Flow of Dry Foam in a Pipe

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Abstract

Due to the coupling of foam flow with foam generation step, the earlier studies on foam flow have not led to consistent results. An increase in flow rate to obtain ΔP vs. Q data changes the foam under investigation itself. The controlled experiments carried out earlier in our group show that ΔP increases with flow rate as Q^2/3, a weaker dependence than that known for laminar flow or plug flow on a slip layer on pipe wall. Simple calculations suggest that when all the liquid present in foam is put in thin film on the wall or slip layer, the magnitude of pressure drop is still over-predicted significantly. Alternatively, if plug-slip layer interface is considered as free surface, the pressure drop predicted is zero. COMSOL Multiphysics, a commercially available software, was used to simulate actual fluid flow in wall region between two deformed bubbles. The detailed simulations accounted for curved shape of deformed bubbles near the wall, rheological behaviour of surfactant loaded interface, surfactant transport and diffusion in the bulk of liquid, surfactant adsorption/desorption on the gas-liquid interface, surfactant transport and diffusion on gas-liquid interface, and Marangoni stresses. The complete simulations with the inclusion of all the above mentioned physical processes show only a slight weakening---ΔP ∝ Q^0.9. The simulation results for fixed thin film thickness show that the computed pressure drop receives zero pressure drop from the region where the bubble surface is parallel to the wall. An increase in film thickness, which is of the order of tens of microns, however decreases the pressure drop sensitively. The dominant contribution to pressure drop comes from the liquid being squeezed under an advancing bubble. An increase in foam velocity increases the pressure under the rolling and advancing bubble, which, due to the deformable shape of bubble, is expected to increase the thickness of the slip layer left behind. The increased slip layer thickness at increased flow rate, in agreement with the experimental observations, requires less squeezing of liquid under the advancing bubble and therefore the weakened dependence of ΔP on Q. A hundred fold increase in flow rate requires the slip layer thickness to increase by a factor of about four to match the experimental observations.