

# " KINETICS AND THERMODYNAMICS OF MODEL COLLOIDAL PARTICLE DEPOSITION ON SYNTHETIC POLYMER SURFACES "

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## Introduction

Ability to study and quantify deposition / detachment processes is of a high scientific and industrial importance. Such phenomena are virtually active during colloidal particle/surface interaction at solid–liquid interfaces. The latter are important from several technological aspects e.g. in biofouling of membranes or artificial organs (in general of biocompatible surfaces), in immobilization of enzymes etc. The most important sphere–wall interactions are those leading to the deposition of a spherical particle onto the surface. The flow near the collector can be decomposed into a local stagnation–point flow and a local simple–shear flow [1]. The connective–diffusion equation can be written as follows:

$$\frac{\partial n}{\partial t} + \nabla \cdot J = Q \quad (1)$$

$$J = -D \cdot \nabla n + un \quad (2)$$

where  $J$  is the particle flux vector,  $Q$  is a source term,  $D$  the diffusion tensor and  $u$  the velocity which can consist of several contributions:

$$u = u_{hydr} + u_{coll} + u_{ext}$$

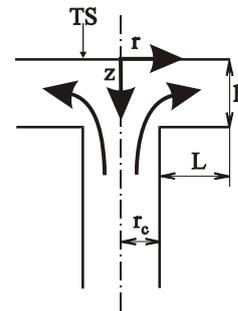
The hydrodynamic velocity is usually obtained by solving the Navier–Stokes equation, neglecting the presence of the dispersed phase:

$$\rho \left( \frac{\partial v}{\partial t} + v \cdot \nabla v \right) = -\nabla p + \eta \nabla^2 v + \rho F_{ext} \quad (3)$$

where  $v$  is the fluid flow velocity,  $\rho$  is the fluid density,  $p$  is the pressure,  $\eta$  is the dynamic viscosity,  $F_{ext}$  is the body volume force exerted on the fluid and  $t$  is the time. For the incompressible fluids eq. (3) is complemented by the continuity equation (4):

$$\nabla \cdot v = 0 \quad (4)$$

The numerical analytical solution of eqs. (3), (4) for a given initial velocity field and specified boundary conditions is available for simple geometries. In our case a *stagnation–point flow collector* was used (Fig. 1) which in experimental configuration is called “*impinging jet*” [2].



**Fig. 1.** Schematic representation of stagnation–point flow collector. The tested surface is a top part of the collector (TS).

The fluid velocity components (radial and normal) in the vicinity of the stagnation point can be described:

$$v_r = \alpha_r (\text{Re}, h/r_c) \frac{v_m}{r_c^2} r z \quad (5)$$

$$v_z = -\alpha_r (\text{Re}, h/r_c) \frac{v_m}{r_c^2} z^2 \quad (6)$$

where  $r$  is the radial distance from the symmetry axis,  $z$  is the distance from the adsorbing interface,  $\alpha_r$  is a flow intensity parameter and  $v_m$  is the mean linear velocity given in (8). The latter parameter  $\alpha_r$  is dependent on the cell geometry and the flow intensity, which is usually expressed by the *Reynolds number* ( $\text{Re}$ ). For our experimental set–up the ratio of the distance between the confining plate and the collector to the radius of the jet ( $h/r_c$ ) was 1.7 (see Fig. 1). Number of particles depositing per unit area per unit time on the wall is expressed as a particle flux  $j$ . This flux is expressed in praxis in the form of dimensionless *Sherwood number*  $Sh$  (12):

$$Sh = \frac{j a}{D_0 n_0} \quad (7)$$

where  $D_0$  is the diffusion constant, and  $n_0$  is the number concentration of particles. By use of Smoluchowski–Levich approximation for the case when there is no energy barrier between the particle

and the collector (so called fast deposition) and by neglecting gravity forces particle flux is given as:

