et al.* examined the effect of NR rubber powder in adsorbing mercury from polluted groundwaters. They found that the mercury absorptivity diminished with an elevation of the wastewater pH [9]. Tarin *et al.* (1974) employed vehicle waste tire/rubber and could remove mercury from wastewater satisfactorily via an absorption mechanism [10]. Buka *et al.* demonstrated that rubber particles can absorb metal ions. According to the results, the absorptivity of zinc, magnesium, iron, strontium, aluminum, manganese, cadmium, lead and rubidium metal ions diminished with baked rubber [11]. In 2016, Lemim *et al.* modified the surface of waste rubber granulated with poly(3-acrylamidopropyl) and could acceptably remove arsenate and arsenide compounds from wastewater. They showed that adding 0.1 M HCl to the granulated and modified rubber particles could cause a release of more than 92% of the adsorbed compounds [12].

The application of waste tire in powder or activated carbon as an adsorbent for removing metal ions and organic compounds has been reported in Literature. To the best of our knowledge, the treatment of the tire industry wastewater using waste rubber powder has not been reported earlier. This study aims to examine the efficiency of waste rubber powder as an adsorbent for wastewater treatment of the tire industry wastewater. The effects of the adsorption temperature and time on the wastewater adsorption efficiency were examined. The UV-Vis Spec. analysis results were used to study the adsorption kinetics based on the pseudo-first- and second-order kinetic models.

Experimental

Materials

The rubber was prepared from Kavir Qom Co. in 2-5 mm sizes. The wastewater tire industry was prepared by Artawheel Tire Co., Iran.

Adsorption studeis

In a typical procedure, 5 kg of the prepared powder was thoroughly mixed each time before usage to keep the equality of experimental conditions. Then, 10 L of Artawheel Tire Co. wastewater was collected in one day; before each experimentation, the entire wastewater was stirred and the required amount was withdrawn. To perform each stage of adsorption, 20 g of rubber powder was poured into an Erlene-Meyer flask 250 cc, to which 100 cc wastewater was added and placed on a shaker for specific intervals (5, 10, 15, 30, 60, 90 and 120 min). Once the adsorbent-wastewater contact time was finished, the mixture was centrifuged at 6000 rpm.

UV-vis spectrophotometer (Nanolytik, Germany) was used to determine the extent of adsorption. At each stage, after completion of the experiment, the wastewater and rubber powder was replaced so that the results of the experiments would not interfere with each other. Based on examining the results of the UV-vis spectrophotometer of the nontreated wastewater, peak 490 was chosen as the reference peak because of no interference and the peak's prominence. To ensure the accuracy of results, each stage of the experiment was repeated three times.

The extent of adsorption capacity or wastewater adsorption rate was calculated using the following Eq. (1):

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

Where, C_0 (mg/L) represents the initial wastewater concentration and C_e (mg/L) denotes the final concentration of the wastewater after adsorption, M is the mass of the rubber powder adsorbent and V is the solution volume.

Thermodynamic studies

To explore the effect of temperature on the adsorption process, the adsorption tests were conducted under three different temperatures of 30, 40 and 50 °C. The thermodynamic parameters, including the change in free energy ($\Delta G°$), enthalpy ($\Delta H°$) and entropy ($\Delta S°$), were calculated from Eq. (2-4):

$$K_c = \frac{C_A}{C_s} \quad (2)$$

$$\Delta G^0 = -RTLnK_c \quad (3)$$

$$lnK_c = \frac{\Delta S^0}{R} - \frac{\Delta H^0}{RT} \quad (4)$$

Where K_C is equilibrium constant; C_A is the sum of adsorbed waste (mg/L); C_S is waste concentration in solution at equilibrium (mg/L); R is equal to 8.314 $J.mol^{-1}.K^{-1}$, T is the temperature (K), $\Delta G°$ is the Gibbs free energy, $\Delta H°$ is the slope of ln K_C versus 1/T and $\Delta S°$ is the intercept of ln K_C versus 1/T [13].

