Design and Installation of a Sand-Separation and -Handling System for a Gulf of Mexico Oil Production Facility

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Summary

A comprehensive system for the separation and handling of sand from produced fluids was designed and installed on a facility in the Gulf of Mexico. This system involves two multicone desander systems, one on the water outlet and one on the oil outlet of a low-pressure separator, to provide separation of sand from produced fluids. The separated solids are collected, dewatered, and transported to a unique, simple-solids handling system designed for complete fluid containment and safe handling. The focus of this paper is to present the design of the separation and handling system and to discuss the various challenges encountered during and after commissioning. The topics covered include desander operation (pressure drop and separation), slurry discharge from the desander, dewatering of slurry, recycling of fluids, and transport of the collected solids from platform to shore.

Introduction

All oil and gas wells produce solids, in varying concentration, with the produced fluids. These solids, such as sand, clay, or silt, may originate from the reservoir, or they may be corrosion byproducts from downhole tubing or other process equipment. These solids are normally smaller than 250 µm in diameter and vary in concentration for different fields, with a typical range of 5 to 250 ppm. This type of solid is designated as a "natural" solid (although corrosion products may not be natural), as opposed to an "artificial" solid, such as fracture sand, which may be larger. The system described is designed to handle "natural" solids.

Even at relatively low flow rates and velocities, solids can cause considerable problems in a production system.[1] Severe erosion of pipe work and valves can be experienced in high-pressure production. As solids accumulate in tanks and gravity separators, the conditions for bacterial growth and associated production of hydrogen sulfide become ideal. This in turn can be a source of further corrosion. Accumulation of solids in process vessels can also affect retention time and thereby reduce separation performance. Typical solids-handling scenarios require periodic solids removal by sand jetting or shutting the system down and digging them out by hand. Either method is only a partial solution at best, and both can significantly impact the quality and quantity of oil production.

Solid-liquid hydrocyclones, termed "desanders" for this paper, are a superior alternative to conventional equipment, such as plate interceptors or filters. Desanders are a solution that can remove solids online, in a controlled fashion, without system disruption or shutdown.[1] Their weight and size is usually 10 to 25% of standard equipment, and the capital cost is proportionally lower. Desanders require little, if any, operator interaction, and owing to the fact that they have no moving parts, maintenance is minimal. Benefits and operation of solid-liquid hydrocyclones are detailed in the Appendix. Owing to a combination of new drilling technologies, tighter environmental regulations, and more compact production facilities with higher uptime requirement, the need for a sound solids-control strategy is greater than ever. Desanders are a proven technology providing a robust solution to these challenges.

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Sand-Production Difficulties

The South Pass 78 field is located in the Gulf of Mexico, and it consists of 41 production wells routed from three satellite platforms.

Once the fluids reach the platform, production is routed through high-pressure (HP), intermediate-pressure (IP), and low-pressure (LP) manifolds. The HP and IP two-phase separators accomplish bulk gas removal, while the liquids flow to a cone-bottomed LP bulk separator. Flash gas is removed in the LP bulk separator, and the produced liquids are separated into oil and water streams. The oil stream flows to a chem-electric treater for removal of residual water, and then to the clean-oil surge vessel for temporary storage. Sales oil passes through the lease automated custody transfer (LACT) system and leaves the platform via pipeline. Bulk water from the LP bulk separator, along with separated water from the chem-electric treater, is first treated by a corrugated plate interceptor (CPI). The CPI skims off any residual oil from the water stream. The water receives final treatment by the mechanically induced gas flotation cell before overboard discharge.

As the South Pass 78 platform's production life matured, problems resulting from solids production began to be encountered in both the oil and water treatment systems. These problems manifested themselves as equipment plugging, emulsion stabilization, and erosion.

The LP bulk separator was designed as a cone-bottomed tank. With the water outlet at the apex of the cone, most of the solids produced would discharge to the water-treatment system. The large solids would settle in the cone-bottomed tank and pass through to the CPI. The plates in the CPI experienced constant plugging, which required frequent operator intervention and resulted in equipment downtime. Some solids would pass on to the flotation, which is the final and most critical piece of water-treating equipment. The cells were filling at a rapid rate, resulting in severe efficiency loss caused by reduced residence time.

Small solid particles would pass through the LP bulk separator in the oil phase. When these fine solids reported to oil treating, they would create emulsion pads, which inhibit the oil/water separation ability. Furthermore, the solid particles are able to pass to the LACT system and erode the metering elements. This reduced sales-metering accuracy and operational life of this costly system.

To remove the sand and solid particles from production streams, a desander was installed on each outlet of the LP bulk separator to improve the efficiency of the platform-treatment systems. In addition to the desanders, a sand-removal system was required owing to restriction of overboard sand discharge by the National Pollutant Discharge Elimination System (NPDES).

Design of Solids-Handling Systems

Solids handling and disposal in the oil and gas industry can be broken down into five areas: separate, collect, clean, dewater, and haulage.[2]

1. Separate: The first step in solids handling is separation of the solids from the well or process fluid stream. Separation may be accomplished by solids-separation-oriented equipment, such as desanders, filters, or sand jets. Serendipitously, the process equipment itself may also perform this duty as a byproduct to fluid-phase separation, producing settled tank bottoms or vessel drains.

2. Collect: To facilitate a simple system design, the separated solids should be gathered into one central location. Collection can be done by a desander accumulator vessel or a dedicated process

sump tank. The solids-collection method is further dictated by hazardous chemical or radioactive contaminants. In such a case, enclosed collection methods are required.

