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Electroextraction Separation of Dyestuffs

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ABSTRACT

Electroseparation technologies have prospects for significant growth well into the next century. Electroextraction, a coupled separation technique of solvent extraction with electrophoresis, was used to remove dyestuffs from their aqueous stream. A study on the characteristics of the separation technique was carried out with *n*-butanol/acid-chrom blue K/water and *n*-butanol/methyl blue/water as working systems. A continuous separation equipment was designed and used in this work. The influences of two-phase flow, field strength, and concentration of the feed on the recovery of solute were studied. The results showed that much higher recovery of solute with less solvent consumption could be achieved by using this technique to remove dyes from their aqueous streams, especially for the separation of the dilute solution. When the field strength is increased, the recovery and mass flux increase. When the feed flow rate and the initial solute concentration are increased, the recovery decreases and the mass flux increases.

Key Words. Electroextraction; Dyestuff; Separation

1. INTRODUCTION

Separation processes play an important role in many industrial fields. With the development of biotechnology and environmental science, and because legislation for controlling pollution in many countries is becoming more severe, many pressing needs and opportunities are provided for separation technologies. Most of the new separation tasks required by industry are separation

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of solutes from dilute solutions. Normally it is very difficult to achieve high recovery by using conventional separation technologies (1).

Dyestuffs removal from wastewater is an example (2–10). Dyestuffs are not efficiently removed by biological treatment or by conventional dye waster water treatment techniques (11). Therefore, the development of a new separation technique to treat dye wastewater is desirable.

Electroseparation technologies have prospects for significant growth well into the next century (12). Electroextraction is a coupled separation technique of solvent extraction with electrophoresis. The new separation technique, *electroextraction*, was first developed by J. Stichlmair et al. (13). The idea of this technique was based on the characteristics of two or more liquid phases. The convective mixing effect caused by the difference of temperature and concentration of solute in the separation solution in electrophoresis separation can be nullified or controlled by a stable liquid–liquid interface. Some research work have been done on solvent extraction under an electric field, and an alternating current electric field has been used to speed phase settling and to improve the rate of the extraction process. Some results on the use of the technique have been reported (14–20). Thus Brooks and Bamberger (15) and Todd et al. (16, 17) gave the results of extraction by using an electric field to speeding phase settling. Stichlmair and his coworkers explained the principle of mass transfer between the two-phase interface under an electric field, and the criteria for choosing the two phases (13, 14). In 1990 Levine and Bier (18) studied the electrophoretic mobility of a protein in a two-phase aqueous system in a U-tube device. More recent Clark et al. (19–22) studied the separation of mixtures of hemoglobin and albumin by applying an electric field perpendicular to the interface of an aqueous two-phase system. They considered that protein migration across the interface was manipulated by varying polarity, pH, separation time, field strength, and volume ratio of the two phases. Luo et al. (23) studied the separation of organic acids from dilute solution by using electroextraction in a U-tube device. Until now there have not been any reports relating the treatment of dyes wastewater by using this technique.

The aim of this work is to use the new technique to remove the dyestuffs acid-chrom blue K and methyl blue from their dilute solutions. The influence of field strength, solute concentration, and the two-phase flow rate on the separation performance will be studied.

2. MATERIALS AND EXPERIMENTAL

Acid-chrom blue K and methyl blue were purchased from Beijing Chemical Products Company, and *n*-butanol was obtained from the Chemical Solvent Products Factory of Beijing. All these products were used directly with-

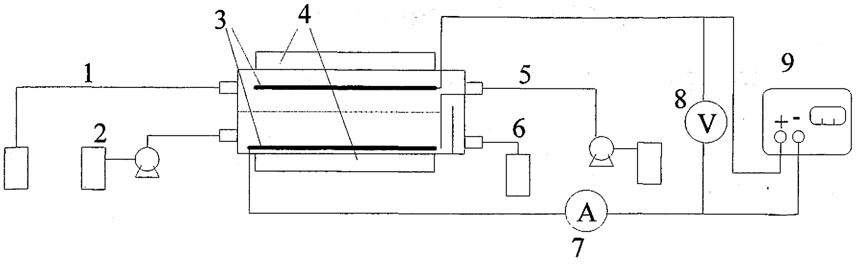

FIG. 1 Setup of the experimental apparatus. (1) Light-phase outlet, (2) feed inlet, (3) electrodes, (4) water jackets, (5) light-phase inlet, (6) heavy-phae outlet, (7) ammeter, (8) voltmeter, (9) electrophoresis apparatus.

