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# Sand Management Methodologies for Sustained Facilities Operations

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## Abstract

Facilities sand management is tasked with the goal of ensuring sustained hydrocarbon production when particulate solids (i.e. sand or proppant) are present in well fluids, while minimizing the impact of these produced solids on surface equipment. Particle size and total concentration of formation sand or proppant determines their net effect on production and the resulting operability of surface facilities. Conventional sand management control focuses on sand exclusion from the wellbore, either by production limits or completion design. Completions may adversely affect inflow due to skin buildup and both controls impede maximum hydrocarbon production. Alternatively, co-production of fluids and solids, with subsequent sand handling at surface facilities, is an inclusion paradigm that allows sustained hydrocarbon production. Produced solids are removed at the wellhead upstream of the choke using fit-for-purpose equipment. This methodology allows for increased or recovered hydrocarbon production, while their removal upstream of the choke protects facilities operations.

A description of the design, performance, operation, and effect on production rate is provided for sand inclusive production through application examples in the Caspian Sea, Indonesia, and South China Sea. Specific reference is given towards wellhead desanding, which forms the greater part of this approach, and has expanded from the first field installation in 1995 in the UK to every major oilfield producing region. Implementation of dedicated facilities sand management technology has resulted in increased hydrocarbon production from sand producing wells, extension of well life on marginal fields, and re-start of shut in wells.

## Introduction

The first industry-wide workshop to address solids handling from downhole generation to topsides disposal inclusive was held by the SPE Gulf Coast Section in April, 2002 in Houston, TX. This workshop was entitled *Facilities Sand Management: Getting the Beach out of Production*. This workshop hosted speakers to discuss sub-surface sand management, sand monitoring & measurement, flow-line erosion, facilities design, separation, solids cleaning, disposal, and slurry injection. Attendee response showed that the leading sand handling needs were subsea separation and disposal, subsurface-surface integration, and increasing the robustness of surface facilities to handle sand production.

Several production companies have started to integrate facilities sand management into their sand control portfolio. Equal merit is given to sand separation at the surface facilities and completion technologies to determine which approach provides sustained hydrocarbon production. Gravel pack and screen completions have a well-established installation and operating base and form the majority of conventional sand control. While controlling sand production in numerous wells, these techniques may still pass sand of <50-125 μm diameter under normal operating conditions, and this sand interferes with facilities operations. In the case of a completion failure, the sand amount and particle size may increase rapidly leading to production restrictions or damaged equipment.

The necessity for a technology that could protect surface facilities equipment (i.e., chokes, flow lines, pumps, separators, valves, etc.) in cases of completion failure, open hole completion, or rapid unplanned sand production led to the development of the multiphase desander for solids removal at the wellhead. Since the implementation of this technology 18 years ago, the wellhead desander has found repeated use as a service tool for the collection of solids during workover or well test operations and as a permanent unit operation to protect surface facilities equipment. Implementation of fit-for-purpose sand handling technology into surface facilities has enabled sustained operations in cases where previous actions were to shut in wells, limit hydrocarbon production, or suffer lengthy and costly maintenance outages.

## Sources, Characteristics, and Problems of Produced Solids

In comparing exclusion approaches (i.e. completions or production limits) versus surface separation methodologies for produced solids, it is necessary to clarify the exact nature of the solids being treated. Produced solids are inorganic, insoluble, non-deformable particulate materials accompanying hydrocarbon fluids production. These solids are produced from oil, natural gas, water, or multiphase wells.

Hydrocarbon liquids may generate particulate-like matter, such as asphaltenes or paraffin waxes, however these materials are typically colloids or gels and are organic, semi-soluble, and deformable and not included in the produced solids category (Civian, 2000). These materials have a specific gravity near that of the hydrocarbon liquid and an agglomeration tendency that precludes effective treatment by screening or separators. Heat or solvent is required to restore inflow production or remove them from piping and facilities equipment.

Inorganic materials may precipitate due to temperature/pressure changes in the wellbore or mixing of injected fluids with reservoir fluid (Civian, 2000). Examples of such precipitates are carbonates (e.g. $CaCO_3$) and sulfates (e.g. $BaSO_4$). These precipitates generally form a continuous scale in rock pore structure or wellbore equipment, and thus discrete particles are only present in very dilute quantities when flow shear or mechanical abrasion removes them from the surface on which they form. Homogeneously formed free-floating scale particulates are thermodynamically unstable and thus they are also present in very dilute quantities. While precipitated crystalline scale can severely reduce inflow, the treatment mechanism is generally chemical (acid or chelating agent), thus topsides separation is not a feasible methodology.

