Abstract
Sand production is a common challenge for processing facilities and well test equipment, as solids degrade the mechanical integrity and separation efficiency of surface equipment through erosion, settling, and plugging. Where exclusionary sand control methods fail or do not exist, inclusionary surface handling methods can be used to maintain or increase the total hydrocarbon production. The best approach is to remove sand at the wellhead, which protects all downstream flow lines and equipment. The multiphase (wellhead) desander was developed in the late 1990s as a unit operation to separate solids at wellhead conditions. This technology has been deployed in onshore and offshore production, well cleanup, and well testing operations. In addition to protecting downstream equipment, wellhead desanding enables the easier design and operation of solids-handling systems.

Multiphase desanders were developed from solid-liquid cyclones used in the mining industry. Laboratory and pilot-plant tests conducted in 1994-1995 defined an initial hydraulic model, which was applicable in mixed-phase flow. The liquid-based model was paired with a dense-gas pneumatic cyclone model. The pressure drop and solids removal efficiency of the resulting multiphase model were evaluated at the Wytch Farm producing facility in Dorset, UK in 1995. This approach continues to be refined using field data, and the current mechanistic-empirical model has a high accuracy across the 0-100% gas void fraction range. The hydraulic and pneumatic models are discussed with respect to the pressure drop, solids removal, turndown, and slugging.

Mechanical design improvements, including material selection, construction to API-6A code, and apex-flux balancing, have doubled the multiphase desander operating life while reducing the size and weight by 40%. Design improvements are discussed with respect to the system layout and proper operation. A comparison is made between single and multiple cone vessel designs with respect to the particle size, solids concentration, and fluid partitioning.

Facilities Sand Management
All oil and gas wells produce sand; therefore, all production facilities must be capable of managing sand in the flow streams. The most common methods of sand management attempt to exclude solid particles from the well flow using a production limit or completion string. When these approaches are not
economical or technically feasible, or when they fail, the surface facilities (subsea, offshore, or onshore) must manage the produced sand. Surface sand handling is termed Facilities Sand Management (FSM).

Sand co-production, which requires Facilities Sand Management, is shown to increase hydrocarbon recovery (Andrews et al. 2005; Fadillah et al. 2004; Geilikman et al. 1994; Guinot et al. 2009; Kaura et al. 2001; Sanfilippo et al. 1997; Selfridge et al. 2003; Vaziri et al. 2000). This approach completes the well without a completion string – either barefoot or open-hole with large slots. Sand is produced with the hydrocarbons to increase the reservoir interface area, decrease skin, and improve inflow. Sand must be separated and handled in the surface facilities without interfering with the equipment uptime.

A thorough facilities design requires five steps (illustrated in Fig. 1) to fully manage and handle the sand produced (Rawlins and Wang 2000). Each step – from separation to disposal – must be integrated into the facility design to maintain hydrocarbon production and prevent flow interruption or equipment shutdown. A definition and purpose for each step helps to identify the equipment needed.

1. **Separate**: to partition solid particles from liquid, gas, or multiphase flow to a separate stream. Unit processes include a hydrocyclone desander (liquid or multiphase), production separator, or filter.

2. **Collect**: to gather partitioned solids into one central location and remove from process pressure and flow. This is accomplished using a hydrocyclone accumulator, vessel drain, or sump tank.

3. **Clean**: to remove adsorbed hydrocarbon contaminants from sand particles using an attrition scrubbing system. This is an optional step, which is only used to treat sand for overboard discharge.

4. **Dewater**: to remove free water from sand slurry to minimize the disposal volume. This can reduce the disposal volume by >90%. The simplest method involves a hanging mesh bag or screen lined bin.

5. **Transport**: to bring solids to the disposal location. The design of the transport system depends on the facility location (subsea/onshore/offshore) and environmental requirements. Common options include overboard discharge, truck to landfill, ship-to-shore, and slurry injection.

The first step is the separation of sand from the production stream. Fig. 2 depicts four nodes in the facility scheme where the sand separation equipment is commonly located. Four node options are available to ensure the removal of sand at the proper location in the process system. Sand should only be removed at a location that is pertinent to solving the problem caused by sand. If protection of produced water reinjection (PWRI) wells is the primary concern, then a liquid desander at Node 4 would be sufficient. If the choke is eroding rapidly and the production separator is filled with sand, then a wellhead desander at Node 1 would be recommended.

The produced sand initially reports to the wellhead in Node 1, which is the first location where sand can be removed. Separation of sand with a wellhead desander (WHD) protects the choke, flow-lines, separator, and produced water treating equipment (Rawlins 2013). A properly designed multiphase desander operates efficiently in multiphase flow from a 0-100% gas void fraction (GVF). The WHD is designed to full wellhead mechanical specifications (i.e., API-6A) to meet the flowing and shut-in pressures. The wellstream desander (WSD) in Node 2 operates in a similar way as the WHD, but it is designed for multiphase flow between the choke and the separator. The WSD is installed on a manifold or near the inlet to the separator, and it may be used to process multiple wells. The mechanical design of the WSD matches the manifold piping or production separator (i.e., typically ASME Sec VIII). With the WSD, the separator and produced water system are protected, but the choke or flow-line are not protected.

Solids are separated within the production separator in Node 3, but on-line removal requires a jetting system. In this node, the separator and produced water system are not protected from sand, but sand is handled without shutting down the facility. The final location at Node 4 removes sand from the produced water stream using a standard (liquid) desander. This technology protects the oil removal equipment (i.e., deoiliers and flotation cells), PWRI equipment, and disposal reservoir.

Separating solids first, using a wellhead desander, offers the most beneficial FSM design. The equipment is compact and simple to operate. A WHD protects all downstream equipment and processes. Solids removed at Node 1 or 2 are fluidized and easy to work with. The wellhead temperature, a high particle mobility, and un-adulteration by surface-active processing chemicals all ensure that the sand is
easy to clean, dewater, and transport. Static settled solids, such as those sitting in production separators at Node 3, become harder to remove as time increases. These solids will both consolidate (mechanical effect) and bind (chemical effect) due to gravity, vibrations, scale, precipitates, waxes, bitumen, etc., making them difficult to remove and process. Consolidated or cemented sand requires chemical, thermal, or and/or mechanical action to unbind. The best approach is to keep sand fluidized and move or remove frequently at the beginning of the facility.

Cyclonic Technology
The Wellhead and Wellstream Desanders are both subsets of the cyclonic unit process. Cyclone devices partition two or more phases based on their weights and separate gas-liquid-solid components in a variety of applications. In the petroleum industry, cyclones are used to remove grit or droplets from gas pipelines, segregate sand or oil from produced water, debottleneck gravity settling vessels, or even split mixed gases with different densities. Fig. 3 presents the two main types of cyclones, with examples of cyclone devices. The continuous phase flowing through the unit designates the cyclone as a pneumatic (gas) or hydraulic (liquid) cyclone.

A cyclone converts the potential energy (pressure) of the transport fluid into rotating kinetic energy (vortex flow) using only the shape of the device to partition two or more phases in that fluid into the respective number of concentrated outlet streams. Key factors for this technology include – the absence of moving parts (static device), a tangential or involute inlet, a cylinder-cone body (see central graphic in Fig. 3), a combined free-forced vortex flow pattern, and a classifying operation (i.e., separation based on particle weight not size). Other swirling devices provide efficient phase separation, such as centrifuges with motor driven rotating discs, but if they are without the key factors listed, they are not characterized as cyclones.

