Application of CFD for Improved Vertical Column Induced Gas Flotation (IGF) System Development

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ABSTRACT

NATCO has completed the design and development of a single-cell vertical column flotation system for use in treating produced water on floating oil and gas production platforms. Computational Fluid Dynamics (CFD) simulations helped identify the cause of performance problems with early versions of column flotation and provided the insight required for design improvements. A combination of CFD simulation and physical model testing significantly reduced the time and cost required to develop the enhanced design. The physical testing validated the results of the first part of the CFD study and suggested additional modifications that were then included into later CFD simulations for further improvement. The development program culminated with the successful operation of a 10,000 BWPD column flotation system installed on a spar platform in the Gulf of Mexico.

VERTICAL COLUMN FLOTATION

Induced gas flotation (IGF) is a technology used to clean up oily water that is co-produced along with oil and gas. Oilfield exploration and production companies continue moving to ever-increasing water depths to produce oil and gas reserves and thus cause the shift from traditional fixed-leg platforms to floating structures such as the TLP (Tension-Leg Platform), SPAR and FPSO (Floating Production, Storage and Offloading). Due to space restriction on floating platforms and high cost of their construction, the oil and gas industry increasingly applies IGF in the configuration of a single-cell vertical column rather than the conventional four-cell horizontal design for onshore processing.

Flotation cells work by hydraulically introducing small gas bubbles, typically in the range of 100 to 500 microns, into the produced water stream. Column flotation units use a vertically oriented cylindrical vessel for the produced water treatment. Figure 1 shows the general layout of the vertical IGF Column. The produced water enters at the upper part of the vessel and flows downward. Gas bubbles are introduced into the lower portion of the vessel and float upward. The gas bubbles attach to and/or drag the oil and oil-coated solid contaminants and together they rise to the liquid surface on the top of the vessel. The agglomerated contaminants are removed by a skimming mechanism and treated clean produced water exits from the bottom of the vessel beneath the point of gas entry. The clean water can then be sent to overboard disposal.

NEW PRODUCT DEVELOPMENT

Instead of using a sparging tube, the formation and distribution of gas bubbles inside a vertical IGF Column can be better achieved by using a properly designed eductor that uses recycled, clean produced water as the motive liquid. Gas from the top of the vessel is routed to the eductor through a small diameter tube. As the clean produced water is pumped through the specially designed eductor, a low pressure zone is created in the eductor and gas is pulled into the eductor by the vacuum and mixed with the clean water prior to entering the vessel (basically a controlled Venturi effect). The gas/water mixture enters at the lower part of the vessel and encounters the oily produced water in a countercurrent flow pattern. Experience has shown that it is extremely difficult to obtain a uniform dispersion of gas bubbles in a column flotation unit for effective mixing with contaminated produced water, thus necessitating the CFD-assisted design for this purpose.

In order to reduce the cost and time required to develop an improved single-cell vertical column IGF technology, NATCO engineers applied FLUENT Version 6 with the Eulerian Multiphase Model running an unsteady state segregated solver. Flow of water and gas bubbles with various sizes were simulated within the IGF unit. Variables studied in this development project included the Gas Volume Fraction (GVF) introduced into the flotation cell through the eductor, the size of bubbles in the gas/water mixture flow through the eductor, the geometry of the device used to introduce contaminated water into the IGF, and the geometry of internal baffles, which assist optimized bubble distribution within the flotation cell, as well as various means to suppress wave induced sloshing near the gas-liquid surface in the skimming section of the IGF vessel.

The initial CFD simulations showed that the use of a traditional header and lateral inlet device for produced water causes a fluid short circuiting path to develop. This problem was resolved by replacing the inlet distributor with a cyclonic inlet device. The produced water exits the cyclonic inlet device in a radial swirling pattern and the water is smoothly distributed across the IGF vessel. This avoids the development of a fast down-coming stream from dragging the oily contaminants along the vessel wall and directly toward the bottom water outlet while by-passing contact with the flotation gas bubbles. Through the use of particle tracking during the post-processing phase of the CFD analysis, it was possible to estimate the average size of oil droplet, solid particle or gas bubble that will rise in the vessel against the net downward flow of the produced water.

The following CFD simulations predicted, and later physical testing with a test vessel (60” I.D. x 14’ Height) conducted at NATCO’s Gloucester, UK, laboratory verified, that the bubble distribution obtained from earlier versions of the column flotation technology were exceedingly poor. As illustrated in Figure 2, using a commercially available eductor, the larger gas bubbles released from the eductor mostly remained within a fairly small cylindrical area and formed a straight fast-rising plume as they travel up to the top of the IGF vessel. This poor distribution of the gas bubbles across the vessel limits the contact of gas bubbles with contaminants in the produced water stream and adversely affects the performance of the flotation cell.

