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Reducing Separation Train Sizes and Increasing Capacity by Application of Emerging Technologies

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Abstract

Recent developments in the understanding of separator hydrodynamics and the development of high G-force separation technologies allows offshore operators to significantly increase separator capacity/size ratios. By viewing the gas/oil/water separation train as an integral system, performance demands on upstream, higher pressure components can be relaxed, allowing for further reductions in the size of high-pressure vessels. This paper will review design options for reducing the size and weight of separation trains while maintaining or improving their performance.

Recently designed separation trains are used to illustrate the compact separations concepts as compared to more conventional systems. Separator performance is illustrated by computational fluid dynamic (CFD) analysis.

Introduction

The state of the art in gas-oil-water separations has been advancing rapidly in response to the demands for lighter, less expensive separation equipment. As a result of the introduction of various cyclonic technologies, and the development of mathematical modeling tools such as computational fluid dynamics, the performance of separators can be improved even as vessel size and fluid residence times decrease. In addition, the philosophy of separations is changing as operators recognize the benefits of trading reduced size and performance of expensive high pressure separators for more efficient, lower cost second stage equipment which is capable of providing on-spec products (gas, oil, and water) from variable and highly contaminated feed streams.

To minimize size, the primary separator in a production train generally effects only gas/liquid separation. The liquid residence time in a 2-phase separator varies typically from 1 – 3 minutes, depending upon fluid viscosity and density, while the liquid residence time in a corresponding 3-phase separator will be 3 – 10 minutes, depending both on the relevant fluid properties and the operator's tolerance for risk relative to separator performance.

The downside of high-pressure, 2-phase separations is the formation of tight emulsions and reverse emulsions that are more difficult to break in downstream equipment. Consequently, the size and/or complexity of second stage separators, FWKO's, oil dehydrators, and water treatment equipment is often increased.

Despite all efforts to properly engineer a separator, process upsets will happen. Unexpected severe slug flow, control system failure, and pipe or flow line pigging are common operational causes of such upsets. It thus becomes important to design oil dehydration and water treatment equipment to accept the resulting separator upsets with minimal impact on product quality.

In this paper, the technological concepts for increasing separator efficiencies and improving their ability to mitigate process upsets is described. Also, concepts for improving the performance of oil dehydration and water treatment systems are discussed. By utilizing and integrating the spectrum of separation systems, a reduction in equipment size and weight can be realized without compromising process performance or robustness.

Gas/Liquid Separation

Conventional Separation. Traditionally, bulk gas/liquid separation is accomplished in short liquid residence time horizontal or vertical separators. Often, fluid flow into the separator is gas-dominant, forcing fluid level in a horizontal separator to be minimized. To compensate, the vessel size is increased to reduce gas velocity and minimize gas carry-under to lower pressure separators. The propensity of a separator to allow gas carry-under is often unrecognized and can contribute significantly to compression costs for a platform.

Alternatively, vertical separators are used for 2-phase separation. These require less retained gas volume, but can allow significant liquid carry-over from foaming or mist formation due to high inlet fluid velocities. At times, the size of a vertical 2-phase separator is set not by liquid residence time, but by the required volume for installation of a suitable demisting vane pack.

Cyclonic Gas/Liquid Separation. The use of cyclonic technology for gas/liquid separation helps a vessel designer minimize both liquid residence time and liquid carry-over simultaneously. Because the phase separation is rapid and occurs at a high G-force, it tends to be more robust relative to upset conditions and to production problems such as foaming.

Advances in 2-phase separation can be defined by three general categories:

- External separation of high gas:liquid ratio fluids (e.g., <500 bbls of liquid/MMSCF of gas)
- External separation of low gas:liquid ratio fluids (e.g., >500 bbls of liquid/MMSCF of gas)
- In-vessel separation of gas and liquids

Examples of the external options are shown in Figures 1 and 2. Figures 1a and 1b show a vertical recycling separator that depends upon high G-forces generated along the vessel walls by very high velocity inlet fluids. The gas, with some entrained mist, is further accelerated within the vessel as the inlet; downward spiraling gas reverses flow to upward in the center pipe. A slot in the outlet pipe allows entrained mist that is gathered on the pipe wall to be recycled back to the liquid section of the vessel along with a small fraction of the gas. Low pressure generated by the vortex in the vessel provides the motive force for this recycle stream.

As the liquid volume fraction increases, the Gas Liquid Cylindrical Cyclone (GLCC) developed by the Tulsa University Separation Technology Project consortium, see Figure 2, becomes more viable as an option for compact 2-phase separation. GLCC development began in 1994 and the number of these units currently in service exceeds 200. Most units are serving as test separators, but more recently, actively controlled GLCC's are being installed as primary 2-phase separators.

Figure 3 shows a vertical 2-phase separator equipped with a vortex tube inlet cluster. The inlet velocity for the vortex tubes is set to provide the desired G-forces for effective gas/liquid separation. In practice, the applied G-force can vary from 50 to 1000, providing the vortex tube cluster with a turndown ratio as high as 20.

3-Phase Separation

Reduced vessel sizing for 3-phase separators comes as a result of advances in two general areas: inlet design and vessel baffling. For critical service vessels, e.g., deep water, higher pressure, variable service with time separators, vortex tube clusters have already become the standard of the industry. Vortex tube inlet technology improves separator performance by eliminating foam, pre-coalescing oil and water phases, and effecting rapid, efficient gas/liquid separation. Fluid residence time in these 3-phase separators, when properly engineered, can be as low as 3 minutes.

