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Two-phase electrophoresis separation of dyestuffs from dilute solution

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Abstract

Dyestuffs are not efficiently removed by biological treatment or by conventional dye treatment techniques. New separation techniques are required. Two-phase electrophoresis, a coupled separation technique of solvent extraction with electrophoresis, can be used to remove dyestuffs from dye effluents. A study on the characteristics of the separation technique has been carried out with *n*-butanol–acid-chrome blue K–water, *n*-butanol–methyl blue–water and *n*-butanol–methyl red–water as working systems. Continuous separation equipment has been designed and used in this work. The influences of the two-phase flow rate, field strength and feed concentration on the recovery are studied. The results show that a high recovery with less solvent consumption can be achieved using this technique, especially for the separation of dilute solutions. As the field strength is increased, the recovery and mass flux increase. When the feed flow rate and the initial solute concentration in the feed are increased, the recovery decreases and the mass flux increases. © 1999 Elsevier Science S.A. All rights reserved.

Keywords: Dilute solution; Dyestuffs; Two-phase; Electrophoresis

1. Introduction

With the development of biotechnology and environmental science, industry is required to separate solutes from dilute solutions. Normally, it is very difficult to achieve high recovery using conventional separation technologies. One example is the removal of dyestuffs from dilute solutions [1–5]. Dyestuffs are not efficiently removed by biological treatment or by conventional dye treatment techniques [4,5]. Therefore, a new separation technique is required to treat dye wastewater.

Two-phase electrophoresis is a coupled separation technique of solvent extraction with electrophoresis. The new separation technique was first developed by Stichlmair et al. [6,7]. The convection mixing effect caused by the difference in temperature or by the solute concentration difference in electrophoresis separation can be nullified or controlled by a stable liquid–liquid interface. Some results [6–11] have shown that the new technique is promising. In this work, the new technique is tested in the recovery of dyestuffs from dilute solutions. *n*-Butanol–acid-chrome blue K–water, *n*-butanol–methyl blue–water and *n*-butanol–methyl red–water were used as working systems.

2. Materials and experimental

Acid-chrome blue K, methyl blue and methyl red were purchased from Beijing Chemical Products Company, and *n*-butanol was obtained from the Chemical Solvent Products Factory of Beijing. All of these products were used directly. Deionized water was prepared in our laboratory. The dyestuff concentration was analysed with a PC 801 colorimeter at a wavelength of 520 nm.

The set-up of our experimental apparatus is shown in Fig. 1. A water jacket was designed to take away the heat produced by the electrode reactions to keep the experimental temperature at room temperature. The two electrodes were made of platinum wire. The anode was inserted in the organic phase, and the cathode in the water phase. The electroextraction equipment was 8 cm in length, 5 cm in width and 2 cm in height. The distance between the two electrodes was 1.7 cm. The gas produced by the electrode reaction was discharged from a hole in the top of the equipment. The voltage applied to the working system was read on a voltmeter, and the electric field strength was defined as the applied voltage divided by the distance between the two electrodes.

The flow volumes of the two phases were controlled by two metering pumps, and were loaded into the equipment in opposite directions. In order to ensure that the volumes of

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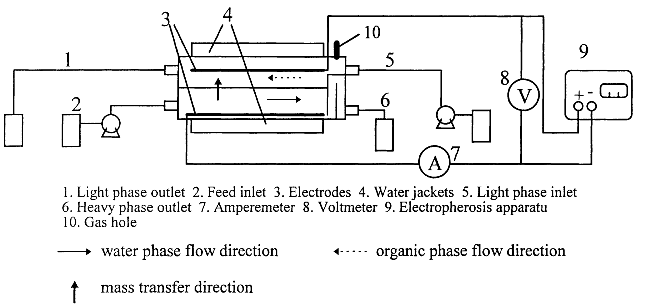

Fig. 1. The set-up of the experimental apparatus.

the two phases were constant during operation, water and n-butanol were mixed with each other for 24 h until the water phase was saturated with n-butanol and the organic phase was saturated with water. For a comparison of the experimental results, the recovery R was defined by

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

In this work, the conventional liquid–liquid extraction experiments were carried out with n-butanol as solvent. The distribution coefficients of acid-chrome blue K and methyl blue are less than 0.1; conversely, the distribution coefficient of methyl red is larger than 100. So, in the new separation process, n-butanol was used to extract acid-chrome blue K and methyl blue from aqueous solution, and water was used to extract methyl red from organic solution.