Kinetic studies

The time-dependent adsorption results were analyze using the linear forms of pseudo-first-order (Eq. (5)) [14], pseudo-second-order (Eq. (6)) [15] kinetics models as follows:

$$Log(q_e - q_t) = logq_e - \frac{k_1 t}{2.303} \quad (5)$$

$$\frac{t}{q_t} = \left(\frac{1}{k_2 q_e^2}\right) + \left(\frac{t}{q_e}\right) \quad (6)$$

Where q_e and q_t are the adsorption quantities (mg/g) of waste at equilibrium and at any time t, respectively; k_1 (min^{-1}) and k_2 [g/(mg. min)] are pseudo-first-order equation’s rate constant and pseudo-second-order equation’s rate constant, respectively.

Results and discussion

The effect of contact time

The contact time of wastewater and waste rubber powder as adsorbent is critical in practical uses of the adsorption process. As illustrated in Figure 1, the adsorption capacity of rubber powder grows dramatically with time in the primary stages. With the decline of the adsorption rate at 60 min, the curve ascends until reaching equilibrium. The presence of microscopic adsorption voids on the rubber powder at initial times is the reason for this ascending trend. Then, with a reduction of the adsorption sites for the rubber powder, the wastewater adsorption occurs at a lower rate until reaching equilibrium adsorption, whereby there are no more adsorption sites on the adsorbent. As revealed in Figure 1, the equilibrium adsorption time can be considered 60 min.

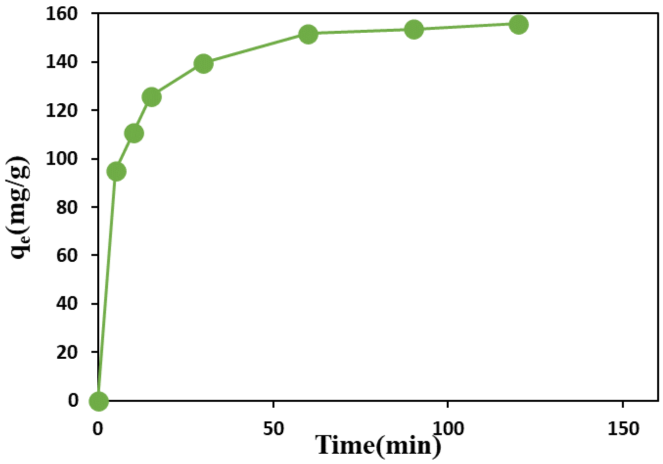

Figure 1. The changes of the adsorption capacity by time using the waste rubber powder

Thermodynamic study results

To evaluate the thermodynamic parameters, the adsorption capacity was measured at various temperatures of 30, 40 and 50 °C using the waste rubber powder.

Figure 2 shows the plot of ln K_C versus 1/T. According to the linear integration, since the enthalpy and entropy of this process have positive values [9], thus adsorption is an endothermic process; with temperature elevation, the extent of wastewater adsorption on the rubber powder surface increases. Positive entropy value suggests randomness of the rubber powder-wastewater interface, which has increased along the adsorption process.

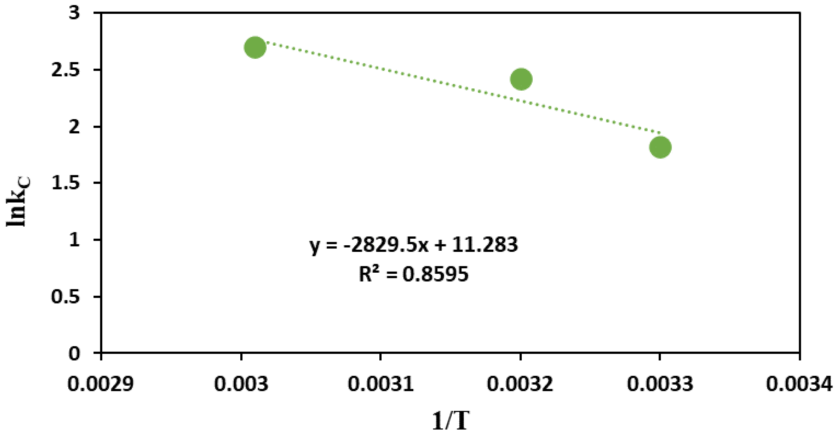

Figure 2. The thermodynamic Plot of ln K_C versus 1/T for wastewater adsorption using waste rubber powder

Adsorption kinetic results

The wastewater adsorption kinetic is essential in assessing the adsorbent efficiency for treating industrial wastewater.

