The Case for Compact Separation

C.H. Rawlins, SPE, FuelCell Energy

Introduction

The mission of a production facility is to separate produced well fluids into individual phase components (oil, gas, water, and sand) and process these phases into marketable products or dispose of them in an environmentally acceptable manner.[1] Gravity-based vessels (two- or three-phase, horizontal or vertical) perform most of the separation duty; however, the demands of deepwater production and remote environments command a new portfolio of technology.

The term compact separation is commonly applied to separation-unit processes that do not rely on (large) gravity-settling vessels. In the evolving world of facilities technology, compact separation promises to revolutionize topside design by saving space and weight while improving process performance. Compact separation is both necessary and unavoidable because it provides benefits to separation design beyond minimal facilities. However, evaluation of any compact-separation technology should fully review all aspects of performance, not just size.

Separating Forces

Compact separation applies to partitioning of distinct phases—specifically oil, water, gas, and sand. All four phases are separable by gravity settling; however, "enhanced" physical forces reduce equipment size. Specie separation within a phase (e.g., hydrocarbon fractionation, water deoxygenation, or desalination) is not covered in this review, because it requires more than mechanical forces to be accomplished.

Gravity. Horizontal or vertical vessels relying on gravitational force provide most of the separation duty in oil and gas production. Efficient separation can be easily achieved with minimal complexity. However, the large size and weight of these vessels, especially at high pressure, is the main driver for development of compact-separation technology. Additionally, floating production performance deteriorates because of wave motion. Normally, these vessels are the largest and heaviest pieces of production equipment in the process facility. When relying only on gravitational forces for separation, residence time and low velocity are the keys to efficient separation.

Impact/Interception. One of the first developments in compact separation was the addition of impact or interceptor internal devices to reduce gravity vessel size. Including devices such as momentum breakers to aid in gas/liquid separation, perforated plates for motion suppression, matrix packing to aid oil/water separation, and vane packs and mist pads to aid in droplet removal from gas greatly increase the separation efficiency compared with bare gravity vessels and enable significant size/weight reduction in many cases. Momentum breakers provide a partial defense against motion sensitivity, but they are susceptible to plugging or channeling.

Cyclonic. The current trend in compact separation is cyclonic technology. Harnessing vortex flow provides an effective separation force of 10 to 5,000 times gravitational acceleration (g force), significantly decreasing separation equipment size. Static cyclones use pressure drop to produce spinning flow patterns, which in turn applies the high g forces to separate phases of different densities. Common equipment in this category includes cyclonic inlet devices for separators, axial flow and multicyclones for gas scrubbing, and deoilers and desanders for produced-water treatment. Cyclones provide the highest throughput-to-size ratio of any separation equipment, coupled with the least complexity. They are a net consumer of pressure drop, and the high velocities produced may be a source of wear.

Rotordynamic. Rotordynamic forces are developing into the next generation of compact-separation technology. Applied energy to a rotating element promises to increase separation efficiency over that of cyclones because the static wall (boundary layer) effects are eliminated. Moving to rotordynamic equipment is a major step because the complexity of equipment increases significantly; however, in many cases, the benefits are worthwhile. Equipment in this category includes produced-water centrifuges, solid-bowl centrifuges, dynamic cyclones, self- and external-powered separator turbines, and the in-line rotary scrubber.

Driving Benefits

To date, the primary motivating force for compact separation technology has been space and weight savings. Several other features are offered that ultimately may provide more substantial cost and operational benefits.

Space. Offshore, especially on floating facilities, footprint allocation is costly. Large installed area for process equipment equates to larger platform area and support structure. Substantial economic benefit results from reducing required installation area. When evaluating space requirements, total installed and operating space should be taken into account. This includes process equipment, skid base, access to manways/instruments, maintenance approach,

This is paper SPE 80994. **Technology Today Series** articles are general, descriptive representations that summarize the state of the art in an area of technology by describing recent developments for readers who are not specialists in the topics discussed. Written by individuals recognized as experts in the area, these articles provide key references to more definitive work and present specific details only to illustrate the technology. **Purpose:** to inform the general readership of recent advances in various areas of petroleum engineering.

and room for removal of vessel internals. Compact equipment reduces both direct footprint and associated access space, especially because it is normally vertically oriented. This restriction may be less of an issue on floating production, storage, and offloading (FPSO) vessels compared with semisubmersibles or tension-leg platforms. However, any reduction in equipment size will benefit the support structure. In addition, compact devices are more easily retrofitted into an existing process in which debottlenecking is required.

