



## Review

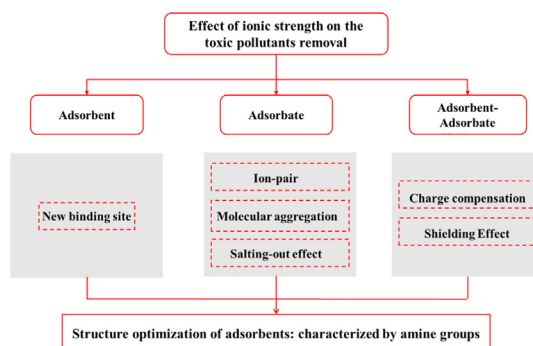
## Effects of ionic strength on removal of toxic pollutants from aqueous media with multifarious adsorbents: A review

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## HIGHLIGHTS

- Six key aspects on the interaction and mechanisms of ionic strength were reviewed.
- The structural optimization of adsorbents affected by ionic strength was detailed.
- Polyamine materials with exciting “salt-promotion” effects were highlighted.

## GRAPHICAL ABSTRACT



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## ABSTRACT

Adsorption is one of the most widely used and effective wastewater treatment methods. The role of ionic strength (*IS*) in shaping the adsorption performances is much necessary due to the ubiquity of electrolyte ions in water body and industrial effluents. The influences of *IS* on adsorption are rather complex, because electrolyte ions affect both adsorption kinetics and thermodynamics by changing the basic characteristics of adsorbents and adsorbates. For a given adsorption system, multiple or even contradictory effects of *IS* may coexist under identical experimental conditions, rendering the dominant mechanism recognition and net effect prediction complicated. We herein reviewed the key advancement on the interaction and mechanisms of *IS*, including change in number of active sites for adsorbents, ion pair for metal ions, molecular aggregation and salting-out effect for organic compounds, site competition for both inorganic and organic adsorbates, and charge compensation for adsorbent-adsorbate reciprocal interactions. The corresponding fundamental theory was thoroughly described, and the efforts made by various researchers were explicated. The structural optimization of adsorbents affected by *IS* was detailed, also highlighting polyamine materials with exciting “salt-promotion” effects on heavy metal removal from high salinity wastewater. In addition, the research trends and prospects were briefly discussed.

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## Contents

|   |     |
|---|-----|
| 1. Introduction . . . . .   | 266 |
| 2. Dominant mechanisms for adsorbents: change in number of active adsorption sites. . . . . | 266 |
| 2.1. Availability variations of binding sites . . . . .                                     | 266 |
| 2.2. Creation of new binding sites . . . . .  | 267 |

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|        |   |     |
|--------|---|-----|
| 3.     | Dominant mechanisms for adsorbates . . . . .  | 268 |
| 3.1.   | For inorganic pollutions: ion pair and activity coefficient . . . . .   | 268 |
| 3.2.   | For organic pollutions . . . . .  | 269 |
| 3.2.1. | Molecule aggregation . . . . .  | 269 |
| 3.2.2. | Salting-out effect and hydrophobic interaction . . . . .  | 270 |
| 3.3.   | For both inorganic and organic pollutions: site competition . . . . .   | 271 |
| 4.     | Dominant mechanisms for adsorbent-adsorbate reciprocal interactions: charge compensation and shielding effect . . . . . | 272 |
| 5.     | Structural optimization of adsorbents based on ion strength effect . . . . .  | 274 |
| 5.1.   | Methods for enhancing dispersion properties of granular adsorbents . . . . .  | 274 |
| 5.1.1. | Surface modification . . . . .  | 274 |
| 5.1.2. | Doping and supporting technology for composite preparation . . . . .  | 275 |
| 5.2.   | Methods for enhancing resistance to site competition . . . . .  | 275 |
| 5.2.1. | Ion/molecular imprinting technology . . . . .   | 275 |
| 5.2.2. | Polyamine adsorbents and “salt-promotion” effect . . . . .  | 275 |
| 6.     | Conclusion and perspectives . . . . .   | 276 |
|        | Acknowledgements . . . . .  | 276 |
|        | References . . . . .  | 276 |

