Operating Limits of the Desanding Hydrocyclone for Produced Water Treatment

C.H. Rawlins[1*]
[1]eProcess Technologies, Butte, MT, USA
*Corresponding author; email: hrawlins@eprocess-tech.com

Abstract

The desanding hydrocyclone, also termed a desander, is a cyclonic-based unit process technology for removal of particulate solids from produced water. A desander is the first step in produced water treatment to remove sand before oil-in-water separation and disposal. With the smallest footprint and weight of any separation technology, combined with no moving parts, insensitivity to motion, and particle removal to 10 microns – the desander is ideally suited for offshore facilities. Knowing the operating limits for pressure drop, turndown, fluid properties, particle size, and solids concentration, are fundamental to optimize the operation of a desander. The guidelines provided for process and mechanical requirements are applicable in new or retrofit systems.

Introduction

All oil and gas wells produce sand; therefore, all surface facilities must be capable of handling solids in production. Producing limits or completion systems are common methods to exclude solid particles from well flow. When these methods are not economically or technically feasible – or when they fail – the surface facilities (subsea, offshore, or onshore) address the produced sand. Surface sand handling, termed Facilities Sand Management (FSM), follows a five-step methodology – Separate, Collect, Clean, Dewater, and Transport (Rawlins 2022). Integrating each step into the facility design will maintain hydrocarbon production and prevent flow interruption or equipment shutdown (Rawlins and Wang 2001). The first step identifies the four-nodes of separation as depicted in Fig. 1. These nodes include sand removal at the wellhead, wellstream, separator, or produced water locations (Rawlins 2017).

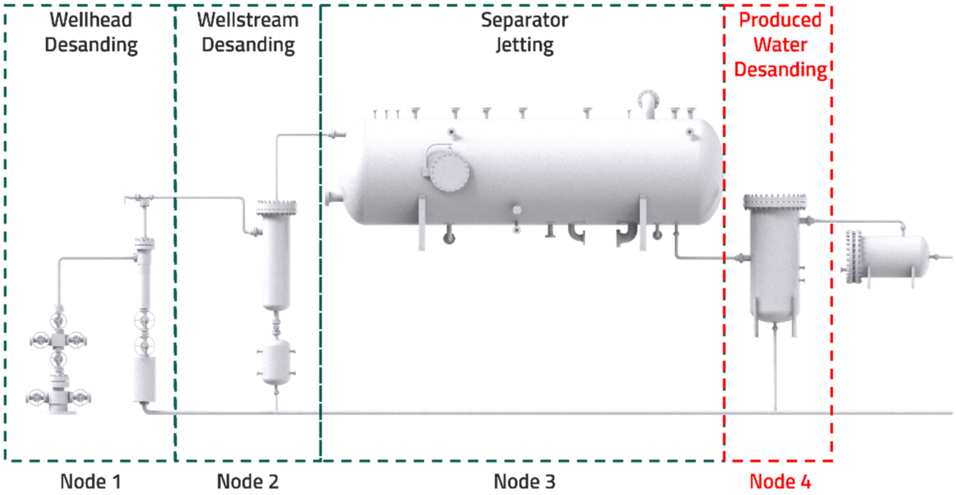

Fig. 1—The four nodes of separation are locations to remove sand from process flow: Wellhead (Node 1), wellstream manifold (Node 2), vessel jetting (Node 3), or produced water stream (Node 4).

Where it is not feasible to remove sand at the source (Node 1, wellhead) the sand will flow to the production manifold (Node 2, wellstream) then to the facilities (Node 3, separator). Coarse sand particles settle by gravity in the production separator requiring jetting or physical removal. Sand particles at <150 microns exit the production separator with the produced water stream (Rawlins 2016). Sand particles in the produced water stream reduce the efficiency or cause damage to oil removal equipment (e.g., deoiler, flotation, or media filtration), damage injection pumping systems, or plug in disposal wells. Removing sand particles from the produced water stream as it exits the production separator or free water knock out (FWKO) will protect these downstream processes and maintain disposal system uptime.

For more than thirty years, a common solids-removal unit process used at Node 4 is the desanding hydrocyclone (Ditria and Hoyack 1994, Hodson et al. 1994, Lohne 1994). This device removes dispersed solids to protect all downstream produced water oil removal equipment and disposal processes. The desander is a subset of the cyclonic unit process. The most attractive feature of cyclones to the upstream oil & gas industry is the equipment size combined with excellent separation efficiency. A cyclone has the highest throughput-to-size ratio of any partitioning device. Thus, for a given flowrate, a cyclone will have the smallest footprint and weight of any separating technology, making it attractive for deployment in offshore, subsea, and remote facilities.

Standard versus Flooded-Core Hydrocyclones (Desanders)

A cyclone using liquid flow as the transport phase is a hydrocyclone (i.e., hydrocyclone is a contraction of hydraulic cyclone). The hydrocyclone finds predominant use and research in the mineral processing industry. The desanding hydrocyclone – simply termed a "desander" – is a derivative technology from these mining hydrocyclones. Adapting a hydrocyclone into a desander took place in the 1950s for use in protecting agriculture spray nozzles from fresh-water well sand production. These original desanders had large diameter bodies (>50 cm) and operated at low inlet pressure (<20 psig) with low sand concentration (<10 ppm). Their further adaptation for the oil & gas industry started in 1964 with Saudi Aramco (Rawlins 2017) for produced water well sand removal.

The primary difference between a hydrocyclone and a desander is that the latter operates with an enclosed underflow chamber, as shown in Fig. 2. Both devices have continuous inlet and overflow streams, but the desander has a batch underflow. Whereas the mining hydrocyclone treats fluids with high solids content (30-50 wt.%), the enclosed underflow on a desander limits the unit to extremely low solid concentration (<<1 wt.%). Enclosing the underflow also prevents air-core formation in the center of the vortex. The air core – present in mining hydrocyclones – is a key feature in their modeling and operation but is absent in a desander. The desander is therefore properly termed a "flooded-core hydrocyclone."