The most attractive feature of cyclones to the upstream oil & gas industry is the equipment size. 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.

Hydrocyclones versus Desanders.
The term hydrocyclone indicates a liquid continuous classification device (i.e., Fig. 3). Hydrocyclone is a contraction of hydraulic cyclone. The hydrocyclone is used widely in process industries, with its predominant use and research in mineral processing. There, the technology is used in closed-circuit grinding of ore to partition particles in a highly concentrated slurry stream (solid-solid classification). These devices were primarily developed in the 1940s (the first patent was filed in 1891), and they are found in every mining region. The mineral processing hydrocyclone operates at a low inlet pressure (10-30 psig) and a high solids concentration (40-60 wt.%) with an atmospheric discharged underflow and overflow.

The desanding hydrocyclone – simply termed the “desander” – is a derivative technology from mining hydrocyclones. They were initially developed in the 1960s to keep sand out of agriculture irrigation nozzles. The original desanders had a simple design for operation at a low inlet pressure (<20 psig) and a low sand concentration (<50 ppm). They were first used in the oil & gas industry in 1964 with Saudi Aramco.

The primary difference between a hydrocyclone and a desander is that the latter operates with an enclosed underflow chamber, as shown in Fig. 4. Both units have continuous inlet and overflow streams, but the desander has a batch underflow. Whereas the mining hydrocyclone processes fluids with a high solids content, the enclosed underflow on a desander limits the unit to a low solids concentration (<<1 wt.%). Enclosing the underflow also prevents air-core formation in the center of the vortex flow. The air core, which is present in mining hydrocyclones, is a key feature in their modeling and operation but is absent in a desander. The desander is properly termed a “flooded-core hydrocyclone”. The first research
on the flow pattern and particle trajectory within a flooded-core static hydrocyclone was recently published (Rawlins 2014a).

**Multiphase Desander**

The development of the multiphase desander began in 1994 as a joint industry project (JIP) with eight sponsoring operator and service companies. This technology, originally referred to as a wellhead desander, is also used downstream of the choke on flow line manifolds and prior to separators; therefore, the term “multiphase desander” is more inclusive. The first phase of the JIP included the laboratory testing of a 10-inch mining hydrocyclone fit with an accumulation chamber. The flow response and solids removal efficiency of this desander was tested using low-pressure air-water-sand mixtures at varying GVFs. The data generated the first empirical pressure drop response curve and mechanistic simulation model.

In 1995, a pilot scale skid, with an ASME 300# rated 10-inch desander, was built and tested at the (BP) Wytch Farm field in Dorset, UK. This onshore operating field allowed the delivery of controlled flow from one or more wells with a range of gas-oil ratios (GORs) or GVFs. The selected wells had negligible sand, which enabled a controlled solid removal analysis. Each trial injected a fixed quantity of sand into the multiphase desander inlet flow stream. The sand collected in the accumulation chamber is compared to the amount injected to determine the removal efficiency. Pilot testing data, combined with lab results, were used to generate a robust simulation model that predicts the separation performance for a range of oil and gas well conditions. The model evolves continuously to meet the needs of HPHT, sour gas, subsea, and heavy oil wells.

Following the success of the JIP, the first commercial wellhead desander was deployed in 1996 on the Brent D platform in the North Sea (Gordon and Shittu 1997). This unit, shown in **Fig. 5** (left), was used for solids handling during a coiled tubing cleanout. Designed to an ASME 5K rating, the unit treated 6-20 MMSCFD gas in addition to 16,000 BPD liquids at a <75 psi pressure drop. A photograph of the removed sand and coal is shown in **Fig. 5**. The measured separation size averaged 20 microns. With the replacement of the cyclone insert, this WHD is still operable in the fleet today.

**Wellhead or Wellstream.**

**Fig. 2** shows the multiphase desander installed upstream (Node 1) or downstream (Node 2) of the choke. Both locations have multiphase flow with specific benefits at each location. A comparison the process and mechanical design attributes of both locations is presented in **Table 1**.

Placing the multiphase desander upstream or downstream of the choke primarily depends on the solids problem to be solved. Normally, only a small fraction of wells at a facility produce most of the sand; thus, placing a desander on one or a few wells is more effective than treating the full production stream. The WHD at Node 1 protects the choke and all the downstream facilities and serves as the base case design. The WSD is used where choke wear is not a major issue, or where the WHD cannot currently be used (i.e., subsea wellheads). The costlier API rating pre-choke, compared to the post-choke ASME design, is balanced by the reduced gas volume at the wellhead, which yields a smaller size unit. The installed costs for both designs are comparable. The WSD has a larger skid size; thus, the WHD may be more easily deployed in space-constrained facilities.

The separation size, solids removal efficiency, and sand handling are similar for both the WHD and WSD nodes. Both locations operate in full multiphase flow, which increases removal efficiency, and both locations have a higher temperature and less chemical interference compared to solids that settle in the production separator, which improves sand cleaning and transport. At either node, the separation size averages 15-25 microns for high GVF wells. Particles larger than 50 microns cause the majority of problems in facilities (i.e., erosion or settling in the separator), and thus, the total solids removed at either location is commonly >95%.
Applications in Upstream Oil and Gas.

The multiphase desander is used in both permanent and temporary applications (Hagemeijer and Jagernath 2003; Peruzzi et al. 2013; Dreher et al. 2014). Fixed systems integrate the WHD components into the flow scheme just off the wing valve of the choke. A wellhead desander in this application offers long-term solids removal from wells that are too costly to complete or where completions have failed, and rework is not feasible. The WSD at the inlet of the production or test separator is at an alternate fixed location. Since completions may hinder the full hydrocarbon recovery, removal of the completion often yields increased flow from a well. Sand co-production offers the benefits of reduced well costs and increased reservoir yields. Sand is managed at the surface with FSM design – not as a maintenance issue. Operators are the primary users of fixed WHD and WSD installations.

Skid-based temporary WHD systems are widely used by service companies for solids control during well-testing and cleanup operations. Frac flow-back, extended well tests, coiled-tubing cleanup, and underbalanced drilling are all applications with short-term high-solids production. The WHD in these cases protects the control chokes and prevents filling of the test separators. The WHD is one of the service toolkit skids that are transported to each well site.

Fig. 6 shows three photographs of upstream oil & gas multiphase desanders. The left photo shows a 5K-rated WHD, which is permanently installed on an offshore Malaysian platform gas well. A 15K-rated WHD skid used in Oman for solids control during well testing is shown in the photo in the center, while a 900# WSD on a shallow-water platform in Turkmenistan is shown on the right. The WSD prevents filling of solids in the test separator on the platform. This unit began as a temporary rental skid that was converted to a permanent installation after a 250% increase in oil production was achieved by not reworking the completion (Rawlins 2013).

General Design and Operation

A multiphase desander has three integrated components that permit efficient solids removal from wellstream fluids. Fig. 7 shows a WHD schematic with these components installed between the wellhead wing valve and choke. The three components are the desander housing, cyclone insert, and solids accumulator. A WSD would have the same configuration; however, the inlet would come from the manifold flow line, and the outlet would go to the production or test separator.