out any further purification. Deionized water was prepared in our laboratory. The concentrations of acid-chrom blue K and methyl blue were determined with a PC 801 colorimeter at a wavelength of 520 nm. The two electrodes were made of platinum wire. In order to keep the volumes of the two phases constant during operation, before the dilute solution was prepared the water and *n*-butanol phases were mixed with each other for 24 hours until the water phase was saturated with *n*-butanol and the *n*-butanol phase was saturated with water. For the comparison of the experimental results, the recovery ratio, E, was defined by

$$E = \frac{\text{removed solute}}{\text{total solute}} \times 100\% \tag{1}$$

The setup of the experimental apparatus is shown as Fig. 1. Water jackets were designed to remove the heat produced by the electrodes reactions to keep the experimental temperature at room temperature. The anode electrode was inserted in the organic phase, and the cathode electrode in the water phase. The electroextraction equipment was the 8 cm in length, 5 cm in width, and 2 cm high. The distance between the two electrodes was 1.7 cm. The two phases flowed through the equipment in a countercurrent flow. The gas produced by the electrode reaction was discharged from the top hole of the equipment.

In this work the conventional liquid–liquid extraction experiments were carried out with *n*-butanol as solvent. Almost no acid-chrom blue K and methyl blue were extracted by *n*-butanol, which shows that it is very difficult to remove acid-chrom blue K and methyl blue from their dilute solutions.

3. RESULTS AND DISCUSSION

3.1. Influence of Electric Field Strength on the Recovery, *E*

It is well known that when the effects of gravity and diffusion are neglected, the velocity, v, of a solute migrating to the phase interface in an applied electric field depends on the field strength, U, and the solute electrophoretic mobility, u:

$$v = uU \tag{2}$$

The solute electrophoretic mobility, u, depends on solute size and net charge, as well as on the solution viscosity.

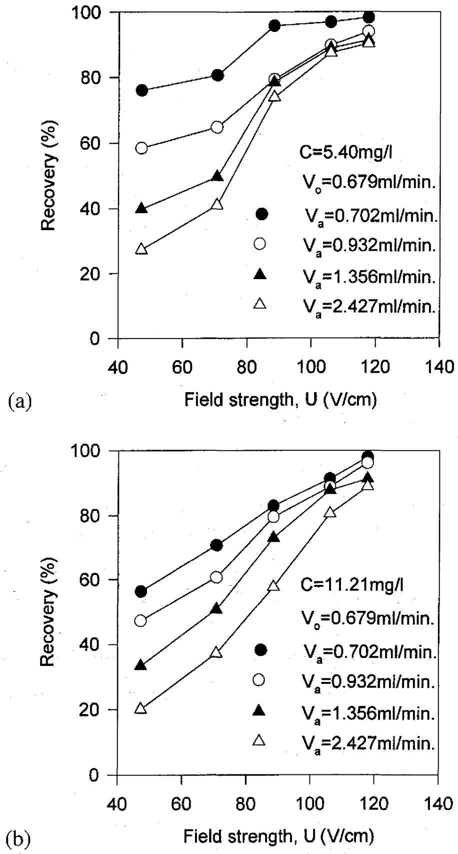

FIG. 2 Influence of field strength on recovery of acid-chrom blue K.

Figures 2 and 3 show the influence of field strength, U, on the recovery ratio, E, of acid-chrom blue K and methyl blue, respectively. In these figures V_0 and V_a are defined as the butanol and aqueous phase flow rates. It can be seen that E increases with an increase of U when all other experimental conditions are not changed. This can be explained from Eq. (2). When the other experimental conditions are not changed, the v of a solute migrating to the phase interface will increase with an increase in the field strength. Therefore, for the same flow rate there will be more solute passing through the interface to be recovered and much high recovery will be achieved. If the field strength is increased enough, a recovery of 100% will be achieved. These figures show even at a low volume ratio, a much higher recovery ratio can be reached.