Inorganic particulates that are produced at sufficient size and concentration to require exclusion or separation treatment are generally termed "produced solids". This material can be broadly classified into two categories: indigenous (natural) and foreign material (artificial). Of key interest are the particular physical properties of each solids class that can be exploited for exclusion or separation. These properties include particle size (distribution), shape, density, and concentration. Table 1 lists average properties of these solids that are used in the design of a solids management system.

**Table 1 – Physical Properties of Produced Solids**

| Property | Natural Solids | | Artificial Solids | | |
|---|---|---|---|---|---|
| | Sand | Clay | Proppant | Corrosion Product | Gravel Pack |
| Specific Gravity | 2.5-2.7 | 1.8-2.8 | 2.6-3.6 | 5.5-6.0 | 2.6-3.0 |
| Shape Factor | 0.2-0.5 | 0.1-0.3 | 0.5-0.9 | 0.1-0.5 | 0.5-0.9 |
| Size Range (µm) | 25-600 | <20 | 500-3000 | 10-10000 | 250-3500 |
| Concentration (ppmv) | 5-100 | <5 | to 20000 | <2 | 0 (unless failure) |

**Natural Solids.**

Natural solids arise from the indigenous reservoir minerals. Broadly these are sands, which are detrital grains of mineral oxides (i.e. $SiO_2$), and clays, which are hydrous aluminum silicates that may be detrital or authigenic (Civian, 2000). Sand particles are the load-bearing solids of the formation, while fines (clay) are not part of the mechanical structure (Morgan, 2006).

The majority of sand produced has a specific gravity averaging 2.65. These particles have high angularity leading to poor shape factors (approach to roundness) (Zwolle, 1982). The angularity helps in grain-to-grain locking necessary for good gravel pack filtering. However, the high surface area due to angularity has been shown to detrimentally stabilize oil emulsion, making oil-water separation more difficult. In addition, an increase in particle sharpness increases the erosion potential (Schramm, 1992). The average size varies from well to well, even within the same formation, but typically sand particles are in the range 50-150 µm. Solids concentration will vary day to day within the same well, but even with a good completion a sand prone well may produce 5 ppmv sand. At this concentration, a 10,000 BPD (1590 $m^3$/d) well will produce 5 BPD (0.8$m^3$/d) sand which weighs 2,100 kg. Clays have a similar specific gravity but smaller particle size and usually present in lower concentration. The plate-like structure of clay along with its very fine particle size (<10 µm) make gravity or enhanced-gravity separation difficult. Typically clay particles will flow through the production system in the oil phase to report in the BS&W.

Figure 1 shows optical micrographs of solid particles from an oil well in the South China Sea. These particles were collected in a wellhead desander accumulator and analyzed for apparent density using water immersion pycnometry, particle size distribution using sieve analysis, packing void fraction by bulk density submergence, and particle shape using optical microscopy. The solids exhibited three discrete particle types as delineated by particle size. The <38 µm fraction (15 wt. %) was clay (1.88 s.g.) and the 38-600 µm fraction (83 wt.%) was sand (2.65 s.g.) with traces of corrosion product. The third fraction at >600 µm (1-4 wt. %) showed fossil structures and sandstone agglomerates. The overall average particle size was 110 µm which corresponded well with the design point of 125 µm. However the top particle size as this application showed particles up to 5 mm diameter. Particles of this size cannot be captured through side-pipe sample ports or in Millipore grab samples however they must be factored into equipment design when determining plugging and erosion issues.

Reservoir detritus is generated through workover operations, degradation of the formation rock, or fluid transportation from deeper in the reservoir. Production and workover operations lead to residual drilling debris and breakdown of the formation rock near the wellbore, by hydraulic fracturing, or acid stimulation. Natural solids generated by workover methods may have a very high initial concentration (up to 1 vol.%) after production is resumed, but they rapidly taper off within a few days to a background level <1 ppmv. Therefore, the effects of this type of natural solids are temporary.

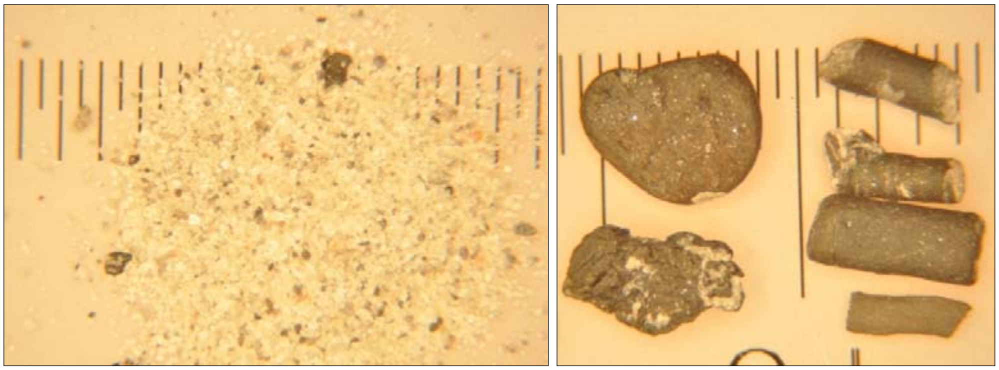

**Figure 1 – Photomicrographs of produced sand from South China Sea oil well. Left photo shows 106-600 micron sand fraction, and right photo shows >600 micron fraction with fossils, corrosion product, and gravel (scale gradations are 500 microns). The solids handling system was designed for 125 micron average sand size, however initial sampling did not detect the presence of oversized particles at 4-5 mm.**