In the process shown, solids-laden well fluids enter the desander housing directly from the wellhead. The fluid-solid mixture is directed to the cyclone insert contained within the housing. The housing contains the process pressure, while the cyclone insert acts as the separator and contains erosion. The cyclone insert is removable, for inspection and replacement, and interchangeable, i.e., there are different diameter inserts for large turndown requirements. Fluids enter the insert through a tangential inlet: the pressure differential (inlet-outlet) and insert shape create a vortex flow pattern. The insert has a cone-cylinder design to increase fluid spin down its length. Solid particles are subjected to forces, which are several thousand times larger than that of gravity and are forced to the inner wall of the cone. These particles migrate down the length of the cone to the lower section of the desander housing. The solids-free fluids change direction and flow up and out through the top of the desander housing. The solid particles continue their migration downward through a double block and bleed (DBB) valve arrangement into the solids accumulator. The solids are captured for batch discharge, while well production is continuously maintained.

Once the accumulator is full, which is determined by level measurement or time, the collected solids require discharge. The solids discharge process can be manual or automated, and it takes 10-15 minutes. The accumulator is first isolated by closing both DBB valves. After isolation, the pressure in the accumulator is vented through a side valve. A purge liquid – clean water from any source – is used to push the solids out of the bottom nozzle. After solids removal, the accumulator is filled with clean water, and the purge and vent valves are closed. The accumulator is repressurized, and the DBB valves are opened to continue sand collection. Filling the accumulator with clean water prevents high-pressure slurry from discharging into an empty space and provides a cleaning bath for the sand to settle in. During the
accumulator batch discharge cycle, the separated solids are held in the lower section of the desander housing. This operating mode maintains the production while removing the solids in a batch cycle.

Fig. 7 shows a desander housing with a single cyclone insert. This packaging arrangement is called an insert or single-cone style. An alternate method of packaging the desander inserts into a vessel is the liner or multi-cone style shown in Fig. 8. The insert style is best used for multiphase flow (i.e., wellhead desanding), while the liner style is best used for liquid-only flow (i.e., produced water treatment).

The insert style, with one cyclone per housing, is a smaller/lighter unit, which is critical for high-pressure wellhead applications. The single cyclone insert can handle particles up to a diameter of 2-inch and solids concentrations as high as 5 wt.% without plugging. Sand production from the wells is relatively unpredictable, both in terms of particle size and amount, and a resilient design is required at this location. The liner style desander, with many small diameter liners, can plug if the particle diameter is greater than 0.25-inch or the solids concentration exceeds 0.25 wt.% Most importantly, a single insert packing treats all fluid phases (oil, water, and gas) together in one flow pattern. The multi-cone design has an unequal fluid partitioning, with some liners used to treat all liquids, and some used to treat all gases. The unequal distribution results in particle bypass and reduced separation efficiency. The liner style is more suited for produced water treatment, which has a smaller average particle size, a consistent solids concentration, and a proper distribution of a single-phase for each liner. The multiphase desander is designed based on the insert style packaging.

**Particle Travel and Fluid Flow.**

The particle trajectory and fluid flow profile are illustrated in Fig. 9. The left figure shows the path traveled by solid particles within a fluid-packed multiphase desander, while the illustration in the middle shows a close-up plan view of the inlet transition from this unit. The inlet flow of the cyclone insert transitions from linear (in the pipe) to vortex flow (in the cyclone). Gas, liquid, and solids enter the multiphase desander through a nozzle connection and are directed to the inlet of the cyclone insert. The high g-forces of the swirling flow quickly disengage the gas where it reports to, and the flow exits the vortex finder. The liquids swirl outside the gas-core to form a spinning annulus through which the solid particles move. The sand particles transition from linear flow at the inlet, and they impact and slide along the inner wall of the cyclone insert. The vortex finder prevents particles from short-circuiting to the overflow with the gas.

Liquids and solids both spin down the cylinder section of the cyclone and enter the cone section. The cone section accelerates the rotational velocity (e.g., increase g-forces) and reverses the liquid flow direction up towards the vortex finder. The heavy/large solid particles continue to spin down the inner wall of the cone and report to the apex of the cyclone. The small/light particles are swept with the liquids to the overflow through the vortex finder. This flow pattern imparts separation, with the gas, liquid, and small particles reporting to the overflow, and the heavy/large particles captured and sent to the underflow. The captured particles pass through the apex, which pushes the particles together and forms a central collection point. Upon passing through the apex into the integral accumulation section, the particles fall due to gravity through the liquid bath.

The captured particles continue to fall due to gravity through the integral accumulation section, through the double block and bleed valves, and into the (external) accumulation unit. The dense sand particles displace the water in the accumulator. The displaced water is forced out of the accumulator up through the DBB valves into the desander unit. The water continues upwards through the apex, mixes with the solids-free fluids, and eventually reports to the overflow stream. This particle-liquid volumetric swap allows sand to displace clean water; however, oil (with less density than water) will not “fall” into the accumulator. The strong particle-particle and particle-cyclone shear forces, along with sand-water displacement, form the primary cleaning mechanism for the sand as long as the fill water in the accumulator is obtained from a clean source.

The sand collected in the accumulator forms a level, flat interface in the liquid bath, and it can be accurately measured with an internal level probe or an external gamma-ray device. Sand particles do not
form a dense settled phase and will have a certain amount of void fraction space between the grains. This void space is filled with water, and it enables the particles to flow when pressure (purge liquid) is applied. The packing fraction of settled reservoir sand in water has an approximate value of 0.62; thus, in a given volume, 62% of the space is sand, and 38% is water. The 0.62 packing fraction is an average from laboratory measurements on many field samples, so this value will vary with the particle size distribution.

**Multiphase Desander Sizing and Performance**

The multiphase desander simulation model, which was first developed in 1994, computes the pressure drop, separation size, and solids collection efficiency (Rawlins 2002, 2014b). The initial model combined empirical and mechanistic calculations from single-phase mining hydrocyclones and industrial pneumatic cyclones. These models were combined to form a dense-fluid hybrid for multiphase flow. All sections of the model are validated for high-pressure, high-temperature oil & gas flow to provide a robust simulation for well production.

**Pressure Drop and Throughput.**

The throughput response portion of the model, which determines the pressure drop at varying gas-liquid flow rates, was generated from the Plitt (1976) and Stairmand (Benítez 1993) relationships. Liquid-dominant flow uses the Plitt empirical model for hydraulic cyclones, while gas-dominant flow uses the Stairmand mechanistic model. Both models are modified for multiphase flow fluid properties.

