MODELING ON DYNAMIC BEHAVIOR OF LUNG SURFACTANT USING SMOOTHED PARTICLE HYDRODYNAMICS

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ABSTRACT

Surfactants in solution migrate to an interface and reduce its surface tension. The air spaces of the lung bubble are coated with a thin film containing surfactant. During breathing, this film periodically expands and contracts, resulting in continuous variation of surfactant concentration by de-/adsorption and the diffusion processes, and thereby surface tension. These processes are believed to stabilize alveoli at low lung volume and reduce the work breathing. This problem is usually studied with the help of an oscillatory surfactometer, the surface tension is measured as a function of bubble surface area over a range of cycling rates of the bubble and surfactant bulk concentrations [1].

In this work, the dynamic behavior of lung surfactant is modeled by using smoothed particle hydro-dynamics (SPH), which is a fully Lagrangian, grid free method for generalized applications of fluid dynamics. Based on a new SPH formulation for multi-phase flows with surface tension effects [2], the diffusion and the de-/adsorption of surfactant at the interface are modeled. Furthermore, the coupling between diffusion and de- and adsorption are formulated in a strictly conservative algorithm.

To validate the developed models, three types of simulations have been performed: (i) the evolution of surface tension for a fresh bubble with constant area, (ii) the evolution of surface tension after a bubble has been cycled a given number of times and stopped at the maximum area, and (iii) the changes of surface tension versus interfacial area during dynamic cycling of a bubble. Figure 1a shows how the surface tension decreases in a freshly formed bubble with two sets of adsorption rate coefficients and diffusion coefficients. The bulk concentration of surfactant is $C_{bulk} = 1 kg/m^3$ in both cases and the maximum equilibrium interfacial concentration $\Gamma^* = 3 \cdot 10^{-6} kg/m^2$. The evolution of surface tension after a bubble has been cycled a given number of times and stopped at the maximum area was measured, shown in Fig. 1b. It is found that the drop in surface tension is much slower after the bubble has been cycled several times (here 6) than in a bubble that has not been cycled so often, which is in agreement with Ref. [3]. Figures 2 shows the surface tension loops for the first, the second, the fourth and the sixth cycles with and without diffusion effects. It is found that the maximum surface tension is higher if diffusion is included, which is again in agreement with the results of Ref. [3]. Further studies on the interplaying among the time scales of bubble cycling, the de- and adsorption and the diffusion of surfactant, which may lead to the explanations on the so called "subsurface depot" and "pseudo-film collapse" phenomena, will also be presented in the conference.
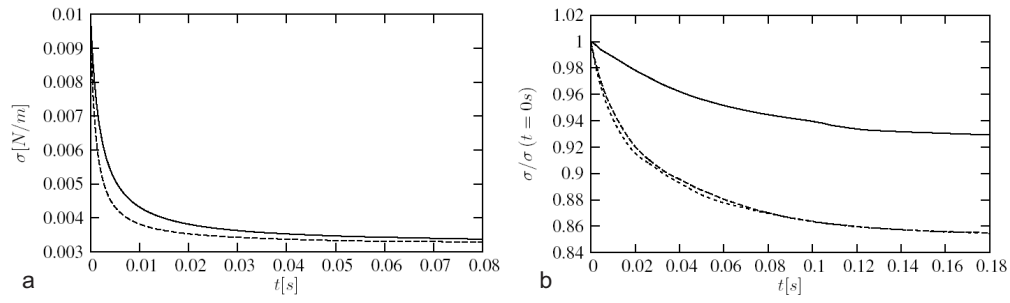
Figure 1: Surface tension vs. time, (a) in a freshly formed bubble, solid: $k_1 = 40m^3/(kgs)$, $D = 4 \cdot 10^{-6}m^2/s$, dashed: $k_1 = 80m^3/(kgs)$, $D = 8 \cdot 10^{-6}m^2/s$, (b) at maximum bubble area after consecutive dynamic cycles with $k_1 = 80m^3/(kgs)$ and $D = 8 \cdot 10^{-6}m^2/s$, solid:cycling stopped after 6 cycles, dashed: cycling stopped after 2 cycles, dotted: cycling stopped after 1 cycle.
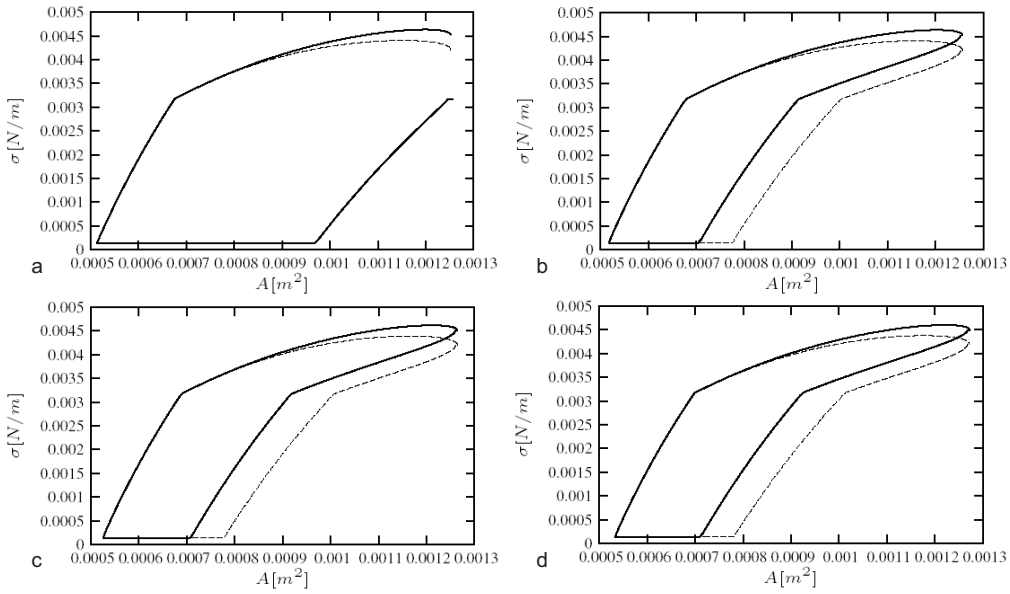

Figure 2: Surface tension vs. interfacial area for (a) the 1st, (b) the 2nd, (c) the 4th, and (d) the 6th circles with $k_1 = 40m^3/(kgs)$, solid: with diffusion and $D = 4 \cdot 10^{-6}m^2/s$, dashed: without diffusion.

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