

VORTEX FLOW ADSORPTION TECHNOLOGY

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Abstract

Vortices are a secondary flow pattern that appears above a critical rotation rate in the annular gap between inner rotating cylinder and outer stationary cylinder. When adsorbent resins are suspended in the vortices, a unit operation, vortex flow adsorption (VFA), is created. VFA could be applied to recover protein directly from fermentation broths or cell homogenates due to high void fraction and multiple equilibrium stages resulting from distinct vortices.

The effect of several operation variables, including rotation rate of inner cylinder, axial flowrate of loaded fluid, and volume fraction of adsorbent resin particles in the annular gap, on the adsorption behavior represented by the breakthrough capacity of the model protein in vortex flow system has been investigated. Bovine serum albumin (BSA) and Streamline DEAE (Amersham Pharmacia Biotech) were used as model protein and adsorption resin respectively. The experimental results showed that breakthrough capacity of BSA increases with the increase of volume fraction of adsorbent resin in the annular gap and decreases with the increase of axial loading flowrate. It was also shown that rotation rate of inner cylinder has no apparent effect when it is above a certain value.

Introduction

One strategy to reduce costs in manufacturing a biotech product is simplification of the downstream process [1]. This may be achieved by reducing the number of unit operations. Integrative technologies seek to combine steps into a new single unit operation [2]. The aim is to maintain product integrity and purity to high levels, to increase process compactness and yield, and to reduce processing time, equipment numbers, and labor costs [3].

Primary biological product recovery is often from feedstock that contains particulates, e.g., cells and debris for extracellular product or cell homogenates for intracellular product [4]. In the conventional downstream process, the initial steps are clarification, concentration, and purification. Disadvantages associated with such processes are long cycle time and low product yield due to product loss through the sequence of unit operations [5]. The concept of integration of the early steps is economically promising.

One novel and promising technology, vortex flow adsorption (VFA), can be applied to deal with fermentation broths or cell homogenates directly due to high void fraction and multiple equilibrium stages resulting from distinct vortices. Vortices are a secondary flow pattern that appears above a critical rotation rate in the annular gap between inner rotating cylinder and outer stationary cylinder. When an axial flow is superimposed to this system, the resulting

flow is Taylor-Couette-Poiseuille flow. In VFA technology, biological products can be separated or purified by adsorption to resins suspended in the vortices. Due to the existence of rotation, adsorbent particles can be suspended or fluidized easily.

Methods

In this paper, the adsorption behavior represented by the breakthrough capacity of the model protein in vortex flow system has been investigated. Bovine serum albumin (BSA) and Streamline DEAE (Amersham Pharmacia Biotech) were used as model protein and adsorption resin respectively.

Results and Discussions

In the protein vortex flow adsorption process, there are three sub-processes occurring simultaneously. When the loaded fluid passes the annular gap filled with the adsorbent resin particles, first, the protein molecule needs to be transported from the bulk fluid to the surface of the particles, and then through internal mass transport to the interior surface of the resin particles. After it reaches the interior surface of the resin particles, the adsorption reaction between the resin and the protein occurs.

When only the axial loading flowrate in the annular gap changes, the basic experiment results showed that the breakthrough capacity decreases with the increase of the axial flowrate, shown in Figure 1. The possible reason is that the adsorption process of

BSA on Streamline DEAE is a rate-controlling step. Therefore, when the axial flowrate is increased, BSA protein molecules in the bulk fluid have no enough time to be adsorbed on Streamline DEAE resin before the bulk fluid entrains it downstream. On the contrary, when the system is operated under low axial flowrate, the protein molecules have enough time to react with the resin particles and it is difficult for Streamline DEAE to be broken through.