Weight. Reduction in installed weight may provide an even greater gain for floating offshore facilities compared to space. Both empty- and operating-vessel weights increase with the cube of diameter; therefore, substantial savings can be realized for high-pressure and high-flow applications. Vessel-weight savings correlates with less structure required to support (float) the equipment. Operating weight also is reduced immensely as holdup volume is reduced along with vessel diameter. Reducing weight simplifies equipment transport and installation, both onshore (factory to terminal) and offshore (terminal to platform to deck).

Motion Tolerance. One of the most important side benefits with compact-separation equipment is motion tolerance or insensitivity. On all floating systems (especially FPSO-based), wave- or weather-induced motion causes a corresponding wave motion in separating vessels. Internal motion leads to process upsets, spurious alarm trips, and poor separation performance. Compact separation equipment, especially cyclonic and rotordynamic that operate at 10 to 5,000 times gravitational acceleration, are motion insensitive and operate equally well under static or moving conditions.

Chemical Reduction. Another important side benefit is reduced chemical consumption. Two chemicals commonly reduced with compact separators are foam and emulsion breakers. In many cases, foam or emulsion can be broken by modification of fluid surface tension (chemicals) or application of a centrifugal field.[2] The centrifugal field applied by cyclonic or rotordynamic devices have been proven to break foam and, in some cases, break a loose emulsion. In all cases, reduced chemical consumption should occur.

Reduced Instrumentation. An overlooked benefit of compact equipment is reduced instrumentation. As holdup volumes are eliminated, level control devices can be removed. In some cases, the compact device is so small that pressure-relief devices are eliminated. Reduction in required instrumentation leads to less direct instrument cost, electrical/signal wiring cost, and maintenance.

Environmental Effect. The compact nature of these technologies offers secondary environmental benefits beyond reduced chemical use. Other gains include reduced raw material consumption in manufacture, reduced product inventory within the equipment (less to spill or combust in case of accident), reduced surface treating (painting) maintenance, less surface area for heat loss, and less wetted area for corrosion protection.[3]

Evaluation

Compact-separation technologies offer benefits that are currently being exploited. However, all aspects must be evaluated with any new technology, and according to engineering wisdom, "You can't get something for nothing." To achieve dramatic space and weight savings, degrees of freedom may be lost in either operability or performance.

Holdup Time. Holdup time is often overlooked when evaluating compact separation technology, but it may be the most important lost aspect. Reduced residence time provides significant space and weight savings. However, reducing or eliminating holdup time greatly reduces the time lag built into the system for reaction and operability of the control system. Reducing fluid retention time from 4 minutes to 2 seconds will result in 80% space and weight savings; however, the effect of dynamic flow fluctuations (slugs) on performance will be magnified as damping volume is eliminated. Typically, off-the-shelf electropneumatic control systems are not fast enough to react to slugging in compact separation devices. Therefore, the entire system must be modified to reduce/eliminate slugs or allow alternative damping. The control system must provide a more rapid, but still stable response. Even though the number of instruments may decrease, the level of complexity of the control system may increase.

Pressure and Energy. Increasing separation forces beyond standard gravitational acceleration requires input of energy into the system. Cyclonic devices derive energy from system (inlet) pressure, which is converted to pressure drop. The required pressure drop is proportional to density difference of the separated phases. A large density differential, such as water and gas or sand and water, may require only 2- to 25-psi pressure drop. However, a small density differential, such as oil and water, may require 50- to 250-psi pressure drop. In all cases, the inlet pressure provides the necessary energy. Rotordynamic devices acquire energy from an external power source (shaft power), from system pressure, or a combination of both. The shaft power or pressure drop is used to drive the internal moving mechanism. Generally, the higher the external power supplied, the lower the pressure drop required. For example, the rotary separator turbine may operate at a 50% pressure drop with no external power or with a 20-psi differential and several hundred shaft horsepower. While the power requirement is not substantial (few kW to several hundred kW), it is a cost factor.

Velocity/Wear. Part of the magic of compact separating devices is that they accomplish highly efficient separation in a small volume. Normally this is accompanied by increase in fluid velocity. Cyclonic devices may exhibit fluid velocities of several hundred ft/second in the vortex, while the spinning mechanism in a rotordynamic device may exhibit surface speeds even higher. The obvious concern with high velocity is increased erosion potential, especially if solids are in the fluid stream. Abrasive wear in cyclones is proportional to velocity to the fourth power. Therefore, a balance must be maintained between required performance and erosion.[4] Typically, wear is combated by flow path optimization (impacting a high-velocity stream against a static liquid bed instead of a component) or

TABLE 1—COMPARISON OF GAS-SCRUBBING METHODS.

