Tiny bubbles scrub oily water

An innovative new water treatment module features a greatly simplified, computer-aided design particularly advantageous for use on offshore floating production units.

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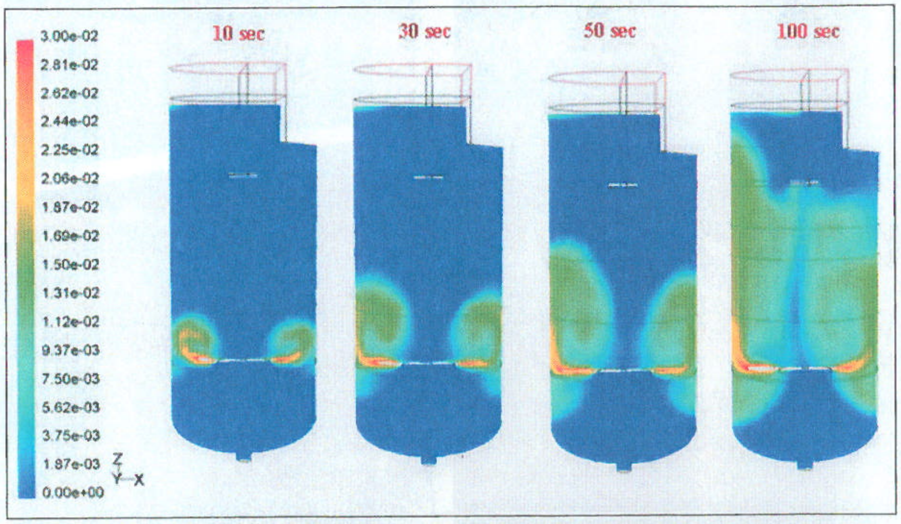


Improved bubble distribution is provided by a new eductor design. ***(Graphic courtesy of NATCO)***

Computer simulation has helped NATCO engineers make dramatic improvements in a new single-cell vertical induced gas flotation (IGF) system to clean up oily water that has been co-produced with oil and/or gas. Single-cell vertical column flotation systems represent a major design challenge because there is a need to accomplish the same degree of separation in a single cell that is traditionally achieved by four cells in a conventional horizontal tank design.

Creating an effective design and optimizing it is particularly difficult using conventional physical testing methods because building prototypes is both time consuming and costly. Even if the task is accomplished, they provide very limited information as to why a particular design did or did not work.

Problem analysis

Water is produced along with oil from most wells and must typically be cleaned to a purity of less than 29 parts per million (ppm) of total oil content prior to disposal. This is true whether disposal is downhole, that is, by injection into a dump aquifer or into a producing reservoir as part of a water flood, pressure maintenance or anti-subsidence scheme; or overboard, where permitted. IGF systems work by introducing small bubbles between 100 and 500 microns in diameter into the vessel containing the contaminated water. By controlling the volume and rate of gas and water introduced, the development of the proper bubble-size for effective lifting of oil droplets and suspended solids is achieved. In traditional treatments using horizontal units, oily water enters the unit from one end and passes sequentially through a series of flotation cells where clouds of bubbles are used to lift the oil droplets. The hydrophobic oil droplets and oil coated solids attach to the water/gas interface and float to the surface as the bubbles rise to the top where they can be removed by skimming. Not only do horizontal units require a large amount of deck space, but when used on floating production units their performance is significantly degraded by vessel motion, which causes sloshing of the cell contents. Vertical units weigh less and take up less deck space, but can be problematic if the bubble cloud is not uniformly distributed throughout the column.

Unfortunately, it is much more difficult to obtain the required level of separation with a single-cell vertical column, which typically requires removing 90% of the oil contamination. With a single cell, there is only one chance to remove the oil droplets and the residence time is limited to 4 minutes in order to meet throughput requirements. It is difficult to obtain effective dispersion of the gas bubbles so they contact all of the contaminated water in the vessel. This problem is called short-circuiting and is characterized by a relatively compact plume of bubbles that rises in the column bypassing most of the contaminated water.

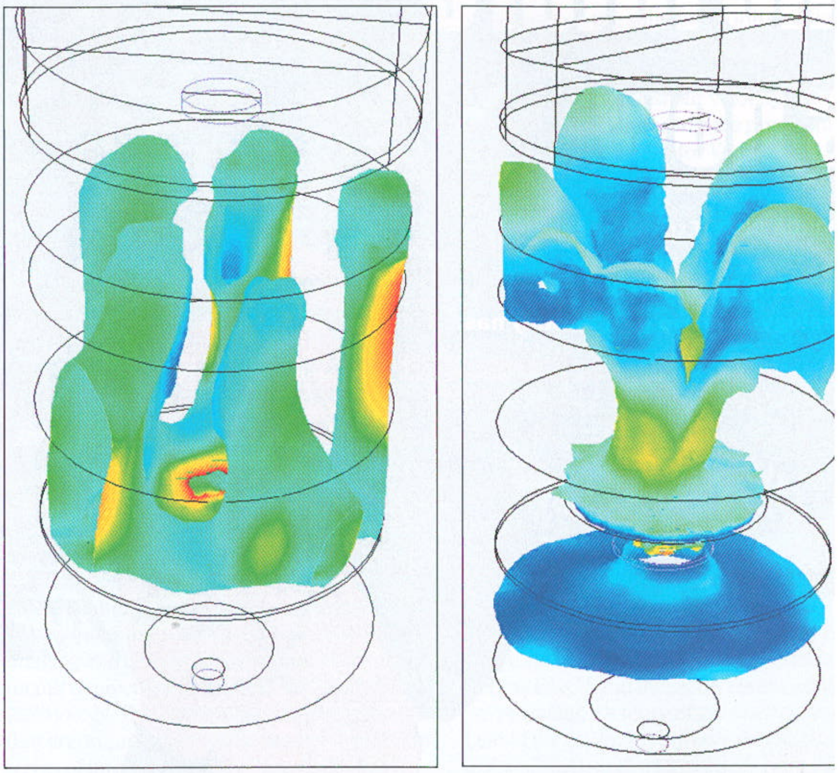
Dynamic simulations

Using computational fluid dynamics (CFD) to simulate the performance of the initial design concepts enabled NATCO engineers to quickly zero-in on the most promising designs. This reduced the time and expense of prototype construction. During the design stage, engineers used the latest and most extensive Eulerian multiphase model of FLUENT CFD to simulate the behavior of both oily water and gas within the IGF system.