Solids produced by fluid shear degradation of the formation face or from transport deeper in the reservoir have a much longer impact on production. High fluid velocities through the formation pores shear sand and clay particles from the formation matrix and transport these particles to the wellbore. The amount of sand transported reaches a steady state resulting in constant production of sand at generally 5-10 ppmv. Sand production spikes are associated with multiphase flow where transient pressure events impart high instantaneous forces on the formation matrix, or when the fluid front switches from oil to water (i.e., water breakthrough). These events can push the sand concentration to 100 ppmv for short periods.

Predicting the rate of natural solids production is difficult due to the challenge of obtaining robust data from the formation face and surrounding volume. A number of models are available to predict the onset of sanding, but the actual rate has a high amount of uncertainty. Sand monitoring and measurement devices are available to detect catastrophic sanding events or provide on-line measurement of sand concentration. These instruments are necessary in the case of gravel pack failure or to predict the onset of critical sand rates with drawdown. Failure of a gravel pack or screen will result in the production of a large amount of reservoir material built up in the well skin outside the pack plus the associated gravel pack sand. This type of event can be catastrophic to production leading to rapid erosion, well shut-in, lost production, or costly workover.

**Artificial Solids.**

Artificial solids are foreign material introduced by external intervention. This is a broad category that can include fracture sand or proppant, drill mud, cement fines, corrosion products, gravel pack material, and injection fines. Sand from hydraulic fracturing and mud particles from overbalanced drilling have a very high concentration (1-3 vol.%) immediately after workover. This drops to near zero ppmv once the reservoir fluids have flushed the well skin. Gravel pack solids are produced only upon catastrophic failure. A gravel pack does allow small particles of formation material to pass.

Corrosion products have a low concentration level. As the total surface area of metal in the wellbore is very large, they may be produced for months or years. Insufficient filtering of injection water generates injection fines. These fines can migrate through the formation and report into the production well fluids. The amount produced is proportional to the amount injected plus the amount picked up by the fluid as it travels through the reservoir.

Artificial solids have a higher specific gravity compared with natural solids due to their engineered properties of high strength and hardness. Frac sand and gravel pack sand also have a high shape factor for flowability and controllable packing. The particle sizes are also much larger, again due to their design purpose. The concentration of artificial solids is very transient. Frac sand is normally only present for a few days after workover. Gravel pack sand is not normally present except for the case of gravel pack failure when it can spike to a very high concentration for a short period of time.

Generally treatment of artificial solids can be handled as a planned event, especially in the case of hydraulic fracturing or overbalanced drilling. Gravel pack failure is not generally predicted, but the fraction of gravel pack sand reporting to the wellbore is only a small percentage compared with the formation sand.

## Facilities Sand Management Methodology

Incorporating solids management into surface facility design requires more than just installing a separating device. The separated solids may require central collection, cleaning, measurement and monitoring, storage, transport to a disposal site, overboard discharge, or injection disposal. Surface facilities sand handling can be segmented into five unit process areas: separation, collection, cleaning, dewatering, and transportation (Rawlins, 2000).

- <u>Separation</u> is the unit process of diverting the solids and liquids contained in a multiphase stream to different locations. Solids are separated from well fluids with a gravity vessel (i.e., FWKO with a sand jet), desanding hydrocyclone, sand trap, or filter system.
- Upon separation, the solids are <u>collected</u> into a central location and physically isolated from the production process. Gathering the solids to a central location minimizes the pressure letdown points involving sand (i.e. reduces wear

areas), and allows for common subsequent processing. Collection can be accomplished with a simple device such as a desander accumulator vessel or a dedicated sump tank. Physical isolation from the production process may require significant pressure letdown, and thus an appropriate wear resistant slurry valve must be used.

