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NUMERICAL MODELING OF FLUID–BIOFILM INTERACTION

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ABSTRACT

Biofilms are formed when bacterial cells attach to submerged solid surfaces and accumulate to form a multilayered cellular structure. During the biofilm development process, bacterial cells may detach from the biofilm into the surrounding fluid. The phenomenon of detachment is now recognized as having an important role in promoting dissemination from and initial infection point to other sites in the body [1]. An example of this is endocarditis caused by detachment of biofilm growing on heart valves whereby the production of emboli may cause serious complications when they are released into the bloodstream [2]. Biofilm detachment is also of concern in the management of water distribution systems as detached biofilm can contribute to the distribution of pathogens [3].

The key question in relation to detachment from bacterial biofilm is the response of the biofilm to hydrodynamic forces. In this study, a Finite Volume Method (FVM) based Fluid-Structure Interaction (FSI) partitioned solver implemented in OpenFOAM framework [4] is applied. Dynamic interaction is simulated between an incompressible Newtonian fluid and a bacterial biofilm modelled as a linear viscoelastic solid. Laminar fluid flow is modelled by the Navier-Stokes equations in an Arbitrary Lagrangian-Eulerian (ALE) formulation while the large deformation of the viscoelastic solid is described by the geometrically nonlinear momentum equation in an updated Lagrangian formulation. Biofilm stress history is related to the strain history via the hereditary integral form of the constitutive relation while the relaxation modulus is expressed by the Prony series which is fitted using collocation method through the creep test experiment data.

Spatial discretization of both domains is performed using the second-order accurate unstructured cell-centered FVM. The fluid model is discretised on the moving mesh, while the solid model is discretised on the fixed mesh in an updated configuration. Automatic vertex-based mesh motion solver is used to accommodate the fluid mesh to the fluid-solid interface deformation [5]. Temporal discretization of both models is performed using a fully implicit second-order accurate scheme. Coupling between the domains is achieved using a strong implicit coupling algorithm.

Both fluid and structural parts of the FSI solver are extensively tested [5, 6] before

application in FSI simulation. Finally the FSI solver is used to simulate interaction between the fluid flow and bacterial biofilm deformation. The biofilm is considered as semi-hemispherical shape attached to the centre of the bottom boundary of the square cross-section flow cell. Thickness and width of the biofilm are 100 μm and 350 μm respectively, and flow cell dimensions are 3 × 3 × 100 mm. Fluid flow through the flow cell was in laminar regime. Result of the simulation show good agreement with the available experimental results.

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