Model and App of Hydrophobic Meshes Used in Oil Spill Recovery

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Abstract

Accidental oil spills in aquatic environments are a recurring problem in the oil and gas industry and have severe ecological, social and economic consequences [1]. One of the most promising clean-up techniques is the use of hydrophobic meshes, which are generally made of stainless steel and coated with hydrophobic and oleophilic [2, 3, 4]. They act as a filter: the oil passes through the mesh, while water is retained outside (Figure 1a) [5]. Hydrophobic meshes are still at an early development stage (Figure 1b) but offer many advantages (clean, continuous operation, low energy demand, good recovery capacities), which allows to recycle the spilled oil. However, when a hydrophobic mesh is submerged below its breakthrough pressure depth, water will intrude and contaminate the recovered oil.

In the present work, a hydrophobic mesh is conceptualized as an equivalent porous medium with a selective wettability, where the porosity, specific surface area and permeability are a function of the wire and opening radii. A mathematical model of a hydrophobic mesh was implemented in COMSOL Multiphysics® software using the coefficient's form of the PDE interface with multiple dependent variables. The model solves 1D isothermal two-phase flow through porous media [6]. Water pressure and oil-water capillary pressure are adopted as the state variables. The initial condition in the mesh is full oil saturation. At the boundaries the water pressure is set at the hydrostatic pressure and the capillary pressure is calculated from the hydrostatic pressure difference.

Also, the COMSOL Application Builder was applied to create a practical and user-friendly tool tailored for mesh designers and/or operators. The app allows the user to set the main parameters that define the system, such as mesh, oil and water properties, and retention function parameters. For instance, the "Pore Analysis" window can be used to determine an optimum mesh pore radius (Figure 2). Wider mesh pores enhance both water content and oil fluxes. Hence, the optimum mesh size must be chosen to maximize oil flux while maintaining a low water content. These variables can be compared for a set of depths and pore radiuses.

Given the fast dynamic of the system, simulations were run in steady state. A simulation case was dedicated to evaluate the conditions for which water breakthrough occurs. The model shows the characteristic behavior of a hydrophobic-oleophilic mesh system, displaying two distinct flow regimes: (i) pure oil recovery and (ii) oil recovery with water breakthrough (Figure 3). These two operational regions are separated by a critical depth of

mesh immersion that depends on the fluid and mesh properties. A sensitivity analysis demonstrated that water breakthrough and oil recovery efficiency are affected majorly by the mesh opening radius. Large openings favor high oil fluxes but also water breakthrough. Finally, a performance curve of the mesh is proposed as a practical tool for designing and dimensioning purposes (Figure 4).

Reference

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Figures used in the abstract

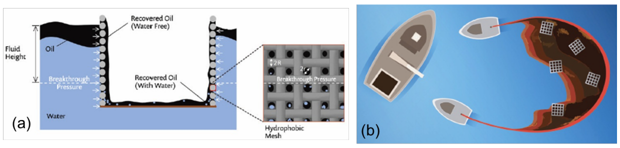

Figure 1: (a) Conceptual model of a hydrophobic mesh; (b) field operation: a boom towed by boats hems in the oil while hydrophobic meshes collect it.

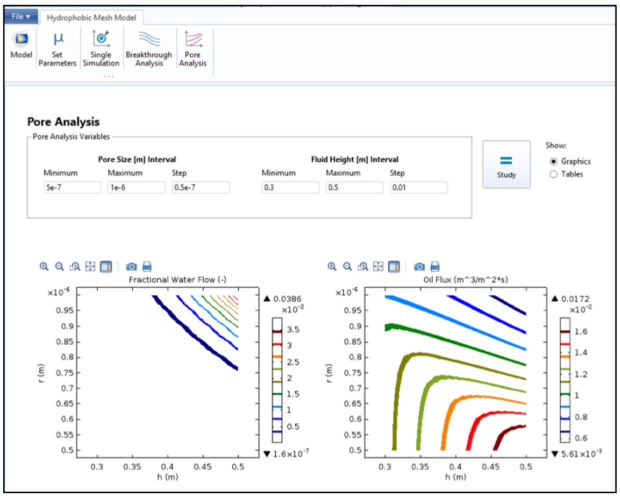

Figure 2: “Pore Analysis” windows of the Hydrophobic Mesh App.

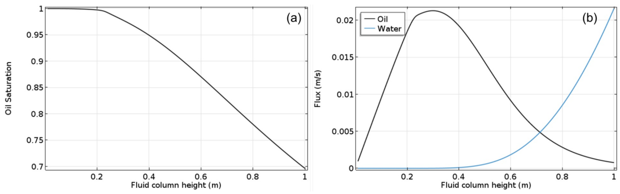

Figure 3: Steady state two-phase flow through a hydrophobic mesh: (a) oil saturation and (b) oil and water fluxes as a function of the fluid column height at the inlet.

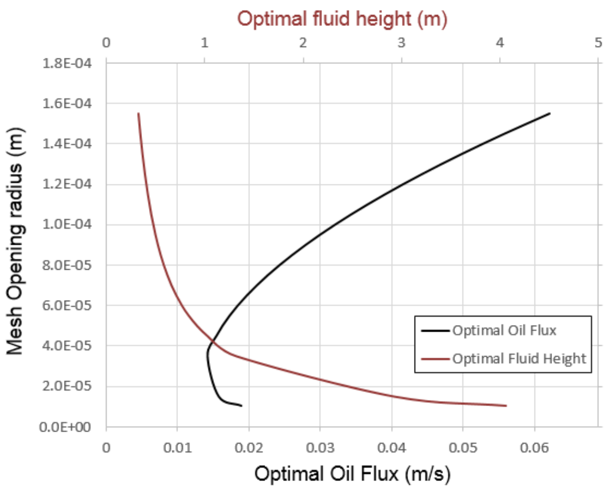

Figure 4: Performance curve: optimal oil flux versus water column height for meshes with different opening radius.