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Design of a Cyclonic Solids Jetting Device and Slurry Transport System for Production Systems

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Abstract

Production separators require increased sand handling capability as watercut grows due to field maturation and EOR use. A compact cyclonic jetting device allows on-line fluidization and removal of sand and solids from production vessels and tanks. The cyclonic transporter combines the jetting and evacuation functions into a single device for integration into new build or retrofit separation vessels. Using an optimized hydrocyclonic platform this technology converts jetting spray water into shielded vortex flow that affects sand in a circular zone with no disturbance of the oil-water interface. The area of influence for the device is a function of set height, spray flow, and spacing. The optimum placement of a single unit was determined at 10 cm (4") set height with 0.7 barg (10 psig) spray pressure. At 28 cm (11") sand bed depth in an atmospheric tank, the device has a circular area of influence of 1.1 m² (11.7 ft²).

Placing two units in parallel with overlap of their affected zones does reduce the egg-carton effect. Optimum operation, in terms of total sand removed, occurs when the units do not overlap. The discharge slurry concentration has a peak of up to 60 wt.% solids which follows an exponential decay profile as the sand is evacuated. The concentration decreases to negligible sand at 10-15 minutes of operation which validates the process jetting time. The design of the cyclonic jetting device allows on-line solids removal using less water than conventional spray jetting with no disturbance of the oil-water interface during operation and elimination of mechanical wear.

Production Separator Sand Jetting

All oil and gas wells produce sand. Even with exclusionary well design (i.e. completion controls or maximum sand free production rate), solids will report to the surface facilities through equipment failure, completion limitations, or a step-change reduction in well production, such as water breakthrough. In addition, an operating model of sand co-production is becoming more relevant as a method of improved oil recovery (Fadillah et al. 2004, Andrews et al. 2005, Rawlins 2013). Particle size and total concentration of these solid determine their net effect on production and the resulting operability of processing equipment. Facilities sand management is tasked with the goal of ensuring sustained hydrocarbon production when particulate solids are present in well fluids, while minimizing the impact of these produced solids on surface equipment (Rawlins 2013).

Produced solids may erode flow lines and chokes or interfere with flow assurance, but the first place of accumulation in large quantities is the production separator (Tronvoll et al. 2001, Chin 2007, McKay et al. 2008). The preferred location for facilities sand removal is prior to the choke using a wellhead desander (Rawlins 2013), however in cases where this technology is not currently employed the produced solids will collect in the primary separating vessel. Accumulated solids in gravity settling vessels results in loss of residence time, corrosion enhancement zones, increased sediment in oil, increased oil content in produced water, and degraded injectivity of produced water (Andrews et al. 2005).

Several approaches exist for removal of sand accumulated in production separators. The most basic is isolation of the vessel and manual removal of the sand (McKay et al. 2008, Rawlins 2013). This method has low capital expenditure but results in loss of production, with the significant resultant revenue loss. Various internal devices can be installed to provide on-line sand removal negating the need for equipment isolation. These devices include spray jets and pans (Chin 2008), conveyance sprays (Fantoft et al. 2004), vortex desanders (Jasmani et al. 2006), and eductors (Coffee 2008). All of these devices should be sized and designed to remove the sand accumulated in the separator water zone while minimizing interference with oil-water and gas-liquid disengagement action of the production vessel. The cyclonic solids jetting device, termed eJECT™ for eProcess Jetting Cyclonic Technology, is a state-of-the-art iteration of these internals to provide on-line sand removal for production separators and tanks.

Cyclonic Solids Jetting Device

The cyclonic solids jetting device was designed to use the flow pattern from a standard solid-liquid hydrocyclone to combine fluidization, evacuation, and hydrodynamic transport of particulate solids. Cyclonic technology is extremely versatile and can be used to clarify liquid or gas, concentrate slurries, classify solids, separate immiscible liquids, degas liquids, demist gases, wash solids, break agglomerates, and mix phases (Svarovsky 1984). The principle and basic design of the solid-liquid hydrocyclone was first patented in 1891 (U.S. 453,105). This device gained significant momentum in the mining industry after the Second World War, and became the standard for slurry classification in closed-circuit grinding by the 1960s. As a unit process they have the highest throughput-to-size ratio of any classification device.

Operating Principle.

A hydrocyclone is a static device (unlike a centrifuge) that generates centrifugal force through fluid pressure to create rotational fluid motion (Green and Perry 2008, Chapter 15). Figure 1 (left) shows a schematic diagram of a hydrocyclone of conventional design, along with the helical flow patterns produced. Fluids are introduced tangentially into a stationary cono-cylindrical body to produce the characteristic vortex flow. A pressure differential (P_i-P_o) drives the fluid throughput and the tangential inlet to a cylindrical section changes the incoming pipe axial flow to rotating flow. A vortex finder extends into the cylindrical section to form an annulus wherein an irrotational (free) vortex is formed. This vortex travels down the cylinder and into the cone section wherein the reduction in diameter increases the angular velocity of the fluids. A second rotational (forced) vortex exists at the center of the hydrocyclone and is located by the vortex finder. The free and forced vortices are coupled throughout the open length of the hydrocyclone.