Plitt’s model for liquid-only flow is shown in Eq. 1, where $Q$ is the liquid flow rate, $\Delta P$ is the pressure drop (inlet-overflow), and $a$ and $b$ are geometric factors for the specific cyclone configuration. The power factor $b$ normally ranges from 0.4-0.6 with an average of 0.5 commonly used.

$$Q = a(\Delta P)^b$$

Rearranging this equation in terms of the pressure drop results in Eq. 2. The $k$-factor is measured empirically at a fixed condition (typically fresh water at ambient temperature) to yield a standard curve.

$$\Delta P = \left(\frac{Q}{k}\right)^2$$

The gas content, based on the gas-liquid ratio, is incorporated using the dimensionless $G$-factor, as shown in Eq. 3. The $G$-factor is determined empirically to yield a range of curves. This form of the equation is the basis for the liquid-dominant pressure drop.

$$\Delta P = G\left(\frac{Q}{k}\right)^2$$

The pressure drop is also a function of the fluid viscosity ($\mu$) for a power ($n$) and volume fraction of solids ($c$), as shown in Eq. 4. However, these are minor factors, which are commonly at unity values, since the gas-liquid mixture viscosity and inlet solids concentration are often <<1.

$$\Delta P = f(e^{0.55c}, \mu^{-n})$$

The gas-dominant flow pressure drop is derived from the Stairmand mechanistic model. Eq. 5 shows this relationship, which is modified for a gas-liquid mixture. In this equation, $N_{H}, K_{o}$, and $K_{b}$ are cyclone geometric configuration constants, $\rho_f$ is the fluid mixture density, $Q$ is the total fluid flow rate, $D_{c}$ is the cyclone diameter, and $\mu$ is the fluid mixture viscosity raised to power $n$.

$$\Delta P = \frac{N_{H}fQ^2}{2K_o^2K_b^2D_c^4\mu^{-n}}$$

The pneumatic model works well at gas-dominant conditions (GVF >98%), while the hydraulic model is valid in the liquid-dominant region (GVF<95%). Convergence between the models (95%-98% gas fraction) is smoothed using the multiphase model. The mixed model ensures that specific velocity regions
within the cyclone body stay within critical limits for efficient solids removal balanced with a suitable wear life.

The recommended pressure drop depends on the fluid GVF and the duty. In permanent installations, gas- and liquid-dominant flows may exhibit 3-5 psi and 25-50 psi pressure drops, respectively. The upper values of these ranges increase to 20 and 100 psi, respectively, on temporary applications where the desander may only operate for a few days per month, and where it will receive frequent inspection. These values provide a balance for the separation performance, throughput, and insert wear life.

**Separation Size and Collection Efficiency.**

The calculation of the particle separation size and total solids collection efficiency follows a similar approach using hydraulic and pneumatic models. The hydraulic model follows the Arterburn (1978) and Lynch-Rao (1975) bases, while the pneumatic model uses the Leith-Licht (Benítez 1993) formulation; both approaches are corrected for multiphase flow.

For both pneumatic and hydraulic models, all cyclones exhibit a graded efficiency curve for particle capture, as shown in [Fig. 10](#). This curve forms the basis for obtaining the separation size and solids collection efficiency. The graded efficiency curve, also called the reduced recovery curve, plots the normalized particle size (x-axis) versus the particle recovery (capture) to the underflow (y-axis). Dividing the absolute particle size in the inlet stream by the cut size (D50) yields the x-axis value. The D50 is the particle size with a 50% chance of capture in the cyclone. Furthermore, the separation size (D98) is the particle with a 98% chance of capture.

The capture of each particle size is a function of the curve in [Fig. 10](#), with larger particles (in relation to D50) exhibiting higher recovery values. All classifying devices, which separate particles based on the particle weight, exhibit this s-shaped curve. In contrast, size-partitioning devices, such as screens, show a straight line at the aperture (D50) size. A cyclone shows imperfection compared to screens, with an imperfection defined as a deviation from a vertical line. However, a cyclone is “tunable” within the process, as the cut size can be adjusted by changing the operating conditions, while a screen with a specific size always has a fixed separation point.

The curve in [Fig. 10](#) is defined from the cut size and slope. Liquid-dominant flow uses the Arterburn method, where the D50 is calculated from the cyclone geometry (to give a D50-base) and then corrected for operating conditions. The correction factors are (C1) the inlet solids concentration, (C2) the multiphase pressure drop, (C3) the fluid mixture density, and (C4) the fluid mixture viscosity. The D50-base is multiplied by the correction factors to yield the operating D50. The D50, slope (α), and particle size (D) are combined in the Yoshioka-Hotta relationship (Eq. 6) to yield the classification curve (Yoshioka and Hotta 1955). The inlet particle size range, from a very small to a very large range normalized to D50, are plotted from the curve in [Fig. 10](#).

\[
Y(x) = \frac{e^{ax-1}}{e^{ax}+e^{-a}} \times 100, \quad x = \frac{D}{D_{50}}
\]  

(6)

The slope or sharpness of separation has a value of 4.0 for sand in water. The particle size with a 98% chance of capture is termed the separation size. At a slope of 4.0, the D98 is approximately twice the size of the D50. A desander with a 15 micron cut size has a 30 micron separation size. The total solids recovery is calculated by determining the percentage recovery for each inlet particle size and summing the individual weights. The total mass of solids that report to the accumulator divided by the total inlet solids mass results in the recovery efficiency.

Gas-dominant flow uses the Leith-Licht mechanistic model, which is modified for wet gases. This relationship, shown in Eq. 7, calculates the individual particle size (Dp) collection efficiency (η) from geometric parameters (K, Cc, and Dc), volumetric throughput (Q), particle and fluid mixture density (ρp and ρf), temperature (T), and fluid mixture viscosity (μ). The collection efficiency summed for each inlet particle size yields the total recovery. The particle at 98% collection efficiency is the separation size.
\[ \eta(D_p) = 1 - \exp(-\psi D_p^M), M = \frac{1}{m+1}, m = 1 - (1 - 0.67D_p^{0.14}) \left( \frac{T}{283} \right)^{0.3}, \]

\[ \psi = 2 \left[ \frac{K Q (\rho_p - \rho_f) \mu T (m+1)}{18 \nu_f D_p^3} \right]^{M/2} \]

Similar to the pressure drop model, gas-dominant flow (>98% GVF) uses the pneumatic model, while liquid-dominant flow (<95% GVF) uses the hydraulic model. Convergence in the 95%-98% gas fraction range is smoothed with the multiphase model. A multiphase desander has a 10-20 micron and 30-40 micron separation size in gas- and liquid-dominant flows, respectively. As a rule of thumb, a multiphase desander will remove the size of solids that would settle in the production separator.

**Turndown and Slugging Response.**

The turndown (flow rate change) performance of the multiphase desander is strongly dependent on the gas void fraction of the inlet fluid stream. With liquid-only flow (0% GVF), the turndown is approximately 3:1, while gas-only flow (100% GVF) may have an 8:1 turndown. An average for multiphase conditions is 5:1. The basis of the turndown is to maintain the multiphase desander within a recommended pressure drop range; therefore, the pressure drop is more important than the throughput. Whether the turndown is intentional from the operator or induced from liquid slugging, the unit must be maintained within this recommended range.

The separation size of the multiphase desander will vary as the pressure drop increases or decreases. Fig. 11 illustrates an example of the effect of the flow rate turndown on the pressure drop and separation size. This specific example is based on a 10-inch multiphase desander operating at an inlet pressure of 4500 psig and a temperature of 60°C. The fluids are natural gas, 35 API oil, and produced water at a density of 1060 kg/m³. The watercut in each case is held at 10%. The gas and liquid amounts vary in each example, as listed by the gas void fraction percent.

The upper left figure shows the hydraulic (0% GVF) turndown performance for this unit. Starting from an operating baseline of 13,000 BPD, the desander shows a 25 psi pressure drop and a 24 micron separation size. At the lower recommended operating limit of a 5 psi pressure drop, the liquid flow rate drops to 5,800 BPD, which coarsens the separation size to 38 microns. With a lower pressure drop, there is less rotating energy in the fluid, and therefore, less particles are separated. Increasing the flow to 18,400 BPD brings the unit to a 50 psi pressure drop (the upper operating limit), which decreases the separation size to 19 microns, i.e., the higher spinning energy captures smaller particles. The liquid turndown for this scenario is 3.17.

