ADSORPTION KINETICS OF POLYOLS ARABITOL AND XYLITOL ON DIFFERENT ADSORBENTS

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ABSTRACT

Interest in polyols such as arabitol and xylitol has grown due to their industrial applications and health benefits. Arabitol, a five-carbon polyol, is used as a sweetener and texturizing agent in the food industry, offering a low-calorie alternative for diet products. Xylitol, a low-glycemic index sweetener, is valued by several industrial segments. Using waste biomass for polyol production through biotechnological routes offers an environmentally friendly alternative to fossil fuel-based methods. However, efficient purification of the produced polyols is challenging. Adsorption is a promising technique to remove impurities. This study investigates the adsorption of polyols on different adsorbents. Batch adsorption experiments were conducted using activated carbon, strong anion resin HPA512L and porous resin SP700, for the pure polyols and in simulated solution with lignin. The results showed that activated carbon was the evaluated adsorbent that adsorbed xylitol under the studied conditions, while none of the adsorbents significantly adsorbed pure arabitol. The best adsorption results were observed for the colored compounds. Both adsorbents were efficient in clarifying 100% of the synthetic medium that simulated the fermented broth. Highlight for activated carbon and HPA512L resin that in 2 and 4 hours, respectively, clarified the medium.

Keywords: Arabitol. Xylitol. Polios. Adsorption. Purification.

1 INTRODUCTION

In recent years, interest in polyols such as arabitol and xylitol has grown significantly due to their various industrial applications and health benefits[1,2]. Arabitol, a five-carbon polyol, can be used in the food industry as a sweetener and texturizing agent, providing desirable sensory properties in various products. Additionally, arabitol has a low-caloric value, making it an attractive alternative for diet products and foods for individuals with sugar restrictions. Conversely, xylitol, a low-glycemic sweetener, is highly valued in the dental and pharmaceutical industries. Due to its anticariogenic properties, xylitol is often incorporated into chewing gums, toothpaste, and mouthwashes, aiding in the prevention of dental caries. Furthermore, studies have demonstrated that xylitol may have beneficial effects in controlling upper respiratory tract infections, further enhancing its therapeutic value[2,3].

Sustainable production of polyols from renewable sources is a highly relevant topic in current scientific research[4]. The utilization of residual biomass, such as agricultural waste and food processing by-products, as feedstock for polyol production via biotechnological routes offers an ecological and economical alternative to traditional fossil fuel-based methods[5]. This process not only promotes a circular economy by valorizing agricultural by-products but also reduces reliance on non-renewable resources, contributing to environmental sustainability. However, one of the main challenges in this area is the efficient purification of the produced polyols, which often contain impurities such as residual sugars, proteins, and inorganic salts that can compromise their quality and final application. Removing these impurities is crucial to ensure that the polyols meet the purity standards required for industrial and food applications[6].

In addition to being an essential process to ensure the quality of final products, the purification of polyols through adsorption can contribute to cost reduction and minimize environmental impacts. Adsorption is a highly efficient method that allows for the selective removal of impurities using adsorbent materials with high affinity for undesirable compounds[7]. The choice of suitable adsorbents is crucial for optimizing the purification process, improving the efficiency and selectivity in impurity removal. Adsorbents such as activated carbon and ion exchange resins have been extensively studied due to their unique adsorption properties.

Therefore, the present study aims to investigate the adsorption of the polyols arabitol and xylitol on different adsorbents, as well as to observe the adsorption in a simulated broth. By studying the adsorption on different materials, we seek to identify the most effective adsorbents for the purification of polyols from the fermented broth, providing a basis for future research and industrial applications. The results obtained can guide the development of scalable and sustainable industrial processes, expanding the commercial applications of polyols and promoting innovations in purification biotechnology.

2 MATERIAL & METHODS

<u>2.1 Chemicals and adsorbents:</u> Adsorption studies of polyols on different adsorbents were evaluated. Model solutions of D-xylitol (Sigma, purity 99.5%) and L-arabitol (Sigma Aldrich, purity 98%) were prepared in deionized water. Adsorption experiments were performed with three different adsorbents: activated carbon (Clarimex), strongly basic anion resin, Diaion HPA512L and highly porous resin, Sepabeads SP700 (both Mitsubishi Chemical Corporation).

<u>2.2 Batch adsorption studies:</u> Single-component batch experiments for arabitol and xylitol were conducted with 0.0012 L of 30 g L^{-1} solutions of each compound. The amount of adsorbent was fixed at 0.06 g dry weight. Batch samples were shaken in a

thermoblock (model D3HS, Loccus) with 1500 rpm agitation for 36 h at 30°C and the pH of the medium was maintained at 7.0. Each sample was immediately filtered through a 0.2 μm syringe filter. The initial feed concentration and adsorption equilibrium concentrations were quantified by HPLC-UV.