3. Results and discussion

3.1. Influence of the electric field strength on the recovery *R*

Figs. 2–4 show the influence of the field strength, U, on the recovery ratio of acid-chrome blue K, methyl blue and methyl red, respectively. It can be seen that the recovery ratio, R, increases with an increase in the field strength when all other experimental conditions remain unchanged. This is because, when the other experimental conditions remain unchanged, the velocity, v, of a solute migrating to the phase interface will be increased as the field strength increases. Therefore, the amount of solute passing through the interface is increased as the field strength increases, and a much higher recovery is obtained. If the field strength is increased sufficiently, a recovery of as high as 100% will be achieved. For methyl red, n-butanol can be regenerated very well, although the solubility of methyl red in n-butanol is very high.

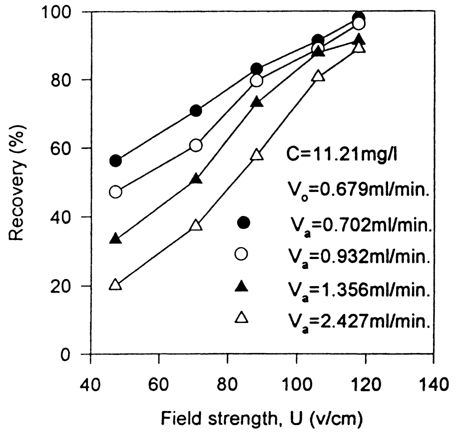

Fig. 2. Influence of the field strength on the recovery of acid-chrome blue K.

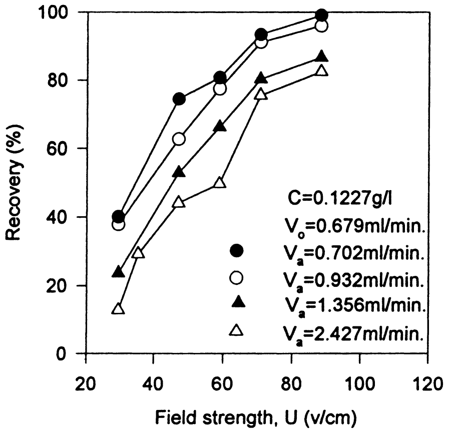

Fig. 3. Influence of the field strength on the recovery of methyl blue.

3.2. Influence of the feed flow rate on the mass flux and recovery

In the present work, we defined the mass flux as the amount of solute passing through the interface per second. The relationships of the mass flux vs. the feed flow rate are plotted in Figs. 5–7. The mass flux increases with an increase in the feed flow rate when the other experimental conditions remain unchanged. The results indicate that the mass transfer coefficient of the solutes increases as the feed

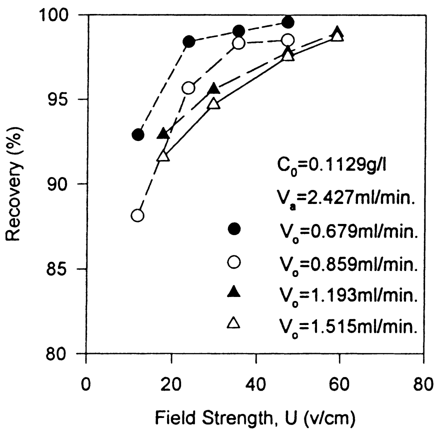

Fig. 4. Influence of the field strength on the recovery of methyl red.

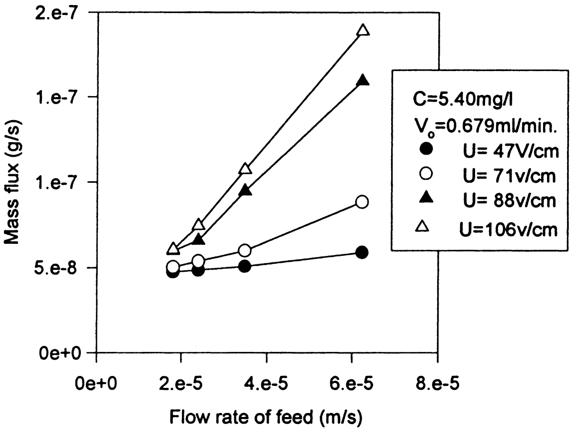

Fig. 5. Influence of the feed flow rate on the mass flux of acid-chrome blue K.