The upper right graph in Fig. 11 shows the effect of gas introduction. For this graph, all operating points are kept at 50% GVF. Starting with a 25 psi pressure drop baseline, the mixture flow rate is 11,600 BPD of the liquid plus 18.8 MMSCFD of the gas. Reducing the mixture density and viscosity, among other factors, reduces the baseline separation size to 16 microns (compared to 24 microns in the hydraulic case). Free gas has an important benefit in decreasing the separation size and thus increasing the total solids recovery. Lowering the pressure drop to 5 psi reduces the liquid and gas flow rates to 5,000 BPD and 7.9 MMSCFD, respectively, and coarsens the separation size to 26 microns. Ramping the pressure drop to 50 psi increases the liquid flow rate to 16,400 BPD and the gas flow rate to 26.7 MMSCFD, and the new separation size is 13 microns. For this case, the liquid turndown is 3.28, while the gas turndown is 5.45.

In the final scenario, the gas fraction is increased to 90%. All other characteristics remain the same. The baseline pressure drop is decreased to 5 psi, which occurs at a 3,300 BPD liquid flow rate and a 48 MMSCFD gas flow rate. When the baseline pressure drop is decreased, the flow mixture generates the same velocities within critical regions of the cyclone. The baseline separation size is now 13 microns. This fluid mixture has a lower density and viscosity, which allows particles to migrate more easily through the fluids. The lower operating limit is a 2 psi pressure drop, which occurs at a 1,950 BPD liquid flow rate and a 30 MMSCFD gas flow rate. The separation size has slightly coarsened to 17 microns. The new
upper limit is a 12 psi pressure drop (which generates same velocities as the 50 psi pressure drop in the other two cases), with liquid and gas flow rates of 4,400 BPD and 72 MMSCFD, respectively. The separation size drops to 10 microns, which is the practical limit for multiphase desanders.

Turndown may be generated from a long-term fundamental change in the well output (i.e., a change in the choke setting) or induced by slugging conditions. The multiphase desander can handle either type of turndown – generated by changes in the total volumetric throughput or the gas void fraction – as long as the unit stays above the minimum pressure drop limit. The residence time in a multiphase desander is short, and it varies from 0.5-3.0 seconds, depending on size of the unit and the gas void fraction; thus, the residence time responds rapidly to these changes in flow rates. Slugging that imparts a temporary increase in the pressure drop does not hurt the separation efficiency (it will actually improve solids removal); however, if the slugging decreases the pressure drop below the recommended minimum, then the cyclone vortex may collapse, which temporarily negates solids separation. If slugging conditions are expected, the multiphase desander should be undersized to properly treat the lowest flow rate expected.

**Accumulator Operation**

The accumulator must be operated properly to maintain efficient solids removal in the multiphase desander, aid in sand cleaning, and permit slurry transport to other processes or disposal. Fig. 12 shows the accumulator configuration and the order of operation. The operating procedure is the same for both wellhead and wellstream units.

In Step 1, the accumulator is filled with solids from the desander. During this step, the double block and bleed isolation between the desander and accumulator is open, and all other valves are closed. Solids fall freely from the insert apex, through the lower section of the desander, and into the accumulator. These solids displace the water in the accumulator to form a nearly flat layer within the liquid-filled vessel. This solid-liquid interface is measured (Step 2) with a vibrating paddle/rod probe (for ANSI ratings <900#) or a radiometric gamma-level device (for ANSI ratings >900#). Level measurement is used to automate the operating cycle.

Once the solids accumulator is full of solids (determined by the level measurement or timed cycle), the collected solids are purged. The double block and bleed valves are closed to isolate the accumulator. Contained pressure and gas is released through the vent valve (Step 3). The purge valve is opened (Step 4), and water is introduced through the flush/fill port (Step 5) to push out the slurry and transport it to the next handling step. The purge water should be at a 50 psig pressure and from a 25-50 gpm flow rate, depending on the transport distance.

Once the solids are completely purged (3-5 minutes), the purge valves are closed, and the accumulator is filled with clean water. This clean water can be from any source (i.e., produced, fire system, utility, etc.), but it should be substantially free of oil. Filling the accumulator with water prevents the introduction of high-pressure slurry into an empty volume and provides the initial sand cleaning. Sand displaces water as it falls down, but oil does not, and it stays in the desander. The clean water bath also prevents mechanical consolidation of the particles and allows the slurry to flow more freely during the purge cycle. When the accumulator is full of clean water, all utility valves are closed, and the double block and bleed valves are opened to re-pressurize the accumulator and bring it back on-line. A separate re-pressurization line may be installed to minimize wear on the DBB valves.

The entire isolation-purge-fill cycle proceeds for 15-20 minutes under manual operation. During this time, the multiphase desander unit has enough hold-up volume in the lower portion of the housing to maintain solids separation within the cyclone. In this manner, solids separation is continuous, while the solids removal process is a batch process. The operation of the accumulator can be fully automated by adding actuators on all the valves and sequencing the operation based on a level measurement or timed cycle.
Operating Boundaries

The following process boundary conditions should be observed for efficient operation of the multiphase desander.

- **Pressure Drop**: The minimum and maximum pressure drop is a function of the fluid gas void fraction and critical velocities within the cyclone insert. Increasing the GVF decreases both the minimum and maximum pressure drop. The recommended ranges are 3-5 psi for the minimum pressure drop and 25-75 psi for the maximum pressure drop, with the lower value in each range for gas-dominant wells and the higher value for liquid-dominant wells. The operating pressure drop will impose a back pressure on artificial lift wells.

- **Fluid Mixture**: A properly designed multiphase desander, with a correct cyclone flow path, will operate effectively from 0-100% GVF – all liquid, all gas, or anywhere in between. Increasing the gas reduces the fluid density and viscosity, which improves the solids collection efficiency.

- **Turndown**: The operating turndown of the multiphase desander is a function of the fluid mixture rates. For hydraulic flow, the turndown is 3:1, while in multiphase flow, the turndown is approximately 5:1. The multiphase desander is designed to have interchangeable cyclone inserts across a size range (i.e., 4, 6, 8, and 10-inch inserts for the same unit); thus, the turndown can be extended to 20:1 by changing the inserts.

- **Slugging**: The multiphase desander can handle liquid, gas, or multiphase slugs as long as the pressure drop is maintained above the minimum limit. Due to the very low residence time (0.5-3.0 seconds), the multiphase desander can react to slugging conditions while maintaining solids separation.

- **Fluid Properties**: The multiphase desander will separate solids as long as they are denser than the continuous phase fluid. The continuous phase is a mixture of gas and liquid, and the gas fraction significantly decreases the effective density. The Fluid viscosity is a practical concern in oil & gas, as heavy oils are frequently encountered. The recommended fluid viscosity limit is 200 cP; however, this is the in-situ value (i.e., at P and T, and with solution gas) and not the dead oil value (Marquez and Brito 2014). In addition, this practical limit assumes multiphase flow (gas, oil, water mixture); therefore, even heavy oil with a high gas content may be operable.

