



# Fixed-bed adsorption for industrial wastewater purification: An in-depth review

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## Abstract

The increasing discharge of industrial wastewater contaminated with hazardous pollutants requires innovative and efficient treatment technologies. This review addresses the potential of fixed-bed adsorption systems for the effective removal of a wide spectrum of contaminants from industrial effluent. It explains the basic principles, characteristics and mechanisms of fixed-bed adsorption systems and examines important factors affecting their performance. Through a comparative analysis of different adsorption models, the paper provides insights into the efficiency and applicability of these models in assessing the characteristics of adsorption system using breakthrough curves. The findings advocate for policy support to integrate fixed-bed adsorption technologies into existing wastewater management systems to improve environmental protection and public health.

**Keywords** Adsorption · Fixed-bed adsorption · Fixed-bed column design · Industrial wastewater · Mathematical models

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## Introduction

Access to water is essential for the survival of all living beings. However, water sources are increasingly threatened by industrial wastewater containing harmful substances such as dyes and heavy metals. In response to these challenges, countries have enacted strict regulations, such as the Industrial Effluents Directive 2009 in Malaysia, which mandates the treatment of industrial effluents to meet certain environmental standards before they are discharged into water bodies. Various technologies have been developed to meet these standards, including coagulation, flocculation, membrane filtration, microbial degradation, chemical oxidation and ozonation (Aniagor et al. 2021; Bushra et al. 2021). Despite their effectiveness, these methods can generate toxic by-products, incur high maintenance costs and involve complex operating procedures (Lin et al. 2023; Sağlam et al. 2023). As a result, adsorption has become the preferred method in the industry due to its straightforward operation, high efficiency and potential reusability (Zhang et al. 2021b; Zhao et al. 2021). The availability of various adsorbents, especially environmentally friendly options, emphasizes the importance of adsorption for the removal of industrial contaminants and promotes environmentally friendly development in industrial practice (Nureen et al. 2023a, b).