3. Clean: In many cases the solids may require cleaning to remove hydrocarbon or chemical contaminants before subsequent handling. Specific sand cleaning and "washing" systems are available from several vendors and are employed as a modular add-on system.

4. Dewater: The total volume of solid slurry to be disposed of is significantly reduced in a dewatering step. Simple dewatering methods use gravity-drain containers, such as hanging mesh bags or screen-lined bins. More comprehensive or controlled systems may require a filter press or screw classifier for water removal. In most cases, a dewatering step will reduce the disposal volume by 90% and produce a solids "cake" with < 10% water weight.

5. Haulage: Haulage is a term used to define transport and disposal of the solids. The design of the haulage system is dependent upon the location (land based or offshore) and local disposal requirements (i.e., disposal well, overboard, landfill, road surfacing, etc.). In many cases, the solids may be mixed with water and disposed overboard or injected into wells. Other facilities require transport to shore for landfill disposal.

These five steps are further detailed in the decision diagram shown in **Fig 1.** A procedure for almost all solids-disposal systems in oil and gas operations can be generated with this method.

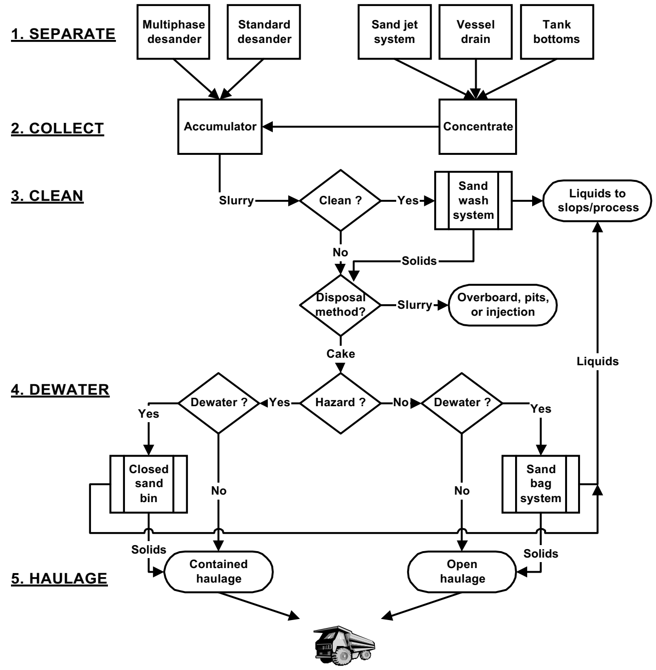

Fig. 1—Decision diagram used to decide outline of solids-handling system.

Design of Gulf of Mexico System

A solids-handling system was required for the South Pass 78A platform that would remove sand from the production streams, and then "package" the sand for transport to shore for landfill disposal. The key parameters were simple design, minimal operator intervention (automated), and proven technology. Using the five-step approach as outlined above, a system was designed to meet these criteria. A schematic diagram of the oil and water desanders, as well as the integral dewatering and haulage system, is shown in **Fig. 2.**

Separation. The main separation-design requirement was to remove the maximum amount of sand from the oil and water outlet streams. Further requirements were minimal footprint, 40-psi available pressure drop, and minimal operator intervention. Based upon simulation analysis, a liner style desander was chosen, with a separate unit required on each outlet stream of the LP separator. Because the design flow rates and separation requirements were similar, and to simplify design and maintenance, identical size desanders were installed on both the oil and water streams. The desander vessels have a 20-in. outside diameter by 82-in. overall height (flange-to-flange), built to the American Society of Mechanical Engineers (ASME) 150-lb rating.

Each desander is installed on the liquid outlet of the LP separator, upstream of the level-control valve. This allows control of the flow rate through the unit to maintain the design-pressure drop. The desander acts as a fixed-size orifice and provides a constant pressure drop at a constant flow rate. The desander has a bypass loop to allow maintenance without production shutdown. Pressure-