- **Particle Size**: Raw well flow introduced into a multiphase desander will have a wide range of particle sizes. Produced solids may have not only formation sand and rocks but also debris from drilling or completions. Particles with diameters of several centimeters are often encountered, as gravel, agglomerated solids and broken scale or chunks of rubber from packers or ESP stators. The cyclone insert within the multiphase desander must be capable of handling large particles without plugging. The rule of thumb for cyclones is that they can handle particles up to 1/3 the size of the smallest opening. That smallest opening is usually the inlet or apex orifice within the cyclone insert. A 10-inch multiphase desander can handle particles up to a diameter of 21 mm, which is sufficient for oil wells. Small diameter cyclones, such as that used in the multi-cone design with a diameter of 2 or 3-inch, can only handle 6-9 mm particles and should not be used at the wellhead location due to potential plugging.

- **Particle Concentration**: A high particle concentration in the inlet stream may also cause plugging if the solids overload the cyclone insert. High particle concentrations are encountered during the initial frac flowback or from damaged completions. A 10-inch wellhead desander with a static accumulator (i.e., solids enter the top nozzle, and displaced liquids exit the same nozzle) can treat fluids with 10,000 ppmw (1.0%) solids. Higher solids concentrations may plug the apex; therefore, an apex flux balancing design (see the reference) should be implemented. This minor design change can increase the handling capability up to 10% solids. At a very high solids concentration, the limitation for the operation will be the filling and purging of the
accumulator in a sufficient time to enable continuous separation; therefore, the accumulator may need to have a continuous purge.

- **Installation Location**: The multiphase desander can be installed anywhere in the surface facilities. Upstream of the choke has API-6A design, while downstream of the choke has ASME/ANSI design. A subsea version of the multiphase desander with the API-17D design is in development.

- **Applications**: The multiphase desander is used in well testing, well cleanout, ongoing produced solids from failed or open-hole completion, proppant removal, or underbalanced drilling.

- **Utilities**: Clean water, from any source, is required to flush and fill the accumulator during the solids purge cycle. This water should be at a 50 psig pressure and a 25-50 gpm flow rate, depending on the slurry delivery distance.

- **Consumables**: Standard cyclone inserts are made of duplex stainless steel with a 1-2 year life under normal operating conditions. A monolithic silicon carbide insert can be used for extreme wear applications.

- **Process Connections**: A multiphase desander system has five standard process connections: the inlet, clean fluid outlet, solids discharge, accumulator vent, and accumulator flush & fill (water).

- **Effects of Chemicals**: Well fluids have natural and artificial chemicals present. Any chemical that increases the fluid viscosity, stabilizes emulsions, or allows oil to wet the solids is detrimental to the operation. Beneficial chemicals are those that decrease the fluid viscosity, break emulsions, or reduce oil wetting on solids. Flocculants are not effective for increasing the solids recovery, as the agglomerated fine solids, “flocs”, break apart in the cyclone vortex flow due to the high shear stress.

**Limitations to the Operation.**

The multiphase desander, especially at the wellhead location, is the most important sand management tool for surface facilities. Limitations to its operation are summarized as follows:

- The required operating pressure drop, up to 25-50 psi, will impose a backpressure on artificial lift wells. Thus, the energy required to operate the unit may be too high for wellhead pressures.

- Solids separation is very poor when the liquid viscosity exceeds < 200 cP. The wellhead desander may not be applicable to some production installations such as SAGD, CHOPS, or heavy crude.

- The subsea wellhead desander is still in development; therefore, the technology is currently only applicable on surface facilities.

- A multiphase desander may require a 4-6 meter installation height, which exceeds the available limit of some structures.

**Mechanical Design**

A multiphase desander has three main components: the desander housing, cyclone insert, and solids accumulator in addition to an assembly of valves, piping, and instruments. The layout of this technology, as a wellhead desander system, is shown in Fig. 7.

The desander housing contains the operating pressure and holds the cyclone insert. When installed at the wellhead, the housing conforms to API-6A/ISO-10423 and ASME BVPC Section VIII Division 2 codes at 5K/10K/15K ratings. The post-choke installation is an ASME BVPC Section VIII Division I vessel with a 150#-1500# rating. The API-6A unit is designed for full shut-in pressure, and thus, no PSV is required. The housing is made from forged 4130 carbon steel or UNS31803 duplex stainless steel, and it has NACE MR0175/ISO-15156 compliance. The solids accumulator is built from the same material and to the same specifications as the desander housing.

The cyclone insert is specifically designed for multiphase flow solids separation and to contain erosion. Inserts are replaceable and interchangeable within the desander housing. A wellhead desander housing
can fit a 4, 6, 8, or 10-inch diameter insert, with each insert sized for a specific flow range. The standard material for constructing the insert is a duplex stainless steel base with a tungsten carbide internal coating. An alternate construction is from monolithic silicon carbide. Both designs are shown in Fig. 13. At recommended operating conditions, the standard material offers a 1-2 year wear life, while the silicon carbide unit is used for extreme erosion cases. Inserts weigh from 20-85 kg, depending on the diameter.

A double block and bleed valve arrangement, shown in Fig. 14, is used to isolate the accumulator during the solids purge cycle. Valves for this duty should be designed for a high-pressure slurry application. The recommended design is a slab gate type valve with a forged 4130 CS body and a 410 SS wetted component. A hard facing (tungsten carbide or nitride or Stellite®) on the trim is also recommended. Valves are normally specified with material class DD-NL or EE-NL and PSL3/PR1 certification. These valves can be automated, but they are normally used under manual operation.

**Housing Design: API versus ASME.**

At wellhead conditions, an API-designed single cone housing is more compact than a multi-cone ASME design. Fig. 15 shows the size and weight of wellhead desanders designed for a 10,000 psig maximum allowable working pressure (MAWP). Each unit processes 100 MMSCFD gas plus 7,500 BPD liquids. The left wellhead desander is a multi-cone design built to ASME Sec VIII Div 1 code. The operating weight of this unit is 11,800 kg. For the same flow rate and using a manual API-6A approach, a central unit, which weighs 62% less, is obtained. Refinement of the API design using advanced design analysis results in the design on the right, which has an operating weight of 1,771 kg. This weight is only 15% of that of the first unit shown. A wellhead desander does not have to be a large, heavy piece of equipment; instead, it can be strategically designed to fit within most any wellbay scenario.

**Mechanical Requirements.**

A summary of the mechanical design requirements for the multiphase desander is listed as follows:

- **Footprint:** A multiphase desander has a 1.0 m² footprint for the bare equipment and a 1.5-2.0 m² footprint for a basic skid with valves, piping, and instruments
- **Height:** The installation height ranges from 3-5 meters, depending on the accumulator size
- **Weight:** The bare equipment ranges from 2,000-4,000 kg, with the full skid at a 10,000-25,000 kg total weight
- **Pressure Rating:** Wellhead units are API-6A designed at 5K, 10K, and 15K rating, with wellstream units at ASME designs from 150#-1500# rating.
- **M.O.C:** The standard material for fabricating the desander housing and accumulator is carbon steel (4130, 75K min. yield forgings), with alternate materials, such as F22, UNS 31803, and UNS 32670. Inserts are made from duplex SS (UNS 31803) with an HVOF tungsten carbide coating. An alternative insert material is monolithic silicon carbide.
- **Instrumentation:** The minimum instruments required are a pressure indicator on the desander inlet and accumulator vent and a differential pressure indicator from the desander inlet to overflow
- **Valves:** Slab gate valves are required for accumulator isolation (2), solids discharge, accumulator vent, and accumulator fill. Valves are normally manually operated, but they can be automated.

