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Kinetic mass transfer adsorption model for treating dairy wastewater with stone cutting solid waste

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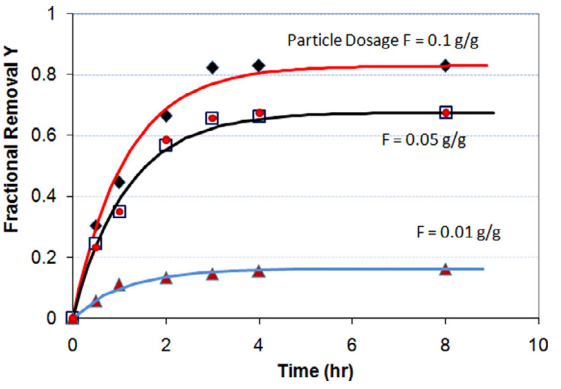
HIGHLIGHTS

- A closed form solution is obtained for a presented kinetic adsorption mass transfer model.
- The effects of the various parameters on the theoretical kinetic curves are presented and discussed.
- The model is used to fit experimental curves for treating dairy wastewater with stone cutting waste.

GRAPHICAL ABSTRACT



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ABSTRACT

This paper presents a mass transfer model for the kinetics of the batch adsorption process, with a closed form solution. The model is applied to the adsorption of organic pollutants from the industrial wastewater onto mineral particles obtained from stone cutting waste. Theoretical adsorption curves are plotted as dimensionless concentration in the wastewater, and on the particle surface, as functions of the dimensionless time. They are obtained from the mathematical solution of a system of ordinary differential equations, derived from the differential mass balance and the rate equation. The effects of the dimensionless equilibrium parameter, the particle dosage and the mass transfer coefficient on the fractional removal of the pollutants are presented. Experimental adsorption data for treating dairy wastewater with stone cutting solid waste are fitted well with the model. A simplified fitting methodology is illustrated. The obtained fitting parameters, including the equilibrium and the mass transfer coefficients, are summarized.

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Nomenclature

a	Specific surface area of the sample ($cm^2\ g^{-1}$).
c	Concentration of the solute in the bulk of liquid phase ($g\ cm^{-3}$).
C	Dimensionless concentration of the solute in the bulk liquid phase
c_e	Equilibrium concentration of the solute in the bulk of liquid phase ($g\ cm^{-3}$).
Er	The sum of the deviations squared between the experimental value (Y_{exp}) and the theoretical value (Y).
F	Particle dosage in wastewater ($g\ cm^{-3}$).
K	Distribution coefficient ($cm^3\ g^{-1}$).
k_L	Mass transfer coefficient ($cm\ s^{-1}$)
q	Surface concentration of the solute (pollutant) on the adsorbent ($g\ g^{-1}$)
Q	Dimensionless surface concentration of the solute (pollutant) on the surface of adsorbent.
t	Time (s).
V	Total volume of the adsorption vessel (cm^3)
Y	Fraction removal of the pollutant from wastewater.
Y_e	Equilibrium fraction removal of the pollutant from wastewater.
Y_{exp}	Experimental fractional removal.

Greek letters

ε	Void fraction which is occupied by the liquid phase.
ρ_s	Particle density of the adsorbent ($g\ cm^{-3}$).
θ	Dimensionless time.

1. Introduction

Adsorption onto solid surfaces has various industrial and environmental applications. Wastewaters discharged from industry are usually polluted with organics, chemicals, and heavy metals, …etc (Crini, 2005). In wastewater treatment, various types of adsorbents are used to remove pollutants. Investigated adsorbents included particles ranging from micro to nano levels (Pollard et al., 1992). Research in this field covers experimental and modeling works. Scientific background of the modeling aspects is summarized here.

In dairy wastewater treatment (and similar cases), adsorption of organics is believed to be of a physical type; it is controlled by the mass transfer of the solute from the liquid bulk towards the surface of the solid particles (Zahdeh et al., in press). Recently, the technical feasibility and the kinetic behavior of adsorption of organic pollutants from dairy wastewater onto various natural mineral particles were investigated experimentally (Al-Jabari et al., 2015). Adsorbents investigated included particles of marl stone, stone cutting solid waste, and soil. In other previous studies, the author and coworkers handled the chemical adsorption of heavy metals onto similar mineral particles (Al-Jabari et al., 2012, 2009b,a). Differences in equilibrium and kinetic behaviors were observed between the two systems. Langmuir and linear equilibrium models were used for equilibrium modeling.

Kinetic modeling work covered the two types of operations: fixed bed columns (Xu et al., 2013; Shafeeyan et al., 2014) and batch processes (Hameed et al., 2009; Imaga and Abia, 2015; Ahmad et al., 2007; Mittal et al., 2015; Demirbas et al., 2004; Ho and McKay, 1998; Cruz et al., 2004; Karaca et al., 2004; Wang and Li, 2007; Hameed and El-Khaiary, 2008; Guzel et al., 2015; Ho, 2006). This paper focuses on batch adsorption models.

In most kinetic batch adsorption models, empirical equations were used to describe the concentration of pollutant in wastewater as a function of time. The used empirical models include: Lagergren pseudo-first order model, pseudo-second-order model, and Elovich models. Ho reviewed the second-order models for adsorption systems (Ho, 2006). A more recent critical review of the adsorption kinetic models is available in the literature (Qiu et al., 2009). Other published modeling approaches included: intra-particle diffusion modeling (Wang and Li, 2007; Hameed and El-Khaiary, 2008; Guzel et al., 2015; Qiu et al., 2009), site adsorption modeling (Manning and Goldberg, 1996), thermodynamic framework and Langmuir kinetics (Sun and Chakraborty, 2015), and general kinetic rate equation (Qiu et al., 2009). Tosun determined kinetic parameters by analyzing an nth-order kinetic model, and a double exponential model (Tosun, 2012).

Mass transfer analysis based on the diffusion equation was used for modeling adsorption in packed beds. This was done by coupling the particle diffusion model with the axial diffusion equation (Xu et al., 2013). Qiu highlighted the use of the mass transfer rate equation in adsorption modeling (Qiu et al., 2009). Yao estimated the film mass transfer coefficient from the initial adsorption rate (Yao and Chen, 2015).

From the modeling point of view, the reversible adsorption process is the reverse process of solid/liquid extraction, and the reverse process of the supercritical fluid extraction (SFE). Physically, the two transport processes differ in the solute transfer direction (Al-Jabari, 2002). Thus, extraction is analogous to the reversible adsorption processes. Such a transport similarity was used to make an analogy between SFE and conventional reversible adsorption processes (Al-Jabari, 2002). Such an analogy was used to establish models for SFE (Al-Jabari and Weber, 1999; Al-Jabari, 2003). The transport analogy