# Impacts of hydrodynamic conditions and surface roughness on the critical conditions and thickness of early-stage biofilm development

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## Abstract

Biofilms can increase pathogenic contamination of drinking water, cause biofilm-related diseases, alter the sediment erosion rate, and degrade contaminants in wastewater. Compared with mature biofilms, biofilms in the early-stage have been shown to be more susceptible to antimicrobials and easier to remove. Mechanistic understanding of physical factors controlling early-stage biofilm growth is critical to predict and control biofilm development, yet such understanding is currently incomplete. Here, we revealed the impacts of hydrodynamic conditions and surface roughness on the development of early-stage *Pseudomonas putida* biofilm through a combination of microfluidic experiments, numerical simulations, and fluid mechanics theories. We demonstrated that early-stage biofilm growth is suppressed under high flow conditions and that the critical local velocity for early-stage *P. putida* biofilms to develop is about 50 µm/s. We further illustrated that micron-scale surface roughness promotes the growth of early-stage biofilm by increasing the area of the low-flow region. Furthermore, we showed that the critical average shear stress, above which early-stage biofilms cease to form, is 0.9 Pa for rough surfaces and 0.3 Pa for flat or smooth surfaces. The important control of flow conditions and surface roughness on early-stage biofilm development, characterized in this study, will facilitate future predictions and control of biofilm development on the surfaces of drinking water pipelines, blood vessels, and sediments.

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