Cyclonic Inlets for 3-Phase Separators. In actuality, the "short residence time" for vessels equipped with vortex tube inlet devices is somewhat of a misnomer. This is illustrated in Figure 4 where 3-phase separation in a dual compartmented acrylic separator can be seen. The right hand side of the separator is equipped with a vortex tube cluster, while the left hand side is not. In essence, without vortex tubes, effective separation is occurring in only about half of the liquid volume. Thus the true impact of a vortex tube installation is to increase the *effective* residence time for separation in a vessel. By reducing or eliminating unproductive volume in a separator, total fluid residence time can be reduced without deterioration of vessel performance. Also, additional vessel volume required to accommodate foam generation can be eliminated.

Controlling Vessel Hydrodynamics. Although introducing fluid to a 3-phase separator by way of a cyclonic inlet device may be considered as necessary for maximizing separation efficiency, it is often not sufficient. As oil and water are released into the vessel, fluid dynamic considerations become dominant. Depending upon vessel L/D ratio, flow conditions, inlet devices, and outlet configuration, dead zones and fluid short-circuiting may occur.

Figures 5 and 6 show results from a CFD model on a vessel equipped with a conventional splash plate inlet. The as-built vessel, Figure 5, exhibits significant short-circuiting with calculated fluid paths near the liquid surface showing velocities up to 10 times the nominal fluid velocity for the vessel. By tracking artificial particles through the vessel, in much the same manner as a tracer test is conducted on an installed separator, the CFD model can determine a relative value for the liquid's residence time.

Figure 6 shows flow contours for the same vessel after it is equipped with a flow-distributing perforated plate. The introduction of the baffle decreased the near-surface short-circuiting and increased the liquid residence time for liquids by about 50% on a relative basis.

Oil Dehydration

Electrostatic dehydration of crude oil is widely applied both offshore and onshore to crude as heavy as 12 ^{o}API. Technical advances have been commercialized over the past several years that allow treaters to be designed with flux capacities (bbls of emulsion processed per ft^2 of electrode grid per day) of 150 to 300. These values are 3 to 6 times higher than capacities typical of the 1980's.

Dual Polarity® Electrode Grid. Conventional AC electrostatic treaters are relatively inefficient in that the polarized water droplets are subjected to a field reversal within each voltage cycle. A dual polarity treater combines the polarizing AC field with a constant DC field. The AC field promotes bulk coalesce and separation of the emulsion, while the DC field provides further deep dehydration by charging the droplets. Typically a dual polarity treater will operate at a flux that is 20 to 50% higher than a similarly sized AC treater.

CFD Design of Emulsion Distribution. Electrostatic treaters typically have grid sections that are rectangular with aspect ratios of between 3 and 10. Emulsion flows vertically upward through the electrodes as coalesced water droplets settle into a continuous water lay in the vessel bottom. The proper distribution of emulsion entering the treater is critical. By performing CFD calculations on distributors, it was determined that up to 20% of the feed emulsion could by-pass the electrode grid and flow along the vessel walls. After verifying this behavior in laboratory testing, CFD was employed to design emulsion distributors that all but eliminated this short circuiting, allowing treater design flux to be increased by 10 to 20%.

Composite Electrodes. One problem faced in electrostatic treaters is the formation of local electrical shorts through the emulsion. These shorts decrease the voltage between the electrodes and thus reduce dehydrator efficiency. With composite electrodes, the current draw to a short circuit is severely limited both spatially and temporally. Thus voltage between electrodes is maintained, even if the BS&W of the emulsion between the plates is inadvertently high due to vessel motion (e.g., on an FPSO or TLP) or process upset conditions.

Load Responsive Controller®. Under some circumstances, the conductivity of an emulsion will increase to the point where the current between electrodes becomes excessive. When this occurs, the voltage between the electrodes drops and electrostatic dehydration becomes inefficient. To combat this behavior, a technique has been developed which cycles the voltage to the electrode grid. Applying high voltage allows small water droplets to become sufficiently charged. Then slowly ramping the voltage down permits these droplets to coalesce. At the reduced voltage the droplet growth is maximized allowing the emulsion to lose its emulsion-induced conductivity. Cycling the electrode-to-electrode voltage for periods ranging from 1 to 20 seconds can maintain the efficiency of dehydration even when the emulsion is highly conductive.

Water Treatment

Over the past 10 years, the application of hydrocyclones to water treatment has become relatively routine. Although highly efficient, hydrocyclones have limitations. They are not effective at removing oil-coated solids from produced water, or capturing stabilized reverse emulsions with oil droplet sizes less than 10-15 microns. Thus an Induced Gas Flotation (IGF) vessel is often installed downstream of the hydrocyclone.

For moving platforms such as TLP's, FPSO's, etc., conventional flotation in horizontal vessels is impractical since fluid levels constantly change. To obviate this problem, vertical column flotation has been developed. Vertical vessels are much less susceptible to the affects of platform movement. One major drawback of column flotation is the fact that it is single stage. A second drawback is that the vessel still holds a relatively large and heavy volume of water (4 minutes water residence time being typical).

Recently, vertical column flotation systems have been developed and deployed that divide the column into several cells, see Figure 7. The cells are defined by a series of baffle plates, each of which provides a quiescent volume for contaminants to accumulate. Gas also accumulates under the baffles and serves to move the contaminants to the surface of the flotation column via an internal, gas-lifted oil riser. Gas is introduced into each successive cell by either a sparger or an eductor. Thus cell-to-cell contaminant removal efficiency is maintained as gas bubbles do not grow to an ineffectively large diameter as they rise in the flotation column.

To further take advantage of column flotation, at least one manufacturer was modified the design to permit the unit to be mounted off the side of a platform, mostly below sea level. The submerged column flotation configuration substantially reduces both the space and weight requirement that is attributed to conventional flotation units, be they horizontal or vertical. Figure 8 shows a submerged column flotation unit ready for shipment to be installed on a deepwater spar type platform.