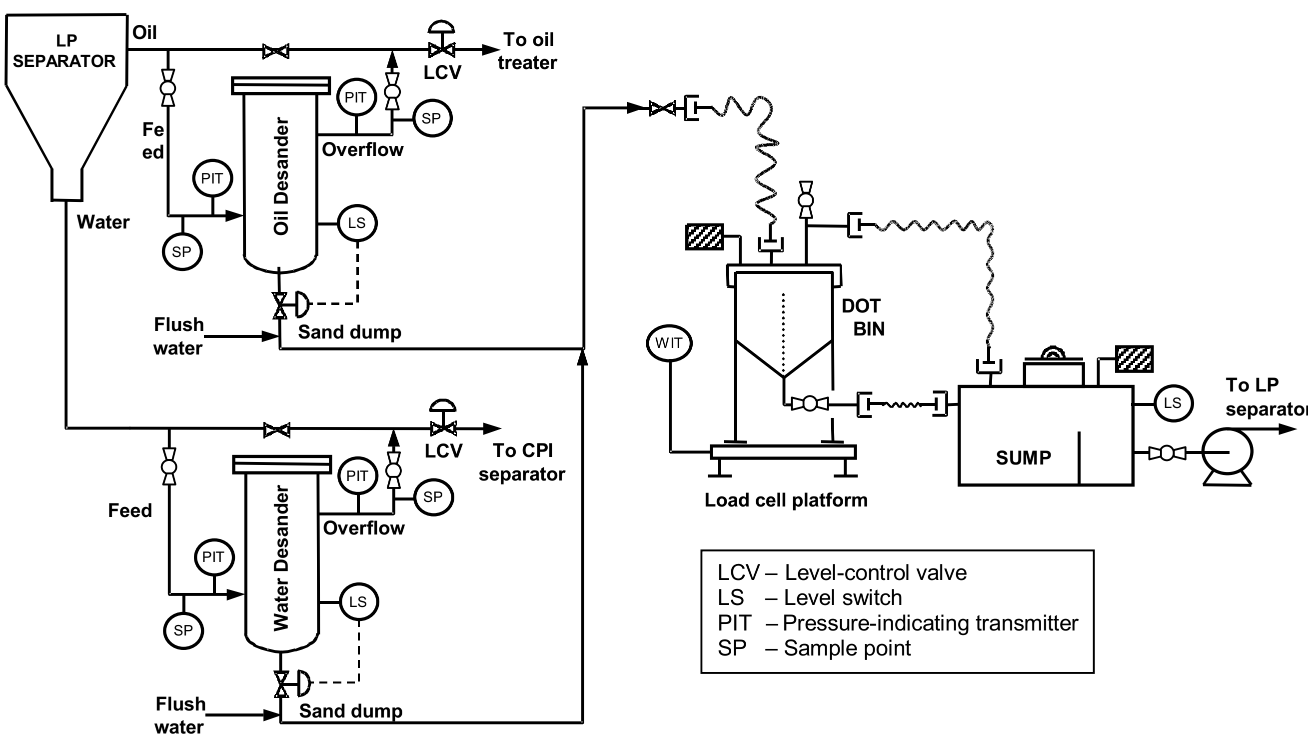

Fig. 2—Process layout of oil and water desanders with integral solids dewatering and haulage system.

indicating transmitters are located at the inlet and overflow to monitor operation. A thermal dispersion-level switch is used to activate the dump sequence, and a rotating disc valve is used for the dump operation. Both the thermal-dispersion probe and the rotating disc valve were chosen because of proven performance in this type of operation. Each desander vessel is made of carbon steel, with 316 stainless steel liner plates, and alumina ceramic liners.

Using an automated analysis based on the calculation procedure shown in the Appendix, the separation size for each desander was determined. The liner style desanders are 1.5 in. in diameter. This value was used to calculate the base d_c of approximately 7 µm. Correction factors were applied for inlet concentration (500 ppm sand in water and 100 ppm sand in oil), pressure drop (40 psi for each stream), solid/liquid density (2.51/1.05 specific gravity solid/water stream and 2.29/0.857 specific gravity for solid/oil stream) and in-situ liquid viscosity (0.64 cp for water and 2.0 cp for oil). With the liner-geometry-specific correction factors, the actual d_c came out to be 4.6 and 9.0 µm for the water and oil cases, respectively. This results in a separation size, d_s, of 8.5 and 16.5 µm for the water and oil units, respectively. At an inlet particle mean size of 50 µm for the water stream and 10 µm for the oil stream, the estimated total solids recovery is > 99% and > 65%, respectively. The actual separation efficiency for the water desander has been confirmed by sampling.

The design flow rate is 20,000 B/D for the water desander and 15,000 B/D for the oil desander. Based upon the 1.5-in. liner diameter and its associated capacity curve, these flow rates require 28 and 21 active liners respectively. It was decided to use a 20-in., 150-lb.-rated pressure vessel for each desander, which could hold a maximum of 31 active liners. The required active liners are located in the vessel, and blank units are used to blind unused slots. Blank liners allow the system to be uprated in capacity as production changes. In this case, each desander could handle a maximum flow rate of around 24,000 B/D.

The separated solids report to the integral accumulator section, while the oil and water discharge continuously from the overflow.

Collection. The separated solids are collected into the underflow section of the desander vessel, called the accumulator. Because the accumulator is integral to the vessel, it operates at the same pressure as the desander. The solids are collected and purged on an intermittent basis.

The sand collected in the accumulating section is purged by trip of the sand-level switch, which is a thermal dispersion probe. This instrument is located protruding into the accumulation chamber, about two-thirds the height of the cylindrical section. The level probe acts as an insurance against slugs of sand into the desander. The rate at which the sand is collected is shown in **Table 1.**

The slurry is dumped from the accumulator through a 2-in. rotating disk valve. This type of valve has proven reliable in abrasive service. The amount of solids and liquids dumped during the purge cycle is a function of the valve diameter, pressure differential between accumulator and collection bin, and length of purge time. Based on a 10-second purge, 85-psid differential, and 2-in. nominal line size, the amount of slurry discharged is approximately 180 gal, as shown in Table 1. This will include approximately 88% liquids by volume for the total dump volume. The 2-in. discharge line carries the slurry approximately 60 ft for the water desander and 25 ft for the oil desander. Velocity in this line is over 10 ft/sec (3.05 m/s), which is typically sufficient to prevent solids saltation. An injection port was installed onto the elbow of the discharge line, just below the dump valve, for additional flush water to clean the line after each dump.

Cleaning. A sand-cleaning system was not required at this location because all solids are shipped onshore for landfill disposal. For reference, visual indication of the sand collected showed virtually no oil adhering to the sand particles.