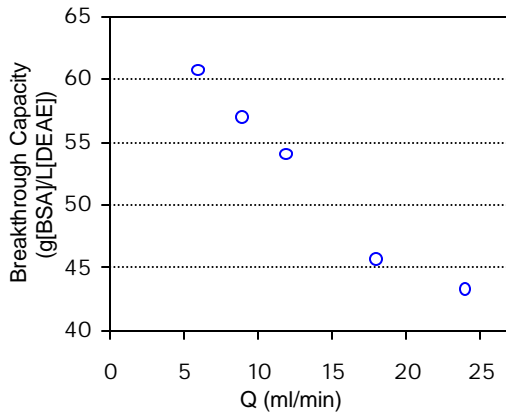


Figure 1: The effect of the axial loading flowrate on the 10% breakthrough capacity of BSA on Streamline DEAE. The rotation rate of inner cylinder is 200rpm. The volume fraction of Streamline DEAE is 0.2.

Additionally, the effect of the volume fraction of adsorbent resin particles was also investigated. Figure 2 showed that with the increase of the resin volume fraction, the breakthrough capacity of BSA increases. When the volume fraction is above 0.2, the capacity doesn't change too much and almost approaches the equilibrium capacity. The actual situation occurring in the annular gap is that when the resin volume fraction increases, the resin is densely distributed. Therefore, it is very easy for the protein molecule to be adsorbed on the resin particles. On the contrary, when the volume fraction is very low, the possibility of the protein molecule to knock on the resin particles is very low.

The rotation of inner cylinder produces vortices, fluidizes adsorbent resin particles, and also brings about backmixing due to inter-vortex mass transfer. The simultaneous appearance of vortices and backmixing requires that vortex flow system should be operated in low rotation rate regime. Additionally, adsorbent particles should be fluidized in this regime. The minimum rotation rate for fluidization is determined by adsorbent particle's physical properties, including particle density and size. Therefore, the optimization of vortex flow system

operation finally lies on physical properties of adsorbent particles.

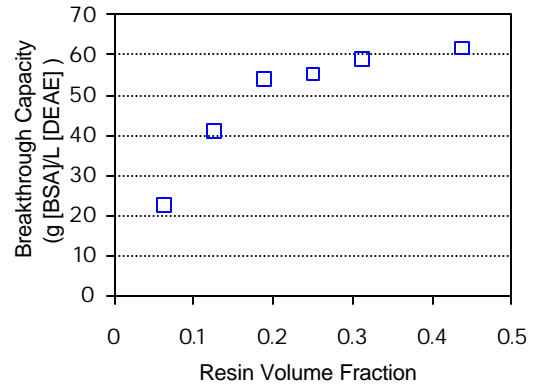


Figure 2: The effect of the volume fraction of Streamline DEAE on the 10% breakthrough capacity of BSA on Streamline DEAE. The rotation rate of inner cylinder is 200rpm. The axial loading flowrate is 12 ml/min.

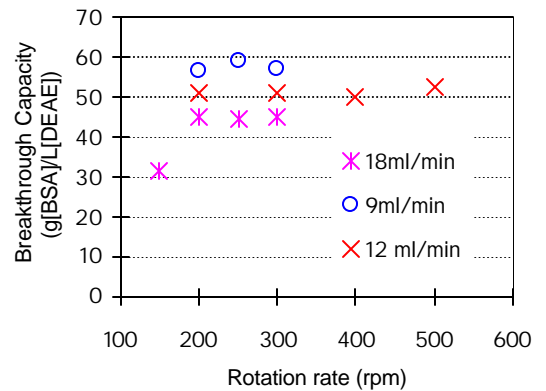


Figure 3: The effect of the rotation rate of inner cylinder on the 10% breakthrough capacity of BSA on Streamline DEAE. The volume fraction of Streamline DEAE is 20 % and the axial flowrate is 9, 12, and 18 ml/min respectively.

The effect of the rotation rate of inner cylinder on the adsorption capacity is shown in Figure 3. The minimum fluidization rotation rate for Streamline DEAE is around 230 rpm from experimental results (not published). When the rotation rate is below the minimum fluidization value, the breakthrough capacity increases with the increase of the rotation rate; when the rotation rate is above a certain value

where Taylor vortices begin to stop downstream displacement, the breakthrough capacity keeps invariant.

Conclusions

In this paper, the novel application of Taylor vortex flow, vortex flow adsorption (VFA), was studied. Some adsorption characteristics of VFA were studied using a model system with BSA and Streamline DEAE. These results will be used to the future study of the VFA application to fermentation broths to recover the objective proteins.

References

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