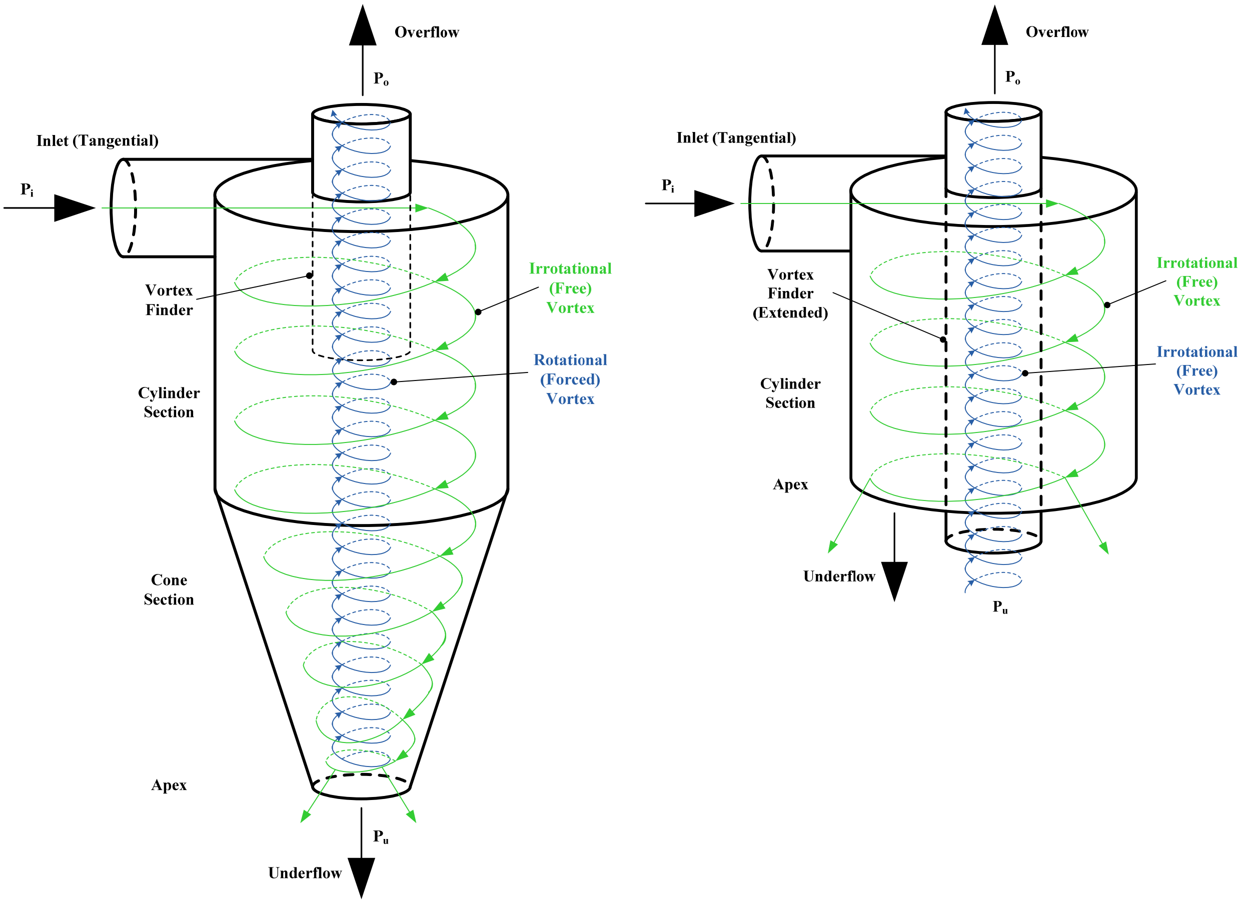

Figure 1 Schematic of standard hydrocyclone (left) and cyclonic jetting device (right) geometry and flow patterns.

Fluids discharge from both the overflow and the underflow orifices. The flow split (S) is the ratio of underflow volumetric flow rate (Q_u) divided by overflow volumetric flow rate (Q_o), and is governed by the two discharge orifice diameters (underflow is D_u and overflow is D_o) and the pressure differential ratio (PDR). Empirical correlations have the form $S=(D_u/D_o)^x$, where x ranges from 3.0-4.4 (Plitt 1976).

The standard hydrocyclone operates at $P_i>P_u=P_o$; with the overflow and underflow pressures atmospheric the PDR=1.0. At this PDR, and using standard Bradley geometry for D_u and D_o, the solids-free flow split averages 0.25. At atmospheric discharge 80% of the feed liquid reports to the overflow stream. A siphon can be induced onto the overflow piping to reduce the flow split to 0.10-0.15 thus pulling more liquids to the overflow (i.e. $P_i>P_u>P_o$ and PDR=1.1-1.2). The increase of liquid flow to the overflow stream imparts a higher suction force at the apex which entrains solids (US patent 3,923,210, 1975).

The right schematic in Figure 1 shows the flow pattern of a cyclonic jetting device. The geometric differences compared to the hydrocyclone are truncation of the cone and extension of the vortex finder. Due to extension of the vortex finder the two hydrocyclone vortexes are uncoupled. The outer irrotational vortex still exists and discharges from the apex. The discharging swirling flow imparts rotational motion below the device which induces an internal irrotational (free) vortex. The internal vortex is located by the vortex finder. A PDR in the range of 1.3-1.5 is maintained to increase the overflow rate. The external vortex exiting the cyclone body forms a discrete spray angle >90° that fluidizes the sand below and around the device. Within this spray cone the internal vortex picks up the sand in a swirling motion to report through the vortex finder and discharge with the overflow stream. A photograph of this action of the jetting device inside a clear pressure vessel is shown in Figure 2. The action of the external vortex to induce the internal vortex, fluidize the sand, and form a discrete volume within which the sand is removed is termed “shielded vortex sand removal”.

