Influence of surface properties of particles on their adhesion and removal

M. Tagawa, K. Gotoh, M. Yokokura, A. Syutoh, and S. Takechi

Department of Clothing Science, Nara Women's University, Nara, Japan

Abstract: The effect of surface properties of particles on their adhesion and removal was investigated using an immersed system consisting of nylon particles and a quartz plate. The nylon particles were dyed with a reactive dye in order to change their properties and were used for the adhesion and removal experiments in comparison with undyed particles. The electrokinetic potentials of the particles were measured by micro-electrophoresis and the Hamaker constants were independently evaluated using experimental values of dispersive component of surface free energy determined by the Wilhelmy technique. The experimental results were used for the discussion of particle adhesion and removal on the basis of the heterocoagulation theory. The differences in adhesion and removal efficiencies between dyed and undyed particles were explained in terms of the electrostatic and dispersive van der Waals interaction by considering the differences in their properties, the electrokinetic potential and the Hamaker constant, due to dyeing.

Key words: Nylon particle, adhesion, removal, electrokinetic potential, Hamaker constant, heterocoagulation, electrostatic and van der Waals interactions.

Introduction

The adhesion and removal phenomena of particles to and from a flat substrate in aqueous solutions are expected to depend on the particle size and shape [1], the surface potentials, the overall Hamaker constant [2, 3], the surface roughness [4], and the presence of adsorbed layers [5, 6]. We studied the adhesion of nylon, silver iodide, and iron(III) oxide particles to a quartz plate and their removal from the plate in aqueous solutions [1, 7-10]. Since the different kinds of particles are usually different in their size, shape, surface roughness, surface free energy and electric potential, it is difficult to discuss in detail phenomena such as adhesion and removal, even if they have no adsorbed layers. In the present study the influence of surface properties of particles on their adhesion and removal was investigated by using nylon particles whose surfaces were modified by dyeing without changes in the particle geometrical properties. The modification by dyeing with a reactive dye has the advantage of strong fastness due to covalent bond. In addition, the dye molecules will diffuse into the amorphous region of nylon and will change the van der Waals interaction between the nylon particle and the quartz. Therefore, the adhesion and removal processes were analyzed on the basis of the heterocoagulation theory using the experimental electrokinetic potential and the Hamaker constant estimated from the surface free energy of the modified particles in comparison with those of the unmodified ones.

Experimental

Materials

Spherical particles of nylon 12, obtained from Toray Co., Ltd., have the modal diameter of 5 μm with standard deviation of 2.7 μm, the density of 1.02 g/cm³ and the chemical structure of H [-HN--(CH₂)₇-CO--OH] [7, 8]. The particles dispersed in liquid were cleaned in an ultrasonic bath and centrifuged. The supernatant was discarded and the precipitate resuspended in the liquid. The procedure was repeated three times using doubly distilled water and ethanol successively. Then the particles were purified with ethyl ether for 10 h using Soxhlet’s extractor.

The nylon particles were dyed with a reactive dye, Procion Blue HB. The structural formula is shown in Fig. 1. The dyeing procedure was as follows: the particles (2 g) were put into the dyebath (0.2 dm³, 40 °C) consisting of 1 g/dm³ in dye and 0.05 g/dm³ in ammonium acetate. Uptake of dye was carried out at 95 °C for 1 h after
adding 90% formic acid (0.06 cm³). The dyed nylon particles were rinsed by centrifugation, discard, and ultrasonic resuspending. The procedure was repeated until the dye could not be spectrometrically detected in the supernatant liquid, and the particles were dried at reduced pressure in a desiccator. The dye-uptake by the particles was determined to be $4.9 \times 10^{-3}$ g/g by absorption measurements.

The cell was turned over and allowed to stand on the stage of a light microscope for 2 h in order to allow formation of particle deposit on the inner wall of the cell. The number of particles deposited in $3.3 \times 10^{-3}$ cm² of the wall ($n_t$) was determined by counting only single particles on the wall through micrographs. The cell was then returned to its original position and photographs were again taken after 30 min so the number of particles adhering to the wall ($n_o$) could be counted. The adhesion efficiency of particles was given as the ratio of $n_o$ to $n_t$ ($= n_o/n_t$).

**Particle removal by electro-osmosis**

After determining the adhesion efficiency, an electric field was applied parallel to the wall of the cell by using platinumized platinum electrodes changing the polarity every 5 min to prevent bubbling, thus generating the electro-osmosis on the wall. Some of the particles adhering to the wall were removed by electro-osmotic flow. The number of particles remaining on the wall at time $t$ ($n_t$) was determined from photographs. The removal efficiency of particles was given as $(n_0 - n_t)/n_0$. The increase in temperature of solution in the cell by applied electric field was within 2 °C.

The electric field, $X$, was calculated from

$$X = \frac{I}{iS^2}$$

where $I$ is the electric current flow, $i$ the specific electric conductivity of liquid, and $S$ the cross-sectional area of the cell ($S = 0.471$ cm²).

All experiments were carried out in a room maintained at constant temperature (20 °C) and constant humidity (RH 65%).

**Results**

**ζ-potentials**

The pH dependence of ζ-potentials of nylon particles and the quartz plate is given in Fig. 2. Undyed