To simulate a complex fermented medium, batch experiments of a model solution containing the polyols (10 $g \cdot L^{-1}$ xylitol and 5 $g \cdot L^{-1}$arabitol) and lignin (2 $g \cdot L^{-1}$) were carried out in a shaker. The adsorbent concentration was fixed at 50 $g \cdot L^{-1}$, shaking at 200 rpm for 48 h at 30 °C. The samples were immediately filtered through a 0.2 μm syringe filter. The initial feed concentration and adsorption equilibrium concentrations were quantified by HPLC-UV. The colored compounds were determined by reading the absorbance of the optical density (OD) in a spectrophotometer at wavelengths of 420 nm and 560 nm, as established by the International Commission for the Unification of the Methods of Sugar Analysis (ICUMSA). Normalized concentration ($C \cdot C0^{-1}$) or Absorbance ($Abs \cdot Abs_0^{-1}$) was also evaluated in terms of feed concentration or baseline.

2.3 Analytical method: The concentration of polyols was determined by High Performance Liquid Chromatography with Refractive Index detector (HPLC-RI). The samples were diluted and filtered through filters (Millipore) and analyzed in an HPX-87H column (300 x 7.8 mm), temperature 45°C, eluent 0.01 N sulfuric acid in milli-Q grade water, flow rate 0.6 mL min^{-1} and 20μL of sample volume, according to the methodology of Rodrigues et al.[8].

3 RESULTS & DISCUSSION

The adsorption kinetics for the polyols xylitol and arabitol on three different adsorbents were obtained. Adsorption kinetics is an important parameter because it expresses the rate of removal of the adsorbate (polyol) from the fluid phase in relation to time. It involves the transfer of mass of this component contained in the liquid to the interior of the adsorbent particle, where it continues to migrate through the macropores to the innermost regions of the adsorbent.

Figure 1 presents the kinetic data obtained for polyols in batch adsorptions at 30 °C and a concentration of 50 $g \cdot L^{-1}$ of adsorbent. For xylitol, the HPA512L resin and the SP700 synthetic adsorbent did not cause a decrease in concentration over time. At the last point evaluated (36 hours), for example, the adsorbate concentration was 97% and 98% of the feed, respectively. This shows that there was no adsorption under the conditions evaluated. The values found for both adsorbents were close to or equal to zero. On the other hand, activated carbon was the one that obtained the best adsorption for xylitol. After 1 hour of adsorption, the concentration value fell to close to 90% and remained constant in this range until the end of adsorption. According to Cardoso and Forte[9], activated charcoal has already interacted with xylitol and was able to adsorb it.

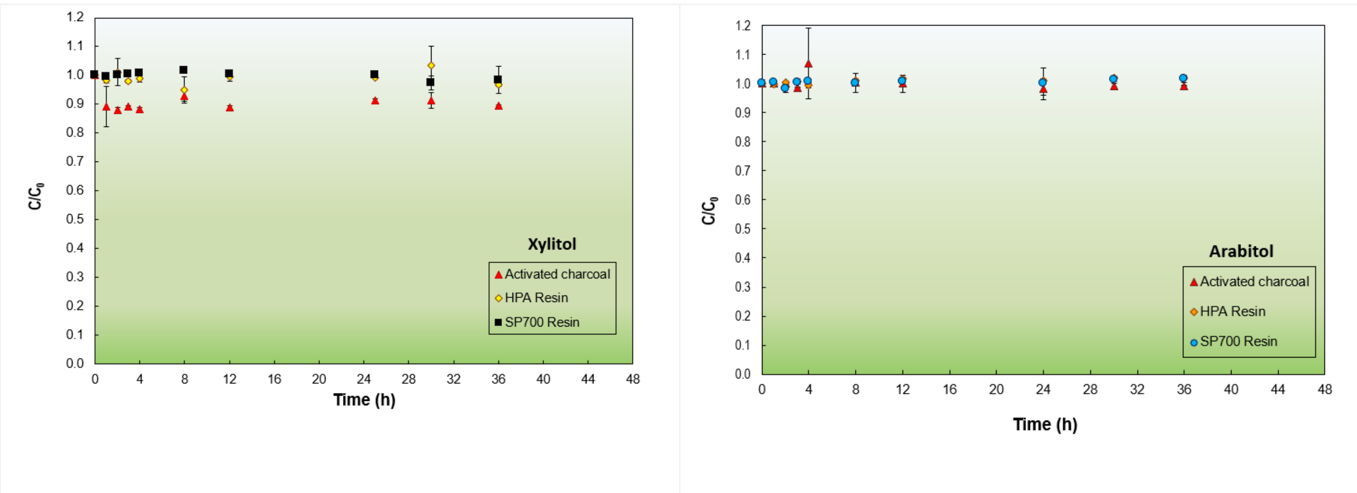

Figure 1. Normalized concentration of xylitol and arabitol polyols as a function of adsorption time, values relative to the initial fed concentration.

