



## Adsorption of paraquat from aqueous medium by Amberlite XAD-2 and XAD-4 resins using dodecylsulfate as counter ion

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### H I G H L I G H T S

- ▶ The use of the Amberlite XAD resins for the removal of the herbicide paraquat is reported.
- ▶ The results show the fundamental role played by the sodium dodecylsulfate in the adsorption process.
- ▶ The adsorption process followed a pseudo first-order kinetic.
- ▶ Amberlite XAD resins presented high efficiency for the removal of paraquat from aqueous medium.

### A R T I C L E I N F O

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### A B S T R A C T

A study is reported about the adsorption of the herbicide paraquat ( $\text{PQT}^{2+}$ ) by the polymeric resins Amberlite XAD-2 and XAD-4, in a medium containing sodium dodecylsulfate (SDS). The strategy employed in this study was based on the adsorption of the ion-associate complex, formed between the cationic  $\text{PQT}^{2+}$  and the dodecylsulfate anion, which presents high affinity by the hydrophobic resins. The effect of several parameters that could affect the efficiency of adsorption (SDS concentration, pH, mass of adsorbent and initial concentration of  $\text{PQT}^{2+}$ ) was investigated. Also, a detailed kinetic characterization of the system was performed. The SDS concentration added to the medium affected the adsorption efficiency, while the pH of the solution did not present any effect on the efficiency in the range of 2–9.5. The mass of adsorbent was studied in the range of 100–500 mg and did not influence the adsorption efficiency, changing only the adsorption rate. The kinetic evaluation of the system indicated that the adsorption of the  $\text{PQT}^{2+}$  followed a pseudo first-order model and that the adsorption rate was controlled by an intraparticle diffusion mechanism.

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## 1. Introduction

The use of herbicides dates back approximately 2000 years before Christ, by the Romans, who used organic wastes to maintain roads. However, only in 1935 the first organic herbicide was developed (dinitro-ortho-cresol, DNOC) [1]. Nowadays, the application of herbicides is an effective option in controlling weeds and their use has increased exponentially, primarily due to the intense expansion of the agriculture worldwide [2].

Paraquat ( $\text{PQT}^{2+}$ , 1,1-dimethyl-4,4-dipyridinium chloride) is a non-selective herbicide that belongs to the class of the bipyridines (Fig. 1). It was firstly synthesized by Widel and Russian in 1882. However, at that moment, no one knew about the herbicidal properties of the  $\text{PQT}^{2+}$  [3], which were only discovered in 1955. The commercialization of  $\text{PQT}^{2+}$  was initiated in 1962 by the Plant Protection Division of the Imperial Chemical Industries (formerly ICI,

now Syngenta). The first application of  $\text{PQT}^{2+}$  as an herbicide occurred in Malaysia in rubber plantations and, from that on, its use is widespread [3–5]. The great use of  $\text{PQT}^{2+}$  is related to its rapid effect at low concentrations, low cumulative effect on soil and low price compared to other herbicides [4].

In the last years, special attention has been given to  $\text{PQT}^{2+}$ , mainly due to the high rate of poisoning and fatalities attributed to it. The current literature reports that a significant number of deaths, deliberated or accidental, occurred after ingestion or dermal exposure to  $\text{PQT}^{2+}$  [6] and, because of this, several countries have suspended or severely restricted its use [7]. The toxicity of  $\text{PQT}^{2+}$  for humans is manifested in different organs, including liver, brain, kidneys, heart, adrenal glands and muscles. However, the main damage occurs in the lungs, where  $\text{PQT}^{2+}$  can transform the oxygen available into free radicals, culminating in respiratory failure and death [8].

The  $\text{PQT}^{2+}$  is classified as a highly toxic compound with a lethal dose for humans of  $35 \text{ mg kg}^{-1}$  [8]. In this context, some countries have established maximum contamination levels for  $\text{PQT}^{2+}$  in

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