Figure 2 Shielded vortex sand removal demonstrated by cyclonic jetting device within a clear pressure vessel.

Installation in Production Separators.

The cyclonic jetting device removes accumulated sand settled in process tanks and vessels. In a small diameter (<1.5 m) diameter vertical vessel a single device placed in the centerline removes all settled solids. Larger diameter (>1.5 m) vertical vessels require multiple units at appropriate spacing or a cone bottom (false or pressure-retaining) to bring the sand to a smaller collection area.

Most production separators have horizontal orientation to accomplish sufficient residence time and surface area for gas-oil-water dissociation. Sand that has settled into the liquid zone of these horizontal pressure vessels is removed by multiple cyclonic jetting devices. Figure 3 shows the installation of this technology into horizontal vessels (end view). The top two graphics show the orientation for a small diameter (≤2.0 m) horizontal vessel. A single row of cyclonic jetting devices is located axially along the centerline of the vessel in the sand accumulation zone. The influenced area is an ellipse with the major axis aligned with the vessel axial length. The units are spaced so the center-to-center (c/c) distance provides minimal overlap between the corresponding ellipse major axes.

The bottom set of graphics in Figure 3 show installation of multiple cyclonic jetting devices in a large diameter (>2.0 m) diameter horizontal vessel. Two rows of devices are placed axially to straddle the vessel centerline in the sand accumulation zone. The units are oriented at a 15° angle away from the vertical centerline diameter. The influenced area of each device is an ellipse with the major axis aligned with the vessel transverse diameter. The units are spaced so the c/c distance provides minimal overlap between the corresponding ellipses at a point midway between the major and minor axes. The units are correspondingly staggered along the length of the vessel to cover the sand accumulation zone.

Each cyclonic jetting device requires a pipe connection for both spray and evacuation functions. The inlet and outlet piping for a single unit is nominal 2.5 cm (1”) diameter. Multiple units are aggregated internally within the operating vessel with a maximum of four units per section. The inlet/outlet piping for a four unit aggregate is a nominal 5.0 cm (2”) diameter. The operating pressure vessel will require separate wall penetrations of the corresponding size for the inlet and outlet piping. In large horizontal vessels with multiple operating zones, each zone will require a single inlet and outlet piping connection.