As illustrated in Figures 3 and 4, pseudo-first- and second-order kinetic models were used for evaluating the obtained results.

The results show that the correlation coefficient has been larger in the pseudo-second-order equation. Also, the values of q obtained for the rubber powder adsorbent have a greater match with q_{exp}. The variable of k_2 for the adsorbent has been smaller than k_1, suggesting the suitability of the pseudo-second-order kinetics.

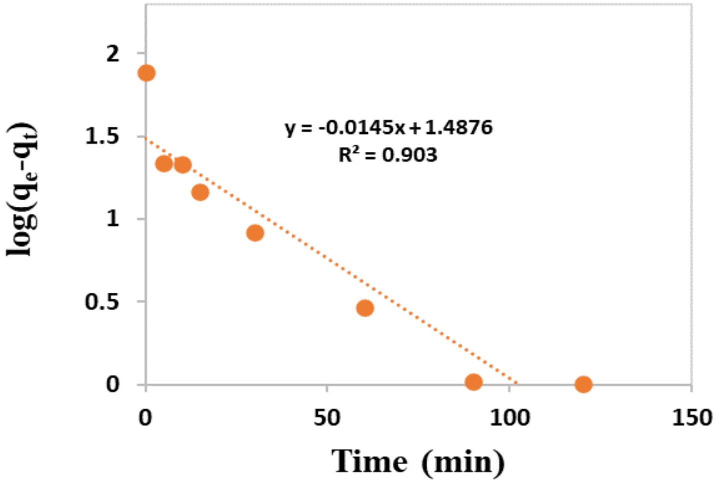

Figure 3. Pseudo-first-order kinetic model for the adsorption of tire industry wastewater using the waste rubber powder

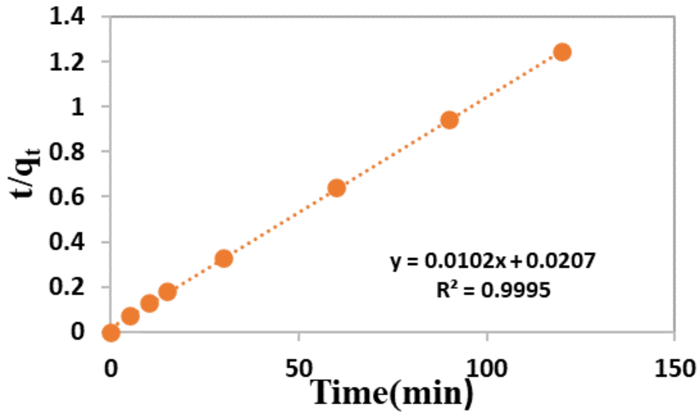

Figure 4. Pseudo-second-order kinetic model for the adsorption of tire industry wastewater using the waste rubber powder

In Table 1 the adsorption capacity of waste tire powder is compared with the several waste tire based adsorbents. The comparison supports that the untreated tire powder used in this study has relatively good adsorption performance compared to others.

Table 1 Comparison of the adsorption performance of several waste tire based adsorbents

Adsorbent	Pollutant	Maximum adsorption capacity (mg/g)	Ref.
sulfuric acid treated waste tire material	Tetracycline in deionized water	303	[16]
nano-zinc oxide doped scrap tire derived activated carbon	Cr (VI) in deionized water	152	[8]
activated carbons derived from tire char	Pesticides in deionized water (methoxychlor, atrazine and methyl parathion),	88.9-112	[17]
Collagenic waste and rubber based resin-cured biocomposite	Safranine in deionized water	156.6	[18]
Untreated waste tire powder	The wastewater of Tire company	155	This study

Conclusion

The obtained results showed that waste rubber powder is an inexpensive, durable and available adsorbent, causing significant reductions in pollutants from wastewater of Artawheel Tire Co. as a real sample. The UV-vis spectrophotometer results showed that the rubber powder could lower the wastewater adsorption characteristic peak. The maximum adsorption capacity of the waste rubber powder was 155 mg/g. Thermodynamic studies reveals an endothermic asorption process. Moreover, the kinetic results revealed a good match of data with the pseudo-second-order model. The adsorption data obtained for the rubber powder justifies the usability of this adsorbent for industrial consumption purposes.

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Disclosure statement

The authors reported no potential conflict of interest.

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