ADDRESSING OIL SPILL CLEANUP USING HYDROPHOBIC MESHES

Since current oil spill cleanup and containment methods are often costly and operate with only limited success, engineers at Amphos 21 have devised a numerical simulation app for testing new cleanup techniques using hydrophobic meshes.

by LEXI CARVER

Oil spills are notorious for being urgent and unexpected, known for the villainous damage they cause to aquatic environments and marine life, and must be contained swiftly before they cause long-term disaster. Techniques for containing and recovering spilled oil are readily available in the form of booms and skimmers that collect it, but these rarely fully rectify the problem.

Booms are used to curb the spread of oil into wider areas and keep the oil from reaching sensitive coastlines. Some designs absorb oil in an effort to remove it, while skimming techniques are also used to clear oil away. In other cases, controlled fires burn oil off of the water — though this creates another pollutant — or chemical dispersants are added to the water to accelerate the breakdown of the oil components.

These methods, while helpful, are not able to collect much of the oil during cleanup and are only effective if deployed very quickly to the site of the accident. Much of the oil sinks to the seafloor. For instance, cleanup efforts after the 1989 Exxon Valdez oil spill off the Alaskan coast were unable to recover most of the oil.

What is collected is often an oil-water mixture that is only partially usable. This means that in addition to the obvious environmental concerns, the wasted oil results in even more pumping after the cleanup attempts, in order to access the original amounts of oil.

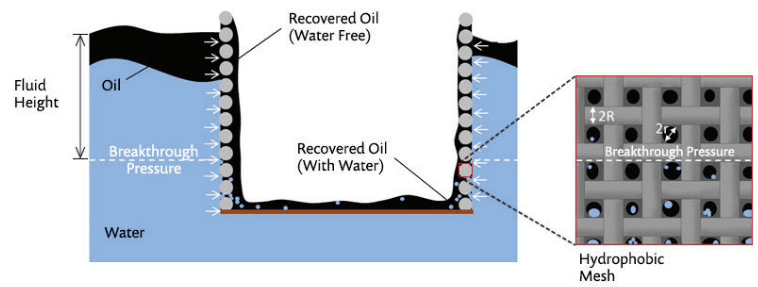

FIGURE 1. Concept of a hydrophobic mesh operation.

In response to the need for cleanup methods that prevent ecological disaster and oil waste, Amphos 21, a consultant group specializing in environmental technology, has developed numerical models of hydrophobic meshes, a concept for collecting spilled oil that is being studied by scientists and technologists. Their goal? An answer to this quandary that would be fast, easy to use, and environmentally friendly.

After conceptualizing the hydrophobic mesh as a porous medium, they developed computer simulations and custom applications to distribute to people in product development, disaster response, and environmental organizations. Through simulation apps, they intend to make virtual testing capabilities available for the engineers, researchers, and cleanup crews seeking the appropriate response for a given oil spill scenario as they race against the clock to stave off destruction.

⇨ POTENTIAL FOR NEW OIL RECOVERY METHOD

The meshes being studied at Amphos 21 are usually made of steel or copper and coated with a hydrophobic polymer to repel water and attract oil. They act like filters; water remains on one side, while oil passes through (see Figure 1). The rates of oil flux through the holes of the mesh depend on the water depth, oil properties (which can vary depending on where the oil is pumped), and the coating on the metal.

"In addition to being an effective option for clearing oil from the water, this offers the possibility of recycling

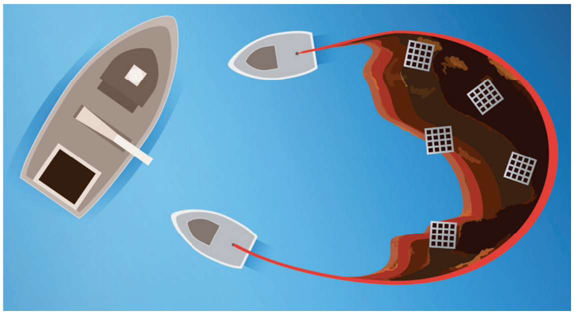

FIGURE 2. Concept: a boom towed by boats hems in the oil while hydrophobic meshes collect it.

the spilled oil without having to process it — which is often another costly step in the cleanup process," said Emilie Coene, consultant at Amphos 21. "These meshes could be used for continuous operation, are very clean, and potentially have good recovery efficiency and capacity."

Hydrophobic meshes could, hypothetically, be used alongside equipment designed for blocking the oil from spreading out. For instance, while a boom surrounded the spill, meshes and collection containers could be deployed directly into the oil to collect it (see Figure 2). The collected oil could then be pumped out of the container at regular intervals to ensure the correct pressure difference from one side of the mesh to the other.

