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A new approach for scaling up fixed-bed adsorption columns for aqueous systems: A case of antibiotic removal on natural adsorbent

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ABSTRACT

The scaling up of adsorption columns is a crucial step toward the removal of emerging pollutants from domestic and industrial wastewaters. In this study, a fixed-bed column to remove sulfamethoxazole packed with sugarcane bagasse was scaled up from laboratory (D_L = 2.2 cm) to pilot unit (D_P = 4.4 cm) using a scaling factor (K = 2). In addition to the basic similarity rules for scaling, three new criteria were proposed for the mass adsorbent, flow rate, and bed volume. Then, three lab-scale tests at flow rate of 5 mL/min and bed heights of 15, 25, and 35 cm were transferred to the pilot-scale column at flow rate of 20 mL/min and bed heights of 30, 50, and 70 cm, respectively. The breakthrough curves and the fixed-bed parameters (residence time t_R, saturation time t_s, adsorption capacity q_e, volume of solution treated V_{ef}, and removal percentage $\%R$) obtained in both scales were compared to define their effect with the increase of scale. Finally, a mechanistic model was proposed to predict the breakthrough curves in both columns. The results exhibited that the breakthrough curves in the pilot-scale prolonged in time with higher breakthrough and saturation times than the laboratory breakthrough data. Additionally, t_R, t_s, and V_{ef} changed in function of the K value used: t_s and t_R doubled their value in the pilot column or $t_{RP} = Kt_{RL}$; V_{ef} was eight times higher in the pilot column than the lab-column or $V_{efP} = K^3 V_{efL}$; q_e and $\%R$ remained constant in both scales; these results were corroborated with the predicted breakthrough curves. Besides, the mechanistic model predicted with great precision the breakthrough data in both scales ($R^2 > 0.9$), which means that the model can be used confidently for scaling up purposes. This study demonstrated new criteria which can be easily applied to scale up adsorption columns whit results that showed a correlation between both scales.

1. Introduction

Liquid-phase adsorption is an age-old process that has been widely used to remove conventional pollutants from industrial wastewaters and drinking water supplies. Initially, it was used to remove heavy metals, pesticides, herbicides, detergents, nitrosamines, trihalomethanes, and other pollutants from aqueous environments using conventional adsorbents like activated carbon, silica gel, clays, among others. However, recently, liquid-phase adsorption has become one of the most studied technologies for removing emerging pollutants such as residues of antibiotics, analgesics, and anti-inflammatory agents (Ahmed and Hameed, 2018). The positive reception for this technology is due to its multiple benefits such as easy operation, high performance at low contaminant concentrations, simple design, and regeneration of used adsorbents; the process is even more conducive and cheaper when agro-industrial residues are employed as adsorbents since there is no significant cost associated with the material's synthesis.

Natural adsorbents, such as sugarcane bagasse (SB), are locally available in large amounts in Ecuador and have not been harnessed yet in any practical application. Therefore, SB might be a potential adsorbent to remove emerging pollutants from aquatic systems. In particular, antibiotics like sulfamethoxazole (SMX) presents a risk to human health as it can contribute to the development of bacteria resistant to antibiotics. To date, SMX has been found in distinct aquatic environments, including wastewaters, groundwater, surface water, and even drinking water (Anh et al., 2021; Ashfaq et al., 2019; Meng et al., 2021). Consequently, aquatic animals and human beings are constantly exposed to SMX through the consumption of contaminated water or food, which represents a great threat to food safety and human health. Accordingly, SMX must be removed entirely, and adsorption is an economical, green, and clean technology for this purpose (Torres, 2020).

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