Application I: Increasing the Capacity of a Vertical 2-Phase Separator

In April of 1996, an original design vortex tube cluster was installed in a vertical, high-pressure, two-phase, gas separator on the Shell Auger Platform as part of a continuing debottlenecking effort to increase overall throughput. After installation of the vortex tubes, the need for injection of defoamer chemicals decreased significantly and the separator efficiency improved. In particular, the amount of gas carry-under in the oil feeding IP system was significantly reduced.[1]

By the year 2000, production on the Auger platform had increased sufficiently that the same high-pressure vertical separator was again identified as a bottleneck. At flow rates of 170 Mmscfd and 43,000 BLPD of oil through this vessel, excessive gas carry under in the liquid outlet was pinpointed as the source of the bottleneck. This performance was consistent with the vortex tube cluster's engineering design equations which predicted initial gas carry-under from the bottom of the tubes at flow rates of 170 Mmscfd and 37,000 BLPD. Experience indicates that as the liquid flow rate increases, gas bubbles will be drawn into the liquid outlet line.

To confirm the operational problems and the design equation predictions, a Computational Fluid Dynamics (CFD) model was built for the existing high-pressure separator with the original design vortex tube cluster. Figure 9 is a CFD plot of the separator showing effective operation of the vessel with the dual vortex tube inlet at flow rates of 120 Mmscfd and 25,000 BLPD. The flow rates are well within the designed dual vortex tube operating window, The CFD calculation illustrated in Figure 9 shows no evidence of gas carry under from the tubes. It also confirms the successful operation of the separator at the trial flow rates. A second CFD plot of the vessel, Figure 10, at flow rates of 170 Mmscfd and 43,000 BLPD clearly shows gas carry under from the bottom of the vortex tube cluster. Predictions of gas carry under from the CFD model are remarkably consistent with actual observed operating conditions and vortex tube design equation predictions.

To alleviate the new bottleneck, an updated version of the vortex tube cluster was designed and installed to meet the higher throughput requirements. The new model vortex tube cluster incorporated design improvements to mitigate both gas carry under and liquid carryover. Figure 11 offers an outline view of the new design. Actual CFD plots with the new design are still being developed, but Shell has achieved flow rates through the vessel of 215 Mmscfd and 50,000 BLPD with no indication of gas carry-under and very minimal liquid carryover.

Application II: Compact 3-Phase Separation for Gas Dominated Production

A recent inquiry presented the challenge of removing water from a gas-dominated three-phase production stream. Discharge water specifications of less than 25 ppm TOG and condensate discharge specifications of less than 0.1% BS&W added to the complexity of the system.

Traditional solution methods called for the installation of a three-phase horizontal production separator with vane-type demisting sections and approximately 5 minutes of liquid retention time for both oil and water. At the flow rates considered, the size of a traditional 3-phase separator would be 9.5' ID x 40' S/S at a design pressure of 1440 psig. A vessel of this size was not considered an acceptable solution for this system.

Vortex tube inlet devices were considered for the vessel to eliminate any foaming potential and to perform the gas-liquid separation. However, in this case, the internals were not a practical solution. As designed for the proposed flow conditions, the internals ran the full length of the vessel and only a minimal reduction in vessel size was achieved.

A GLCC was not considered for this application because the overall production stream was heavily gas-dominated. The GLCC relies on stratified inlet flow and lower g-forces than the vortex tube cluster as a separation driving force. Due to the potential for mist flow and slug flow, the GLCC was considered an inappropriate technology for this application.

The proposed solution consisted of a vertical recycling separator and a liquid packed separator. See Figure 12 for a sketch of the system. The vertical recycling separator was selected to perform the gas breakout because it develops high g-forces for handling the mist flow and it is capable of handling liquid slugs. Also the centrifugal force generated by the vertical recycling separator coupled with the recycle stream provides high efficiency separation over a wide range of flow conditions. At an operating pressure of 1400 psig and flow rates of 1,000 Mmscfd and 16,000 BLPD, the size of the vertical recycling separator is 48" OD x 18' S/S.

To achieve the 5 minutes residence time proposed for the liquid packed separator, the proposed vessel size is 60" OD x 20' S/S. To speed the liquid-liquid separation process, inlet pipe spreaders, perforated baffles, matrix plate coalescing media, and vortex breakers were all incorporated into the design of the separator. Recent CFD studies have highlighted the importance of proper distribution of the inlet fluid, and the proposed design takes advantage of the new designs developed through these CFD studies. The perforated plates and coalescing media have been proven to be very effective in field trials for preventing "channeling" and for improving liquid-liquid coalescence.

Overall, the empty weight of the proposed system is 67% lighter than a traditional system and the operating weight is 62% lighter. Additionally, better performance over a wider range of operating conditions can be expected due to the cyclonic and recycle action of the separator and the design of the internal components of the liquid packed separator.

To ensure that the desired low level of oil in water is achieved, de-oiling hydrocyclones and 2-stage column flotation were recommended for installation downstream of the liquid packed separator.

Application III: Integrating Technologies for Maximum Weight/Space Reduction

A hypothetical example can be used to illustrate the degree of weight and space saving possible by the application of emerging separations technologies. For this example, a conventional process was designed and vessels sized to separate 50 Mmscfd of gas, 100,000 BOPD (35°API), and 50,000 BWPD. The fluids are assumed to arrive on the platform at 1000 PSIG and 120°F.