$$Sh_{fast} = \frac{\exp\left(-\frac{Pe}{6}\right)}{\int_1^{\infty} \exp\left[-\frac{Pe}{6}(z)^3\right] dz} \quad (8)$$

where  $z$  is the dimensionless distance between the sphere center and the wall, and  $Pe$  is the *Peclet number* defined as:

$$Pe = \frac{2\alpha_r a^3}{D_0} \quad (9)$$

For spherical particles diffusion constant is given by *Einstein equation* (15):

$$D_0 = \frac{kT}{6\pi\eta a} \quad (10)$$

where  $k$  is the Boltzmann constant,  $T$  is the temperature and  $\eta$  dynamic viscosity of the suspension. In the case when the energy barrier is present, the deposition rate is reduced and for the particle flux we obtain:

$$Sh = \alpha_d Sh_{fast} \quad (11)$$

where  $\alpha_d$  is called the *deposition efficiency*. When electrostatic repulsion is acting between the particles and the surface  $\alpha_d < 1$ ; while for electrostatic attraction  $\alpha_d > 1$  [6]. When only Van der Waals forces are acting  $\alpha_d \approx 1$ . Equation (11) describe the initial deposition rate on a base surface. As deposition proceeds, deposited particles slow down the deposition. In the absence of particle detachment [6]:

$$n_t = n_{\infty} \left( 1 - e^{-\frac{t}{\tau_{bloc}}} \right) \quad (12)$$

where  $n_t$  is the number of deposited particles at time  $t$ ,  $n_{\infty}$  they steady state number, and  $\tau_{bloc}$  is the characteristic time required to reach the steady state, referred to as the *blocking time*.

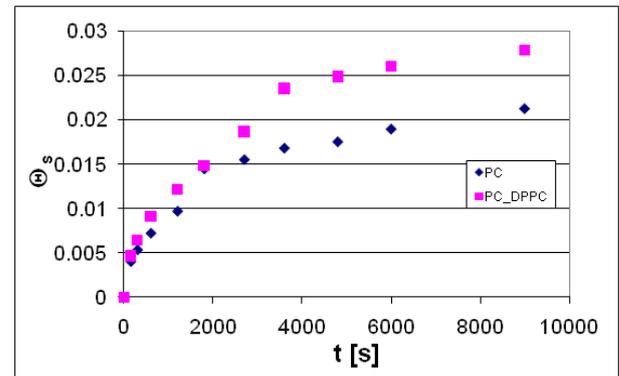
### Materials and methods

As target surfaces (1 mm thick plates) of the copolyester PET (Simolux, SIMONA AG) and PC Makrolon (GP clear 099) (BAYER SHEET EUROPE) were used. For deposition PS latex particles (Sigma-Aldrich) of 3  $\mu\text{m}$  diameter size in water were used. Target surfaces were coated with phospholipid layer (1,2-dipalmitoyl-sn-glycero-3-fosfocholin (DPPC) (Sigma)).

### Results and discussion

Study was aimed on the effect of chemical coating on the change of substrate surface properties.

Changes of the surface properties were followed by measuring static contact angles of wetting (sessile drop method) and Impinging Jet deposition method. Contact angle measurements show, that phospholipid treatment in all studied samples (PET, PC) led to the vigorous increase of the surface free energy. For coated samples major part of the surface free energy was dominated by polar component in contrast to the non-treated materials. Here the dispersive component was dominating. Results of the deposition experiments of polystyrene particles (particle diameter 3  $\mu\text{m}$ ) correspond with trends obtained by contact angle measurements. Surface treated materials exhibited higher surface activity reflected in increased deposition rates. Simultaneously there was confirmed the fact, that with increasing value of Reynolds number of the dispersion flux the higher deposition rates were observed.



**Fig.2.** Dependence of the PS dimensionless surface coverage on deposition time at jet flux  $Re \approx 8$  for PC and PC\_DPPC.

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