# The Effect of Polymer Adsorption on Particle Settling in Polymer Solutions

**YORAM COHEN**

**Department of Chemical Engineering**
**University of California, Los Angeles**
**Los Angeles, CA 90024**

## INTRODUCTION

The sedimentation of solid particls is of interest in numerous applications, including rheology, suspension and colloid stabilization, and "sand control" in oil recovery operations (Torrest, 1983). It is well known that polymer molecules adsorb well at solid interface (Lipatov and Sergeeva, 1974). Therefore, in systems where particles are in contact with polymer molecules for a sufficiently long time, polymer adsorption is likely to occur. The presence of an adsorbed polymer layer may then affect the settling velocity of the particles. In this communication, the use of a simple method of assessing the effect of polymer adsorption on the sedimentation of solid particles is reported.

## EXPERIMENTAL

The experimental method of studying the effect of polymer adsorption on particle sedimentation was based on the determination of the terminal settling velocity, for a given particle in a given polymer solution, in the presence and absence of absorption. The case of adsorption refers to the natural adsorption of polymer onto the particle surface. This was achieved by a static adsorption step for a period of about 24 hours to ensure a proper equilibration. In contrast, the case of no adsorption was achieved by chemically treating the particles with a solution of 2% dimethyldiethoxysilane in a solvent mixture of 95% ethanol and 5% distilled water, adjusted to a pH of about 4.5–5.5 with acetic acid. The details of the surface treatment procedure can be found elsewhere (Christ, 1983; Cohen and Metzner, 1982, 1983).

Settling velocity measurements were carried out for a single size spherical glass particle, 0.025 cm in diameter, in different polyacryalmide solutions. The polymer solutions were 0.05, 0.06, 0.072, and 0.16% wt. partially hydrolyzed polyacrylamide (J333, MW = 4.5 × $10^6$, Dow Chemical Co.) in a 2% aqueous NaCl solution. NaCl was added in order to maximize the amount of hydrophobic adsorption (Lakatos et al., 1981). The zero shear viscosity and the density of the solutions are given in Table 1. The amount of polymer adsorbed onto the particles, from the above polymer solutions, was determined from static adsorption experiments that closely followed the procedures of Mungan (1969) and Szabo (1975). The polyacrylamide concentrations, however, were determined using an iodometric technique (Scoggins and Miller, 1979). The adsorbed polymer phase corresponded to a surface coverage of 0.74 mg polymer/m$^2$ adsorbent. This amount of adsorbed polymer corresponded approximately to the maximum adsorption isotherm that was reached at a concentration lower than 0.05% wt. This is in agreement with other adsorption studies, with high molecular weight polymers, that have shown that the maximum adsorption isotherm is reached at low polymer concentrations (Lipatov and Sergeeva, 1974; Cohen et al., 1982; Furusawa, 1980; Lakatos et al., 1981). Static adsorption experiments with the silylated particles confirmed the effectiveness of the surface treatment procedure in eliminating polymer adsorption.

## RESULTS AND DISCUSSION

The terminal settling velocities in the absence and presence of an adsorbed polymer layer, $V_t$ and $V_{ta}$, respectively, are given in Table 1. Each reported value represents the average of at least 50 determinations. These results reveal that polymer adsorption on the particle surface leads to an enhancement of the settling velocity. This behavior is expected if it is assumed that the adsorbed layer merely increases the apparent size of the particle. Since the Reynolds number for the measurements was less than 0.67, the effective hydrodynamic thickness (EHT) of the adsorbed layer can be estimated by comparing the settling velocities $V_t$ and $V_{ta}$ using Stokes's law for the drag coefficient (Bird et al., 1963). The resulting adsorbed layer thicknesses are shown in Table 1. The EHT values for the 0.07%w and 0.16%w solutions are in agreement with EHT values reported for similar polymers in cylindrical pore geometries (Cohen and Metzner, 1982; Gramain and Myard, 1981). At lower polymer concentrations, namely, the 0.05 and 0.06% wt. solutions, the EHT values exceed the estimated root-mean-square end-to-end distance of the free macromolecules in solution (approximately 0.3 $\mu$m) by more than an order of magnitude. This behavior suggests that in dilute polymer solutions the adsorbed polymer layer is expanded, with loops extending from the surface far into the solution without significant interaction with free polymer molecules, thereby increasing the effective hydrodynamic radius of the particle. It is speculated that such adsorbed layer expansion may be

TABLE 1. POLYMER SOLUTIONS AND ADSORBED LAYER THICKNESS

| Polymer Concentration wt. % | Solution Density[1] g/cm$^3$ | Viscosity at Zero Shear Rate[2] g/cm·s | Terminal Settling Velocity[3] cm/s | | Effective Hydrodynamic Thickness of Adsorbed Layer micron |
|---|---|---|---|---|---|
| | | | $V_t$ | $V_{ta}$ | |
| 0.05 | 0.968 | 0.0448 | 1.2404 | 1.4401 | 19.4 |
| 0.06 | 0.984 | 0.0629 | 0.8752 | 0.9503 | 10.5 |
| 0.07 | 0.997 | 0.0860 | 0.6401 | 0.6522 | 2.3 |
| 0.16 | 1.053 | 0.5725 | 0.0920 | 0.0925 | 0.68 |

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[1] Estimated error ± 0.001 g/cm$^3$.
[2] Estimated error ± 5 × $10^{-4}$ g/cm·s.
[3] Estimated percent error less than 0.1%.

of particular significance in the settling of concentrated suspensions in polymer solutions.

Although a limited number of data points were presented, the present experimental procedure clearly demonstrates the effect of polymer adsorption. Data on rates of adsorption are not readily available for water-soluble polymers, hence possible adsorption effects are difficult to assess in advance. The current study, however, suggests a simple procedure of evaluating hydrodynamic adsorption effects in various solid particles-polymer solution systems. The use of the surface treatment method with substrates other than glass should be feasible with a suitable selection of a silylation treatment.

## NOTATION

$V_t$ = particle settling velocity
$V_{ta}$ = particle settling velocity with an adsorbed polymer

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