The conventional system consists of the following:

- 2-phase high pressure separator (1000 PSIG)
- 3-phase intermediate pressure (IP) separator (300 PSIG) that accepts all liquid from the high pressure separator
- 3-phase low pressure (LP) separator (100 PSIG) that accepts wet oil from the intermediate pressure separator
- A conventional AC electrostatic dehydrator (flux of 100 bbls/ft^2-day) with a top-mounted degassing vessel
- Water treatment via two sets of hydrocyclones (IP and LP) and a 4-cell horizontal flotation unit
- A conventional tank-type test separator

For maximum reduction in the weight and space required for an integrated separation system that makes maximum use of emerging technologies, the following changes were made to the above-described process design:

- The high-pressure separator is replaced with a GLCC. In line with the gas leg of the GLCC is a Whirlyscrub I to remove liquid mist that carries over from the GLCC.
- Vortex-tube inlet devices are installed in the IP separator and the liquid residence time in this vessel is decreased from 5 to 3 minutes.
- Wet oil from the intermediate pressure separator flashes through a low pressure GLCC (100 PSIG) before going to the degasser vessel (20 PSIG).
- The conventional LP separator is eliminated.
- Water from the IP separator discharges through a

single set of hydrocyclones before being cleaned to overboard discharge quality in a 4-cell submerged column flotation unit.

- ➢ The degasser vessel is downsized by the installation of vortex tube inlet devices.
- ➢ A Dual Polarity® electrostatic treater is installed with composite electrodes and load-responsive control (flux of 200 bbls/ft^2-day).

Figure 13 summarizes the weight savings for the major vessels in the process train. All together, the reduction in vessel dry weights totals 725,000 lbs, while the process operating weight is reduced by over 1,400,00 lbs. The weight savings between the two hypothetical processes is nearly 70%.

A similar reduction in required floor space is realized. The conventional process as outlined above requires approximately 3600 ft^2 of platform space, while the integrated system needs about 1400 ft^2, a reduction of 60%.

Summary and Conclusions

Advances in separation technology that extend from production separators through oil dehydration and water treatment are permitting significant reductions in the size and weight of oilfield process equipment. Through the application of mathematical techniques such as computational fluid dynamics (CFD), the performance of separations systems is being improved even as the equipment becomes smaller.

Offshore, the value of smaller, lighter separations trains is further magnified by consequent reductions in platform size and buoyancy requirements. For existing processes, the application of emerging technologies as retrofits can result in significant increases to the original design capacities for separators, dehydrators, and water treatment equipment.

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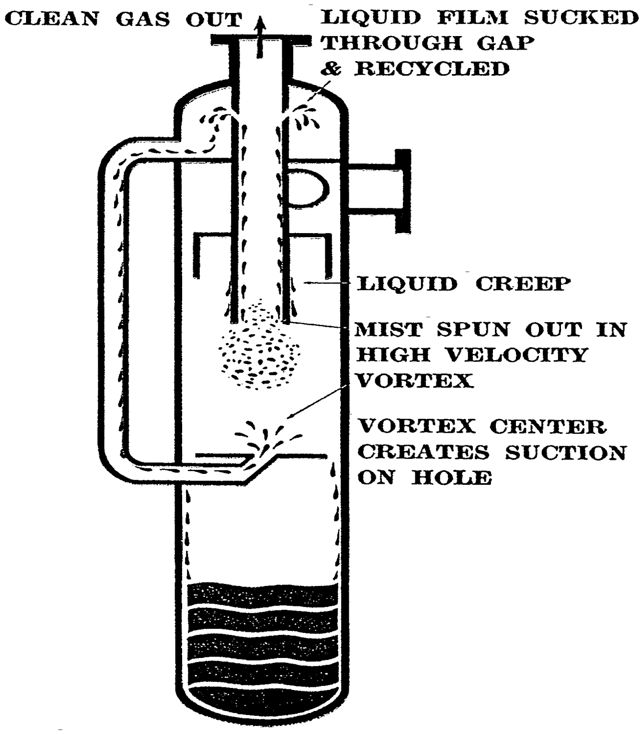


Fig. 1A—A vertical, recycling separator is an efficient means to separate high GOR fluids. This type of separator is most effective for fluids with <500 bbls of liquid per MMSCFD of gas.

Fig. 1B—A field installation for a high G-force vertical recycling separator is illustrated.

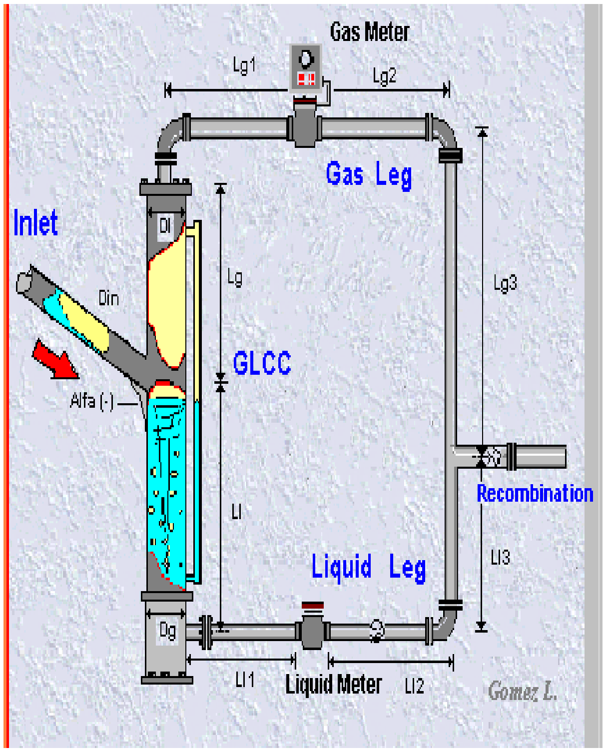


Fig. 2—A Gas-Liquid Cylindrical Cyclone (GLCC) is illustrated. The GLCC is most efficient when applied to low GOR fluids. As a test separator, gas and liquids are recombined downstream of the GLCC, eliminating the need for active level control.