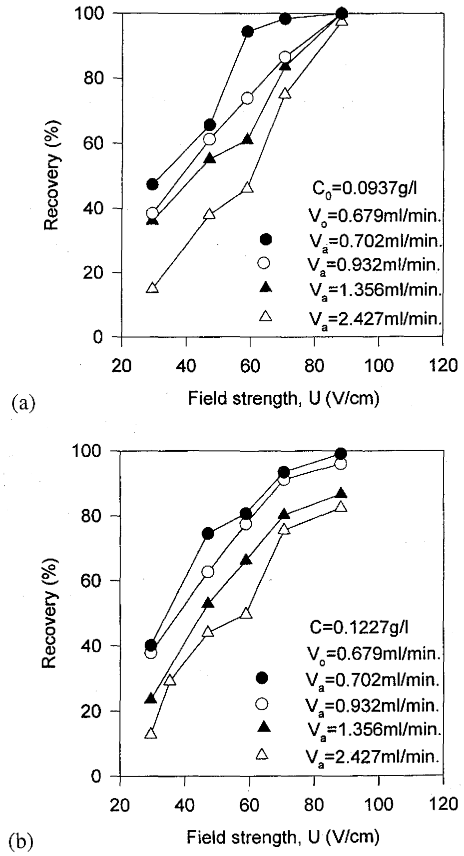

FIG. 3 Influence of field strength on recovery of methyl blue.

From Eq. (2) a linear relationship of the velocity and the field strength exists if the solute electrophoretic mobility is a constant. However, it can also be seen that the relationship between the field strength and recovery is not linear. This is because that when solutes pass through the interface under an electric field, the solute concentration in the organic phase will be increased. The effect of diffusion can be serious. If the solute concentration in the organic phase is higher than the equilibrium concentration, this type of concentration-driven mass transfer will be in the direction opposite of the electric force. It should also be noted that when the concentrations in the organic and aqueous phases are changed, the conductivity of the organic and aqueous phases will be changed. This change will cause the field strength applied in the organic and aqueous phases to be changed, although the total field strength applied between the two phases will remain a certain value. Therefore, mass transfer across an interface under an electric field is very complicated. This process is probably governed by the concentrations on both side of the interface, the field strength, and so on.

3.2. Influence of Flow Rate of Feed on Mass Flux and Recovery

Here, we define the mass flux as the amount of solute passing through the interface per second. The mass flux versus the flow rate of the feed is plotted in Figs. 4 and 5. It can be seen that the mass flux increases with an increase of

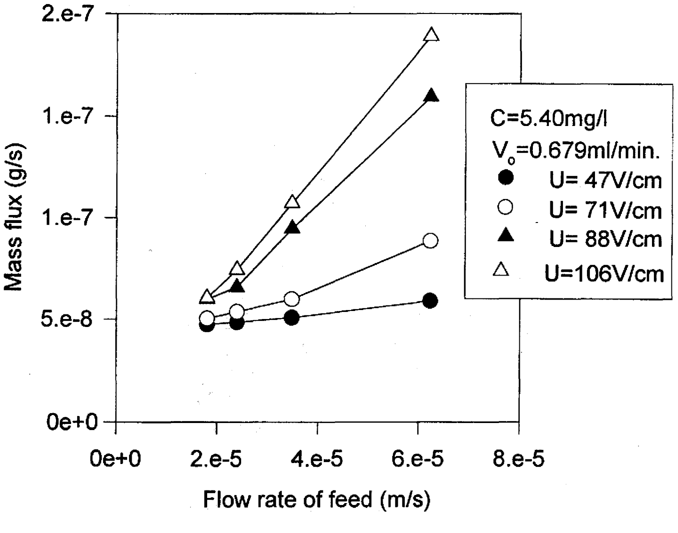

FIG. 4 Influence of feed flow rate on mass flux of acid-chrom blue K.