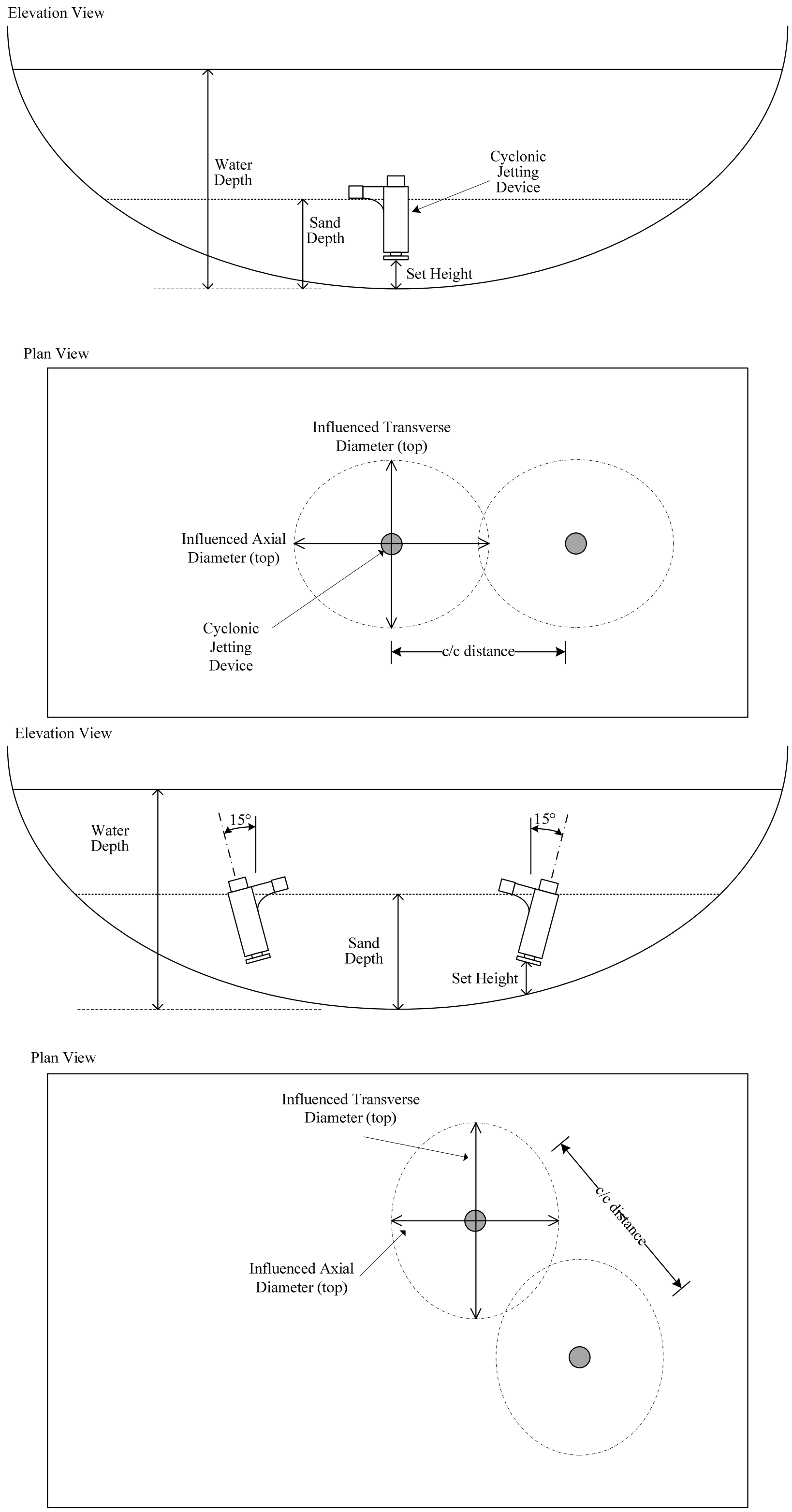

Figure 3 Installation of cyclonic jetting device in horizontal vessels as single row (top) for small diameter (≤2.0 m) vessels and double row (bottom) for large diameter (>2.0 m) vessels.

The inlet (spray) piping header requires either a pressure control valve (PCV) linked to provide solids-free water at the design pressure above the vessel operating pressure, or a flow control valve (FCV) linked to provide the required spray flow for the corresponding number of cyclonic jetting devices. The outlet (slurry) piping header requires a similar set up with either a PCV or FCV used to regulate the flow of slurry discharging from the production vessel. The slurry line control valve can be installed after a desanding hydrocyclone to minimize wear of the valve components, or a suitable slurry valve/choke can be set directly on the slurry discharge line. Both headers require pressure instrumentation (gauge and/or transmitter) for monitoring and control.

Atmospheric Tanks.

For production tanks or vessels operating at or near atmospheric pressure an eductor can be used on the slurry discharge line to assist in the sand evacuation function. An eductor provides the motive differential pressure to remove the accumulated sand in the vessel through the cyclonic jetting device. The eductor should be sized to provide suitable suction flow for the corresponding number of cyclonic jetting device units. Discharge from the eductor (i.e. motive fluid mixed with evacuated slurry) should be sized to discharge the diluted slurry at a flow rate suitable for delivery to the downstream treatment process. Installation, placement, and operation of the cyclonic jetting devices is the same as for a pressurized vessel, however the diluted slurry discharge line after the eductor may be larger due to the increased liquid from the motive flow.

Variables Affecting Sand Removal.

The total affected area is considered the key factor in measuring cyclonic jetting device performance as it indicates how much sand is removed and how much of the vessel is cleaned of the accumulated sand. The affected area, measured as the top area of the influenced ellipse, is a function of the set height, fluidizing and discharge flow rates (or pressure), total sand depth, installation angle, and particulate properties such as density and particle size distribution.

Figure 4 shows the effect of cyclonic jetting device set height on average affected area diameter. The set height is shown previously in Figure 2 as the vertical distance from the tank wall and the bottom edge of the device. The average affected area diameter is the mean value of the major and minor axes of the influenced ellipse. The data in Figure 4 is shown for a single unit at vertical orientation with 28 cm (11”) sand depth. The test sand had a 2.65 specific gravity and 420 micron average particle size. Discharge flow was generated through an eductor from an atmospheric horizontal vessel and was held constant for all tests. The fluidizing pressure is the differential required above the operating pressure of the unit process vessel. At these conditions the 10 cm (4 inch) set height produced a higher average affected diameter compared to 5 cm (2 inch) and 15 cm (6 inch) settings. The peak value was 115 cm (45 inch) which can be achieved at 110 kPa (15 psi) fluidizing flow pressure.

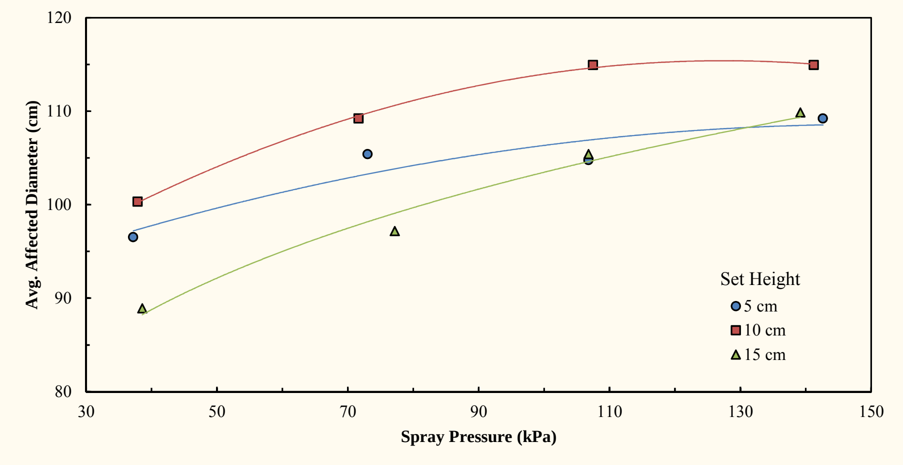

Figure 4 Effect of spray pressure on average affected diameter for a single cyclonic jetting device unit at three set heights. Test conditions include vertical orientation in an atmospheric horizontal vessel (2.5 m ID), 28 cm total sand depth, sand with 2.65 specific gravity and 420 micron average particle size, and eductor generated discharge flow.