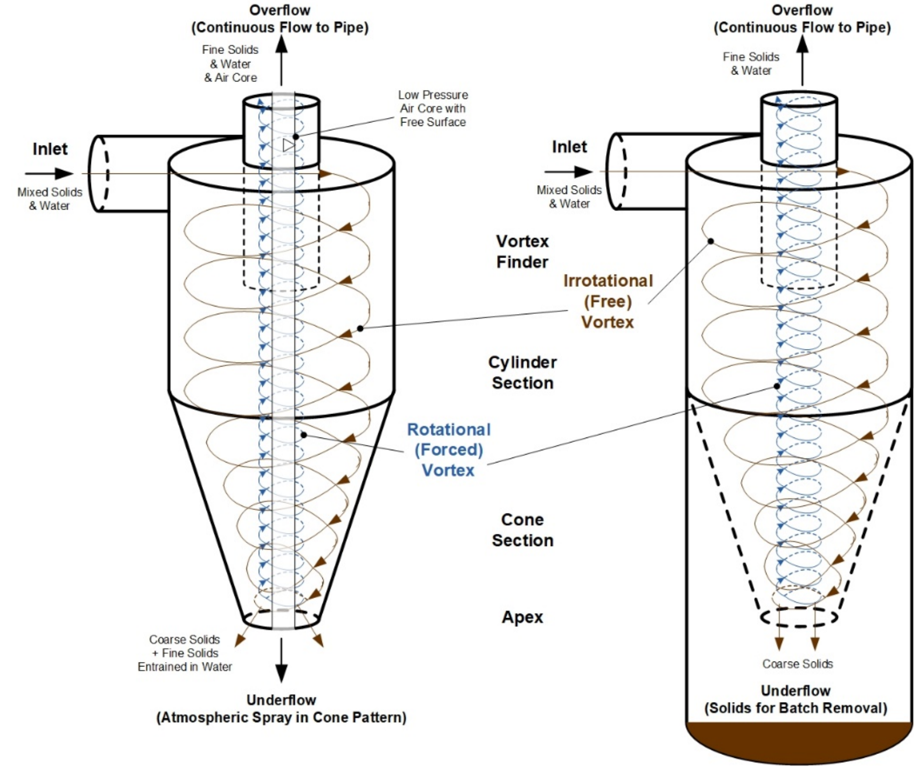

Fig. 2—Comparison of hydrocyclone (left) and desander (right) flow patterns. The hydrocyclone has a continuous open underflow allowing formation of an air-core through the entire height of the unit. In the desander, the enclosed underflow prohibits air-core formation while collecting the solids for batch discharge.

Previous Work on Flooded-Core Hydrocyclones

Operating a mining hydrocyclone with open underflow results in a central air-core along the full-length of the cyclonic body (from the apex to the vortex finder) that has a slight negative pressure. The body of scientific literature on hydrocyclone operation and modeling pertains to open underflow designs including this air-core (Plitt 1984, Svarovsky 1984). Few studies are published on flooded-core, solid-liquid hydrocyclones; and none of these studies were conducted with a static accumulation chamber (Knowles et al. 1973, Witbeck and Woods 1984, Quian et al. 1989). Rawlins (2018) published the first research on a flooded-core static hydrocyclone. That work focused on the flow of solids through the cyclone body and into the accumulation chamber. The goal was to determine the limiting flux-rate through the apex before concentration choking. The operating curves, based on fluid-particle properties and cyclone diameter, permit calculation of the inlet concentration limit for operating a desander, along with the further design of an apex flux balance (AFB) configuration to overcome this limit.

Desander Operating Characteristics

The desander, like a standard hydrocyclone, is a simple device with no moving parts – however both exhibit a complex fluid flow pattern. The flow through the desander imparts energy into the liquid and solids. The cylinder-cone geometry acting on the flow stream creates a coupled free-forced vortex that imparts three-velocities acting together on the dispersed sand particle. The primary velocity is tangential (V_t) generated by the rotating vortex flow. The centrifugal force (F_c) – normalized in comparison with gravity "g-force" – is calculated from the tangential velocity. This force generates acceleration up to two thousand times standard gravitational acceleration allowing capture of small particles thus the high separation efficiency. The axial velocity (V_a <10% V_t) generated by the bulk fluid moving along the axis of the desander to the water outlet (overflow), pulls particles not captured by V_t into the overflow generating a buoyant force (F_b). The radial velocity (V_r <10% V_a), generated by liquid moving to the centerline of the desander as it displaces solid particles sweeping to the desander wall, imparts a drag force (F_d). The net result of the three forces is to pull small/light particles to the overflow while rejecting large/heavy particles to the underflow. Figure 3 shows an illustration of the fluid patterns, velocities, and net forces on a solid particle in the liquid flow.

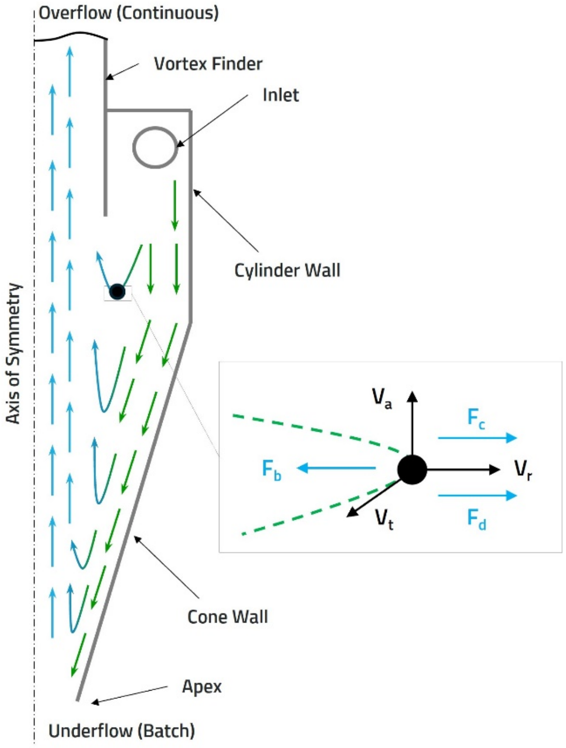

Fig. 3—Illustration of fluid flow patterns (green lines show flow toward the underflow, while blue lines show flow toward the overflow). The three velocity vectors (tangential V_t, axial V_a, and radial V_r) generate three forces (centrifugal F_c, buoyant F_b, and drag F_d) on the particle which balance to determine the size of particle that is captured to the underflow (i.e., separation size) while smaller particles are pulled towards and report to the overflow.