"You can envision a large cylindrical container (the mesh) that could be left in the ocean until saturated with oil and then emptied," added Orlando Silva, senior consultant and project manager. "Or you could deploy the container and keep it connected to a pump for continuous extraction as oil is collected. They could also be tailored to many different operating conditions," he continued. "We're hoping to offer something to R&D engineers trying to design cleanup tools, environmental companies doing research, and the oil companies that have to figure out how to contain a very large problem very quickly."

One challenge arises with the hydrophobic mesh collection method: fluid height. At a certain water depth, hydrostatic pressure will reach a "breakthrough" level, causing water to intrude into the mesh and the collection container. If enough water gets mixed in with the salvaged oil, the oil needs to be treated and processed in order to be usable.

The retention properties of the mesh are a function of the oil-air and water-air surface tensions, and the contact angles of oil and water on the mesh surface. The coating on the mesh creates water repellency, but this is overcome at certain water depths. The flow of oil and water through the mesh depends on fluid properties such as viscosity, density, and surface tension — which vary for different types of oil — and the mesh porosity and permeability.

Given this, how could the team at Amphos 21 design a mesh for different water levels and oil types? Could different hydrophobic coatings work for different ocean depths?

The answers lay in finding the best combination of mesh properties for different oil spill conditions. The team set up numerical simulations to help them in their search to find the best designs to collect the most oil.

⇨ HOW DOES MESH DESIGN AFFECT OIL FLUX?

Seeking the solution to a problem no one has solved can sometimes feel like a needle-in-a-haystack hunt, even though you may have a general idea of where to start. But mathematical modeling techniques vastly simplify the process.

Coene, Silva, and Jorge Molinero, partner and modeling solutions director at Amphos 21, used COMSOL Multiphysics® software to set up a simulation of a hydrophobic mesh in order to analyze how different mesh designs would behave at different water depths and to assess factors influencing the mesh performance.

The success of a mesh is ultimately measured by the oil recovery rate and the purity of the recovered oil. The team's modeling work therefore involved testing different polymer coating properties and mesh operation at different ocean depths, and analyzing flow rates for different oils.

To see how different geometries would affect the oil flux, they also parameterized the mesh wire radius as well as the hole size and spacing. In COMSOL® software, they conceptualized the mesh as a porous medium coupled with two-phase flow to represent water

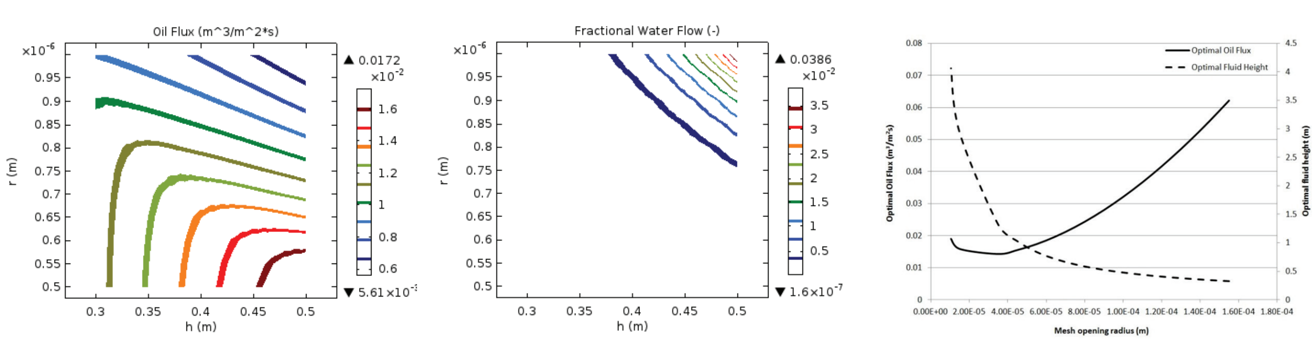

FIGURE 3. COMSOL® software results showing how oil flux through the mesh (left) and fractional water flow (center) vary with wire radius and water depth. Pore analysis showing the relationship between fluid height, pore radius, and oil flux (right).

and oil traveling through. From there, Coene, Molinero, and Silva were able to calculate the oil saturation level, the flux rates for the oil and water, and the fraction of water mixed with oil that passed through the mesh (see Figure 3, left and center). "These results are especially helpful for choosing a pore radius size when designing a mesh for use at certain depths," Molinero commented.