## 1. Introduction

The indiscriminate disposal of contaminants such as heavy metals and organic chemicals into surface and ground water has become a major focus of public and policy debates, due to potential hazardous effects on the availability and potability of freshwater sources (Ma et al., 2018; Zhang et al., 2015; Cheng et al., 2018a). These pollutants possibly enter the food chain without appropriate monitoring or forewarning measures, and eventually threaten human health. Therefore, it is much necessary to remove contaminants from wastewater before their release into the environment (Wilkinson et al., 2017; Tran et al., 2018), and to effectively and simply treat contaminated water (Mohan et al., 2014). Adsorption is one of the most effective strategies to remove various toxic pollutants from aqueous solutions owing to simple design, convenience, low cost, high adsorption efficiency and wide adaptability (An et al., 2011; Shen et al., 2018; Ersan et al., 2017). Various materials like carbon nanotubes (Xu et al., 2018a), graphene (Peng et al., 2017), layered double hydroxides (Gu et al., 2018), metal-organic frameworks (Li et al., 2018a), nanoparticle (Zou et al., 2016a) and boron nitride (Yu et al., 2018) has been widely used to separate pollutants from aqueous solutions. They possess excellent ability in pollutants decontamination but hardly conclude effect facts in removal process systematically.

As is known to all, adsorption can be improved based on two fundamental aspects. One is the preparation of new adsorbents with excellent performances for pollution control, and the other is the optimization of adsorption conditions. The adsorption performance of a given adsorbent varies as a function of adsorption conditions among which ionic strength (*IS*), defined as Eq. (1) (Yang et al., 2013a), is of great importance, especially in actual wastewater treatment (Wang et al., 2012; Jiang et al., 2013).

$$I = \frac{1}{2} \sum z_i^2 c_i \quad (1)$$

where *I* is *IS*, *z<sub>i</sub>* and *c<sub>i</sub>* present the ionic charge and concentration of ion *i* respectively. In this review, ion *i* broadly covers common electrolyte or inorganic salt ion existing in water body and wastewater effluents.

Vast point and non-point sources during industrial production and agricultural cultivation largely contribute to effluents usually containing undesired quantities of salt cations and anions that coexist with toxic organic or inorganic pollutions (Chen et al., 2017a; Rashid et al., 2017). Generally, toxic heavy metals are commonly co-detected with high-level inorganic salts, including Na(I), K(I), Ca(II), Mg(II) and so on, in the waste effluents from mining, metallurgical, tannery, chemical and battery manufactures (An et al., 2013; Wan et al., 2014). Additionally, in manufacturing chemicals like dye and pharmaceuticals, organic chemical-contaminated effluents also usually contain various

electrolyte ions (Wang et al., 2013a). Moreover, widespread surface water and underground water often contain trace toxic pollutants mixed with much more electrolyte ions (Asif Tahir et al., 2016).

Salts at various concentrations exhibit complex influences on the properties of adsorbents and adsorbates, and, consequently, the adsorption efficiency. For instance, Na(I) may interfere with the binding of targeted heavy metal ions by reducing the amounts of other electrostatically bound counter ions that balance the negative charge of the biomass (Schiewer and Volesky, 1997). Polyvalent cations such as Ca(II) can change the conformation of humic material by cross-linking and thus affect the adsorption of organic chemicals (Pivokonsky et al., 2015). *IS* of solution affects both kinetics and thermodynamics (Asif Tahir et al., 2016), also being associated with other solution chemical parameters such as pH, which may change adsorption processes. Cation exchange is the prevailing process at pH < 6, and thus, tetracycline adsorption is decreased by increasing total Ca(II) concentration. On the contrary, Ca-bridging is the prevailing process at pH > 6, so tetracycline adsorption is enhanced by rising Ca(II) concentration (Aristilde et al., 2016). Insights into the role of *IS* in filtrating target adsorbents for treating specific wastewaters can reveal the direction of material modification and provide valuable parameters for process control.

In recent years, urgent environmental management has motivated the development of adsorption technology, and a large number of adsorbents with superb performances have been applied (Repo et al., 2013; Ren et al., 2011; Robati et al., 2016). Meanwhile, particular attention has been paid to the effects of *IS* on adsorption because of the ubiquity of electrolyte ions in actual wastewater. Therefore, it is crucial to comprehensively assess the application potential of one adsorbent at both industrial and commercial scales (Wang et al., 2013b).

For a given adsorption system, multiple or even contradictory effects of *IS* may coexist under identical experimental conditions, leading to the complexity and difficulty in the recognition of dominant mechanism or prediction of net effect. Although this field has been extensively studied up to now, the underlying mechanisms remain elusive. Thus, the objective of this review was to summarize the recent progresses on the *IS* effects. Besides, the structural optimization of adsorbents affected by *IS* was detailed. Moreover, the forthcoming development in this field was anticipated.

## 2. Dominant mechanisms for adsorbents: change in number of active adsorption sites

### 2.1. Availability variations of binding sites

Particles in suspension remain stable due to mutual repulsion when their intersecting diffuse electrical double layers interact upon

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