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Use of current-voltage curves in high-voltage paper electrophoresis

Measurement of the temperature of the paper in high-voltage electrophoresis, particularly in the plate chamber, is difficult and reports on this subject are lacking. The assumption, that the temperature of the electrophoretic system (supporting medium, electrolyte solution, migrant) is equal to the temperature of the coolant is only valid for a limited range of the power produced, and this range should be known. Thus it is of interest to find a method for characterizing the ability of the electrophoretic apparatus to dissipate heat. This will permit the evaluation of the temperature of the supporting medium as well as the possibility of increasing the voltage. This problem may be solved by measuring the current as a function of voltage (I/V curve).

Experimental

A glass plate chamber with two-sided cooling was used¹. The pressure of the upper cooling plate on the supporting medium was 150 g/cm². In all the experiments the size of the paper strips was exactly the same. The moisture content (carefully checked) of the paper was 85%. The current was measured 20–30 seconds after applying the voltage. The results of the experiments are shown in Figs. 1 and 2. The

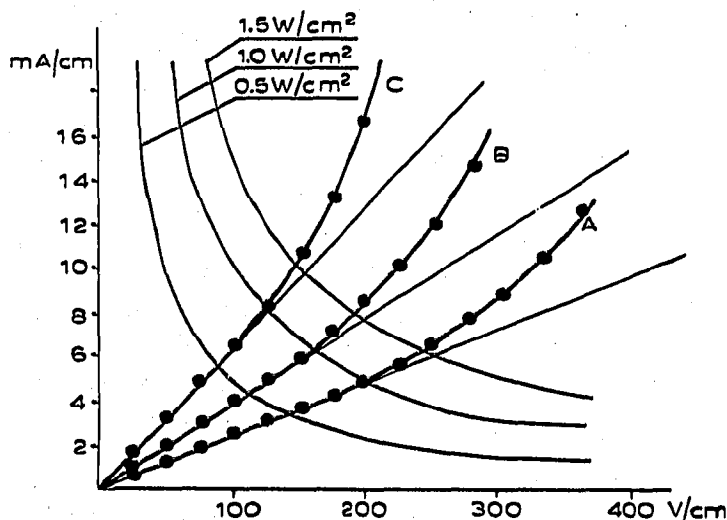


Fig. 1. Effect of the conductivity of the electrolyte solution on the I/V curves. A = $11.6 \times 10^{-3} \text{ Scm}^{-1}$; B = $17.4 \times 10^{-3} \text{ Scm}^{-1}$; C = $29.2 \times 10^{-3} \text{ Scm}^{-1}$.

variable factors in the electrophoretic system were: the concentration of the electrolyte solution which was perchloric acid (Fig. 1), or the temperature of the cooling water (Fig. 2). The hyperbolas of equal powers are also shown in the figures.

During the measurements neither the concentration of the electrolyte in the paper nor its total quantity varied. This was assured by the short time of electrophoresis, lack of evaporation in the plate chamber and separation of the paper from the electrode vessels by a cellophane membrane.