After studying the correlation between optimal oil flux and optimal fluid height, they also used their model to run a pore analysis (see Figure 3, right) based on a given maximum water fraction — the amount of water permitted in the mixture without requiring the oil to be treated.

"For different mesh opening sizes, the model results gave us the oil flux and the maximum fluid column height for the desired oil purity," continued Coene. "For example, imagine I want to operate the mesh at least half a meter below the water level, and I want a maximum of 1% water in my mixture. This shows me what radius I'd need for my mesh holes."

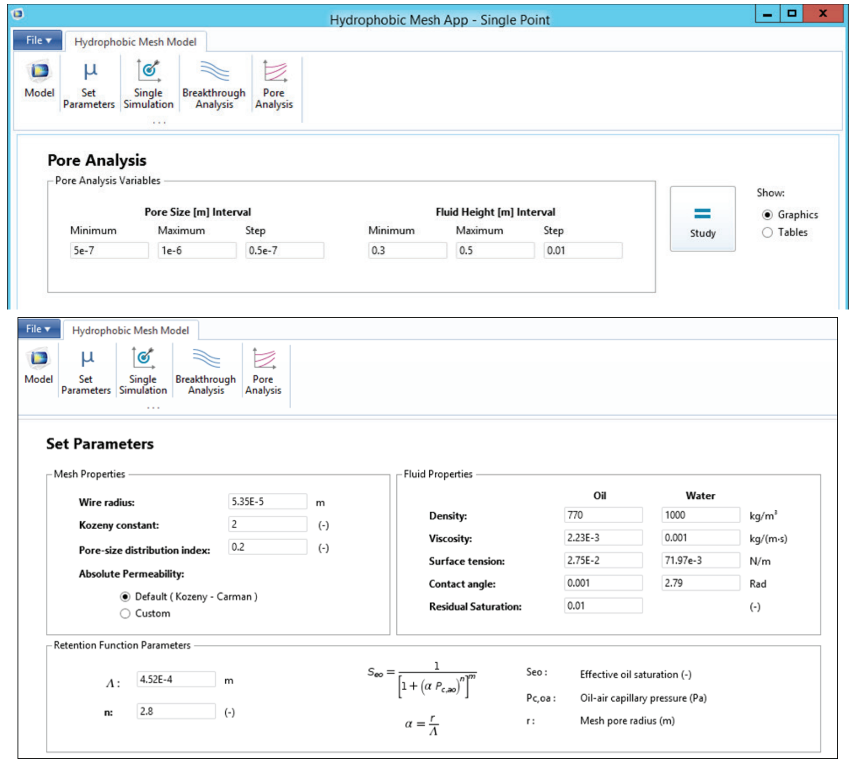

FIGURE 4. A cropped screenshot of the Amphos 21 hydrophobic mesh app showing inputs for a pore analysis (top) and mesh and fluid properties (bottom).

⇨ SIMULATION APPS OFFER DESIGN CAPABILITIES

One feature of the COMSOL software makes it possible to easily distribute the results of a simulation to others without sharing the entire model. "We used the Application Builder available in COMSOL Multiphysics to create a customized user interface around our model," Silva explained. "Simulation apps make it possible to distribute the simulation results to users but not give them the entire model. Companies can use these apps to reduce experiments, save money on testing, and they'll be able to simulate a small section of a mesh and then scale it in order to design the technology they need. This is a promising development in designing hydrophobic meshes."

The Amphos 21 app (see Figure 4) allows the user to predict the mesh performance and quickly check the quality of designs for different operating conditions by changing the mesh and fluid properties. In less than 30 seconds, he or she can run an analysis over a range of pore sizes and water depths to find the best mesh for certain depths based on a chosen maximum water fraction.

The app will also calculate different mesh properties, such as the absolute permeability and other quantities related to the breakthrough pressure, helping designers choose the ideal fit to suit the needs of different circumstances.

"We think this will be very appealing to R&D departments, environmental groups, and others working to solve this problem," said Molinero. "With the COMSOL model and a custom application built around it, we've made headway into a new way to clean up oil spills."

Next, they will distribute their app to engineers who can use the hydrophobic mesh model on a large scale to design the ideal mesh for a given situation, and ultimately deploy new tools to help in real time. ❖

"With the COMSOL model and a custom application built around it, we've made headway into a new way to clean up oil spills."

— JORGE MOLINERO, PARTNER AND MODELING SOLUTIONS DIRECTOR, AMPHOS 21

The Amphos 21 team working on their simulation app. Left to right: Orlando Silva, Emilie Coene, Jorge Molinero.