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Intelligent, Automated Shale Conveyance: Rotary Screen Vacuum Assisted Gas and Solids Separation System for Drilling Fluids

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Abstract

Effective removal of contaminants from drilling fluids is widely accepted as a key factor in achieving best-in-class drilling performance and reducing fluid cost. Current shaker technology reflects incremental advances in functionality related to size, g-forces and screen technologies.

An innovative problem-solving approach that departs from conventional methods created an intelligent fluid management system that addresses multiple needs of a drilling operation:

- Removes cuttings without screen blinding by utilizing a conveyor filtration system.
- Can eliminate the need for HVAC or respiratory systems in the shaker house.
- Minimizes acid gas contamination via negative vacuum pressure allowing safe removal of the gasses.
- Accurately monitors return fluid volumes to rapidly identify well kicks or lost circulation.
- Accurately monitors cuttings volumes to identify poor hole cleaning.
- Records and transmits fluid property and volume data using WITSML language to feed information to real-time operation centers.
- Can use real-time data for rig automation (e.g., density and viscosity control, kick prevention).
- Offers remote control via touch screen eliminating the need for manual equipment monitoring.
- Cleans all cuttings removed from the well with the ability to recover any effluent.
- Can eliminate ancillary equipment (e.g., degasser, settling pits, cuttings dryers, ventilation systems, troughs, pressure washers).

This intelligent system utilizes integrated shale conveyor technology, vacuum system, cuttings transport and cleaning package, real-time monitoring systems, filtration medium failure detection, touch screen controls and automation components. It operates cleanly and safely without high g-forces, degradation of cuttings and fluid vapor pollution associated with conventional technology.

Introduction

The use of solids control equipment in drilling fluids dates back to the early 20th century. The adapted mining technology which utilizes gravitational forces (g-forces) to separate shale and particles from drilling fluids has been used successfully around the globe to drill most, if not all, modern oil and gas wells.

Today's well drilling technologies reflect an increasing focus on safety, automation, real-time and remote monitoring, and environmental considerations.

In 2004 it was this type of thinking that brought together the inventors of the MudCube vacuum conveyor separator (VCS) system (Figure 1). Their goal was to design a completely new system from scratch that would focus on the following principles:

1. Prevent any chance of large particles passing through damaged screens or malfunctioning equipment, helping prevent damage to pumping equipment, and the creation of ultra-fine solids that can be produced from recirculation in the drilling fluid system.
2. Minimize any retention on cuttings (ROC) or loss of drilling fluids over the equipment while maintaining maximum possible flow rates.
3. Effectively and safely remove gasses from the well and the fluid while automating to minimize personnel contact with the equipment, chemicals, fluid, gasses and fumes.
4. Measure, capture and transmit fluid and equipment information (i.e., density, viscosity, cuttings volumes, returned fluid volumes, temperature, etc.).
5. Provide added value that is significantly higher than conventional systems.
6. Provide data analysis and automation that returns fluid with consistent properties to the pits.

The VCS is a new technology with limited field data. The preliminary performance data presented in this paper discusses how the VCS technology is working towards achieving these principles, along with identifying which future projects need to be presented in future papers.

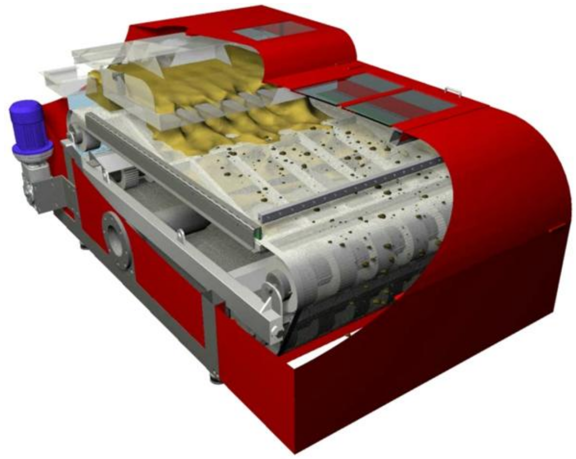

Figure 1 Vacuum Conveyor Separator (VCS)

Basic Concept

One of the difficult things to do is describe the technology without seeing it actually work. The MudCube system replaces shaker technology, and the unit itself does not 'shake'. Therefore describing it as a shale shaker is inaccurate. The MudCube system is a step-change technology in the sense that there is no current generic term in the industry that applies to it. For lack of a better term and for the purposes of this paper, we will generically refer to this technology as a Vacuum Conveyor Separator, or Vacuum Conveyor Separation (VCS) unit.