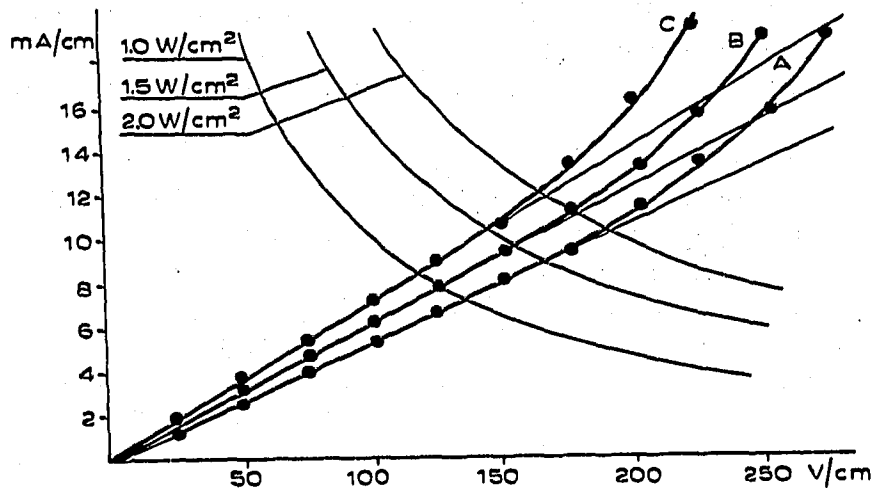


Fig. 2. Effect of the temperature of the cooling water on the I/V curves. A = 2°; B = 10°; C = 18°.

Discussion

Only the mobility of ions is responsible for the nonlinear change in current above point B (Fig. 3). Changes in temperature, in dissociation constant, and in the electromigration mechanism can be mentioned as reasons for variability in electrophoretic mobility.

The change of the dissociation constant with an increase in the potential gradient is theoretically possible as a result of forced dissociation. ONSAGER gives the following equation²: $K_n/K_0 = 1 + 0.0000132 E$, where K_n is the dissociation constant in the electric field and K_0 is the dissociation constant without any applied potential. Therefore the high voltage used in electrophoresis will not give a measurable forced dissociation effect.

Increase in voltage has no effect on the tortuous migration channel accessible to the migrant, but an increase in the GIDDINGS' ion retardation factor R (ref. 3) is possible as a result of the swelling of the paper. This would cause a decrease of current, as yet not observed, however.

It would appear from the above that the only real cause of change of resistance in the supporting medium, as the voltage increases, is the rise in temperature.

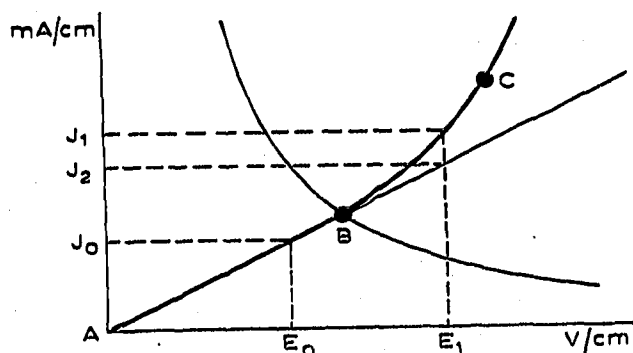


Fig. 3. Schematic plot of the relationship between current and voltage in the electrophoretic system.

On examining the I/V curves it is possible to distinguish three sections (Fig. 3). With only very low power evolved in the strip, its temperature is equal to that of the coolant. As long as the plot of I/V is linear (section AB), the paper has the same temperature as the coolant.

Point B indicates the maximal capacity for the removal of heat without an increase in the temperature of the supporting medium. Points B, obtained under the various conditions, lie on a common hyperbola of equal power. This hyperbola characterizes the ability of the chamber to remove the heat.

In section BC of the curve in question, the temperature of the electrophoretic system exceeds that of the coolant. The difference in temperatures may be found by knowing the difference $I_1 - I_2$ where I_2 is the expected value if the I/V curve were a straight line. The temperature may then be measured according to the formula:

$$T = T_c + \frac{I_1 - yE_1}{yE_1} \frac{100}{\gamma}$$

where $y = I_0/E_0$, T_c = temperature of the cooling water. For this purpose, besides measurements of I_1 and E_1 at which electrophoresis is occurring, an additional measurement of I_0 and E_0 is necessary at any point on the linear section of the I/V curve. The temperature coefficient γ of the current fluctuates within the limits of 2-3% per 1° (ref. 4), and is easily determined if more accurate measurements are needed.

Above point C (Fig. 3), the temperature of the electrophoretic system rises sharply. The position of point C is not fixed precisely and the range of the section BC utilized depends to a certain extent on choice.

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