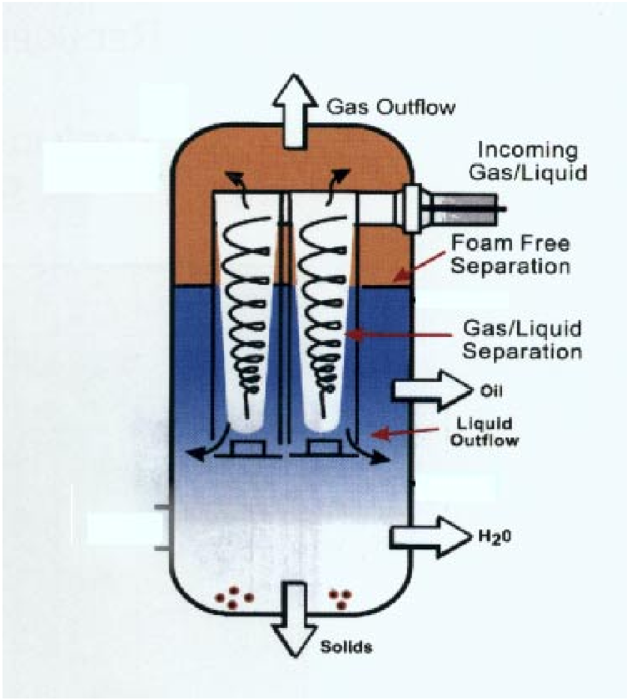


Fig. 3—By installing a vortex tube inlet cluster in a vertical vessel, foam and the volume of gas carry-under with the liquid is reduced. In some cases, vessel capacity can be increased by up to three times the original practical capacity.

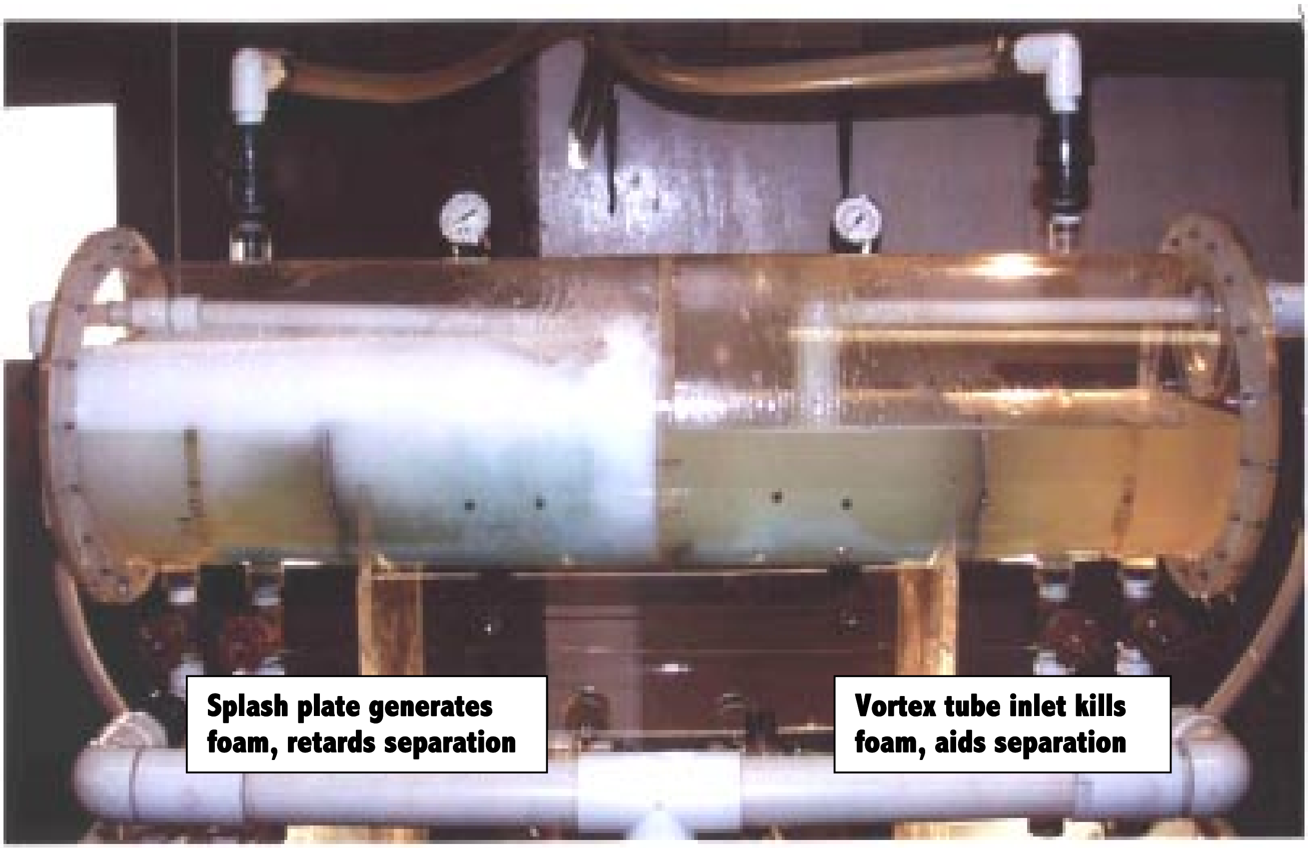


Fig. 4—Compared to a splash plate, a vortex tube inlet increases the effective residence time for separation in a vessel, thus permitting reduced total fluid residence time while simultaneously enhancing the effectiveness of a separation.