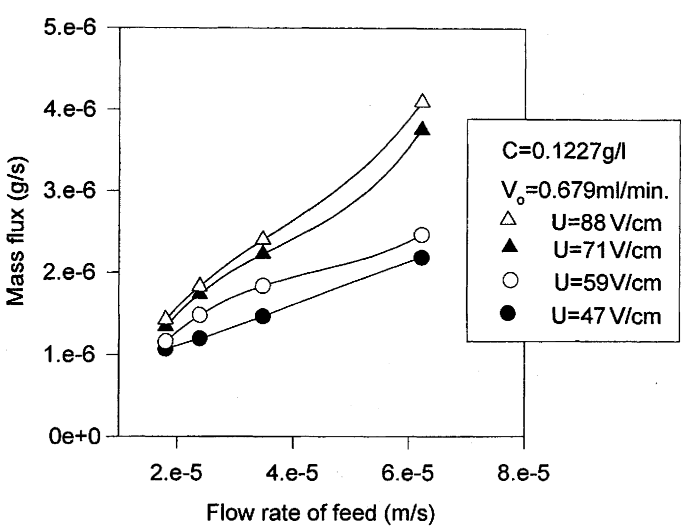

FIG. 5 Influence of feed flow rate on mass flux of methyl blue.

the flow rate of the feed when the other experimental conditions remain the same.

As is well known, the mass flux depends strongly on the driving force for a solute. Here, mass transfer will include electrically driven migration, diffusion, and convective driving forces. In the case of transport across a stable interface, the effect of convection may be negligible. In this separation process the contact time of the two phases will be decrease with an increase of the flow rate. Under the same experimental conditions, the solute concentration in the aqueous stream for a high flow rate decreases much more slowly than that for a low flow rate. This means there is much more charged solute moving to the light phase under the same field strength per second as for a high flow rate, and this causes the mass flux to be increased. Meanwhile, as stated in Section 2, the equilibrium concentration of the dyes in the butanol phase is very low, and backdiffusion will influence the mass transfer when the dyes are extracted from the aqueous phase to the organic phase. A higher flow rate will make the solute concentration in the aqueous phase larger, and therefore the rate of backdiffusion at a high flow rate will be less than that at a low flow rate. Moreover, the boundary layer at the interface may be decreased due to the higher flow rate, which causes the mass transfer coefficients to be increased. All these factors may cause the mass flux to increase with an increasing flow rate. Of course, the charges passing through the interface are not the same as those in the buck phase. There are few research papers on the movement of charges

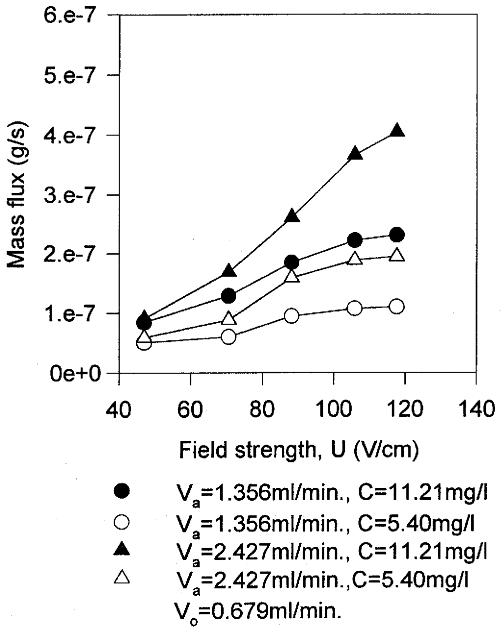

FIG. 6 Influence of solute concentration on mass flux of acid-chrom blue K.

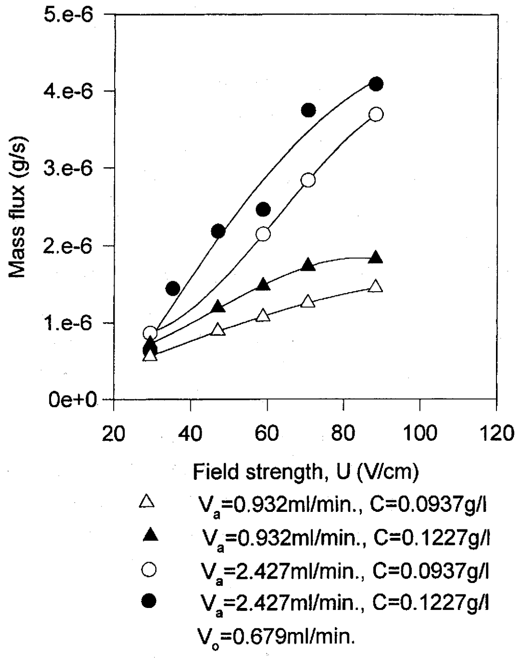

FIG. 7 Influence of solute concentration on mass flux of methyl blue.