Figure 5 shows the effect of total accumulated sand depth on average affected diameter. The total accumulated sand depth is shown previously in Figure 2 and the average affected diameter is as previously described. Sand depth was varied from 2.5 cm (1 inch) to 28 cm (11”). The single unit set height was 10 cm (4 inch) at vertical orientation in an atmospheric horizontal vessel. Fluidizing pressure was 110 kPa (15 psi) and the same test sand was used. Total affected area increases with sand depth in a polynomic relationship. An average affected diameter of 1.0 m (39 inch) is achieved at 20 cm (8 inch) sand depth, while 2.0 m (78 inch) can be influenced in 58 cm (23 inch) accumulated sand. The shape of the affected volume will be an ellipse at the top and forms a truncated cone of decreasing diameter down to the vessel wall. In general the diameter of the sand free area is one-half the top average affected diameter.

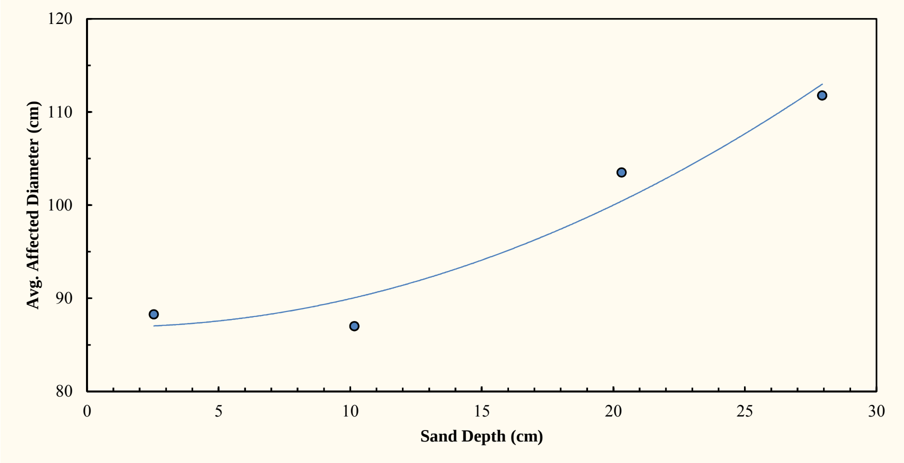

Figure 5 Effect of accumulated sand depth on average affected diameter for a single cyclonic jetting device unit at 10 cm (4 inch) set height and 110 kPa (15 psi) fluidizing pressure. Test conditions include vertical orientation in an atmospheric horizontal vessel (2.5 m ID), sand with 2.65 specific gravity and 420 micron average particle size, and eductor generated discharge flow.

Slurry Discharge Concentration.

The solids concentration of the slurry discharged by the cyclonic jetting device is a function of the sand depth and elapsed time of slurry discharge. Figure 6 shows the slurry concentration as discharged from a horizontal process vessel with 28 cm (11 inch) sand depth (sand properties as previously described). The slurry concentration was measured by rapid grab sampling. The maximum slurry concentration occurred initially as 58 weight percent and decayed exponentially. At three minutes the sand concentration decreased to 10 weight percent and essentially clear water (<1 weight % solids) was achieved by 7 minutes. These values can provide a guideline for initial design of the slurry discharge time (i.e. operating time for the jetting system). A more accurate estimation of operating time should be determined in each installation, but should average 10-15 minutes if the jetting system is operated per schedule.

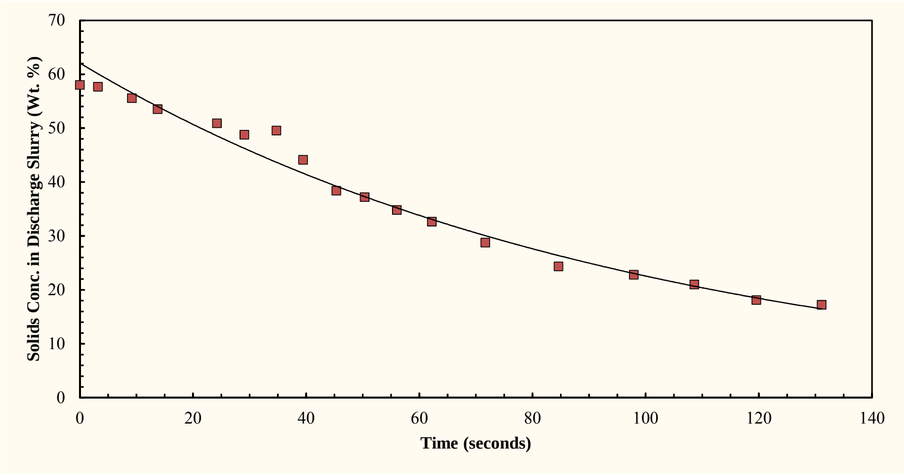

Figure 6 Concentration of solids in slurry discharging from cyclonic jetting device. The operating basis is a single unit at vertical orientation in a horizontal vessel operating in fresh water with sand (2.65 s.g. and 420 microns average particle size).