Recovery Curve

The separating forces acting on the particles within a desander generate an efficiency curve of characteristic shape shown in Fig. 4. The desander does not separate at one specific particle size but exhibits varying recovery depending on particle size. Technically cyclone-based equipment separates based on particle weight – which is a combination of particle size and density. If all the incoming particles have the same density, such as produced sand in a produced water stream, then the efficiency curve applies to particle size only. The desander efficiency curve – also called a recovery curve – plots the particle capture percentage based on particle size. A captured particle travels from the inlet to the underflow chamber. Large (heavy) particles separate to the underflow while small (light) particles report to the overflow. The split between particles separated or lost is not a fixed point – partly due to the crowded particles interacting with each other – thus the desander efficiency curve shows an "S" shape.

In Fig. 4 the x-axis shows particle size normalized by comparing actual particle size with the 50% capture size (termed D_{50} or Cut Size). The Cut Size is a characteristic number in which to compare differing size and design cyclones. A particle size of 2.0 on this curve is twice the size of the D_{50}. The y-axis shows the percentage of that particle size captured. The Cut Size is the 50% value – with half the particles captured to the underflow and half the particles passing to the overflow. The Separation Size for a desander is the D_{98} value (i.e., 98% capture size) which is ~twice the value of the D_{50} for sand in water. An equation based on D_{50} and slope (α) define the shape of this curve (Lynch and Rao 1975).

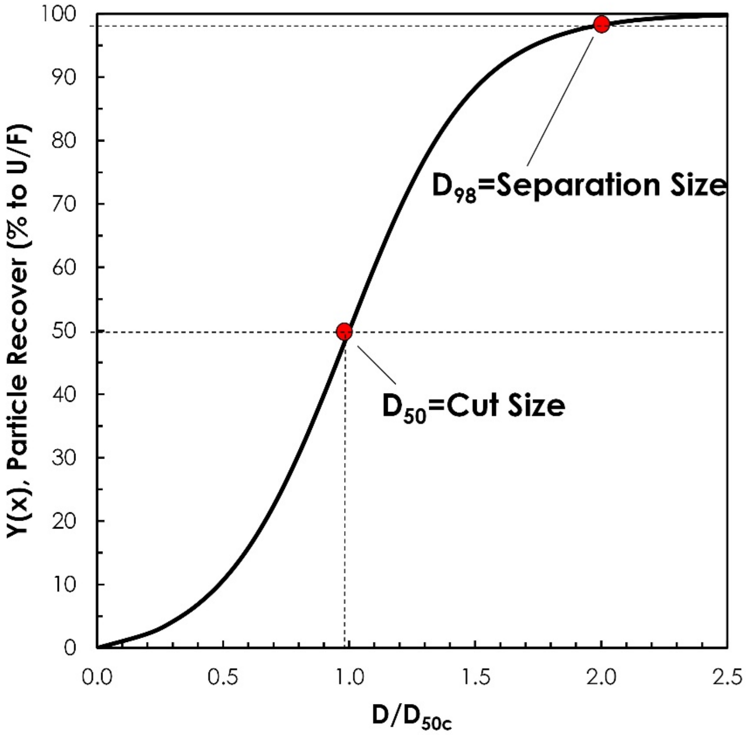

Fig. 4—Desander efficiency curve (generic) showing the Cut Size (D_{50}) and Separation Size (D_{98}).

Classification (Separation) Performance and Limits

The desander efficiency curve shown in Fig. 4 is independent of particle size distribution. The location (D_{50}) and slope (α) of the curve depends on the cyclone geometry, operating pressure drop, fluid density and viscosity, and particle density and shape. Applying the recovery curve percentages to the inlet particle size distribution (i.e., use spreadsheet mass balance) permits calculation of overall solids recovery and separation efficiency. Applying the percent recovery of each particle size on the inlet distribution provides the mass of particles captured at each size. Adding the individual masses together provides the overall mass recovery of solids to the underflow. If the inlet stream contains all large/heavy particles the recovery performance will be high, and if the inlet particles are small/light then the separation efficiency will be low.

There are several published models for estimating cyclone separation size (Lynch and Rao 1975, Plitt 1976, Svarovsky 1984). All use fluid and particle properties (i.e., liquid-solid density differential and liquid viscosity), pressure drop (provides separation energy), and cyclone geometry (e.g., diameter, length, orifice sizes, and cone angle). Typically, fluid and particle properties are fixed within a given process system, and the two variables available to optimize performance are desander geometry and pressure drop. The cyclone geometry is picked to provide sufficient separation size with available pressure drop in balance with particle concentration and upper particle size. Separation size is inversely proportional to desander diameter, and desander diameter is directly proportional to particle concentration and upper particle size. A 38 mm diameter desander can provide down to 10 micron separation but may plug if concentration exceeds 1500 ppm or upper particle size exceeds 1000 microns. However, a 75 mm diameter desander will separate at 20 microns and can treat up to 2500 ppm sand concentration and particles up to 2500 microns.

Flow Rate vs. Pressure Drop and Limits

Each desander has a set geometry and no moving parts. With this design it acts like a fixed orifice with pressure drop proportional to flow rate. For liquid only flow through the desander the hydraulic response is given by the relationship $\Delta P=(Q/k)^2$. The pressure drop (ΔP) from inlet to overflow is given by the square of the flow rate (Q) divided by a geometric constant (k). The k-factor is a constant for a cyclone of specific size and geometry and determined experimentally. All cyclones have a minimum pressure drop required to form the vortex flow pattern – and below that minimum the desander does not provide the characteristic separation performance shown in Fig. 4. For most desanders with liquid only flow, the minimum pressure drop is 35 kPa (5 psi). As the pressure drop increases above the minimum, the tangential velocity increases to capture more particles (i.e., the desander has better separation efficiency). A recommended operating range to balance turndown and erosional wear on the components is 172-345 kPa (25-50 psi). Higher than 345 kPa (50 psi) pressure drop will improve the separation efficiency, however the increased recovery also comes with increased wear on the components and increased energy consumption.