- In many locations, the sand may require cleaning of adsorbed hydrocarbons subsequent to disposal. Dedicated sand cleaning systems based on attrition scrubbing with or without chemicals, or thermal treatment, are available as modular add-on packages or integrated into the separation system (Hess, 1997).
- The total volume of sand slurry transported to disposal can be greatly reduced by dewatering. This involves removing liquids from the collected (cleaned) solids slurry. A range of systems are available for dewatering including a sand drainage bag, filter press, or centrifuge. The final product should have less than 10 vol.% liquid.
- Transportation encompasses the removal, hauling, and disposal of the solids. The design of the haulage system will be dependent upon the location (land-based or offshore) and disposal requirements (i.e., injection disposal well, overboard discharge, landfill, road surfacing, etc.). In many cases, the solids may be mixed with water and disposed overboard or injected into wells (Arfie, 2005).

Surface facility design incorporating solids handling unit processes for both onshore and offshore fields have been documented increasingly in the past 10 years as approaches are taken to increase equipment robustness and minimize downtime (Hadfield, 1996, 1997, Kaura, 2001, Wohlfart, 2006). This work has led to the recognition of facilities sand handling as its own interest area in a previous SPE Production Systems and Facilities technical interest group as well as workshops.

## Methods for Controlling Produced Solids

A wide variety of tools are available to the production engineer for controlling produced solids. These include production limits to maintain sand inflow at a level below a damaging threshold, placement of downhole equipment to prevent sand ingress from the reservoir face, conventional facilities for removing sand that reports to the surface, and separation focused unit process equipment at the surface facilities to improve the robustness of topsides operation.

**Production Limits.**

The simplest method of solids management is to adopt a conservative approach of “Zero Sand Production” (Selfridge, 2003, Tiffin, 2003, Wong, 2003, Palmer, 2003). This approach attempts to establish a maximum sand-free production rate based on drawdown criteria. Using well tests, a map of reservoir pressure versus bottomhole pressure determines the regions of sand free production. While the approach requires minimal CAPEX, it has the drawback of reducing inflow, hence directly reducing hydrocarbon production. In addition, the sand production map is a moving target as any change in the well production profile requires re-determining the map boundaries. Sand monitoring and measurement instruments can detect changes in sand production or actual quantities of sand produced. These instruments can be used as a go/no-go gauge for optimizing drawdown while minimizing sand production (Vaziri, 2006, Balgobin, 2005, Stein, 2005, Musa, 2005). Another approach is dilution of the produced sand. If a single or small group of wells in a large field are the only sand producers, then they can be co-mingled with low sanding wells to dilute the overall sand effect.

**Downhole Equipment.**

In order to maximize hydrocarbon production, the most common method of sand control is installation of equipment to exclude sand from entering the wellbore. Mechanical retention in the form of screens or slotted liners restrains sand from entering with well fluids. Spherical particles will not flow continuously through rectangular slots twice as wide as the diameter of the particle, as long as they flow in sufficient concentration and bridge across the opening due to grain-to-grain contact (Penberthy, 1992). A screen or slotted-liner is seldom used without gravel packing. Placing clean, accurately sized gravel around the periphery of the screen allows for a larger screening area, and the gravel is more robust to erosion than the screen/slotted-liner material. Due to their popularity and frequent installation, gravel pack equipment and techniques have been well studied and are the primary choice for sand control (King, 2003, Price-Smith, 2003, Williams, 2006).

Chemical sand control techniques are available to cement the formation sand grains together for a radius several feet from the wellbore. Plastic consolidation using epoxies, furans, or phenolic resins form a bond between the existing formation particles creating a filter barrier to sand inflow (Penberthy, 1992). This method requires multiple steps to install, such as acid clean, pre-flush, and injection of the resin and catalyst.

Many combinations or offshoots of the above techniques can be used for effective sand control. Expandable and multi-path screens offer greater flexibility and throughput compared with conventional screen liners (Williams, 2006, Iversen, 2006). Pre-coated gravel can be injected to confirm good placement of the consolidating resin. Frac pack incorporates the benefits of hydraulic fracture stimulation with gravel packing. All of these techniques are exclusion methods because they seek to restrain the reservoir material from entering the wellbore.

**Surface Facilities: Conventional Design.**

Conventional surface facility design incorporates equipment to handle normal sand production, however maintenance intervention is still required. These measures include erosion resistant choke design and materials, impact or sacrificial tees in flow lines, profile instrumentation in separators, and sand jet or suction devices for free water knockout (FWKO), 2-phase, 3-phase, and heater-treater separators. All of these techniques, while growing in robustness with proper material selection and improved fluid flow design, still require manual intervention for maintenance. While sand is produced at a steady-state low concentration (<5 ppmv), conventional facilities design will operate satisfactorily between maintenance intervals. However, in the case of transient solid production (i.e., frac flow-back, gravel pack failure, reservoir subsidence leading to formation sand spikes, etc. where solids concentration may jump to 1000 ppmv), these techniques require immediate personnel intervention to prevent shutdown.