Figure 1 also presents the kinetic data for arabitol in batch at 30 °C and 50 g L-1 of adsorbent. It can be observed that for the three adsorbents evaluated, the adsorption value of arabitol was low or nonexistent. The arabitol molecule is electrically stable, that is, like xylitol, it is neutral, therefore, there are no charges, which may explain the lack of absorption and interaction with the adsorbents, especially the ion exchange resins.

The HPA512L resin is a highly porous and strongly basic anion exchange resin. It has higher crosslinking and porosity properties. According to the manufacturer, it is widely used for enzyme purification and industrial separation of large molecules, in addition to being used industrially in the clarification of dark media. Its matrix is composed of styrene crosslinked with divinylbenzene, with trimethyl ammonium as a functional group and ions in the Cl^- form. This characteristic was observed in Figure 2. The HPA512L resin, as well as the charcoal, were the adsorbents that clarified the synthetic medium containing the colored compounds observed at 420 and 560 nm. The activated charcoal, with 2 hours of adsorption, had already clarified 100% of the broth, while the HPA512L resin clarified it entirely in 4 hours. The SP700 resin, in turn, only clarified the model solution entirely in 48 hours of adsorption. Sepabeads SP700 resin is a highly porous styrenic adsorbent. It has a high surface area and a narrow pore size distribution. It can be used for various applications. Its matrix is composed of polydivinylbenzene and ethylvinylbenzene.

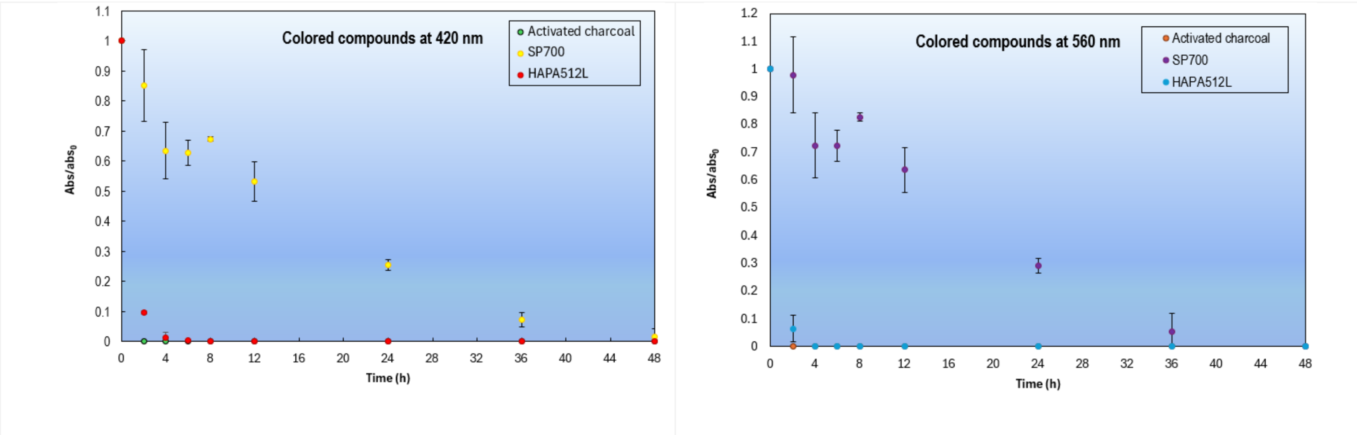

Figure 2. Normalized absorbance of the model solution of colored compounds as a function of adsorption time, values relative to the initial absorbance fed.

Due to these characteristics of the resins and the conditions chosen for adsorption, the resins did not show high adsorption for polyols, since both are small compounds and in pure solutions their pH remains neutral (close to 7.0), which can reduce ionic exchange with the adsorbents. On the other hand, the adsorption results of the colored compounds were very satisfactory (Figure 2), given that the fermented broth of lignocellulosic matrix, in a biotechnological process of obtaining polyols, contains many contaminating substances that give a dark color to the broth.

The classical methodology used industrially for the purification of xylitol in chemical production is through chromatographic fractionation with ion exchange, specifically with cationic resins. The conditions evaluated in this study differ, since an anionic resin (HPA512L) and a highly porous resin (SP700) were used. Although the sweeteners did not adsorb the polyols, they were very effective in purifying the medium of colored compounds from lignin (colored compounds). This highlights their potential use in the clarification of the fermented broth of hemicellulosic hydrolysate.

4 . CONCLUSION

The adsorption investigation revealed that activated carbon is the most effective adsorbent for xylitol, while other adsorbents evaluated showed low or no adsorption for arabitol, indicating the need for further optimization. Understanding the adsorption mechanisms and refining the operational parameters are essential for the development of scalable and sustainable industrial processes. All adsorbents, under the conditions evaluated, were effective in clarifying the synthetic medium, with emphasis on activated carbon, which was able to completely purify the broth of colored compounds in a time of 2 hours. These findings lay the foundation for future research aimed at increasing the commercial viability of polyols through purification techniques, thus expanding their industrial applications.

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