Turndown Performance

Combining the recovery curve, classification performance, and hydraulic capacity range together yields the desander turndown performance curve. This type of curve shows the desander operating range – combining flow rate, pressure drop, and separation size. An example is shown in Fig. 5 for two different diameter desanders commonly used in produced water treatment – 38 mm (1.5") and 75 mm (3.0"). The internal diameter of the upper cylinder section defines a desander diameter. This curve shows the turndown performance of a single desander liner only – whereas process systems normally consist of multiple liners packaged into a vessel.

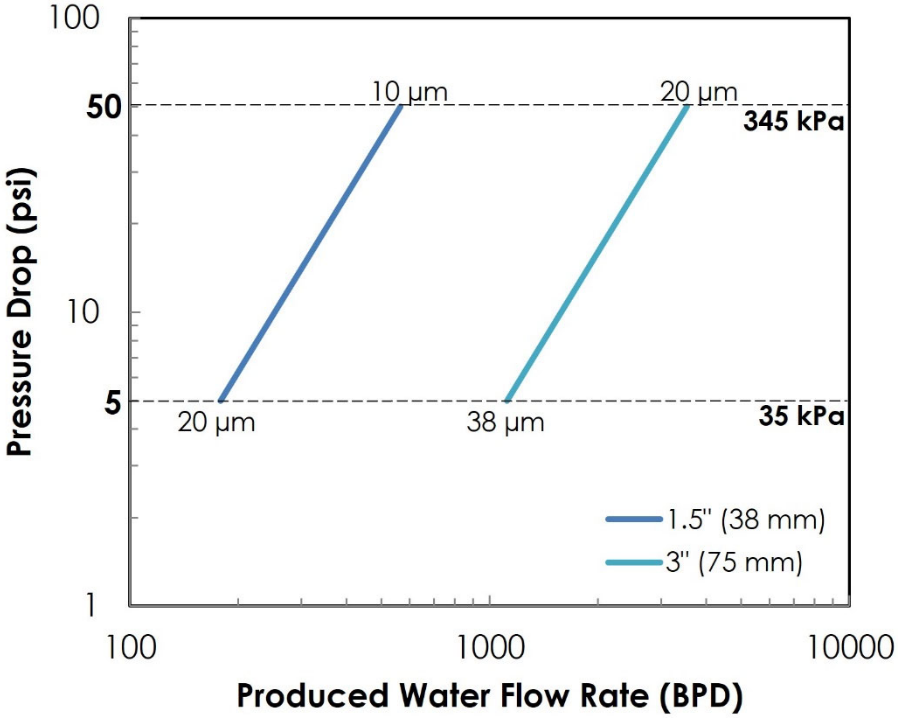

Fig. 5—Operating range for 38 mm (1.5") and 75 mm (3.0") diameter desanders showing both pressure-drop range (5-50 psi) and separation size (D_{98}) at each endpoint.

Figure 5 shows water flow rate on the x-axis versus pressure drop on the y-axis (i.e., from desander inlet to overflow). The plot shows two curves – one for each desander diameter. Each desander liner operates from 35-345 kPa (5-50 psi) pressure drop. The 38 mm (1.5") desander operates from 180-570 BPD and the 75 mm (3.0") desander operates from 1120-3530 BPD, respectively. At the minimum pressure drop (i.e., minimum V_t thus minimal separating forces) each desander has a separation size (D_{98}) of 20 and 38 microns, respectively. As the pressure drop increases, so does the rotational and separating forces, thus decreasing the separation size to 10 and 20 microns, respectively. The residence time (i.e., internal volume divided by flow rate) is less than 0.5 seconds for both sizes at all conditions. (Note: Actual residence time ranges from 0.14-0.44 seconds). Thus, any change in flow rate results in a near instantaneous change in desander operation.

Figure 6 shows another method of visualizing the turndown performance. The data presents a desander vessel using ten active 75 mm (3.0 inch) desander liners. This vessel treats produced water (e.g., ρ=1060 kg/m^3 and μ=0.67 cP) with low solids concentration (100 ppm). The baseline operating point is 25,000 BPD flow rate at which the desander vessel exhibits a 172 kPa (25 psi) pressure drop and 20 micron separation size. As the flow rate decreases the minimum operating point for this system is 35 kPa (5 psi) pressure drop, which is equivalent to 10,800 BPD flow rate at a 32 micron separation size. The system then corrects back to baseline, then up to the maximum operating point of 345 kPa (50 psi) pressure drop – which is at 35,000 BPD flow rate with a 17 micron separation size. The ten desander liners have <5 second total residence time thus can adjust to the new operating points quickly. Slugging, in terms of flow rate change, is tolerated while the desander stays within the desired pressure drop boundaries.