The VCS receives fluid and cuttings conventionally through a distribution box. Once the fluid enters the VCS, the unique processing technique begins. The fluid is distributed evenly via fingers or adjustable gates across a replaceable, non-tensioned, screen cloth with rectangular openings. The VCS currently uses single-layer screen construction, but could also be provided in multi-layer configurations.

This wire mesh is securely fastened to a drive belt, which is comprised of metal rods or composite materials to support the non-tensioned wire cloth, and provides a rotational feed from zero to 1.5 feet per second (0.48 m/s). The screen belt is 16.1 ft long by 3.94 ft wide (4.9 m x 1.2 m) and provides an equivalent screen area of up to 5.9 ft^2 per second (0.55 m^2 per second). All screens are API13C designated and available in various mesh ranges to achieve desired filtration in a single pass.

Figure 2 shows the dynamics of the VCS operation. At A, the fluid is vacuumed through the screen and support belt via the vacuum table. While the VCS does not shake, it has been found that introducing micro-vibration to an area of the screen belt during operation can increase maximum flow capacity in some situations. Between the vacuum table and the drive belt are micro-vibrator devices that can be activated when needed to help increase maximum flow (e.g., large diameter hole, high polymer loading, or using very fine mesh screens). The cuttings drying air knife is located at B, and it blows air on the cuttings, achieving a dryer cutting, putting the fluid back into the vacuum table and returning it to the active system. A secondary air knife is located at C which removes residual solids from the screen and deposits them in the discharge line.

A unique attribute of a vacuum-based system is that as the available screen openings are covered by flow (screen loading) the faster the air travels through the remaining openings. This increase in air velocity, coupled with a continuously rotating screen, and the air-knives to clean the screen with every rotation provides resistance to screen blinding, helping to minimize the potential for fluid to cascade off of the end of the unit as waste.

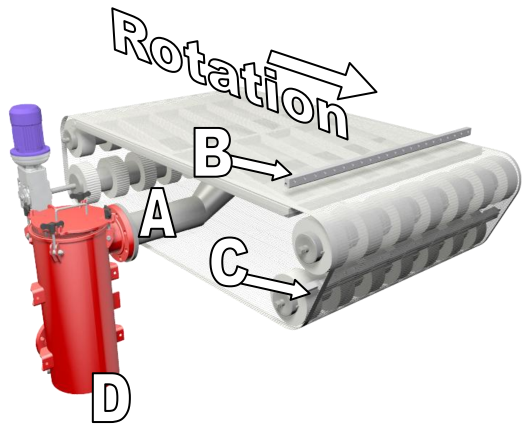

Figure 2 VCS Basic Concept

The screen condition monitoring unit at D provides two functions. One is to alert of a screen failure in real-time by sending a signal to the control panel, so it can be used to notify personnel that the screen should be changed. This is achieved by monitoring the increase vacuum as the filter canister is filled. The signal can also be used in automation to shut down the VCS and divert flow to another VCS. The secondary function is to capture any cuttings that may have passed through a damaged screen. This ensures that unwanted solids do not pass through the system to degrade fluid performance or damage pumps or downhole equipment.

A video clip is available online that demonstrates how the unit works.[1]

Cuttings are discharged over the end of the screen belt and handled in traditional ways, or the vacuum system can be utilized in a cuttings transport system as seen in Figure 3. The cuttings transport system can also be set up to measure volume and weight.

After passing through the secondary filtration system, the clean fluid is separated from air/gasses in the vacuum separation tank (Figure 4).

The air and gas are pulled from the vacuum tank and through the vacuum unit(s) (Figure 5). The cyclone on the unit is used to capture effluent, water mist, or oil mist in the vent and this is returned to the active system. This recovery feature is not only beneficial to the environment; when compared to conventional technologies, it helps reduce losses to evaporation, which can be quite substantial on wells with high flowline temperatures, as based on API evaporation calculations.