The slurry discharge flow rate is primarily a function of differential pressure between the operating vessel and the delivery point. Figure 7 shows the discharge flow rate as a function of differential pressure. Most systems are sized to operate between 40-60 kPa differential which provides a slurry discharge rate of 6-7 m^3/hr. The fluidization flow is sized to match the discharge flow to prevent changes in operating liquid level of the production separator. This discharge differential pressure must be controlled to prevent drawdown or buildup of the liquid level in the vessel. The flow rate in Figure 7 is for a single unit operation. Multiple units aggregated together will have an additive effect on flow rate. The maximum aggregate is four operating unit which will have a slurry discharge flow of 20-25 m^3/hr. This is the volume rate of slurry to be treated by downstream sand management system.

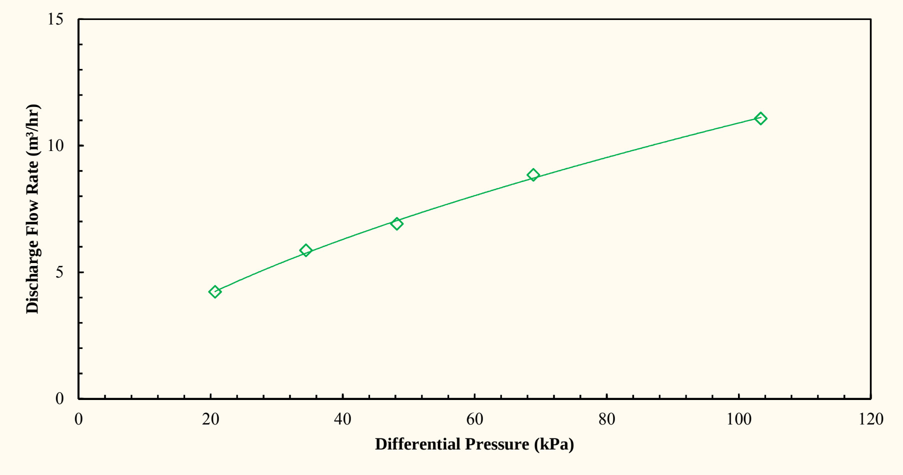

Figure 7 Discharge flow rate as a function of differential pressure between vessel operation and delivery point.

Slurry Transportation

Sand collected by the cyclonic jetting device is mixed with process water to form a slurry. This slurry is discharged from the production vessel in a controlled manner through delivery piping. The slurry transportation piping is designed to minimize erosive wear while preventing saltation blockage from settled particles. Erosion rate defines the upper limit of the slurry velocity while settling of particles defines the lower limit of slurry transport velocity.

Erosion Velocity.

The American Petroleum Institute Recommended Practice 14 E (API RP 14E) is often used to calculate the velocity below which a tolerable amount of erosion occurs. While this method is simple to apply, it has been noted to have several limitations. A detailed analysis of this method and presentation of a more comprehensive method is offered by McLaury and Shirazi (2008). The slurry discharging from the cyclonic jetting device is considered single phase flow even though it contains sand suspended in water. Using the values of c=100 and gas/liquid mixture density (ρ_m) of 1070 kg/m³ (66.8 lb/ft³) for water with 10 wt.% NaCl, the API guideline recommends a maximum velocity of 12.2 ft/s (3.7 m/s). The McLaury-Shirazi model for single-phase flow predicts a much larger value at >100 ft/s (>30 m/s) as estimated from Figures 6-8 in that reference and using zero superficial gas velocity. Using the more conservative velocity along with the discharge values from a single cyclonic jetting device yields a transport pipe with 1 inch (2.5 cm) nominal diameter. Two and four units aggregated can use a 1.5" (3.8 cm) and 2" (5 cm) nominal diameter pipe, respectively.

Horizontal and Vertical Transport Velocity.

Slurry transportation in piping is a complex subject and several treatises are available for an in-depth analysis of the subject (Govier and Aziz 1977, Wilson et al. 2006). Perry's (Green and Perry 2008 Chapter 6) provides a summary of this work and recommendations for calculating the minimum transport velocity for settling slurries. In horizontal piping the minimum transport velocity (V_{MT}) is given by the Durand equation. This equation is shown as follows in modified form with the Wasp correction (Poirier 2000) as the last term in parenthesis.

$$V_{MT} = F_L[2gD(s-1)]^{0.5}\left(d_p/D\right)^{1/6}$$

In this equation F_L is an empirical constant influenced by particle size and concentration (Figure 6-33 in Green and Perry 2008), g is acceleration of gravity, D is pipe diameter, s is ratio of solid to liquid density (ρ_s/ρ_l), and d_p is average particle size. Using 1.5 for F_L, 100 micron silica sand in 10 wt.% salinity water, and a 2 inch schedule 40 pipe yielded a minimum horizontal transport velocity of 0.65 m/s (2.1 ft/s). This equation doesn't factor fluid viscosity or full particle size distribution, but is an accepted estimate for the horizontal transport velocity. For vertical upflow in pipes the minimum transport velocity is taken as twice the settling velocity (Green and Perry 2008). Using this correlation and Stokes' law for particles settling in a viscous fluid yields a maximum lifted particle size of ~610 microns at the same pipe velocity as the V_{MT}. At the nominal cyclonic jetting device outlet flow in a 2" schedule 40 pipe the lifted particle size increases to ~1440 microns (with the two times factor), which should be large enough to carry most particles that are present in production separators.

From these calculations, pipe velocity boundary conditions are 0.65-3.7 m/s (2.1-12.2 ft/s), with preference towards the higher velocity. As this slurry discharge piping does not see continuous use, the upper limit velocity is very conservative. The jetting system would only be used 1-2 hours per day, thus total erosion volume will be reduced further by a significant amount. Two inch nominal carbon steel or duplex stainless steel piping is sufficient for slurry transport duty, however the wall thickness must be appropriate for the full system pressure design rating.