Force Equipment	Gravity Settling Drum	Impact Vane Pack	Cyclonic Axial-Flow Cyclone	Rotordynamic IRIS
Performance (removing a 10-μm droplet), %	31	81	99.9	99.99
Diameter, in.	60	36	30	27
Length, in.	180	90	114	36
Bare weight, lbm	30,875	9,664	8,890	1,577
Operating weight, lbm	33,270	10,409	9,383	1,600
Pressure drop, psi	0.2	0.6	1.9	46.6

material selection (ceramics or hardened metals). In either case, erosion must be monitored and certain components must be considered consumable. A positive attribute of high velocity is that solids are prevented from settling and collecting in the equipment.

Sparing. Consumable wear items must be maintained as stock (e.g., deoiler liners). In addition, rotordynamic devices may have bearing and seal components that must be replaced and maintained and support systems that require attention (e.g., fluids and filters). Sparing support must be considered in the operating expense evaluation. When comparing to simple gravity vessels having few fluid-path components, instrumentation sparing must be considered also.

Turndown. With reduction in holdup time comes a narrowing of turndown available. While a gravity vessel has near 100% turndown, cyclonic devices may be limited to 30 to 40% of design conditions. Turndown below that limit requires multiple units operating in parallel or replacement of internal components to match new flow rates.

Example

One of the most dramatic examples in compact-separation technology evolution is gas scrubbing. A bare gravity vessel is an unwieldy device for removal of liquid droplets from a gas stream. **Table 1** shows the size and weight for a gravity device designed to remove a 10-μm water droplet from a methane stream at 1,350 psig and 100 MMscf/d flow rate. The first step in reducing the size of this large vessel is flow-path interception, such as mist pads or vane packs. The net result is a reduction in weight and footprint to 31 and 12% respectively, with negligible increase in pressure drop. Further requirements for even more compact solutions led to the development of the axial flow cyclone, which reduced the weight and size to 29 and 8%, respectively. However, the pressure drop increases to 2 psi. The next step change in gas scrubbing is to rotordynamic, such as the in-line rotary scrubber (IRIS) from Multiphase Technologies LLC. As shown in Table 1, an 8-in. rotary scrubber can handle the same flow, which gives a weight and space of 5 and 9%, respectively, compared with that of the gravity vessel. In addition, the rotary scrubber is insensitive to motion, breaks foam, and eliminates most instrumentation.[5] The process cost, however, is a 46-psi pressure drop and maintenance on a rotating element.

Conclusions

The mighty big drum (MBD) will never go away. In most onshore installations, except very remote sites, large gravity vessels are the most economic method of separation. While space and weight are often not critical on land, the additional benefits, such as reduced chemical use, reduced instrumentation, or minimized pad size can be realized with compact technology. Offshore, especially deepwater facilities, compact separation will be the driving force in design. Reducing platform space and weight with minimal facilities and increasing motion tolerance are all significant factors ushering in new technology. However, an MBD will most always be in the system somewhere to allow for dynamic flow dampening, which is difficult to achieve with common control systems applied to compact separation systems. Balancing the simplicity of vessel technology with benefits of compact-separation technology will be the path forward. A term such as "partial processing" is aptly applied to debottlenecking a system by using compact technology for simple unit processes while allowing vessels to handle system upsets. Compact-separation technology is fully commercial for separation of all phases; however, the major deployment hurdle that may take years to realize is operator comfort. JPT

References

1. Arnold, K. and M. Stewart: "Surface Production Operations: Volume 1, Design of Oil-Handling Systems and Facilities," Butterworth-Heinemann, Woburn, Maine (1999).
2. Smith, H.V.: "Oil and Gas Separators," *Petroleum Engineer Handbook*, H.B. Bradly (ed.), SPE, Richardson, Texas (1986), Chap. 12, 7.
3. Davies, S.: "Design of Compact, Modular Processing Systems in Deepwater and Ultradeepwater Field Developments," paper presented at the 2001 Deep Offshore Technology Conference, Rio de Janeiro, Brazil, October.
4. Svarovsky, L.: *Hydrocyclones*, Technomic Publishing Company, London (1984), 106–107.
5. Rawlins, C.H. and V.C. Ting: "Testing of an In-line Rotary Separator (IRIS) at the Chevron F. Ramirez Gas Production Facility," paper presented at the 2002 Laurence Reid Gas Conditioning Conference, Norman, Oklahoma, February.

Hank Rawlins, *SPE, is Intl. Project Manager with FuelCell Energy. He holds BS and MS degrees in metallurgical engineering and mineral processing from the U. of Missouri-Rolla. Previously, Rawlins worked 7 years on cyclonic treatment of multiphase flow for oil and gas processing, then spent 2 years working with a Kvaerner Process Systems U.S./Dresser-Rand joint venture to develop multiphase turbines for oil/gas separation and power recovery. The work in this article was generated from process-engineering work in upstream oil and gas processing. In 2002, he moved from the upstream process industry to the power-generation industry.*