The purpose of a sand-cleaning system is to remove the adsorbed oil from the surface of the sand particles. Many cleaning systems typically use a mechanical agitation mechanism to scrub the oil coating. In this manner, the desander internal flow pattern

TABLE 1—PURGE RATE AND LIQUID LOSS

	Water Desander	Oil Desander
Process data		
Liquid flow rate (B/D)	13,650	15,000
Solids concentration (ppm)	100	50
Accumulator sizing		
Underflow volume (ft ≥)	6.1	6.1
Volume of sand (ft ≥)	3.0	3.0
Dumps per day	5	2
Time between dumps (minutes)	288	774
Purge discharge		
Purge time (seconds)	10	10
Pressure (psia)	85	85
Slurry discharge (gal)	179	198
Liquid volume discharge (ft ≥)	20.9	23.4
Bin loading		
Total bin volume (ft ≥)		87
Available solids, weight (lbm)		6,763
Total solids per day (lbm)		1,591
Time to fill bin, weight (hours)		102

itself provides much of the primary cleaning. Owing to high shear-force gradient in the desander vortex flow, and particle-to-particle interaction, the oil layer is abraded from the sand surface. The free oil goes out with the overflow, while the cleaned sand settles in the accumulator. The accumulator is a closed integral system when sand settles and fills this chamber by gravity. Each sand particle settling into the accumulation section replaces an equivalent volume of liquid. In this method, the lower accumulation section will fill with sand and water, as the oil will float upward and out. The dumped sand will typically have < 1% oil weight on dry sand.

Dewatering. The slurry dumped from the accumulator contained approximately 88% liquid by volume (3 ft^3 of sand and 21 ft^3 of liquid). Reducing the liquid volume greatly simplified solids transportation, justifying the dewatering step.

The haulage requirements dictated the design of the dewatering step, as the solids are transported to shore in Dept. of Transportation (DOT)-approved transport bins. A separate dewatering step using filters could have been used, and then the solids placed in the bins; however, to minimize operator intervention and equipment complication, a novel system was designed to accommodate the dewatering within the transport bins.

Stock DOT transport bins were modified to accomplish dewatering. The bins are free-standing, square-sided, slope-bottomed, and steel-fabricated. The slurry is fed into the top of the bin through a connection in the bin lid. The slurry fills up the bin volume, and the liquids are drained through a 2-in. standpipe, with 0.25-in. drilled holes throughout the length and wrapped with 100 µm wedge wire screen. The liquid is gravity-drained through the standpipe into a collection sump. The sump is designed with high and low level switches to activate a diaphragm pump, which sends the liquid back to the inlet of the LP separator. The entire DOT bin and sump system is closed, and a flame arrestor is provided on each, to allow the assembly to breathe. The liquid sump has a maintenance hatch for inspection and cleanout and an internal weir to prevent any solids from going through the pump.

The total available bin internal volume is 87 ft^3, which is sufficient for 29 sand dumps. Using the different dump frequencies of the water and oil desanders, a 50% void fraction for packed sand, and the net available bin weight of 6,763 lbm, the time to fill the bin is approximately 4 to 5 days.

Haulage. Haulage design was dictated by environmental requirements because the solids are required to be disposed of in a facility licensed by the Louisiana Commissioner of Conservation. All sand is collected into DOT transport bins, which are lifted from the platform onto a transport vessel. The ship takes the bin to shore, where it is transported by flatbed truck. The truck takes the bin to the approved landfill, which empties the sand and returns the bin to the platform for reuse.

The design of the bins to meet DOT transport standards and to be reused posed a significant challenge in design of the dewatering and haulage system. Of the greatest concern were the piping connections and instrumentation for measuring solids levels. To minimize the effect of welded connections on bin integrity, it was decided to introduce the slurry by attachment to the removable bin lid. The lid is 18 in. in diameter and attached by a barrel hoop connector. Two lids are used with the bins. The operation lid contains a 2-in. pipe with quick-disconnect fitting and a 4-in. tee with the straight run placed upwards. The quick-disconnect pipe is used for slurry inlet, while the tee has a ball valve on the straight run to allow for visual inspection of the sand height with a yardstick. The tee side run allows for "air" recirculation from the sump in the closed system. The lid used during transportation has no process connections. In this manner, two bins are used with the two interchangeable lids. One bin will be in use for dewatering, while the other will be in transport or standby. The liquids draining from the standpipe are sent to the sump by a 2-in. connection, with isolation valve and quick-disconnect fitting. All connections to the bin, and between the bin and sump, are made with flexible hose to facilitate quick changeout.

Measurement of the solids amount or level in the bin posed a challenge, as no instrumentation was to be located on the bin that could be damaged during transport. A load-cell platform was therefore employed, which is simple and robust. The platform contains load cells on four legs, and is designed for a gross weight of 10,000 lbm. This gives a proper margin over the gross full-bin weight of 7,700 lbm. The load cell is equipped with a local weight indication and tare screen, and a weight-output signal. The output signal is tied into the platform distributed control system to indicate an alarm upon reaching the full state.

Operation

Operation of the desander is very simple. Fluid is introduced through the desander, and once the desired pressure drop is reached, the unit is in operation. Control of the desander is done by maintaining the pressure drop within a certain band. Pressure drop changes proportionally to flow rate, and as long as it stays within the band, operation is acceptable. It is recommended to keep the pressure drop at a maximum for optimum separation efficiency.

The design pressure drop of the unit is 40 psi. If the pressure drop reaches a level of 10 psi, then it is recommended to change the number of liners. The absolute minimum pressure drop for operation is 5 psi, which is the shutdown-alarm level. There is no theoretical maximum pressure drop; however, for practical purposes (operational constraints and wear minimization), the maximum pressure drop recommended is 75 psi.