Piping Design and Operation.

The American Society of Mechanical Engineers (ASME) specification B31.11 provides slurry transportation piping system design codes that should be followed for basic construction procedures. All piping components should be designed to prevent blockage or settling of solids. Horizontal runs should have sloped construction (1:100 downward orientation). Elbows should be long radius style at minimum, with 5R/10R providing better transition. Elbows should not be placed closer than 10 pipe diameters. Upward runs of pipe are acceptable as long as minimum vertical transport velocity is maintained. Pipe transitions should be eccentric reducers with the flat section at the pipe bottom. Valves should be full port with gate or rotating disc style preferred for long-life. Sample ports should be on the side of vertical piping runs only, as horizontal ports may fill up with large particles or plug.

Concentrated slurry should never be introduced into empty piping or process equipment. All piping and process equipment should be pre-filled with liquid. This will dilute the introduced slurry and minimize slugs and associated plugging. The preference is to introduce the concentrated slurry into moving water. In this manner the discharge header which will receive the cyclone jetting device discharge slurry should be prefilled and at the desired operating velocity with solids-free water. The introduced slurry will be diluted and carried away immediately without having a chance to accrete. This pre-fill water can be shut off once the discharge slurry is at the desired flow rate, however once the cyclonic jetting device has completed its full cycle the header piping should be post-flushed with solids-free water to ensure all particles are swept from the system. Proper operation with pre-fill and post-flush will ensure no plugging occurs by the discharged slurry.

Slurry Dewatering and Disposal

Sand is removed from vessels and tanks through the cyclonic jetting device and transported away from the process equipment through a properly designed piping system. The delivery point of this slurry depends on the required disposal route for the solids. Onshore plants may delivery the slurry to a holding pond or disposal site. Offshore facilities may have the option to add the jetted sand to an existing drill cuttings disposal bin or caisson. These options simplify solids disposal using existing processes. In most cases an existing solids disposal route does not exist and a dedicate scheme must be put in place. Solids transport and disposal is one of the five steps in a properly designed facilities sand management system (Rawlins and Wang 2000).

The slurry carried by the piping header from the cyclonic jetting device system will have associated process liquids. These liquids are both a byproduct of the operation of the device and necessary to carry the solids through the piping transport. In most cases these liquids represent >90% of the volume of the discharge slurry. Removal of these liquids from the solids and returning the liquids back to the process system is termed “dewatering”. The resulting solid concentrate can have as low as 10 wt.% liquid which is similar to wet beach sand that can be stacked.

The dewatering process should be done as compact and simple as possible. Most systems involve a one or two step process, using hydrocyclones to remove the bulk water as the first step and filter-bins or filter-bags to remove the remaining water as the second step. The total volume of slurry and the frequency of dewatering will determine the number of steps. Slurry discharged from most production separator vessels through a cyclonic jetting device will require a two-step process. The volume discharge from an aggregate of four cyclonic jetting devices is 20-25 m^3. This volume of slurry can be treated by a single 6 inch (150 mm) diameter hydrocyclone operating at 103-138 kPa (15-20 psi) differential pressure. The hydrocyclone will remove 85-90% of the liquid volume immediately for capture and return to the process or drain system. The concentrated slurry, at up to 75% solids by weight, drops into a collection hopper for further dewatering.

The collection hopper can be designed as a filter-bin or filter-bag, depending on the containment requirements. Both systems use a similar approach; however the bin provides containment of vapors should any hazardous volatiles need to be isolated. A filter-bag comprises of a 1.0 m^3 cubic bulk solids bag designed to pass liquids and contain the sand and a support frame. This bag is made of woven oleophobic material with a multi-layer mesh for maximum solids containment with rapid-weep of the liquids. The liquids are normally drained by gravity however the bags can withstand a small differential of 35 kPa (5 psi) to increase filtrate rate. The filtrate liquids are collected in a skid pan or base for return to the process or drain system. The filter-bin works on the same principle; however the filter-bag is contained within a vapor-recovery bin to prevent any egress to atmosphere. Both the bin and bag are reusable once emptied. In addition the bin or bag both serve as the transport containment device to bring the dewatered solids to the disposal point. Solids can be removed by a vacuum system or the entire bin/bag sent to collection hopper or landfill for emptying.

Figure 8 shows a comprehensive dewatering and transport purpose-built for a deepwater production floating facility. This system receives slurry from a bank of wellhead desanders during periodic accumulator discharge. This station is designed to treat 10 tons per day of sand. The photos show (top left) bank of hydrocyclones for bulk dewatering, (top right) placement of oleophobic rapid-weep filter bag into holding frame, (bottom left) gravity drain of fluids through filter-bag for final dewatering step, and (bottom right) lift of filled filter-bag for disposal to hopper and eventual landfill.

Figure 9 shows a dewatering and transport station located on a shallow water fixed-leg facility in the Gulf of Mexico (Rawlins and Wang 2000). The dewatering and transport station receives slurry from separated produced oil and produced water desanders. The photos show (left) dewatering bin for vapor containment and (right) liquid collection and pumping station. All vapors and liquids are captured in this system for return to production.