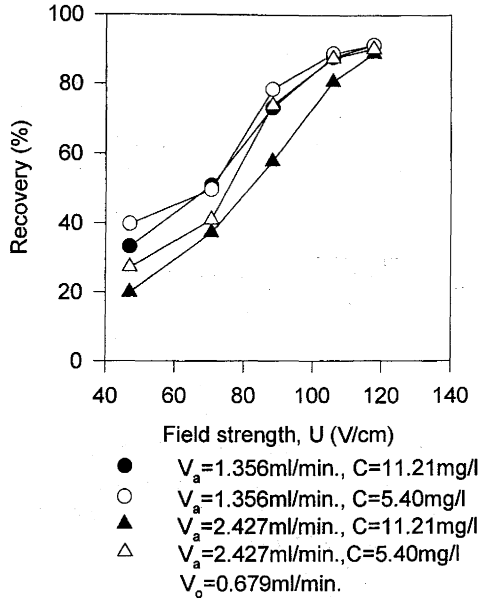

FIG. 8 Influence of solute concentration on recovery of acid-chrom blue K.

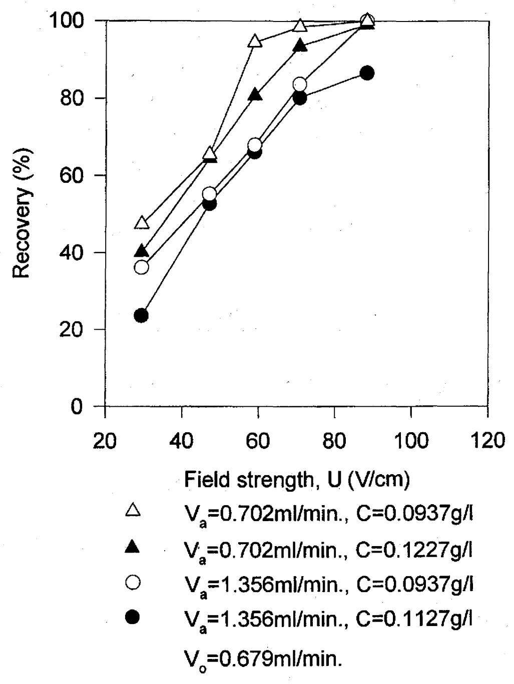

FIG. 9 Influence of solute concentration on recovery of methyl blue.

in the organic phase, so the mechanism of this phenomenon needs further study.

As shown in Figs. 2 and 3, recovery is decreased when the flow rate is increased. This is because with the flow rate increasing, the total solute increases, and consequently the recovery ratio decreases.

3.3. Influence of Initial Solute Concentration of Feed on Mass Flux and Recovery

Figures 6 and 7 show that the initial solute concentration, C_0, has an influence on the mass flux. When the other experimental conditions are the same, the mass flux will increase with an increasing solute concentration. This is because much more solute passes through the interface under the same field strength when the initial solute concentration is increased. But when the initial solute concentration is increased, the total solute increases, and consequently, as shown in Figs. 8 and 9, the recovery ratio decreases.

CONCLUSION

The results show the coupled separation technique of solvent extraction with electrophoresis is a very useful technique for recovering dyestuffs from their dilute solution. When the field strength is increased, the recovery and mass flux increase. When the feed flow rate and the initial solute concentration are increased, the recovery decreases and the mass flux increases. A much higher recovery ratio of solute with less solvent consumption can be achieved by using this technique, especially for the separation of dilute solution. The new technique may be used to control environmental pollution, provided residual *n*-butanol in the aqueous phase can be tolerated or efficiently removed.

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