Chokes and flowlines must be protected from erosive conditions that lead to catastrophic failure. The relatively simplistic API RP 14E guideline sets limits of flow production velocity, in which an increase in solids concentration leads to a decrease in flow velocity. To allow for conservative operation in the case of solids concentration spikes and to prevent erosive failure, production rates are typically reduced.

Solids cause multiple problems in gravity-based production separators. As large solids (>50 µm) settle in separating vessels, the residence time for oil-water separation is decreased resulting in a reduction in throughput. Periodic shutdown requiring manual removal of solids may be required to restore the production rate. In addition, settled solids form a layer in which sulfate-reducing bacteria grow resulting in accelerated corrosion. Small solids (10-30 µm) also report to the oil-water interface where they stabilize emulsions, further reducing separator efficiency (Schramm, 1992). Large solids that travel through the separator (due to short-circuiting or reduced residence time) report to the water treating circuit, where they fill up flotation cells and erode or plug deoiling hydrocyclones. Finally, these solids will report to the disposal well leading to increased injection backpressure.

**Surface Facilities: Solids Separation Design.**

The best location for surface solids removal is prior to the choke as shown in Figure 2. Pre-choke removal protects all downstream equipment, including the choke orifice, flow lines and piping, production separators and treaters, heat exchangers, control valves, and produced water treating equipment. Solids upstream of the choke are at the highest temperature of the facility and uncontaminated from most production chemicals rendering these solids the most easy to clean once separated prior to the choke. In regards to cyclonic technology, solids are most easily removed from multiphase streams as the increased gas void fraction (GVF) reduces the continuous phase viscosity and density permitting increased settling velocity of the solids. The wellhead desander, detailed in subsequent section, is a specific device designed to separate solids from multiphase fluids and can be installed upstream of the choke. The wellhead desander consumes some of the pressure normally taken across the choke bean thus lessening the erosion burden and converts that pressure to useable separation energy.

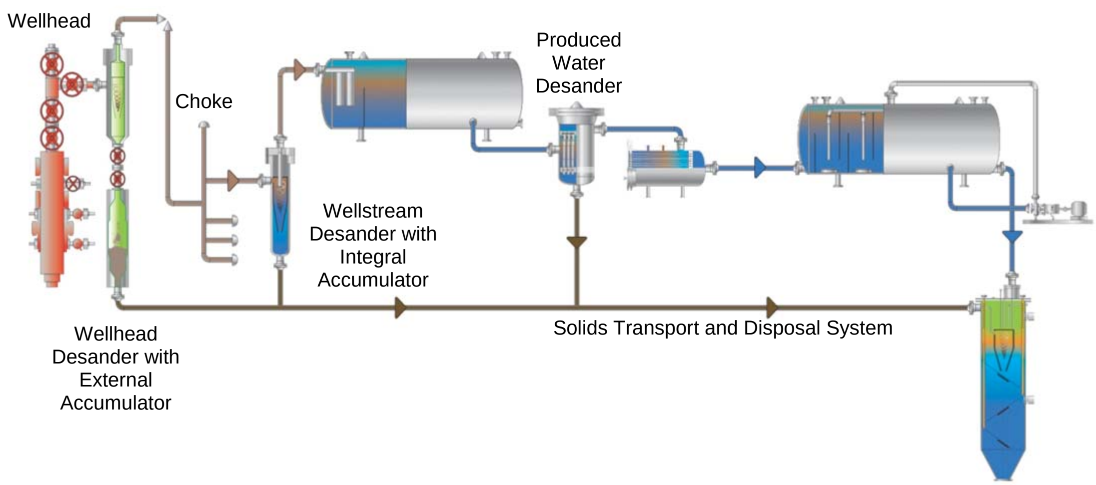


**Figure 2 – Location of cyclonic based solids separation equipment in surface facilities.**

If facility location (i.e. subsea) or space constraints prohibit removal of solids upstream of the choke, then a multiphase (wellstream) desander can be installed downstream of the choke prior to the production separators as shown in Figure 2. This location has similar advantages to that listed previously, however the choke (bean) will not be protected. The lower pressure at this location permits a lower vessel pressure rating, however it also increases the actual gas flow rate which increases the equipment size. Solids collected at this point are normally still easy to clean and handle.

Solids that report to the production separator are still treatable with separation equipment but lose some of the advantages of removal at the choke. Fine solids (<25 µm) in the production separator will either flow through and out with the oil phase or report to the oil-water interface stabilizing the emulsion/rag layer. These solids are normally lost to the oil phase forming part of the BS&W. Large solids (>200 µm) settle in the production separator and require removal by maintenance cleanout or with spray or cyclonic jetting (i.e. eJECT™) equipment.