Figure 8 Dewatering and transport station receiving slurry from wellhead desanders on deepwater floating facility. Photos show (top left) bank of hydrocyclones for bulk dewatering, (top right) placement of oleophobic rapid-weep filter bag into holding frame, (bottom left) gravity drain of fluids through filter-bag for final dewatering step, and (bottom right) lift of filled filter-bag for disposal to hopper and eventual landfill.

Figure 9 Dewatering and transport station receiving slurry from produced oil and water desanders on fixed leg facility. Photos show (left) dewatering bin for vapor containment and (right) liquid collection and pumping station.

System Design

Figure 10 provides a flow schematic of a cyclonic jetting, slurry transport, and dewatering system for use in removal of solids from a production separator. Several variations of the flow scheme are applicable pending the production vessel operating pressure, level of automation, site footprint availability, and method of solids disposal. This scheme is presented for a pressurized production vessel operating at ≥345 kPa (≥50 psi).

A bank of four (4) operating cyclonic jetting devices is shown in a single-row. A larger vessel may require multiple rows or multiple banks, however at most four units will be operating at a time. Using the pre-fill line the discharge header, hydrocyclone desander, and accumulator are filled with fluid and brought to a nominal operating velocity in the header and pressure drop across the desander. The discharge header for the cyclonic jetting devices is opened to provide slurry to the desander inlet line. The spray header is then opened to provide fluidizing water based on flow-control (FC) to the cyclonic jetting devices. The units are allowed to run for the desired time, and then the spray header and discharge header are closed. The post-flush line is allowed to run until all solids are swept through the desander inlet line.

During operation of the cyclonic jetting devices slurry is delivered to the hydrocyclone desander where the solids are separated and the cleaned liquid is returned to the process system. The amount of flow from the cyclonic jetting devices and through the desander is maintained by differential pressure control (DPC) across the desander. The separated solids are collected into the accumulator. The accumulator is discharged based on level switch (LS) or time basis. The slurry concentrate drops into the filter-bag with frame where the final fluids are removed by gravity to the drain system.

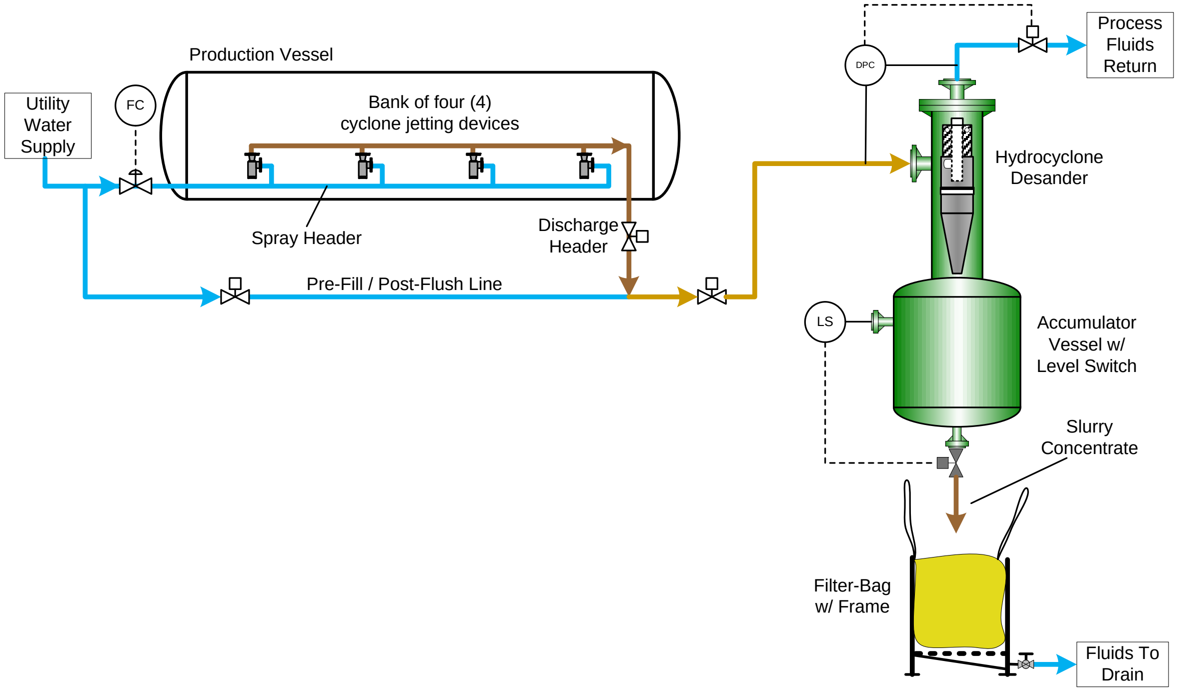

Figure 10 Process schematic of cyclonic jetting, slurry transport, and dewatering system for use in removal of solids from a production separator.

The process in Figure 10 employs the five-step design methodology for facilities sand management that has been in use for more than 20 years with well-established technology (Rawlins and Wang 2000). Sand separation, collection, dewatering, and transport are accomplished by a combination of gravity, cyclonic, and filtration processes. The cyclonic jetting device allows on-line solids removal using less water than conventional spray jetting with no disturbance of the oil-water interface during operation and elimination of mechanical wear. Removal of the sand from the production separator improves facilities uptime and improves product quality. As watercut grows from field maturation or EOR use the cleaned separator can be pushed to a higher production limit to handle the increased water and associated solids.

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