The level probe sends the trip-signal initiation to the 2-in. rotating disk valve. The valve opens for 10 seconds, then closes. The dump time of 10 seconds is chosen as the initial condition, which is a calculation based on the process conditions. It is important to allow the valve to be open long enough to empty the desander, but not too long to drain excess liquids to the collection bin. During the dumping cycle, the desander stays in operation.

The dumped slurry from each desander is sent to the sand DOT bin. This bin is designed to receive the liquid/sand slurry, drain the liquids through the porous standpipe, and retain the sand. The drained liquids are collected in the sump for return to the LP separator.

As the slurry dump enters the sand DOT bin, the load-cell weight readout is erratic until the slurry flow stops. The liquid drains by gravity to the sump, and the weight readout will stabilize at a specific level. The bin is able to continue to receive slurry at the dump intervals until the weight limit is reached. The bins are designed with a gross weight limit of 7,700 lbm and a tare weight of 1,100 lbm.

Once the sand DOT bin is full, it is isolated by closing the inlet and outlet valves. The flexible hose connections are removed, and the bin is removed via crane. The operation lid is removed and replaced with the transport lid. The operation lid is placed on the standby bin, which is put into operation, while the first bin is transported to shore for disposal.

Troubleshooting

As with any new installation, Murphy's law introduced several challenges upon startup of the system. These challenges are listed below with causes and steps taken to remedy these problems.

1. Upon startup, the water desander operated within the design pressure drop of 30 to 35 psi. After several weeks of operation, the pressure drop started to steadily increase, and would reach up to 45 psi during surges. High liquid-flow rate was suspected as the cause. The actual flow was measured at 16,000 B/D, which was higher than the startup design of 13,500 B/D. The unit was taken offline, and four blanks were replaced with active liners. The pressure drop reduced to 35 psi.

2. The dump valve did not operate automatically on the water desander. Upon inspection, the sand level was found to be 3 in. above the sand probe, yet the valve did not open on its own. The valve was eliminated as the fault, so the probe calibration was then checked. The probe was calibrated in the factory based on tap water and beach sand because an actual sample of the fluid and produced solids were not available at the time. A sample was collected from the desander underflow (UF) and used to calibrate the probe. The desander was put back into service and observed to be operating properly. The sand probe on the oil desander was also calibrated based on a sample from the oil desander outlet.

3. Once back in service for several weeks, high-pressure drop was reported once again on the water desander. High flow rate was again suspected, as new wells were recently brought online. An ultrasonic flowmeter was used to measure the flow rate directly at the inlet and outlet of the desander. The new flow rate was established to be around 20,000 B/D. The clean water outlet of the desander is sent to the CPI, which requires a minimum system pressure of 15 psia. With concern that high-pressure drop could cause the system pressure to fall below the minimum required operating pressure for the CPI, it was decided to replace all the blanks with active liners. The subsequent pressure drop was observed to be between 20 and 25 psi, which gave the desander enough pressure-drop variability during flow surges while still maintaining pressure to push to the CPI.

4. Poor drainage was then observed on the DOT bin. After inspecting the bin internals and connections between the bin and sump, several problems were identified. First, the flexible drain hose between the bin and sump was excessively long and poorly routed, resulting in a 10- to 12-ft drop below the sump level. This is a gravity-drain system, and the drop could cause unnecessary backpressure to the bin or blockage in the hose. The hose was rerouted to remove any low points. The sand bin started to drain for a short while, then quit as though it were plugged. The hose was inspected for blockage, and none was found. A hard pipe drain line between the bin and the sump was subsequently installed for permanent repair. System pressure was checked on the bin and sump, and the vacuum lock was checked as a drain block. No significant improvement was observed.

Plugging of the drain screen was hypothesized as the blockage source. The screen was plugged, owing to the very fine particle size of the sand. Because the bin was more than half full of liquid, it was difficult to check for screen plugging. Upon tapping of the hard drainpipe beneath the cone section of the bin, flow was clearly established and a steady, consistent stream of liquid observed. This improvement proved temporary as the flow eventually diminished to almost zero. A permanent solution using a hopper vibrator was tried. Two differently-sized pneumatic vibrators were tested. Each vibrator was installed directly underneath the cone section of the bin, onto the drainpipe. Both vibrators were able to increase the drain flow; however, the force produced was too small to produce steady flow.

A method was then tested involving the introduction of high-pressure air into the screen to blow away the sand. This involved installation of a tee section at the drain line after the block valve for air injection. When the air is introduced, the block valve is closed, and air is forced to go up into the screen to blast off the sand collected onto the screen surface. This method was first tested with a 10-second blast of instrument air at 150 psia. The resulting flow increased by a factor of 10 over that from use of the vibrator alone. Also, the flow-cycle time increased by a factor of 15 (i.e., 30 minutes of flow with the air blast vs. 2 minutes of flow for the vibrator). The air-blast system has been installed as a permanent system; however, it has not been tested in full operation because of changes in the desander-system operation.

The screening effectiveness was confirmed by collecting samples. No measurable quantities of sand were observed in the filtrate liquid. The sump was then opened, and no sand buildup was observed in front of the weir plate.