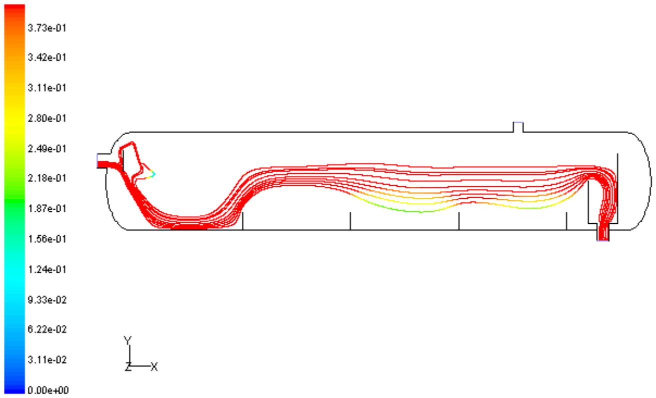


Fig. 5—The high velocity fluid flow contours for a conventional separator were determined by CFD modeling. The model shows that liquid flow bypasses large sections of the vessel volume and short circuits along the top of the liquid in the vessel.

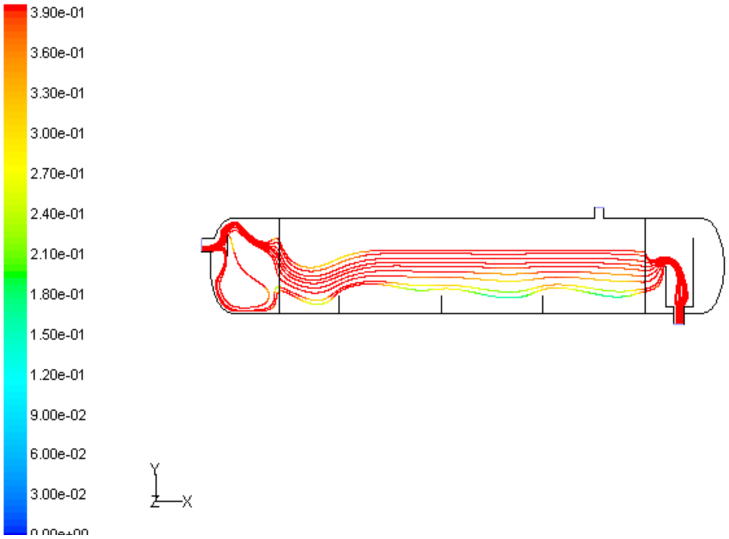


Fig. 6—If a flow-distributing plate is inserted into the separator near the inlet, then the velocity contours show a significant decrease in short-circuiting and, relative to the case of Fig. 5, about a 50% increase in actual fluid residence time.

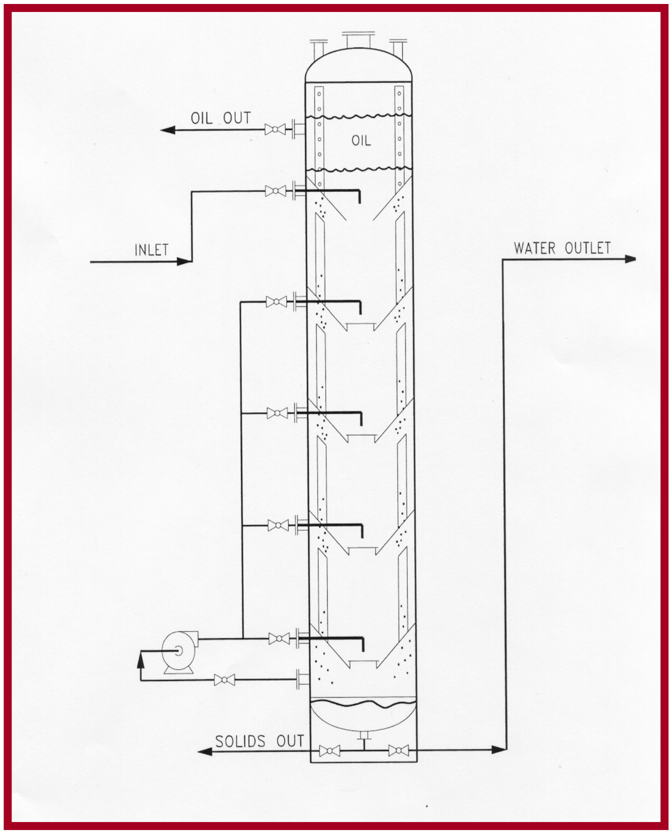


Fig. 7—A 4-cell vertical column flotation unit is illustrated. Each cell is provided with its own source of gas bubbles for flotation and a set of baffles and gas-lifted oil risers to remove contaminants collected in the cell.

Fig. 8—A vertical submerged column flotation unit with a capacity to process 115,000 BWPD is shown ready for shipment to be installed on a deep-water spar-type platform.