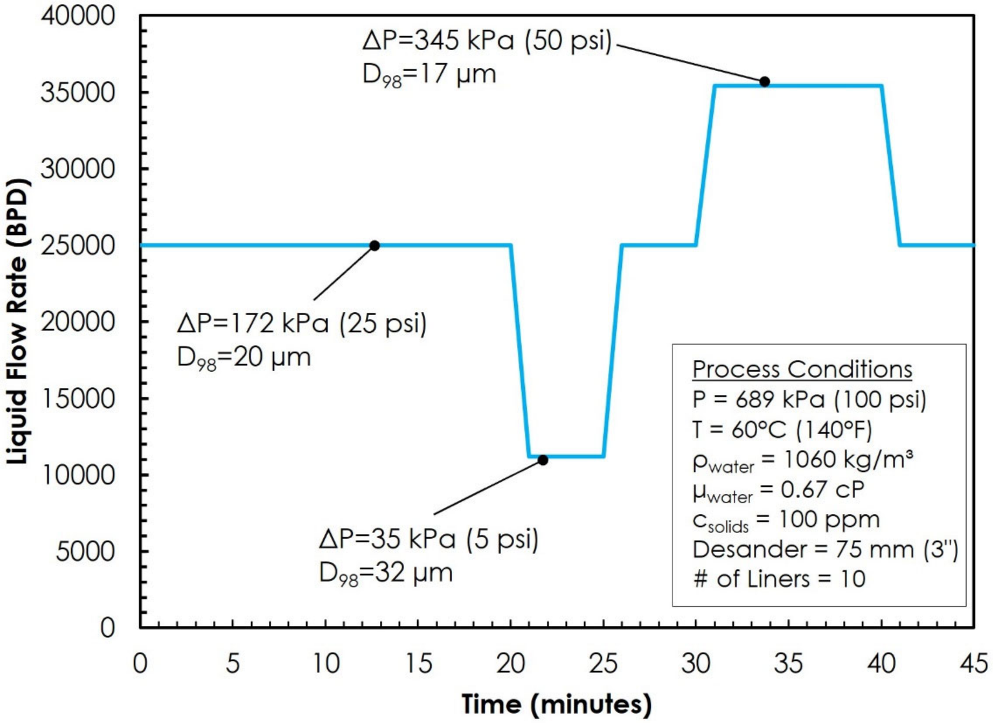

Fig. 6—Hydraulic turndown separation performance of produced water treating system using 75 mm (3.0 inch) desanders.

The turndown data in Fig. 5 is valid for a single liner – either 38 mm (1.5”) or 75 mm (3.0”) diameter. As the quantity of liners increases, divide by the flow rate for the number of active liners. For example, the data in Fig. 6 is valid for ten (10) total 75 mm liners – thus each liner at baseline conditions treats 2500 BPD. Full-scale process systems consist of multiple liners packaged into a vessel, along with piping, valves, instruments, and supports. Turndown therefore should be applied to the entire system for practical use. The turndown shown in Fig. 5 and Fig. 6 is “intrinsic” turndown – that is range of operability based on fixed mechanical conditions and treating changes in flow only. Changes in flow rate can also be treated with “extrinsic” turndown by making changes in the mechanical system itself. One method is to change the number of active liners by swapping some with blank liners. Using the data in Fig. 6 for example, by replacing two of the liners with blanks (thus eight desanders liners are active) the lower flow rate of 10,800 BPD will have a pressure drop of 55 kPa (8 psi) instead of 35 kPa (5 psi). Alternatively, two desander vessels – each with five active liners – could be placed in parallel (2 x 50%). This method doubles the turndown by putting one vessel in standby or in operation. Parallel vessels increase the footprint of the system and an improvement using Package Active Cyclone System™ (PACS™) design combines multiple chambers into one vessel for high turndown and compact system size (Ditria and Rawlins 2023).

Recommended Operating Boundaries

The produced water desander, like all hydrocyclone based technologies, has a finite range through which it operates effectively. Within this range the desander will be the most efficient and most compact separating technology to remove sand from produced water. No other technology combines separation efficiency with small footprint and weight. However, the desander is only effective within the recommended operating boundaries. Outside these boundaries the separation efficiency will decrease, sometimes dramatically.

Pressure Drop

The recommended pressure drop range is 35-345 kPa (5-50 psi) – where pressure drop is from desander inlet to overflow. The minimum pressure drop is the most important, since below that point the desander will fail to separate. The maximum pressure drop is not a firm value. A 345 kPa (50 psi) maximum value balances performance, energy consumption, and component wear life. Increasing pressure drop higher than 345 kPa (50 psi) will improve separation efficiency but with decayed improvement. An increase in pressure-drop from 345 kPa (50 psi) to 689 kPa (100 psi) will decrease the separation size by 18% (e.g., from 20 microns to 16 microns). If the energy to drive the desander is readily available from the existing produced water system, then the improvement may be useful. However, if the desander must be pump fed then an energy consumption versus performance improvement analysis is necessary. Increasing pressure drop has substantial effect on wear life of the desander components. The relative wear on the desander components is proportional to the primary separating velocity (V_t) to the fourth power. While increasing pressure drop will improve separation performance it will drastically reduce wear life. That is an additional cost to consider with energy consumption.

Slugging

Surging or slugging in the produced water flow rate often occurs in real world systems. A desander system should be designed to operate at a nominal pressure drop (e.g., 172 kPa or 25 psi) while allowing for the flow surges that occur. While the desander stays within the recommended pressure drop range then the desander will (near) instantaneously react to the surges and provide suitable separation performance.

Fluid Properties

The produced water physical properties (e.g., density and viscosity) may have a significant effect on separation performance. The range of produced water density changes normally seen – factoring in temperature and total dissolved solids concentration – is a secondary factor. Produced water density may range from 960 kg/m³ (fresh water at 90°C) to 1200 kg/cm³ (room temperature saturated brine). Sand has a density of 2650 kg/cm³ and the driving force for separation is the solid-liquid density differential. Thus, the maximum differential change with liquid density is ~15% showing this to be a minor effect on separation efficiency.

Water viscosity is the primary – sometimes the controlling – factor in desander operability. The viscosity of fresh water and saturated brine at normal oilfield operating conditions (ambient to 90°C) ranges from 0.4-1.7 cP. As a rule-of-thumb the separation size of a desander changes with the square root of the viscosity in cP, thus across this range the separation size can double – with the best separation size in hot fresh water and increasing separation size as the temperature decreases and salinity increases.

An even bigger factor affecting liquid viscosity are the chemicals added to produced water. Chemicals are added to the process system to combat oxygen, corrosion, emulsions, bacteria, friction, or hydrates will change the produced water physical properties. Those that decrease water viscosity will improve performance and those that increase viscosity will decrease performance. The chemicals of biggest concern are viscosity modifiers added for chemical enhanced oil recovery (CEOR) – such as polymer flooding using hydrolyzed polyacrylamide (HPAM). After passing through injection, reservoir sweep, and production return the resulting produced water for treating may have a viscosity up to 10-30 cP. At those values, the desander separation size will increase by 300-500%.