Medium solids (25-200 µm) eventually flow through and out with the water phase to the produced water treating system. In the produced water stream these solids erode or plug oil removal equipment, contribute to oil & grease content through hydrocarbon coating, and interfere with produced water reinjection. Solids in the produced water stream are best removed through a liquid desander located on the outlet piping of the separator and upstream of the level control valve as shown in Figure 2. At this location pressure from the separator is available to drive the cyclonic separation and the solids still have sufficient temperature assist in subsequent handling.

Low pressure unit processes for solids removal are typically employed at the end of the produced water treatment system where flowing pressure and temperature are reduced to near atmospheric. These unit processes include corrugated plate interceptors (CPI), nut shell filters (NSF), and cartridge filters (CF). These devices all have larger footprint and weight than cyclonic technologies and are primarily employed onshore. CPI devices provide coarse (>25 µm) solids removal at very low operating pressure. NSF and CF are mostly used in water injection systems to remove solids down to 2-5 µm in diameter (Rawlins, 2010).

## Wellhead Desander Design

The driving factor for development of the wellhead desander (WHD) was to extend the operability of cyclonic technology to the multiphase flow regime. Since the 1960's, desanding hydrocyclones have been used to remove sand from produced water prior to injection, but their operability in mixed gas-liquid streams was unknown. In 1995, the first wellhead desanding hydrocyclone was tested at the BP Wytch Farm production facility (Hadfield, 1996, 1997). This test culminated the work of a joint industry project (JIP) to develop a multiphase version of a liquid desanding hydrocyclone for continuous removal of solids prior to the choke and resulted in an understanding of the design and operation of the wellhead desander.

The first WHD applications focused on well cleanup applications such as coiled tubing wash and frac flowback capture (Hadfield, 1996, Kaura, 2001). Operating at wellhead conditions, these units were built to 10 ksi (68,950 kPa) rating and handled up to 15,000 BPD (700 m³/d) condensate and 105 MMSCFD (3 MMm³/d) gas. Handling up to 1 lb/bbl (2.85 kg/m³) of solids, the units separated 95-98% of the solids down to 10µm. Multiphase desanders have now been installed in more than 50 surface facilities, both onshore and offshore, with design ratings from 150# ANSI to 15K API. Installations have been made both upstream and downstream of the wellhead choke, in heavy oil, HPHT, gas-condensate, and gas-only applications.

Multiphase desanders operate based on a combination of hydraulic and pneumatic cyclonic principles (Rawlins, 2002). As with all cyclonic devices, pressure energy is converted to radial and tangential acceleration to impart centrifugal forces on the contained fluids. The increased forces accelerate the separation of phases with different densities. In the case of a multiphase desander, solids are separated from the gas-liquid mixture. The forces imparted are 400-5000 times greater than gravity, leading to rapid separation of solids from fluids and also rendering the cyclone unaffected by external motion or orientation. The separated solids collect into an accumulator chamber (external or integral) for periodic isolation and batch discharge while the well fluids maintain continuous flow as shown in Figure 3. Cyclonic technology has the highest throughput-to-size ratio of any type of static separation equipment resulting in minimal installed footprint and weight (Rawlins, 2003). Figure 3 shows a 1500# wellhead desander with oversized accumulator integrated into the well bay of a production spar.

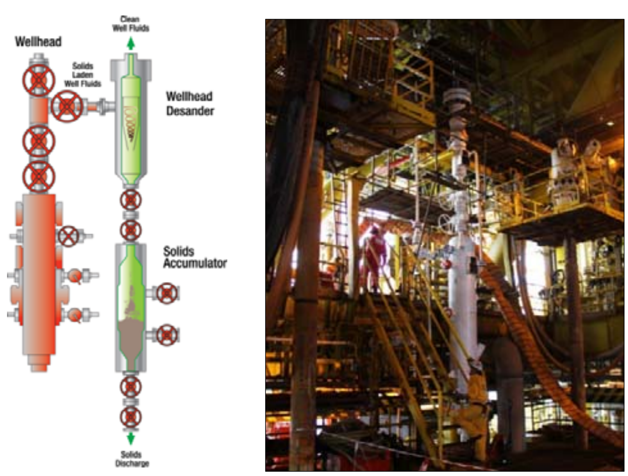


**Figure 3 – (left) Schematic of wellhead desander operation, and (right) photograph of 1500# wellhead desander with oversized accumulator integrated into well bay of spar facility.**

Surface multiphase desanding has found use as a well service tool and as a part of the facilities processing equipment. As a service tool, it is installed upstream of the choke for the removal of solids from workover operations. Applications include frac flowback, well testing, coiled tubing washout, under-balanced drilling, or acid washing. In serving as part of the facilities, the multiphase desander is installed before or after the choke. The only difference in design (pre or post choke) is the pressure rating of the vessels. Operability of the multiphase desander is the same regardless of the pressure rating. Removal of solids prior to the wellhead protects the choke, flow line, and all facility separation equipment. Removal of solids after the choke allows for a lower pressure rating design while protecting facility separation equipment.