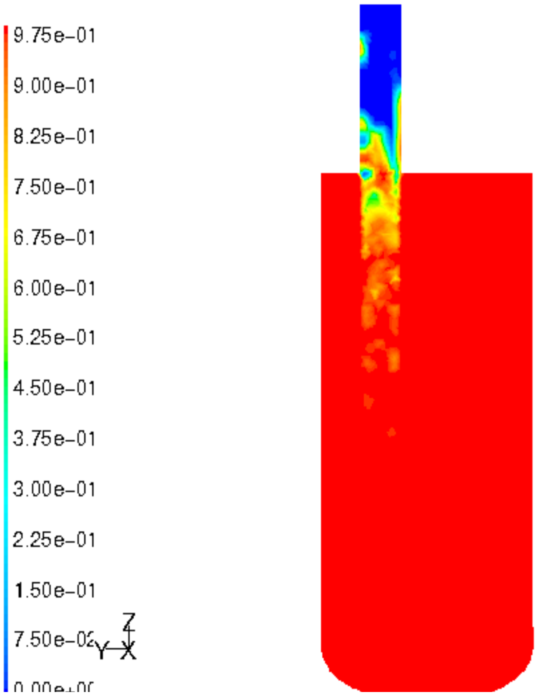


Fig. 9—A side view is shown of gas and liquid flowing into a vertical vessel through a dual vortex tube inlet device. At 120 Mmscfd and 25,000 BLPD, the CFD calculation shows no gas is carried through the tube with the liquid.

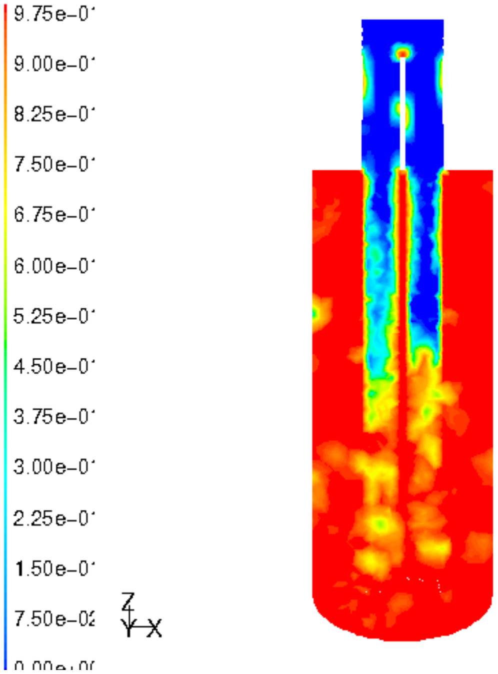


Fig. 10—A front view of the same separator as shown in Figure 9 shows that the CFD calculation predicts that at 170 Mmscfd of gas and 40,000 BLPD, substantial gas will exit the bottom of the vortex tube cluster along with the liquid.

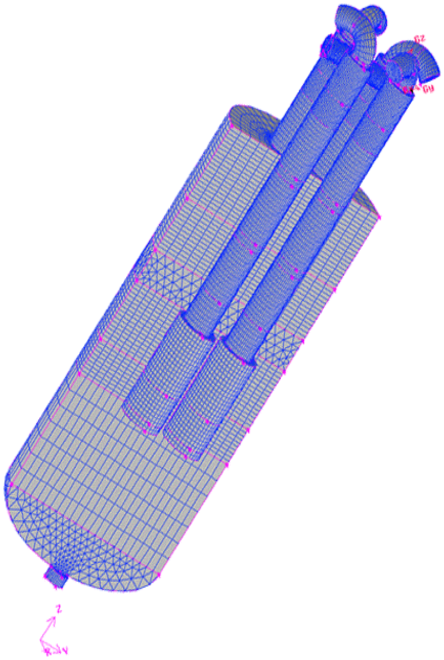


Fig. 11—The updated vortex cluster installed to replace those shown in Figures 9 and 10 included 4 tubes, a re-designed entrance configuration, and external tubes to redirect any gas carry-under during surge conditions back to the liquid surface.