Particle Size and Concentration

As detailed in the Recovery Curve discussion, small/light particles pass through the desander while large/heavy particles are captured into the underflow section. The delineation between small and large depends on the location (D_{50}) of the recovery curve. In general, the smallest sand particle that can be practically separated in a full-scale produced water system is 10 microns. Desanders with very small diameter (5 mm) can separate down to 5-7 microns, but they are not practical on large scale (i.e., >10,000 BPD) produced water treating systems.

The largest particle a desander can treat depends on its orifice geometry. Each desander liner has a fixed geometry – with specific inlet, overflow, and underflow orifice sizes. Orifice sizes are a ratio of the desander diameter. For example, using a Bradley design (Svarovsky 1984), a 38 mm diameter (1.5") desander has a 5.0 mm diameter inlet, 7.6 mm diameter overflow, and 3.8 mm underflow. The largest particle that can be treated is one-third the diameter of the smallest opening. In this example the largest size is one-third the underflow orifice, which is 1267 micron. Particles larger than that size may plug or block the desander, thus should be removed by first-stage larger desander or strainer. These particles include debris material like pipe tape, scale debris, or rubber chunks from electric submersible pumps. The corresponding plugging size for a 75 mm desander is 2500 microns.

A desanders function is to remove solids from produced water containing a dilute concentration of solids. Typical values of sand concentration in produced water exiting a produced water treating unit (i.e., FWKO or three-phase separator) range from 100-500 ppm. During upset conditions high concentration slugs of sand may enter the desander and can overload the unit. Particle travel and effects of concentration are published previously (Rawlins 2018) with general guidelines as follows. In standard produced water (i.e., produced water without viscosity modifier) the 38 mm (1.5") and 75 mm (3.0") desanders can treat 1500 ppm and 2500 ppm, respectively, of 150 micron sand before overloading. During the upset overload condition, the desander still operates, but the excess sand (higher than the concentration limit) passes to the overflow stream. As the slug passes the desander will clean itself out and return to normal operating state. If high concentration slugs are present frequently, then an apex flux balance line should be installed on the desander vessel (Rawlins 2018).

Effect of Chemicals

Produced water systems will have a mix of natural and artificial chemicals present. These include demulsifiers, corrosion inhibitors, drag reducers, antibacterial agents, oxygen scavengers and others. As the desander is a mechanical device providing physical separation these chemicals are classified as either bad or good. Bad chemicals are those that increase water viscosity, stabilize emulsion (e.g., which increases effective viscosity) or allow oil to wet and coat the solids (e.g., reducing the apparent sand density). These chemicals reduce desander separation efficiency. Good chemicals do the opposite – decrease water viscosity, break oil-water emulsion, and aid in removing oil coating of the solids. Awareness of the chemicals present in produced water can help in troubleshooting difficult separation issues.

As the desander separation efficiency is strongly dependent on particle size, attempts have been made to add coagulants or flocculants to the system. These chemicals are used in gravity settling or filtration systems to agglomerate very-small particles into larger "flocs." For non-shear separation technologies these chemicals work well to "grow" particle size. However, the shear forces within the cyclone vortex are such that they will destroy the flocs – thus flocculants are not able to improve separation performance in cyclonic devices.

General Design and Layout

The mechanical design and general layout of a commonly used produced water desander vessel is shown in Fig. 7. These vessels each incorporate three chambers (i.e., inlet, overflow, and underflow) defined by plates which hold multiple desander liners. This type of vessel is optimized for treating produced water (liquid only flow) with low concentration of sand (<500 ppm) and low to medium design pressure (i.e., ASME 150#-600#).

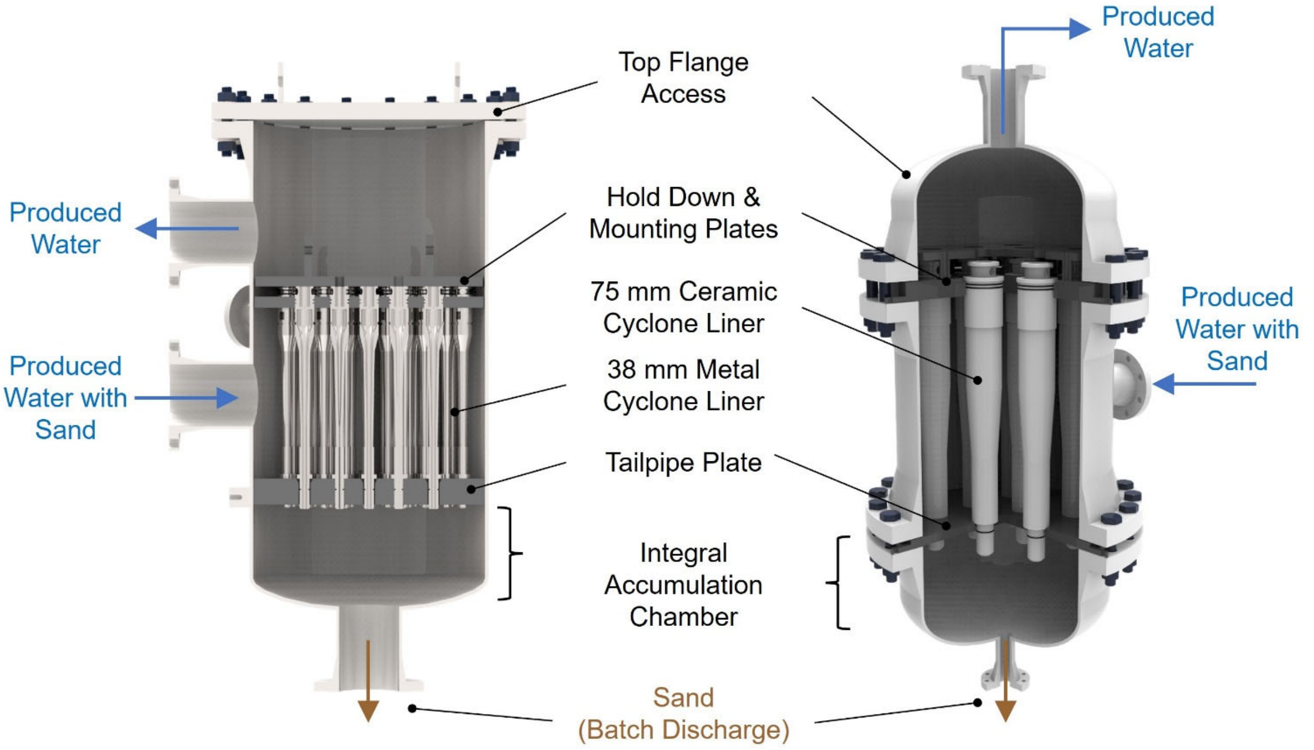

Fig. 7—Mechanical layout of 150# rated produced water desander multi-liner vessels showing (left) flat head with welded plates with 38 mm (1.5") metal cyclone liners and (right) dished head sandwiched plates with 75 mm (3.0") ceramic cyclone liners.