The filtered drilling fluid from the separation tank is pumped back to the active system via a known displacement volume pump (Figure 6).

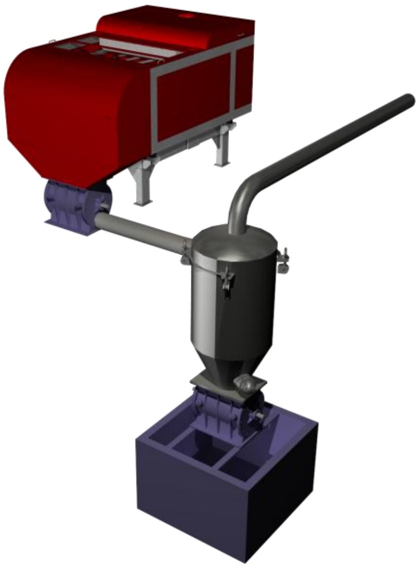

Figure 3 Cuttings Transport

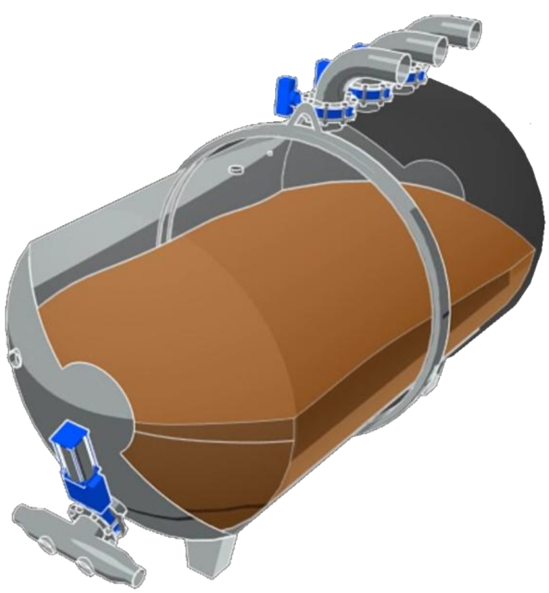

Figure 4 Vacuum Separation Tank

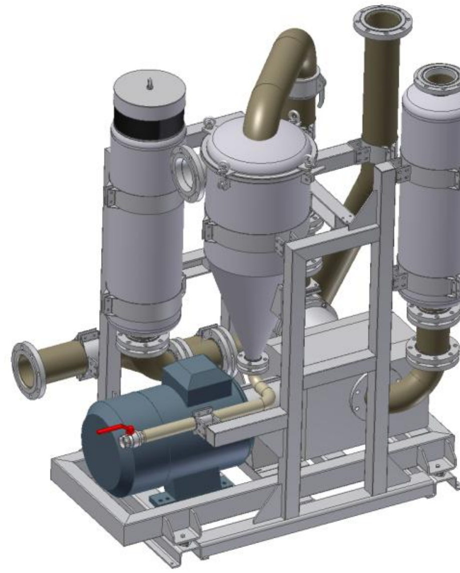

Figure 5 Vacuum Unit

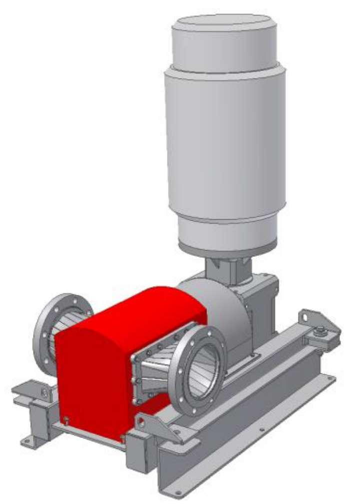

Figure 6 Displacement Volume Pump

By utilizing this pump design, a fluid return signal can be sent to the control unit and the driller's console to be monitored along with rig pump volume to detect either lost circulation events or well control (kick) events in real-time. An additional benefit is eliminating the need for gravitational fluid feed or fluid troughs, creating new opportunities for fluid flow designs.

A complete VCS system can be retrofitted to an existing operation via a modular concept. An example configuration is shown in Figure 7. However, if the VCS system is designed into the rig from the beginning, a very small footprint can be achieved.