To improve the spreading of bubbles into a uniform pattern that would contact most of the cross section of the IGF, the volume of water flowing into the cell through the eductor, the

GVF in the eductor flow, and the geometry of the eductor were all varied in the subsequent CFD simulations. Based upon the CFD simulation results, an improved internally-mounted Radial Eductor™ design was developed that, coupled with properly designed internal baffles, provides a uniform distribution of properly sized gas bubbles throughout the entire IGF vessel (see Figure 3). The CFD simulations also identified the presence of recirculation zones within the IGF that were previously suspected but impossible to detect in physical experiments. Such recirculation zones severely hindered the physical effectiveness of the IGF unit. The impact of the recirculation zones were minimized based on the results of further CFD simulations. These insights were used to modify the hardware design for subsequent physical testing.

Since this IGF system is primarily designed for service on floating offshore production platforms, additional design improvements were developed by applying a UDF (user-defined function) in FLUENT to simulate the vessel motion and the consequent liquid sloshing induced by the six degrees-of-freedom ocean wave motion. This liquid sloshing, if uncontrolled, could affect the performance of the IGF unit during storm conditions. After carefully examining several different configurations, an improved wave motion suppression baffle system was installed in the skimming region inside the offshore version of the IGF system. In the first stage, oil and water flow together into a pre-skim chamber from which water can egress through bottom openings while floating oil is retained. This accumulated oil layer is then skimmed into a conventional oil bucket with a limited amount of water carry-over. The two-stage skimming system ensures efficient contaminant removal is possible during calm and stormy sea states as the IGF vessel moves along with the floating platform.

RESULTS

Table 1 illustrates actual field performance data from a 10,000 BBL/Day offshore IGF system installed on a floating platform in the Gulf of Mexico. As indicated in the table, the effluent of the IGF is well below the federal limit (29 ppm) for liquid discharges into the ocean. Good field performance has been achieved under most sea state conditions, including those when considerable fluid sloshing inside the unit would be expected. Successful operation since start-up in early 2003 has verified the capability of the new vertical column flotation design.

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REFENENCES

K. A. Juniel, T. Frankiewicz, and C-M. Lee, *Novel Vertical Column Flotation Design for Gulf of Mexico Deepwater Floating Structures*, 14th Annual Produced Water Seminar, Nassau Bay, TX (January, 2004).

TABLE 1. Offshore VersaFlo™ Field Performance Data

Date	Flow Rate (BPD)	Wave Height	Inlet Oil Content (ppm)	**Outlet Oil Content (ppm)**
02-07-2003	7000	8’	52	**27**
02-07-2003	6500	8’	48	**19**
02-07-2003	7000	10	37	**13**
02-08-2003	5500	8’	35	**13**
10-04-2003	6800	5’	47	**15**
10-07-2003	7000	5’	55	**23**

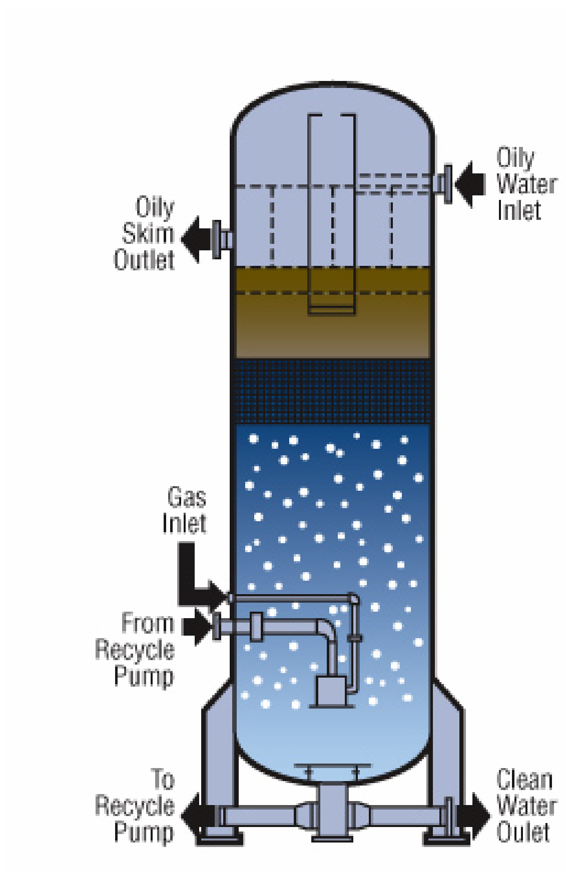
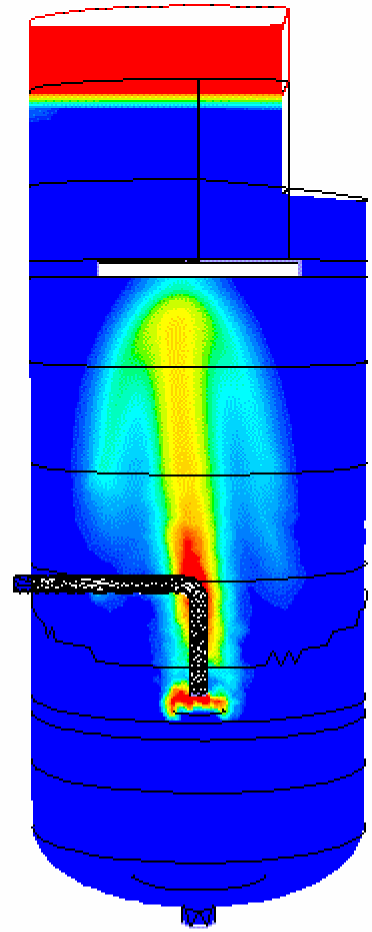


Figure 1. Schematic and Photo of a VersaFlo™ Vertical Column Flotation Unit.