The initial few dozen installations of multiphase desanders occurred in critical applications where downhole equipment provided insufficient protection to topsides equipment. With increased use and improved prediction models, the multiphase desander has become a valuable tool in overall sand management.

## Case Studies

Although sand is present and increasing in the oil fields on the Sinai region, it is most significant in onshore gas dominated production in the Egyptian Mediterranean and Delta regions. At many asset sites the onset of sand from well production and the resulting effect on production equipment was not factored into the initial facilities design. Retrofit of sand management equipment and corresponding mindset in handling the now permanent presence of sand is required to return these assets to sustainable production.

Brownfield installation, or retrofit, of sand separation equipment into facilities is a common method of handling unplanned sand production. Surface facility separation design is shown in Figure 2 and detailed in the paragraphs preceding this figure. The final retrofit design is an economic decision balancing sand production issues (i.e. erosion, plugging, production decrease, etc.) with space, weight, and process constraints. Several case studies are listed showing wellhead desanding equipment that was retrofit into existing application in shallow water, onshore, and deep water. Each case removed the produced sand, thus minimizing interference of sand with the facilities, and resulted in an increase in hydrocarbon production.

### Caspian Sea – Shallow Water Fixed Platform.

In 2011, offshore west of Turkmenistan in the Caspian Sea an operator experienced gravel pack failure of an oil well on a fixed platform in 8 m water depth. The onset of sand production began to interfere with oil production due to filling of the production separator and erosion of valves. A wellhead desander was mobilized to the platform as an expedient measure to remove the sand from production while a completion re-work was scheduled as permanent solution. A 900# rated wellhead desander fabricated was supplied as a minimal skid as shown in Figure 4. The skid comprised of a carbon steel wellhead desander with duplex stainless steel insert, external 180 liter accumulator vessel, skid frame, and manual valves. The unit was connected to the well manifold downstream of the choke, with the clean fluids discharging to the test separator. Separated sand is collected into a tote and shipped to shore for landfill disposal.

Prior to startup of the wellhead desander the wells were flowing at 300 BPD (47.7 $m^3$/d) oil with 2-7% watercut and 0.5 MMSCFD (0.14 $Msm^3$/d) gas. Wellhead tubing pressure and temperatures were 72 barg (7200 kPa) and 15-20°C, respectively. The resulting pressure drop across the wellhead desander was very low at 0.3 bar (30 kPa), however due to low oil density (39 API) and high gas void fraction (>93%) the separation size was 23 microns. Effectively the wellhead desander removed >98% of the sand from the well fluids. Ongoing operation of the well showed a continuous steady removal of sand and the wellhead desander was placed on site beyond initial cleanup. As the wells were unloaded of sand and the skin factor decreased, the wells experienced a serendipitous 500 BOPD (79.5 $m^3$/d) increase in oil production. This benefit resulted in cancelling of the workover and permanent installation of the wellhead desander on the platform.

**Figure 4 – Photograph of 900# wellhead desander system installed on shallow platform in Caspian Sea.**

**Indonesia – Onshore Gas Field.**

An onshore Indonesian operator in East Kalimantan shut in 30 gas wells in the field due to excessive sand production. The sand morphology and piping velocities lead to erosive failure in several of the surface flow lines. The high sand producing wells were shut in to minimize the damage. In 1997, a 10" (254 mm) diameter 900# rated wellhead desander was supplied on a transportable skid base as shown in Figure 5. This unit comprised of a carbon steel wellhead desander vessel with 410 SS cyclonic insert. Additionally the skid contained a 75 liter accumulator and manual valves. During a six month period this unit was connected to various shut in wells. Each well was pulled at high rate to unload the wellbore sand. After 3-5 days operation at each well, the sand loading dropped to acceptable levels thus the wells were unloaded of sand and brought back into production.

The wells varied in gas flow rate from 5-45 MMSCFD (0.14-1.27 MMsm³/d) and each contained a small amount of condensate and water. The calculated solids loading was 100-500 ppm at a 120 µm average solids particle size. The wellhead desanders operated at a nominal 40 psi (275 kPa) pressure drop and exhibited a >99% solids removal efficiency. The accumulated sand was collected in open barrels as shown in Figure 5 for onshore landfill disposal. All 30 wells were restored to production after unloading of the sand.