**Equipment Layout**

Drawing schematics that show the basic and extended wellhead desander systems are presented in Fig. 16. The left image depicts a simple integration scheme with primary inlet and outlet and accumulator connections. The equipment in this design can be integrated directly into the well facility without a support skid. The right image shows the piping configuration for a portable well test skid used in stand-alone operations. Included with the extended scope are an on-skid bypass, various tubing points for pressure monitoring and bleeds, and spec breaks that are integrated with utilities.
Integrated versus Skid Design.

The multiphase desander can be installed as an integrated unit or with a skid-based design. **Fig. 17** (left) shows a photograph of a 1500# rated 10-inch wellhead desander integrated into the wellbay of a deepwater spar offshore facility in Malaysia (Loong et al. 2014). This site has ten wellhead desander units to address long-term sand production, and integrating the equipment into the piping and support structure of the existing wellbay provided the most effective layout option. The spar has dry tree wells, and the wellhead desanders were installed between the flexible jumpers and the wellhead chokes. The middle photo in **Fig. 17** shows a 900# rated 10-inch wellstream desander installed on a shallow-water fixed platform in Turkmenistan. This unit was installed at the feed to the test separator and was initially installed as a short-term unit with a simple skid frame. Oil production from this particular well was increased from 200 BPD to 500 BPD by using the WSD; therefore, the unit was bolted to the deck as a permanent installation (Rawlins 2013). The photo at the right in **Fig. 17** shows a portable frame 15K-rated wellhead desander used for well testing. This skid is transported horizontally and put upright at site. The skid is designed as a portable offshore unit to DNV 2.7-1 and 2.7-3 codes. The multiphase desander can be packaged to meet any onshore or offshore requirements.

Troubleshooting Operation

A matrix for troubleshooting the operation of a multiphase desander is listed in **Table 2**. A corrective course of action can be determined if the unit experiences problems with the pressure drop, separation efficiency, insert life, or accumulator purging.

Summary

All oil and gas wells produce sand; therefore, all process design should include a consideration for sand management facilities. The multiphase desander is specifically designed to protect facilities from the damaging effects of sand. This technology is most commonly installed at the wellhead, where it can protect the choke, flowlines, separator, and downstream processing equipment. An alternate installation location is on the flow line manifold upstream of the separator. Removal of sand at the wellhead can restore production from shut-down wells or increase production from choked-back wells, with the net result being an increased hydrocarbon production at the facilities. The wellhead desander is compact, and it can be integrated into any existing well bay or platform facility. Sand removed at the wellhead is easily transported and handled. A single cone wellhead desander operates on full gas or full liquid flow (0-100% GVF). The multiphase desander can be designed to API-6A specifications (5K/10K/15K rating) or ASME designs (150#/1500# rating).

Nomenclature

- $a$ = cyclone geometric factor for pressure drop calculation
- $b$ = cyclone geometric factor for pressure drop calculation
- $c$ = volume fraction of solids in the fluid
- $C_c$ = cyclone geometric configuration constant
- $D$ = particle diameter
- $D_{50}$ = cyclone cut size
- $D_b$ = cyclone body diameter
- $D_p$ = particle diameter (for gas cyclone calculation)
- $G$ = empirical pressure drop factor for multiphase flow
- $k$ = empirical pressure drop factor for liquid flow
- $K$ = cyclone geometric configuration constant
- $K_a$ = cyclone geometric configuration constant
- $K_b$ = cyclone geometric configuration constant
- $n$ = power factor for viscosity correction
NH = cyclone geometric configuration constant
\( \Delta P \) = cyclone pressure drop (inlet-overflow)
Q = liquid flow rate
T = temperature
x = ratio of particle size to cyclone cut size
Y = percentage solids recovery to underflow

**Greek Letters**
\( \alpha \) = sharpness of separation on recovery curve
\( \eta \) = collection efficiency
\( \mu \) = fluid viscosity
\( \rho_f \) = fluid density
\( \rho_p \) = particle density

**References**
the SPE Annual Technical Conference and Exhibition. New Orleans, LA, USA, 30 September-2 October.


### SI Metric Conversion Factors

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Conversion Factor</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>°API</td>
<td>(141.5/(131.5+°API))</td>
<td>g/cm³</td>
</tr>
<tr>
<td>BPD</td>
<td>(x0.15897E+00)</td>
<td>m³/d</td>
</tr>
<tr>
<td>cP</td>
<td>(x1.0E-03)</td>
<td>Pa·s</td>
</tr>
<tr>
<td>°F</td>
<td>((°F-32)/1.8)</td>
<td>°C</td>
</tr>
<tr>
<td>gpm</td>
<td>(x6.3083E-05)</td>
<td>m³/s</td>
</tr>
<tr>
<td>inch</td>
<td>(x2.54E+00)</td>
<td>cm</td>
</tr>
<tr>
<td>MMSCFD</td>
<td>(x2.831684E+04)</td>
<td>std m³/d</td>
</tr>
<tr>
<td>psi</td>
<td>(x6.894757E+00)</td>
<td>kPa</td>
</tr>
</tbody>
</table>

### Author Biography

C. Hank Rawlins (hrawlins@eprocess-tech.com) is the Technical Director for eProcess Technologies in Houston, TX, USA. He has 25 years’ experience in research and process engineering in the upstream oil & gas industry. He is responsible for development programs in facilities sand management, produced water treatment, and compact separations systems. Dr. Rawlins has fifty-two publications and is an active member of SPE where he served as past chair of the Separations Technology Technical Section (STTS). He holds a PhD in metallurgical engineering from Missouri S&T University, and is a registered engineering in the state of New York.
## Tables

### Table 1. Comparison of WHD and WSD locations

<table>
<thead>
<tr>
<th>Unit Name</th>
<th>Wellhead Desander (WHD)</th>
<th>Wellstream Desander (WSD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process Location</td>
<td>Upstream of choke</td>
<td>Downstream of choke and before separator</td>
</tr>
<tr>
<td># Wells Treated</td>
<td>Single well</td>
<td>Multiple wells (Manifold)</td>
</tr>
<tr>
<td>Equipment Protected</td>
<td>Choke, flow line, separators, and produced water system</td>
<td>Separators and produced water system</td>
</tr>
<tr>
<td>Pressure Drop</td>
<td>Uses wellhead flowing pressure, most which is already lost to choke</td>
<td>Uses post-choke pressure</td>
</tr>
<tr>
<td>GVF</td>
<td>High wellhead pressure yields a lower GVF and a smaller WHD size</td>
<td>Lower flow line pressure yields a higher GVF and a larger WSD size</td>
</tr>
<tr>
<td>Mechanical Rating</td>
<td>API-6A, no PSV required</td>
<td>ASME, PSV required</td>
</tr>
<tr>
<td>Sand Quality</td>
<td>Easy to separate, clean, and handle</td>
<td>Easy to separate, clean, and handle</td>
</tr>
<tr>
<td>Skid Design</td>
<td>Typically, components are integrated into the wellbay (no skid)</td>
<td>Full skid design</td>
</tr>
</tbody>
</table>