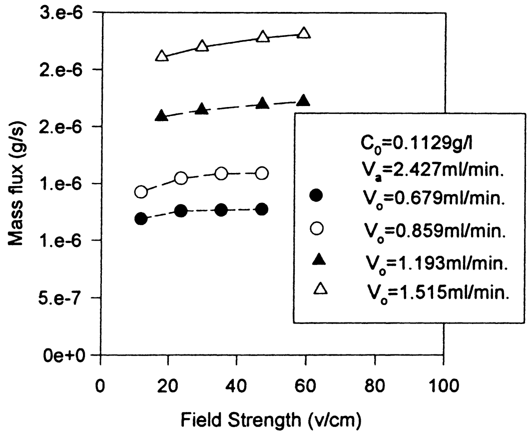

Fig. 7. Influence of the feed flow rate on the mass flux of methyl red.

flow rate increases. The mass flux is strongly dependent on the driving force for a solute. The driving force is decided not only by the field strength, but also by the flow conditions and the solute concentration. The mass transfer will include electrically driven migration, diffusion and convection 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 between the two phases will decrease with an increase in the flow rate. Under the same experimental conditions, the solute concentration of the feed stream at a high flow rate is decreased much more slowly than that at a low flow rate. This means that more charge solutes move to the other phase per second at a high flow rate if the field strength remains the same, which causes the mass flux to increase. Meanwhile, as the equilibrium concentration of the dyes in the butanol phase is very low, or very high, back diffusion will influence the mass transfer. At a high flow rate, the solute concentration of the feed phase will be larger, and therefore the rate of back diffusion 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 at a higher flow rate, causing the mass transfer coefficients to increase. All of these factors cause the mass flux to increase with increasing flow rate. Of course, the charge passing through the interface is not the same as that in the bulk phase. Few studies have investigated the movement of charges across the interface and in the organic phase, and this mechanism requires further study.

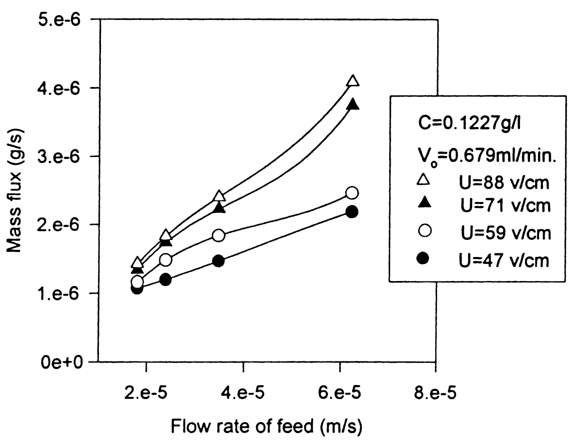

Fig. 6. Influence of the feed flow rate on the mass flux of methyl blue.

As shown in Figs. 2–4, the recovery decreases with increasing feed flow rate. This is because, as the flow rate increases, the amount of solute in the feed increases, and the contact time between the two phases decreases; consequently, the recovery ratio decreases.

3.3. *Influence of the solute concentration on the mass flux and recovery*

Figs. 8 and 9 show the influence of the initial solute concentration on the mass flux for acid-chrome blue K and

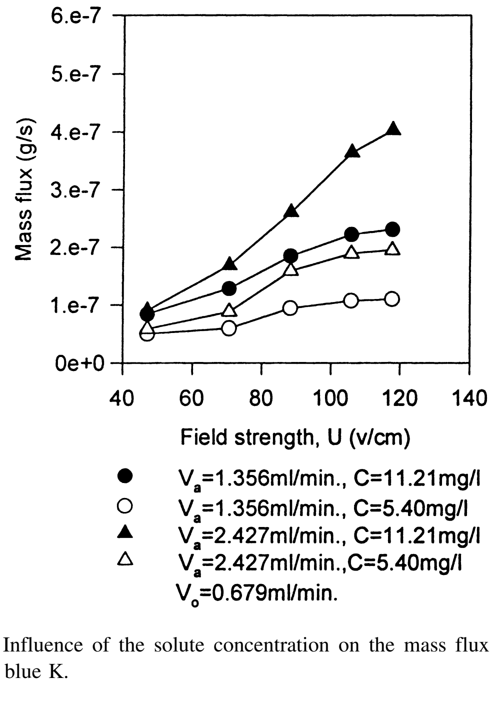

Fig. 8. Influence of the solute concentration on the mass flux of acid-chrome blue K.

