

Electroosmotic Driving Liquid Using Nanosilica Packed Column

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Abstract: The electroosmotic pump (EOP) using nanosilica particles packed-bed column was experimentally studied. The relationship between flowrate, pressure and applied voltage of the pump, and pressure-flowrate (P - Q) characteristic were investigated.

Keywords: Electroosmotic pump, nanosilica, nanochannel, chip.

The packed-bed electroosmotic pump (p-EOP) can manipulate liquid with pressure as high as 50 MPa and micro flowrate ranging from several nL/min to several $\mu\text{L}/\text{min}^{1-3}$. The p-EOP is matching to micro systems and suitable for developing chip liquid chromatography/electrochromatography for proteomics and high throughput HPLC for drug discovery⁴⁻⁶. There are some efforts to improve the performance p-EOP⁷⁻⁸ recently. In this paper, the nanosilica was chosen as the electroosmotic carrier to investigate the performance of the p-EOP.

Experimental

Material and reagent Nanosilica particles SiO_{2-x} , where $x=0.4\sim 0.8$ with particle diameter of 20 ± 5 nm, were bought from Zhoushan Mingri Nanometre Material Co., Ltd. (China). The average particle diameter was 20 nm by TEM analysis (Tsinghua University). Methanol was of chromatographic grade. Sodium dihydrogen phosphate was of AR grade. The water was purified with Milli-Q (Millipore, Bedford, MA).

Packed-column Fabrication The general procedures for fabricating packed column were in three steps using slurry-packing method^{1-4,9}. First, the frit at one end of column was fabricated using a sodium silicate paste mixed with 2 μm silica particles and heated at about 300 °C for 10 s, then a nanosilica particle slurry was pumped into the column and the filter-like "frit" retained the nanosilica particles in place and then the second frit was formed.

p-EOP System The pumping system consisted of one packed column (5 cm \times 530 μm i.d.), power supply (0-4 kV), solvent reservoir, 0-50 MPa pressure sensor, and one multi-channel electrode^{1,2}. Volume flowrate was determined by measuring the volume of the fluid per unit time collecting at the pump outlet.

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Results and Discussion

Feasibility of nanosilica used as electroosmotic material Few people have experimentally used nanoparticle packed column to generate EOF, which has long been believed to be impossible due to the overlap of electrical double layer (EDL), δ . Based on the theoretical work of Rice *et al.*¹⁰, Knox *et al.*¹¹ studied systemically the EOF in packed-bed column related to the capillary electroseparation methods. Assuming the channels in packed-bed of spheres were approximately 1/4 of the mean sphere diameter, the particle diameter below which significant loss of electroosmotic velocity would occur. It was expected to be about $40 \kappa^{-1}$, where κ was the reciprocal of δ , that was about 400 nm for 10^{-3} mol/L solutes. There was virtually no flow through the packed column using the nanosilica. Considering that there is unsaturated incomplete bonds and hydroxyls in different linkage on nanosilica particle surface, and the nanoparticle surface is oxygen in debt, which deviates from stable silicon oxygen structure, the fixed negative charges of the nanosilica surface are far less than that of postulated. In fact, the nanosized particle (10-100 nm) can be used to increase converse flow resistance of the EOF and enhance the output pressure, which is proved by the relative studies¹²⁻¹³.

Flowrate, pressure and applied voltage of the pump The performances of the pump were investigated using methanol, methanol-water mixture (v/v = 1:1) and sodium dihydrogen phosphate buffer (2×10^{-3} mol/L, pH7.0) as the pumped fluids. Maximum pressures P (MPa) vs voltage V (kV) was shown in **Figure 1** (upper). The pressures of the pump for every liquid being pumped were linearly increased with the increase of applied voltage. When the applied voltages were the same, we could obtain the following flowrate sequence: phosphate buffer > methanol-water mixture > methanol, which corresponded to their polarization abilities and intensity with the nanosilica. The phosphate buffer was the first one departure from the linearity, when the voltage increased up to over 4 kV. Maximum flowrates Q ($\mu\text{L min}^{-1}$) vs voltage V (kV) was shown in **Figure 1** (lower), which was similar to the pressure-voltage relationship.

Pressure-flowrate relationship The pressure-flowrate (P - Q) relationship at a certain loading was an important characteristic of the EOP discussed elsewhere¹⁻⁶. **Figure 2** was

Figure 1 (upper) Maximum pressure vs voltage; (lower) maximum flowrate vs voltage

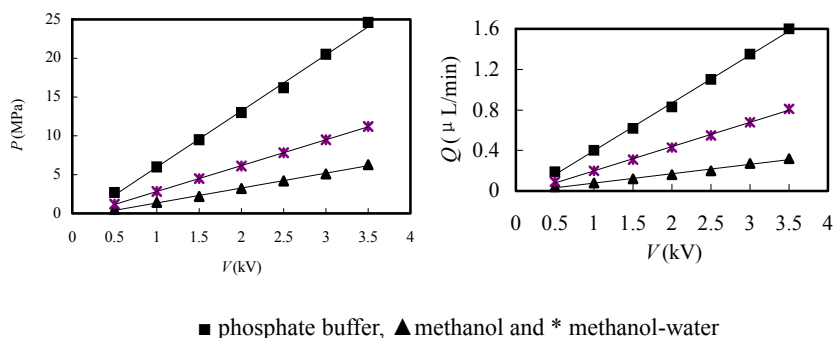
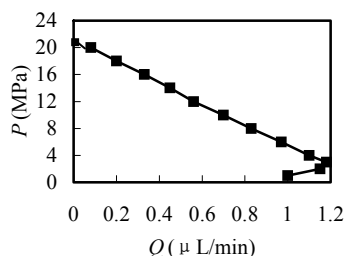


Figure 2 P - Q relationship at a certain load

the P - Q relationship using 2×10^{-3} mol/L phosphate buffer, pH7.0, at 3kV. When the loading of the pump was about 2-3 MPa, we could obtain flow rate about 1.2 $\mu\text{L}/\text{min}$. When the loading was zero, the flow rates of the pump decreased, on the contrary. When the loading was over 2-3 MPa, the P - Q relationship was well consistent with the P - Q relationship reported previously³ and only when the loading was inclined to infinity, the maximum pressure could be generated.

In conclusion, the p-EOP using nanosilica packed column could improve the performances by decreasing the power requirements, which will facilitate miniaturization of micro-total-analysis systems (μTAS) and microfluidically driven actuators¹⁴⁻¹⁶. Moreover, the results were especially valuable for nanochannel study on a microfluidic chip system.

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