5. Once again, the water desander was reported to have a higher-than-normal pressure drop, sometimes high enough to cause problems at the CPI inlet. The measured flow rate had not changed; therefore, plugging of the individual liners was suspected. Large scale, shale, or formation rocks can stick into the inlet slot of each liner. If enough of these rocks lodge in the inlet, they can seal off the entrance opening, not permitting any fluid to enter the desander. Because each liner behaves like a fixed orifice, once the total orifice area decreases, the pressure drop across the non-plugged liners will naturally increase at a fixed flow rate. The desander was isolated and the liners removed. Each liner was plugged completely at the inlet opening, and some were plugged at the vortex opening. The source was found to be rocks and shells up to 0.38 in. in diameter. Once all the liners were removed from the vessel, 3 to 4 in. of small rocks and pebbles were found to have accumulated at the top of the liner plate. All the liners were cleaned and the inlet ports unplugged. The vessel was completely flushed to remove the rocks from the vessel. Because of the rock problem, a basket-type strainer was installed upstream of the desander to remove the particles that were otherwise too big to be processed by the desander. The basket strainers have been installed as a permanent solution for oversize protection.

6. On one occasion, the dump valve on the water desander opened, yet no significant flow into the bin was registered on the load-scale monitor. The drainpipe was opened for inspection and found to be full of sand. Insufficient slope in the drainpipe or fluid velocity will cause the sand to settle and accumulate inside the drain line. The drain line was modified to add a slight slope to assist slurry flow. The desander system is equipped with a flush line that takes a slipstream from the desander inlet. Purge water is programmed to open for 20 seconds to span the dump valve cycle of 15 seconds. This should ensure sufficient purge water to keep the line flowing and prevent sand from settling in the drainpipe, and long-term operation will be monitored.

7. Platform personnel raised a safety concern regarding the sand-separation system. If the dump valve were to fail to open owing to mechanical or electrical failure, a large amount of liquid and sand could overflow the bin and sump. The bin does not have a high-level shutdown; however, it does have an overflow mechanism to the sump tank below. The lift pump (diaphragm pump) at the discharge side of the sump does not have enough capacity to handle the flow during a failed dump-valve situation. Excess flow will end up discharging out of the sump through the flame arrestor. One solution is to install a level controller or switch on the top of the bin through the existing tee opening. Another possible solution is to divert the flow to an existing atmospheric tank, such as a slop tank. Both suggestions are under investigation.

Status Update

The desander and solids-handling system on this facility are currently out of operation. Since the installation of the desanders, the current average water production is higher than the capacity of one desander, so equipment modifications would be necessary either to run part of the water through the existing water desander or to convert the oil desander to water service and split the flow through the two vessels. In addition, a variable recycle loop is required to keep an even flow rate in the desanders, instead of the current situation in which the vessels are unprotected from surges. These upgrades are not within the planned scope of the facility operation.

As part of a water-treatment system upgrade, new (and larger) skimming and flotation vessels will be placed parallel to the existing equipment. The old vessels are available as spares, so little or no downtime will be associated with cleaning out vessels when they fill up with sand.

Nomenclature

C_f = correction factor for feed concentration
$C_{\Delta P}$ = correction factor for pressure drop
C_μ = correction factor for liquid viscosity
C_ρ = correction factor for solid/liquid density
d = particle diameter, L, mm
D = desander internal diameter, L, in.
d_c = desander 50% passing "cut" size, L, μm
d_s = desander 98% passing "separation" size, L, μm
f = feed concentration by volume, L^3/L^3, m^3/m^3
Y = recovery of a particle of size "x"
ΔP = inlet to overflow pressure drop, M/Lt^2, psi
μ_L = liquid phase dynamic viscosity, M/Lt, cp
γ_L = specific gravity of liquid phase
γ_S = specific gravity of solid phase

Superscripts

m = slope of recovery curve
x = particle size to d_c ratio

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Appendix—Desander Selection and Sizing

Produced water treatment represents the largest use of desander technology in the oil and gas industry, based on capacity. Removal of solids from produced water is required by environmental regulations, to prevent formation damage during reinjection, or to protect downstream equipment from erosion or filling with sand.

The two styles of desanders commonly used in oil and gas production facilities are the vessel style and the liner style. The liner style makes up the majority of the installations, but both are detailed here for comparison. **Fig. 3** shows a sketch of both styles of desanders. Each style varies in size range and construction, and selection of each is dependent upon capacity, separation size, and turndown requirements. The vessel style is constructed with the vessel itself as the desander, with a size range from a 3- to 30-in. nominal diameter. The liner style consists of a pressure vessel containing multiple liners, with the individual liner diameter ranging from a 0.5- to 4-in. nominal diameter. The vessel-style units are used in applications requiring large flow rates combined with coarse separation size, while the liner style is used for applications at any flow rate combined with fine separation size.

The type of desander, vessel or liner, is further selected with the additional criteria shown in **Table 2.** Because of the simplistic design (i.e., without ceramic liners or stainless steel plates), the vessel-style desander has a much lower capital cost compared to the liner-style design. In most applications, however, the deciding factor is the required separation size, which is why more than 95%

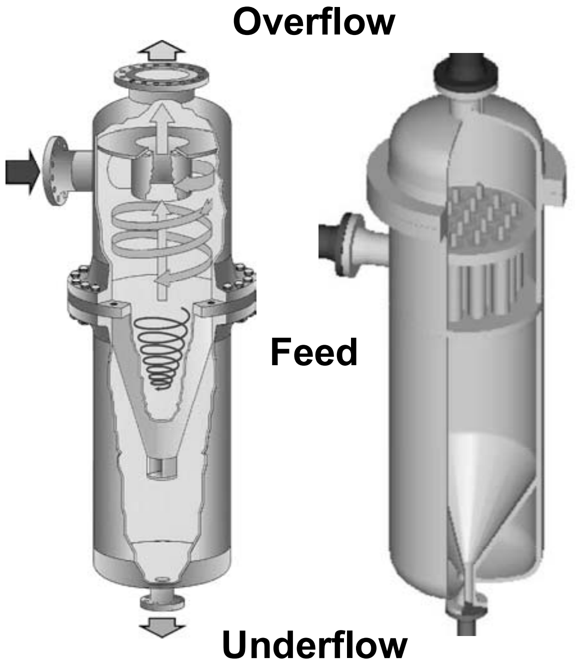

Fig. 3—Schematic drawings of vessel-style (left) and liner-style (right) desanders.

of all conventional desanders in oil and gas production are of the liner-style design.