**Figure 5 – Photographs of a 900# portable wellhead desander installed on gas wells onshore Indonesia.**

**South China Sea – Deep Water Flotating Facility.**

A deep water facility in the South China Sea experienced severe sand production from its multiple wells upon failure of the expandable screen completions. The produced sand limited choke life, filled separator vessels, and eroded level control valves in some cases every 24 hours. The first response was to limit production rates to minimize sand inflow, however that led to a significant reduction in oil and gas output. The long term solution was to re-work each well with new gravel packs, however that process would take three years to complete on all wells. A short term solution in 2011, implemented in eight months, installed wellhead desanders on five of the worst sand producing wells. These units were designed to match the required 3000 psi (20684 kPa) MAWP wellhead rating, and installed after the flexible jumper before the choke. Each unit was integrated into the well bay as shown in Figure 3 and Figure 6 (left). Eventually 10 wellhead desanders were installed making this the largest offshore sand handling system in the world.

The wellhead desanders vessels are fabricated of carbon steel and contain a duplex stainless steel or silicon carbide cyclonic insert. The inserts are interchangeable in material for erosive life and in size to accommodate changes in flow rate. Each desander has an oversized external 588 liter accumulator designed to handle 24 hours of sand production. Each accumulator is isolated by manual double block and bleed valves. The accumulated sand from each accumulator is discharged twice per day into a common slurry header. The collected slurry reports to a central dewatering and bagging station shown as the middle photo in Figure 6. This station uses urethane desilting cyclones to remove the bulk of the slurry water and the concentrated sand is dropped into filter bags for removal the remaining free water. The filter bags also serve to carry the sand to a transport skip shown in Figure 6 (right) with the final sand disposal into onshore landfill.

The wellhead desanders treat 3300-6700 BPD (524-1065 m³/d) fluids with 10-60% watercut and 1.5-12.0 MMSCFD (0.42-3.40 Msm³/d) gas flow. Wellhead pressure averages 1200 psi (8274 kPa) and the wellhead desanders operate at 30-50 psi (207-345) pressure drop. Due to the low oil density and viscosity as well as high gas void fraction the wellhead desanders have a separation size of 16-25 microns. The solids handling system treats 1-2 tons per day of sand, with a monthly average of 25 tons. The addition of a sand cleaning system is being undertaken in 2013 to allow overboard discharge of solids through an integrated system. This solids management system has allowed an increase in well flow suitable to recover 5000-7000 BPD (795-1113 m³/d) oil, and associated gas, to the facility.

**Figure 6 – (left) 1500# wellhead desander integrated into the deepwater spar well bay, (middle) solids collection and dewatering station, and (right) collected solids transported by skip to landfill disposal.**

## Conclusions

All oil and gas wells produce some amount of solids along with hydrocarbon fluids. However, these solids may be present in insufficient quantities, concentrations, or sizes to reduce production. When the amount of solids or the size of the particles leads to lost production due to equipment downtime or reduced inflow, a control method is required to restore production to an economically sustainable level.

Traditionally solids (sand) control equipment is used to prevent sand from entering the wellbore and it can be termed *exclusionary*. Exclusion methods include mechanical retention (screen or slotted liner), gravel packs, chemical consolidation, or a combination of these techniques (Penberthy, 1992). The selection of the best method depends on the well and reservoir conditions, intervention costs, production life, and the treatment that will provide the maximum sustained productivity.

An alternative to keeping solids in the formation is to produce solids with the well fluids and then separate them at the surface facility. This technique is termed *inclusionary* because the solids freely flow with the reservoir fluids to the surface. Principally this method allows produced solids to enter the wellbore and travel up the wellstring for removal pre or post choke, or at the production facilities. A multiphase desander separates the solids from the well fluids at the choke (pre or post) or prior to the separator vessels.

Most E&P companies have started to embrace a wider view of solids control by including surface sand handling as part of their portfolio. BP put in place a program called “Beyond Sand Control (BSC),” which looks at where and how to best manage sand from the reservoir face to ultimate disposal of sand at the surface (Morgan, 2006). Shell has adopted an integrated system team made of completion and facilities engineers to determine the optimum location for controlling sand production, subsurface or surface, considering CAPEX, OPEX, risk, and HSE as presented at the 2002 Facilities Sand Management workshop.

The overarching principal drive for using an exclusion or inclusion method for sand control is sustained production. Downhole sand exclusion protects production tubulars, wellhead chokes, flow lines, and facilities equipment. However, the buildup of solids near the wellbore increases skin damage, which reduces inflow. Allowing the sand to flow freely with the well fluids reduces skin damage thus sustaining (or increasing) inflow. The multiphase desander allows higher well productivity by eliminating the inflow reduction associated with gravel pack skin, and as the number of wells requiring gravel packs increases, a central multiphase desander will become more cost advantageous by a combination of reduced installation costs and production increases. Multiphase desander and associated solids handling systems installed in the Caspian Sea, Indonesia, and South China Sea have shown the flexibility of the technology, the simplicity of operation, and the resultant substantial economic benefits.

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