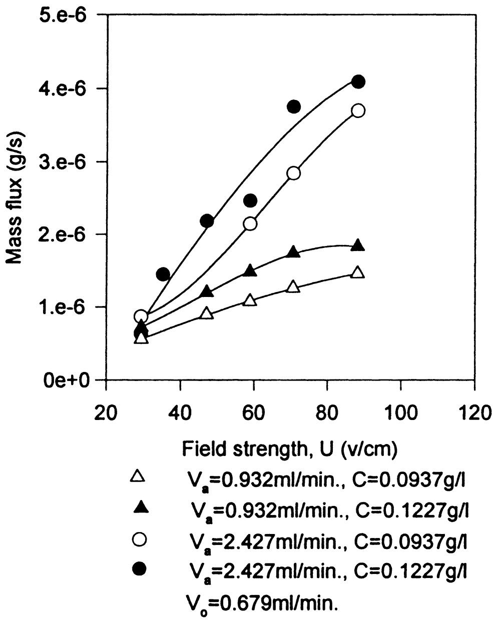

Fig. 9. Influence of the solute concentration on the mass flux of methyl blue.

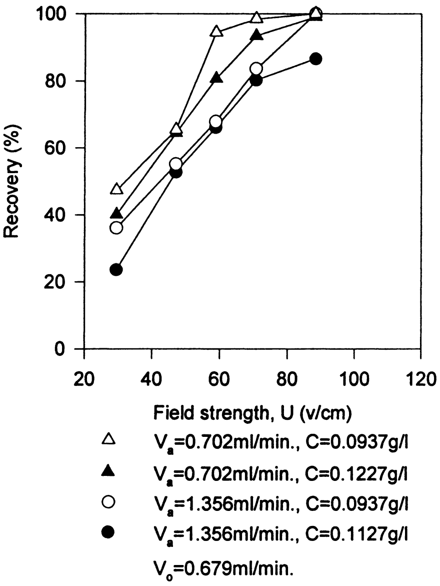

Fig. 11. Influence of the solute concentration on the recovery of methyl blue.

methyl blue, respectively. When the other experimental conditions remain the same, the mass flux will increase with increasing solute concentration. This is because more solute passes through the interface at the same field strength when the initial solute concentration is increased. However, as the initial solute concentration increases, the total solute is also increased. If the increase in mass flux is less than that in the total solute of the feed, then, as shown in Figs. 10 and 11, the recovery ratios are decreased.

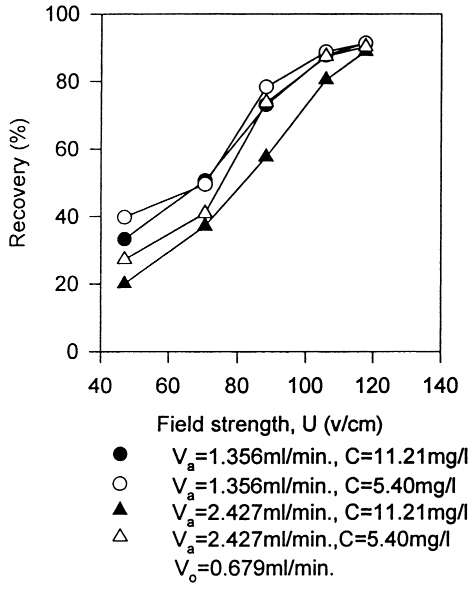

Fig. 10. Influence of the solute concentration on the recovery of acid-chrome blue K.

3.4. A mixed process of extraction and two-phase electrophoresis

Based on the experimental results, a mixed process of extraction and two-phase electrophoresis for the recovery of dyestuffs may be suggested. Most dyestuffs are charged, and can be separated into high-solubility and low-solubility dyestuffs according to their solubility in organic solvents. Dyestuffs of high solubility in organic solvents can be recovered by solvent extraction from dilute solutions, and then the loaded organic solvent can be regenerated by two-phase electrophoresis. Dyestuffs of low solubility in organic solvents, can be separated from dilute solutions by two-phase electrophoresis, and then the solutes can be back extracted by water from the loaded solvent.

4. Conclusions

The results showed that the coupled separation technique of solvent extraction with electrophoresis is very useful for the recovery of dyestuffs from dilute solutions. As the field strength increases, 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. Much higher recovery with less solvent consumption can be achieved using this technique, especially for the separation of dilute solutions. If the field strength and flow rate of the two phases are controlled well, 100% recovery can be reached. A mixed separation process of solvent extraction and two-phase electrophoresis is of high efficiency for the separation of dyestuffs.

Acknowledgements

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