The two vessels shown in Fig. 7 illustrate the mechanical design and layout options available for best integration into process facilities. The left vessel has a side inlet and (clean) water outlet and flat top head. The right vessel has a side inlet and dished head with top (clean) water outlet. While the inlet must always be on the vessel side, the water outlet connection can be modified to match piping layout (top or side). The inlet and clean water outlet are continuous flow, while the collected sand is batch discharged from the bottom nozzle. Both vessels require vertical orientation.

A flat vessel head allows for welding the mounting and tailpipe plates in-place, while a dished head allows for sandwiched (between flange) plates. The design choice depends on internal coating requirement, plate replaceability, and access to internals. A vessel with sandwiched plates is much more costly but allows full internal coating and full plate replacement. The hold down plate for the liners is removable in each design. Both vessel designs – flat top, welded plates or dished head, sandwiched plates – fit either size or type cyclone liner (i.e., 38 mm or 75 mm).

Alternative desander use – very-high pressure (>34,450 kPa or >5,000 psi), multiphase gas-liquid flow, or high slurry concentration (>10,000 ppm) requires a different mechanical design – typically with a single cyclone insert (Rawlins 2017).

Mechanical Requirements

Each produced water desander comprises of standardized internals fitted into a vessel and skid crafted to meet specific site requirements. The guidelines below provide general requirements for fitting or retrofitting a multi-liner desander into your oil & gas facilities.

- Vessel pressure rating: Designed to ASME Section VIII Division 1 150#-600# rating. Multi-liner vessels with rating ≥ASME 900# are difficult to build due to thickness of the body flanges and liner plates.

- Vessel Material of Construction (MOC): The pressure vessel is built to match the process piping and other facilities water treating equipment. Commonly this is carbon steel, 316L stainless steel, or duplex stainless steel (UNS 31803). A vessel designed with removeable (sandwiched) plates allows internal coating for corrosion protection.

- Plates MOC: The internal plates – mounting and tailpipe – are fabricated from non-corrosive material to maintain the integrity of the mounting holes for the liners. This is commonly 316L or duplex stainless steel.

- Desander Liner MOC: The desander liners contain all the erosion and are not required to hold the full pressure differential. Small diameter (<50 mm) liners are made of metal (e.g., Stellite®) while larger diameter (>75 mm) liners can be cast in ceramic (e.g., alumina).

- Footprint: The desander vessel itself has a small diameter. A 610 mm (24”) nominal diameter multiliner desander can treat 25,000 BPD while a 914 mm (36”) vessel can treat 50,000 BPD. That allows for compact retrofit within existing process facilities and design of a small footprint skid. A full process skid for produced water desander will be less than 2.0 m x 2.0 m, including basic valves/piping/instruments.

- Height: The desander vessel requires vertical orientation at 2-3 meters for the vessel alone depending on diameter and pressure rating. Adding a secondary accumulator, valves, piping, and instruments would require 4-5 meters total install height.

- Weight: Bare vessels range from 1,000-3,000 kg, while the full skid may be 5,000-10,000 kg depending on the amount of piping and pressure rating.

- Instrumentation: Typical instrumentation required is inlet and overflow pressure (to monitor pressure drop), level switch (vibrating rod or paddle type for sand collected in accumulator), and valve actuators for automated systems.

- Valves: The critical process valves are accumulator isolation, accumulator (slurry) discharge, and accumulator water fill. These valves will see concentrated sand slurry and should be of suitable type for long life in this application. Recommended valve types are slurry-ball, rotating disc, or gate valves.

Conclusions

The produced water desander is ubiquitous in offshore oil & gas production. Offering all the benefits of cyclonic-based technology – extremely compact size, insensitivity to external motion, rapid response to process changes, and superb separation efficiency – it is the preferred equipment choice to protect produced water treating equipment and disposal systems. To properly integrate a desander into the facilities layout its process and mechanical limitations must be known and understood. It is not a catch-all technology used for any solid-liquid separation situation, but a key part of an intelligently designed produced water treating system.

- Know where to put a desander in your process system. The desander should be the first step in produced water treatment – before deoiling hydrocyclones, flotation cells, corrugated plate interceptors, and nutshell filters. The produced water desander removes low concentrations of harmful sand from the produced water stream on a continuous basis. Do not use a multiliner desander to treat sand slurry batched from a jetting system – that requires a completely different type of desander.

- Know the range of particle size and particle concentration in your produced water stream. Especially the upper limits of both. Particles or tramp material >2 mm may cause plugging in small diameter desander liners, and they can be protected by strainers. High solid concentration (>1000 ppm) – especially occurring in slugs – may overload the desander and deteriorate performance. An apex flux balance system will partially ameliorate this effect.

- Know the produced water flow rate range of your system – both at current and in future – and the needed turndown. As a start, design the produced water desander with a nominal 170 kPa (25 psi) pressure drop – to allow both turndown and turnup with flow changes. Never allow the desander to drop below 35 kPa (5 psi) pressure drop or the cyclone vortex will collapse, and no separation will occur.

- Know the effects of chemicals in your produced water – especially those that increase viscosity or allow oil to strongly coat small particles. The separation size of a desander increases with the square root of water viscosity (in cP). Introduction of viscosity modifying chemicals – usually through CEOR methods – may decrease separation efficiency by 50-90%.