### Table 2. Troubleshooting matrix for operation of multiphase desander

<table>
<thead>
<tr>
<th>Operating Area</th>
<th>Symptom</th>
<th>Cause</th>
<th>Corrective Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure Drop</td>
<td>Too high</td>
<td>Insert too small</td>
<td>Install larger insert</td>
</tr>
<tr>
<td></td>
<td>Too low</td>
<td>Flow rate increased</td>
<td>Check flow rate and install larger insert</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Insert plugged</td>
<td>Remove and inspect insert</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pressure gauge error</td>
<td>Check calibration on differential pressure instrument</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Insert too large</td>
<td>Install smaller insert</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flow rate decreased</td>
<td>Check flow rate and install smaller insert</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Insert worn out/failed</td>
<td>Check integrity of insert</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pressure gauge error</td>
<td>Check calibration on differential pressure instrument</td>
</tr>
<tr>
<td>Separation Efficiency</td>
<td>Too much solids in overflow</td>
<td>Pressure drop too low</td>
<td>Install insert appropriate for well flow</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Accumulator full</td>
<td>Purge accumulator and flush solids from desander</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Insert plugged/damaged</td>
<td>Open desander and unplug insert apex</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High sand concentration in feed stream</td>
<td>Dilute feed stream</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sand particle size too small for insert</td>
<td>Confirm inlet size distribution, increase pressure drop or reduce insert size</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Liquid phase viscosity too high</td>
<td>Add dilution water, increase pressure drop, or reduce insert size</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Insert plugged/damaged</td>
<td>Open desander and unplug insert apex</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DBB closed</td>
<td>Open DBB during desander operation</td>
</tr>
<tr>
<td>Insert Wear Life</td>
<td>Insert lasting &lt; one year</td>
<td>Pressure drop too high</td>
<td>Decrease pressure drop within recommended range</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Accumulator full and solids backing up into insert</td>
<td>Purge accumulator more often</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sand morphology especially abrasive</td>
<td>Use silicon carbide insert</td>
</tr>
<tr>
<td>Accumulator Solids Purge</td>
<td>Solids not purging from accumulator</td>
<td>Insufficient flush water pressure or volume</td>
<td>Increase flush water pressure (to 50 psig) or volume (to 25-50 gpm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Faulty valve operation</td>
<td>Refer to valve vendor manual and repair valve</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flush line downstream of accumulator plugged</td>
<td>Inspect and clear flow line, use higher volume of flush water to increase velocity</td>
</tr>
</tbody>
</table>
Figures

1. **SEPARATE**
   - WELLHEAD DESANDER
   - SC OR MC DESANDER
   - SAND JET
   - VESSEL SLOPS
   - TANK BOTTOMS

2. **COLLECT**
   - ACCUMULATE
   - CONCENTRATE
   - YES
   - SAND WASH
   - Solids
   - Dump / Purge
   - OVERBOARD TO CAISSON
   - Injection to Disposal Well

3. **CLEAN**
   - CLEAN
   - Solids
   - DISPOSAL METHOD
   - YES
   - NO
   - OVERBOARD TO CAISSON
   - Collection

4. **DEWATER**
   - FILTER BIN
   - YES
   - DEWATER
   - YES
   - HAZARDOUS
   - NO
   - DEWATER
   - YES
   - FILTER BAG
   - YES
   - NO
   - CLOSED COLLECTION
   - LAND (TRUCK)
   - ONSHORE (SHIP)
   - PIPELINE
   - CONTAINED TRANSPORT
   - LAND (TRUCK)
   - ONSHORE (SHIP)
   - CONTAINED TRANSPORT
   - LAND (TRUCK)
   - ONSHORE (SHIP)
   - OPEN COLLECTION
   - LAND (TRUCK)
   - ONSHORE (SHIP)
   - OPEN COLLECTION
   - LAND (TRUCK)
   - ONSHORE (SHIP)
   - INJECTION TO DISPOSAL WELL
   - LIQUIDS TO CLOSED DRAIN OR PROCESS
   - SOLIDS
   - LIQUIDS TO CLOSED DRAIN OR PROCESS
   - SOLIDS

5. **TRANSPORT**
   - SOLIDS
   - LAND (TRUCK)
   - ONSHORE (SHIP)
   - PIPELINE
   - LIQUIDS TO CLOSED DRAIN OR PROCESS

Fig. 1–Flow sheet depicting the five steps of sand management to ensure that sand is handled from separation to disposal.

Fig. 2–The four nodes of sand separation showing locations in the process system.

Fig. 3–Types of cyclonic devices and their characterization as pneumatic or hydraulic cyclones.
Fig. 4–Illustration of a standard open-underflow hydrocyclone (left) for the continuous discharge of solids versus a closed-underflow flooded-core hydrocyclone (right), termed a desander, which enables the batch discharge of solids. The desander does not contain an air core at the center of the vortex.

Fig. 5–Photograph of the first wellhead desander deployed on the Brent D platform in the UK for sand/coal removal during the coiled tubing cleanout of an oil well.

Fig. 6–Photographs of multiphase desanders used in upstream oil & gas (left to right): 5K WHD integrated on a gas platform in Malaysia, 15K skid-based WHD for well testing in Oman, and 900# WSD, which protects an offshore test separator in Turkmenistan.
Fig. 7–Schematic of the wellhead desander showing the Desander Housing, Cyclone Insert, and Solids Accumulator along with the flow path of the well fluids, vent and flush lines, and batch solids discharge.

Fig. 8–Images showing the insert style (left) and liner style (right) packing of desanders. The subset images show the gas-liquid-solid flow distribution for each design, with the insert design used for treating the integrated flow, while the liner design exhibits an unequal fluid partitioning.
Fig. 9–Illustration of the trajectory of particles in the multiphase desander unit (left) and accumulator unit (right) along with the distribution of gas-liquid-solids (middle).

Fig. 10–Graded efficiency curve for desander particle capture, showing the cut size ($D_{50}$) and separation size ($D_{98}$).
Fig. 11–Turndown performance effect on the pressure drop and separation size of a 10-inch multiphase desander at 0%, 50%, and 90% gas void fraction amounts.

Fig. 12–Configuration of the solids accumulator for operation steps: (1) fill with solids, (2) level measurement, (3) vent, (4) purge solids, and (5) fill with clean water.
Fig. 13–Photographs of a standard duplex stainless steel cyclone insert (left) and a monolithic silicon carbide insert (right).

Fig. 14–Photograph of an ANSI 1500#-rated double block and bleed valve arrangement between the wellhead desander and accumulator on an offshore deepwater platform in Malaysia (Loong et al. 2014).
Fig. 15–Comparison of wellhead desander designs with 10K rating, which treats 100 MMSCFD gas plus 7500 BPD liquids. The left illustration shows a multi-cone configuration with ASME housing. The illustration in the center shows a single cone design with basic API-6A housing, while the image on the right shows a single cone design with advanced API-6A methodology.

Fig. 16–Schematic drawings of a wellhead desander showing the basic (left) and extended (right) configurations of piping and valves.
Fig. 17–Photographs of (left to right) 1500# rated WHD offshore Malaysia, 900# rated WSD offshore Turkmenistan, and 15K rated WHD portable skid for onshore China.