Continuing with CFD simulations, NATCO's engineers were able to simulate different configurations of vertical IGF units. Among the elements they were able to vary were the water inlet design and configuration, the eductor (gas distribution nozzle) design, the location, number and shape of any baffles within the column, and the volume and rate of gas and water flow. To ensure the unit would perform under typical sea state conditions, a design criterion of 6° of omnidirectional motion was prescribed. Using the simulator, a large number of designs and options was evaluated before the first prototype was built. CFD simulation results provided fluid velocity, pressure, particle trajectories and other relevant variables throughout the entire solution domain for vessel models with complex geometries and boundary conditions. As part of the analysis, a vessel designer may change the system geometry or the boundary conditions and view the distribution of fluid flow patterns or the effects of other variables. FLUENT CFD software version 6.0, which was used in this study, is capable of modeling the hydrodynamics of multiphase mixtures with a wide range of bubble sizes, and accurately simulated the distribution of gas bubbles as they moved through the bulk liquid phase.

Initial models focused on defining the configuration of the eductor, a gas bubble injection device, and the size of the bubbles it introduced into the IGF vessel. Eductors are designed to generate gas bubbles efficiently by discharging fluid into a Venturi tube. The resulting pressure drop creates a vacuum effect that draws gas into the eductor. Initial simulations surprised everyone, because they showed that the distribution of bubbles in IGF vessels was much poorer than had been expected when using the best commercially-available eductor. Rather than covering the vessel's cross-section as required to avoid short-circuiting, the bubbles released from each eductor mostly stayed within a small cylindrical area, creating a straight, fast-rising plume. Just as discouraging, the uneven bubble distribution across the tank created recirculation zones, similar to convection currents, that further increased the tendency toward short circuiting and recontaminated water that had already been cleaned. This helped explain why previous vertical tank designs had performed so poorly. Because this was the first time the uneven bubble distribution had been simulated, a physical model in a clear plexiglas tank was constructed to validate the results. The model behaved exactly as the simulation had predicted.

NATCO engineers then began a series of about 40 additional CFD design variations with the goal of improving the separation efficiency of the vertical IGF design concept. Several simplifying assumptions were made in the model. The 3-D geometry was based on a test vessel of about 5 ft (1.5 m) in diameter and 12 ft (3 m) tall, located at NATCO's laboratory in Gloucester, United Kingdom. The oily water and gas/water mixture inlets were simplified as boundary conditions representing their actual positions inside the test vessel, hence eliminating the need to model the inlet piping as well. Internal tank supports and coalescing packing material were also ignored. FLUENT's Eulerian multiphase model with the unsteady state segregated solver was used to simulate the flow of the gas/water mixture. The fluid volume model with geometric reconstruction scheme was later used for a separate wave motion suppression study. To improve the spreading of the bubbles into a uniform cloud that would contact most of the cross-sectional area of the IGF vessel, a number of solution variables was altered in the simulations, including the geometry of the oily water inlet device, the volume of water flowing into the vessel, the gas volume fraction flowing into the eductor, the size of the gas bubbles and the internal baffle configurations of the vessel.



Internal baffles (on right) help mitigate recirculation zones. ***(Graphic courtesy of NATCO)***

Iterating to a superior design

In the first stage of the study, NATCO engineers performed steady-state single phase test runs involving only oily water flowing downward through the tank in order to be certain that the downward oily water stream could be adequately controlled within the desired flow range. In the next stage, the eductor flow into the vessel was modeled using a high air volume fraction while varying the liquid levels and fluid flow rates. This series of simulations demonstrated flow patterns that matched up well with physical experiments, helping to provide further confidence in the accuracy of the simulations. They then modeled different configurations of gas inlet devices while continuing to vary the gas volume fraction. Through this process, design engineers were able to gain considerable understanding of how bubble distribution over the cross-section varies with different inlet design configurations. As a result, they were able to develop a new patent-pending eductor design that offers far superior performance to conventional designs used in previous IGF systems. The new eductor design features a more radially-directed fluid discharge, as opposed to the downward discharge found in conventional designs. The illustration shows how the new gas inlet configuration promotes uniform bubble distribution across the IGF test vessel.

Subsequently, NATCO engineers experimented with different configurations of internal baffles in an effort to obtain additional performance improvements. baffle plates are designed to control the downward flow of oily water and preve recirculation. By restricting the area in the oily water can flow downward, a mc uniform gas bubble distribution results. Additional wave-motion suppression ba were installed at the top of the vessel to suppress sloshing and facilitate skimmi

The NATCO solution

The final system configuration, now wit and PCT patents pending, dramatically improves upon existing designs by prov a uniform distribution of bubbles acros vessel while effectively eliminating recirculation zones. These improvemen were achieved because rapid CFD simulations made it possible for engine examine more design variables than wo have been possible using conventional l and-test methods, and because CFD prc far more insight into what was actually happening than could be discerned by physical testing. Using CFD, design performance could be easily quantified, leading to optimization. CFD now plays critical role in all of NATCO's new produ designs. E&P