Desander selection is based primarily upon the desired separation size and secondarily on the total system capacity. Using the process design conditions, a cut-size, separation-size, and total-solids recovery efficiency is calculated. The size of desander that meets the separation criteria is then checked against the total flow rate using the desander capacity curve to provide the number of units in operation.

By definition, all hydrocyclones operate because of pressure drop. The feed, a mixture of liquids and solids, enters the cyclone through the tangential or volute inlet at the operating feed pressure. The change in flow direction forces the mixture to spin in a radial vortex pattern. This vortex flow is accelerated as the internal diameter is reduced over the length of the cone. Owing to the angular acceleration of the flow pattern, centrifugal forces are imparted on the solid particle, forcing them toward the internal wall of the cone. The solids continue to spin in a radial vortex pattern, down the length of the cone, to discharge through the apex, creating the underflow stream. Because of the cone convergence, the liquid flow is reversed and returned upward through the vortex finder to form the overflow stream. The solids that exit through the apex collect into an accumulation chamber, where they are periodically purged, while the overflow discharges continually. The closed collection chamber defines a solid-liquid hydrocyclone as a desander.

TABLE 2—DESANDER SELECTION CRITERIA

Criteria	Vessel Style	Liner Style
Inlet solids concentration > 1 vol%	Yes	No
Large solids (> 5 mm)	Yes	No
Fine particle recovery (< 25 μm)	No	Yes
> 900 lbm American Natl. Standards Inst. (ANSI) design	No	Yes
Vessel fabricated of any metal	Yes	Yes
Liner available in ceramic	No	Yes
Pressure vessel subject to wear	Yes	No
Replaceable wear components	Yes	Yes
Inherent turndown of > 3:1	Yes	Yes
Package design available for high turndown (> 10:1)	No	Yes

Solid-liquid hydrocyclones are catalogued as a particle size classification device. As such, each type, size, and geometry of a cyclone will separate particles of a given size. The hydrocyclone acts as a particle cutter or distributor in that, for a given cyclone, large particles will be captured, and small particles will pass through. The cyclone, as a unit operation device, falls into the same category of classification equipment as a sedimentation vessel, filter, screen deck, or mechanical classifier (rake or screw).

Classification equipment exhibits a recovery-efficiency curve as shown in **Fig. 4,** which is indicative of that equipment. This curve plots the particle sizes in the inlet stream to the classifying device vs. the percent probability of recovery (capture) by that device. The particle size is shown not as absolute size, but as a fraction of the classification-device cut size. The cut size is termed as the d_c size, and is defined as the particle size with a 50% probability of capture by that device. Furthermore, the separation size is defined as the particle size that has a 98% probability of capture, and is termed as the d_s size.

The shape of the recovery curve is defined by the cut size and slope. The d_c is a value calculated for each device and each application. The type of device, geometry, operating parameters, fluid characteristics, and solid characteristics will all determine the magnitude of the d_c. The slope is then further defined as the sharpness of the separation. The sharpness or slope of the recovery curve provides an indication of the efficiency of separation. A perfect separation is rarely achievable in practice, and with classification devices some fine material will be present in the large particle-outlet stream, and some large particles will be present in the fine-particle outlet stream. The amount of this misplaced material, and the efficiency of the separation, is calculated from the shape of this curve.

Total solids recovery is defined as the amount of solids captured or separated. The outlet amount is defined as the overflow stream containing the noncaptured particles. Both the d_c and the inlet-particle size distribution will determine the total-solids recovery efficiency. The effect of inlet particle size on recovery efficiency is the most misunderstood parameter in the use of solid-liquid classification devices.

In selecting a hydrocyclone for a separation application, the separation size is calculated, and then the number of cyclones to meet the capacity is determined.

The first step in determining the actual or operating d_c is to determine the base d_c. The base d_c is a function of the hydrocyclone diameter, which is defined as the internal cylindrical section diameter. The base d_c is directly proportional to the hydrocyclone diameter

$$\text{Base } d_c = 5.27(D)^{0.66}. \qquad \text{(A-1)}$$

The actual d_c is then determined by

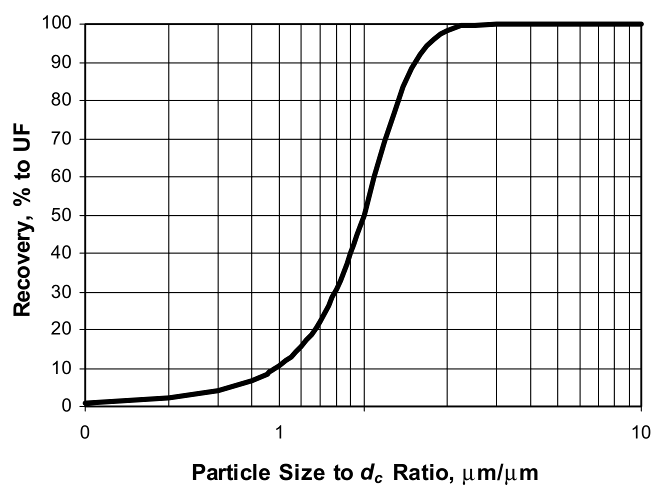

Fig. 4—Reduced-recovery curve for classification equipment.

