Rejection of Charged Spherical Particles by Charged Porous Track-etched Membranes: Implications for Enhanced Virus and Turbidity Control

The effect of surface charge on particle rejection from UF and MF membranes has been examined from both theoretical and experimental perspectives. In this work, a computational model was developed to predict the combined effects of steric, hydrodynamic and electrostatic particle - pore wall interactions on the rejection coefficient of spherical particles in cylindrical pores. The non-linear Poisson-Boltzmann equation was used to determine the electrostatic particle - wall interaction energy, and a computational fluid dynamic model was developed to determine the hydrodynamic particle-pore wall interactions. These were then incorporated in a model of particle transport to calculate rejection. Model results show that particle rejection can be increased significantly when particle and membrane carry like negative charges.

To validate the numerical model, experiments were conducted with four different spherical colloidal silica particles and two spherical viruses (MS2 and PRD1). Track-etch porous membranes were used, providing us with an easily characterized nearly cylindrical pore geometry. Experiments were conducted under conditions where both particle and membrane carry a negative charge as well as under conditions where surface charges have minimal impact. Surface charge densities on the particles were determined from zeta potential measurements. Literature values were used for the surface charge density on the pore surface in the membranes. Experiments were designed to cover a broad range of dimensionless particle sizes by changing particle and pore sizes.

Particle rejections for the colloidal silica and viruses measured in relatively high ionic strength solutions (zeta potential $\rightarrow 0$) agreed very well with model predictions for uncharged systems (Figure 1a). This confirms the validity of the pore size values, the experimental procedures used for the rejection measurements, and the accuracy of the theoretical model incorporating steric and hydrodynamic interactions. In low ionic strength solutions, the zeta potential of silica particles was near -48mV and that of the viruses was near -20mV. With no fitting parameters involved in the comparison, good agreement between experimentally determined rejection coefficients and model predictions was observed for these systems. Results for one of the silica colloids are shown in Figure 1b. Similar results were obtained for other silica particles of different size and for two different viruses.

In all cases, rejection of charged particles was greater than that of uncharged particles showing that one can potentially take advantage of electrostatic repulsion to get complete rejection for particles that are smaller than the pore size.

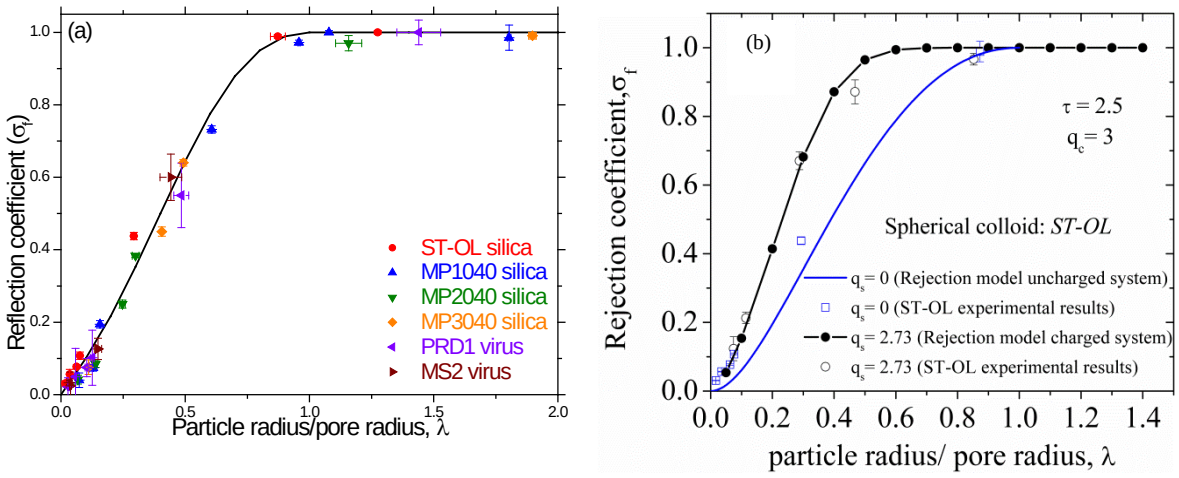


Figure 1: Quantitative comparison of experimental results for spherical particles (a) uncharged and (b) charged with theoretical predictions of the rejection coefficient.