(a) Experiments conducted by laboratory at Gloucester, UK using *Megacell Eductor*



(b) CFD simulation result plot of contour of air volume fraction

Figure 2. Comparison of CFD simulation and physical laboratory testing of gas released by a commercially available eductor used in traditional gas flotation service.

Total Inlet Air Volume = 21% at Run Time = 100 sec

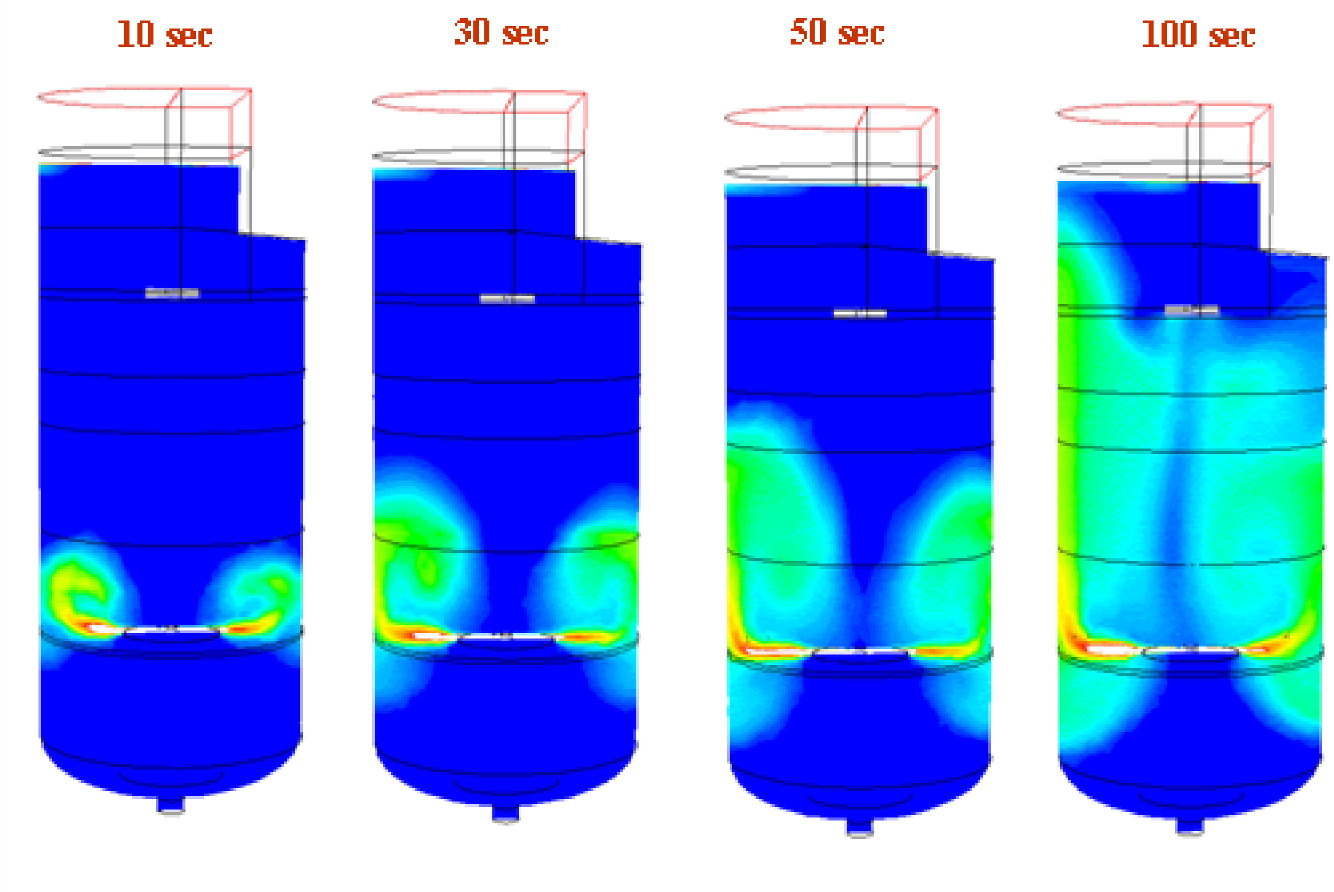


Figure 3. Improved gas bubble distribution provided by the (patent pending) radial eductor designed especially for column flotation service.