$$\text{Actual } d_c = (\text{Base } d_c) \times \text{Correction Factors.} \quad \text{(A-2)}$$

Various corrections are applied for inlet concentration, pressure drop, particle specific gravity, and liquid viscosity as a function of the operating conditions and are detailed below. Corrections for inlet area, vortex-finder diameter, cyclone length, and cyclone cone angle are proprietary to each desander manufacturer.

The inlet slurry concentration will affect the hydrocyclone separation performance, as predicted by hindered settling theory. The hydrocyclone is effectively acting as a Stokes sedimentation classifier, with the gravity term increased greatly owing to centrifugal forces. Low concentrations of particles (< 1 vol%) will not greatly interact with each other during the separation process. As the concentration increases above 1 vol%, the population of particles will inhibit the migration of each other. In most desander applications, the feed concentration is far below 1 vol%; therefore, no correction is necessary. Exceptions to this rule are cyclones used in sand-jetting applications, where the feed concentration may be up to 10 to 20 vol% solids. Correction for inlet concentration is shown by

$$C_f = [(53-f)/53]^{-1.43}. \quad \text{(A-3)}$$

Particle specific gravity, relative to the liquid-carrier specific gravity, is inversely proportional as a correction to the base-cut size. As the particle density increases, relative to the fluid density, its mobility will increase when subjected to centrifugal force. The base correction of 1.0 is for a particle of 2.65 specific gravity, which is silica sand in water. The relationship between density and the correction factor is given by

$$C_\rho = [1.65/(\gamma_S - \gamma_L)]^{0.5}. \quad \text{(A-4)}$$

The pressure drop is defined as the inlet to overflow differential, and it is the only practical operating parameter that can be controlled to change the hydrocyclone performance. Rising pressure drop increases fluid and particle velocities. An increase in velocity is translated to higher centrifugal forces and recovery of smaller particles. This will result in an overall increase in solids separation efficiency. The correction factor for pressure drop is given by

$$C_{\Delta P} = 1.91(\Delta P)^{-0.281}. \quad \text{(A-5)}$$

The most important fluid parameter on separation size in a non-aqueous system is the liquid-phase viscosity. Because the desander is acting as a high-gravity Stokes settling device, the continuous-phase viscosity will greatly affect particle mobility. Most desander applications involve water as the liquid phase, which has a viscosity near 1.0 cp for most applications. The base viscosity correction of 1.0 is for water at 77°F. As the viscosity increases, by change in fluid type or change in temperature, the correction to the base d_c is given by

$$C_\mu = (\mu_L)^{0.5}. \quad \text{(A-6)}$$

Other parameters not detailed that will affect performance are listed below.

- Inlet Area: For a given pressure drop, decreasing the inlet area will increase the fluid velocities. Increase in fluid velocity translates to smaller particle-size recovery, thus having a directly proportional relationship on actual d_c.
- Vortex Finder: The vortex finder prevents the short circuit of fluid from the inlet to the overflow. The diameter of the vortex finder has a directly proportional relationship with the actual d_c, as it will affect residence time.
- Cylindrical Section: The cylindrical section is located between the inlet area and the conical section of the cyclone. The length of this section is typically equal to the nominal diameter. The length of this section directly affects residence time, and therefore has an inversely proportional relationship on actual d_c.
- Conical Section: The conical section typically has an included angle of 20° for larger cyclones and 6 to 12° for smaller cyclones. Smaller angles increase retention time and lengthen the acceleration zone, exhibiting an inverse relationship to actual d_c.

Once the actual d_c is known for the specific hydrocyclone, the separation efficiency can be obtained. The actual d_c and the inlet-feed particle-size distribution are used with the recovery curve to calculate the percent recovery for each particle size. The shape of a recovery curve for a typical hydrocyclone device is defined mathematically by the Lynch-Rao relationship[3]

$$Y(x) = [(e^{mx} - 1)/(e^{mx} + e^{m} - 2)] \times 100. \quad \text{(A-7)}$$

This equation can be used to calculate the recovery probability for each particle size in a range. In this equation, the actual d_c is used, along with each particle size and the slope. Extensive testing has found that the sharpness slope for sand in water is 4.0, which is used as the default. The recovery for each particle is then summed over the complete range to give a total recovery.

The calculated cut size is used to generate the separation size. Using the Lynch-Rao relationship, with a slope of 4.0, the separation size, d_s, is found to be equal to 1.97 times the cut size, d_c.

For general comparison information, in a produced water treatment application, a 0.5-in. desander will have a separation size of 5 to 10 µm, while a 30-in. desander will have a separation size of 100 µm. The practical limit for sand separation from water by a hydrocyclone is 10 µm.

SI Metric Conversion Factors

cp × 1.0*	E − 03	= Pa·s
ft³ × 2.831 685	E − 02	= m³
°F (°F − 32)/1.8		= °C
lbm × 4.535 924	E − 01	= kg
psi × 6.894 757	E + 00	= kPa

*Conversion factor is exact.

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