- Know the pressure changes in your produced water system. The produced water desander vessel has small diameter liners held between mounting plates. These mounting plates have a finite differential to operate (i.e., typically 689 kPa or 100 psi) before they over-flex and potentially damage ceramic liners. Plate over-flexing can occur during pressure spikes – especially if feeding the via positive displacement pump, or through improperly conducted sand discharge.

- Know the limits of separation of a produced water desander. The realistic limit for desander separation size is 10 microns. This is for a practical produced water treatment system – including large flow rates, presence of tramp materials or chemicals, oil-sand interactions, and offshore design codes. Below 10 micron separation is only possible in small flow or very controlled environments.

Nomenclature

AFB = *Apex Flux Balance*
BPD = *Barrels Per Day*
ASME = *American Society of Mechanical Engineers*
CEOR = *Chemically Enhanced Oil Recovery*
D_{50} = *Cut Size*
D_{98} = *Separation Size*
F_b = *Buoyant Force*
F_c = *Centrifugal Force*
F_d = *Drag Force*
FSM = *Facilities Sand Management*
FWKO = *Free Water Knock Out*
HPAM = *Hydrolyzed Polyacrylamide*
k = *Cyclone Geometric Capacity Factor*
MOC = *Materials of Construction*
ppm = *Parts Per Million*
PSD = *Particle Size Distribution*
psi = *pounds per square inch*
PWRI = *Produced Water Reinjection*
PWT = *Produced Water Treatment*
Q = *Flow Rate*
V_a = *Axial Velocity*
V_r = *Radial Velocity*
V_t = *Tangential Velocity*
α = *Efficiency Curve Slope*
ΔP = *Pressure Drop from Desander Inlet to Overflow*

SI Metric Conversion Factors

bbl	x 1.589 7	E-01	=	m^3
inch	x 2.54	E+00	=	cm
micron	x 1.0	E-04	=	cm
mm	x 1.0	E-01	=	cm
psi	x 6.894 757	E+00	=	kPa

References

Ditria, J.C., Hoyack, M.E. 1994. The Separation and Solids and Liquids with Hydrocyclone-Based Technology for Water Treatment and Crude Processing. Presented at the SPE Asia Pacific Oil and Gas Conference, Melbourne, Australia, 7-10 November. SPE-28815-MS. https://doi.org/10.2118/28815-MS.

Ditria, J.C., Rawlins, C.H. 2023. Produced Water Treatment with Deoiling Hydrocyclones – Misconceptions & Corrections. Presented at the SPE Western Regional Meeting, Anchorage, AK, 22-25 May. SPE-213033-MS. https://doi.org/10.2118/213033-MS

Hodson, J.E., Childs, G., Palmer, A.J. The Application of Specialist Hydrocyclones for Separation and Clean-up of Solids in the Oil and Gas Industry. Presented at the 26th Annual OTC, Houston, TX, USA, 2-5 May. OTC-7590-MS. https://doi.org/10.4043/7590-MS.

Knowles, S.R., Woods, D.R., Feuerstein, I.A. 1973. The Velocity Distribution within a Hydrocyclone Operating without an Air Core. Can J Chem Eng 51: 263-271.

Lohne, K. 1994. Separation of Solids from Produced Water Using Hydrocyclone Technology. Chem. Eng. Res. Des. 72 (A2): 169-175.

Lynch, A.J., Rao, T.C. 1975. Modeling and Scale-Up of Hydrocyclone Classifiers. Proceedings of the 11th International Mineral Processing Congress, Cagliari, Sardinia. 245-269.

Plitt, L.R. 1976. A Mathematical Model of the Hydrocyclone Classifier. CIM Bulletin 69 (776): 114-123.

Quian, L., Changlie, D., Jirun, X., Guangai, X. 1989. Comparison of the Performance of Water-Sealed and Commercial Hydrocyclones. Int J Min Proc 25: 297-310.

Rawlins, C.H., Wang, I.I. 2001. Design and Installation of a Sand-Separation and -Handling System for a Gulf of Mexico Oil Production Facility. SPE Prod & Oper 16 (03): 134–140. SPE-72999-PA. https://doi.org/10.2118/72999-PA.

Rawlins, C.H. 2016. Design of a Cyclonic-Jetting and Slurry-Transport System for Separators. Oil & Gas Fac 5 (01): 38–46. SPE-166118-PA. https://doi.org/10.2118/166118-PA.

Rawlins, C.H. 2017. Separating Solids First – Design and Operation of the Multiphase Desander. Presented at the SPE Western Regional Meeting, Bakersfield, CA, USA, 23-27-April. SPE-185658-MS. https://doi.org/10.2118/185658-MS.

Rawlins, C.H. 2018. Particle-Transfer Between the Cyclone and Accumulator Sections of a Desander. SPE Prod & Oper 34 (01): 270-279. SPE-191147-PA. https://doi.org/10.2118/191147-PA.

Rawlins, C.H. 2022. What to do with Produced Solids After Separation: Dewatering, Transport, and Disposal. Presented at the SPE Annual Technical Conference and Exhibition, Houston, TX, USA, 3-5 October. SPE-210003-MS. https://doi.org/10.2118/210003-MS.

Svarovsky, L. 1984. Hydrocyclones. Lancaster: Technomic Publishing Co. Inc.

Witbeck, W.O., Woods, D.R. 1984. Pressure Drop and Separation Efficiency in a Flooded Hydrocyclone. Can J Chem Eng 62: 91-98.

Author Biography

C. Hank Rawlins (P.E.) is Managing Director/CTO for eProcess Technologies LLC in Butte, MT, USA. He has 32 years of experience in research and process engineering in the upstream oil and gas industry. He is responsible for development programs in Facilities Sand Management, Produced Water Treatment, and Compact Separation Systems. Dr. Rawlins has fifty-nine publications and is an active member of SPE, where he served as past chair of the Separations Technology Technical Section (STTS) and as a Distinguished Lecturer (2018-2019). He holds a PhD in metallurgical engineering from Missouri S&T University and can be contacted at hrawlins@eprocess-tech.com.