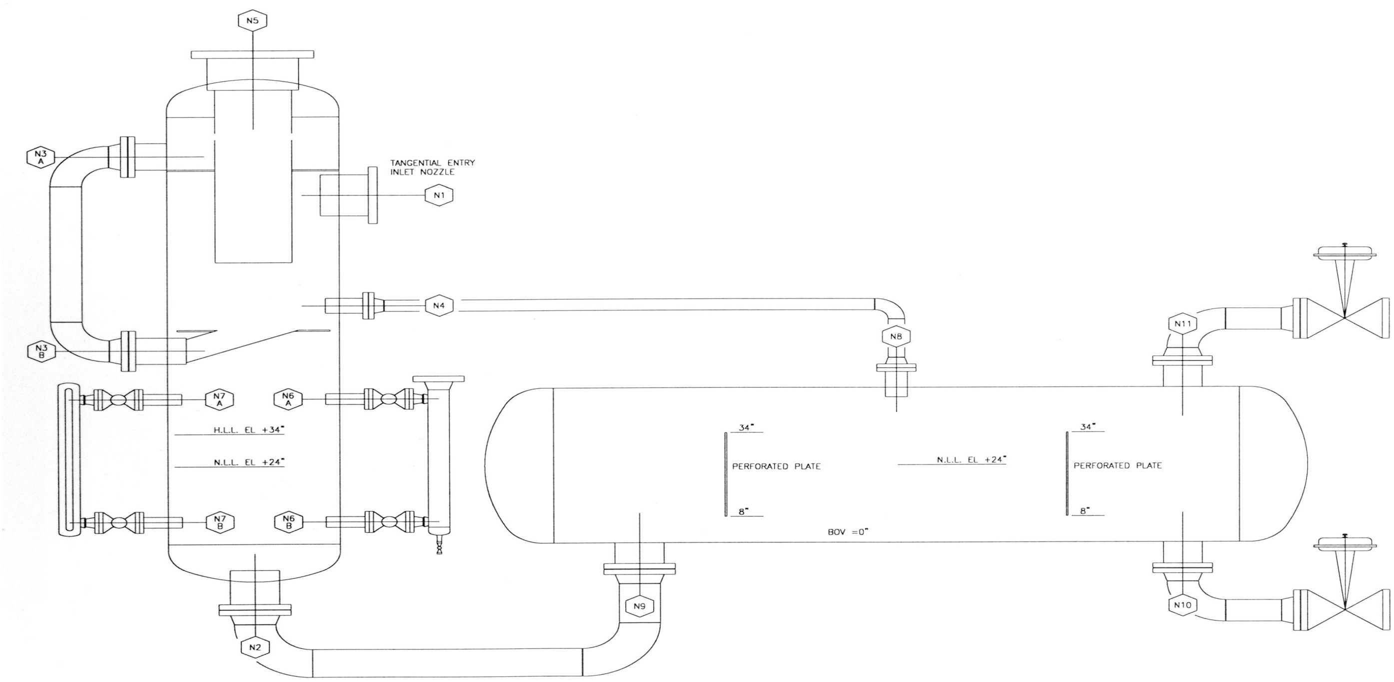
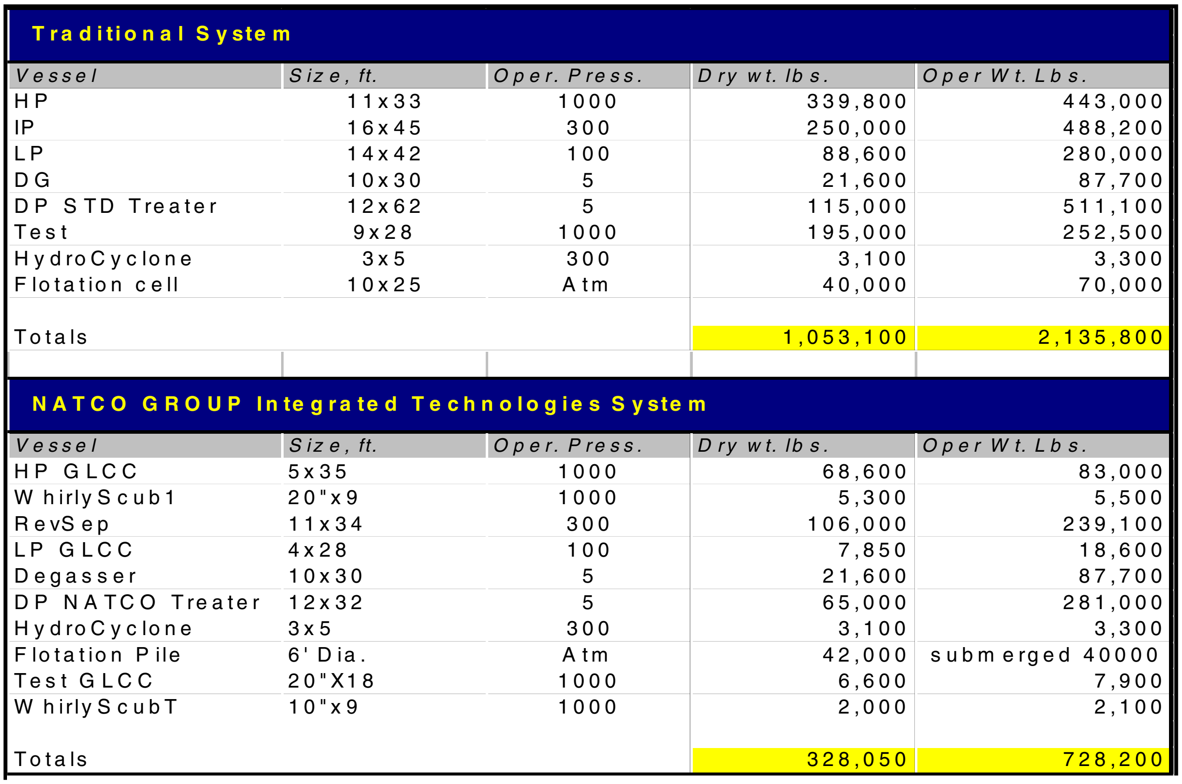


Fig. 12—The configuration is illustrated for a combined 48" by 18' S-S vertical recycling separator and a 60" by 20" S-S horizontal liquid-liquid separator. Together, these two units perform the same 3-phase separation as a 10' diameter by 40' S-S conventional separator. For operation at 1440 psig, the illustrated configuration reduces operating weight by 62% compared to the conventional separator.



Traditional System

Vessel	Size, ft.	Oper. Press.	Dry wt. lbs.	Oper Wt. Lbs.
HP	11x33	1000	339,800	443,000
IP	16x45	300	250,000	488,200
LP	14x42	100	88,600	280,000
DG	10x30	5	21,600	87,700
DP STD Treater	12x62	5	115,000	511,100
Test	9x28	1000	195,000	252,500
HydroCyclone	3x5	300	3,100	3,300
Flotation cell	10x25	Atm	40,000	70,000
Totals			1,053,100	2,135,800

NATCO GROUP Integrated Technologies System

Vessel	Size, ft.	Oper. Press.	Dry wt. lbs.	Oper Wt. Lbs.
HP GLCC	5x35	1000	68,600	83,000
WhirlyScub1	20"x9	1000	5,300	5,500
RevSep	11x34	300	106,000	239,100
LP GLCC	4x28	100	7,850	18,600
Degasser	10x30	5	21,600	87,700
DP NATCO Treater	12x32	5	65,000	281,000
HydroCyclone	3x5	300	3,100	3,300
Flotation Pile	6' Dia.	Atm	42,000	submerged 40000
Test GLCC	20"X18	1000	6,600	7,900
WhirlyScubT	10"x9	1000	2,000	2,100
Totals			328,050	728,200

Fig. 13—Through the application of emerging technologies, the size and weight of a separations train for 50 Mmscfd, 100,000 BOPD, and 50,000 BWPD can be reduced by nearly 70%.