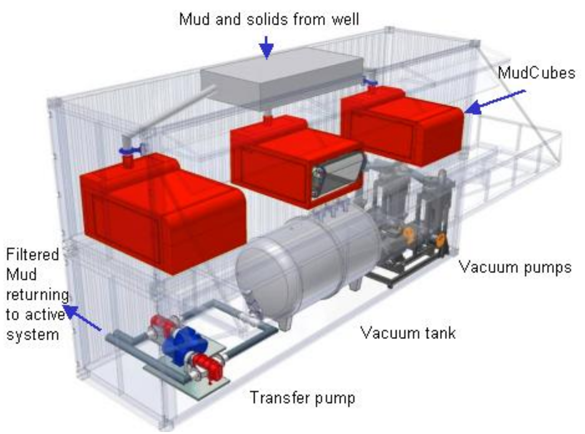

Figure 7 VCS Modular Concept

Benefits

The completely enclosed unit maintains a vacuum on the housing, preventing the entry or accumulation of mist or gasses in the shaker house. Many countries enforce oil-mist exposure limits for personnel when operators use invert emulsion fluids (i.e., oil- or synthetic-based muds). These regulations are becoming more stringent in some areas. Additionally, the sealed design of the VCS does not cause drilling fluid to mist onto the walls, handrails, surfaces, etc., which further reduces HSE risks whether on land or offshore.

It is also important to note that while the unit is sealed and does maintain a vacuum on the unit, the lid can be easily opened at anytime to inspect cuttings loading or condition. However, this is not advisable during H_2S drilling operations, as maintaining the vacuum on the unit at all times will help reduce risk. If an H_2S environment is expected, it is also possible to engineer a completely enclosed scenario by maintaining vacuum on the wellhead, VCS system, active pits, and even the cuttings skips if this is necessary.

The VCS is easily assembled on location. The actual cubes are made of stainless steel and the unassembled parts can be carried through a standard door opening. The cubes can be assembled by hand in approximately five hours per unit. Most replacement parts are off-the-shelf components and are easily serviceable.

The screen belt itself weighs approximately 7 lb (3.2 kg) and each units screen can be changed in less than five minutes with no heavy lifting. Comparing the weight of dressing one 3-cube VCS system to a 3-unit double deck shaker system (conservatively using a 14-lb screen in this example), the VCS system provides significant reductions not only in deck loading and space, but reduce weight that employees have to handle on a daily basis (Figure 8).

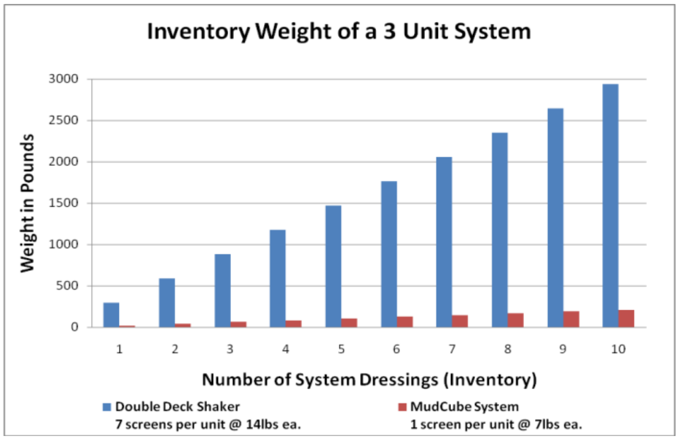

Figure 8 Inventory Weight of a 3-Unit System

Tables 1 and 2 show the specifications of conventional systems and a VCS system. The actual components used in specific scenarios will vary, but the data provides approximations for comparative purposes.

Table 1 Conventional Solids Control System

Conventional System	lbs	ft^2
Double Deck Shaker (3 Scalping x 4 Primary)	5400	86
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Vacuum Degasser	2450	37
Pressure Washer	600	6
Additional HVAC System Capacity	1000	
Small Setting Pit (5' square x 0.25" thick steel)	1275	25
Totals:	**21525**	**326**

Table 2 VCS System

VCS System	lbs	ft^2
Cube	1650	41
Cube	1650	41
Cube	1650	41
Vacuum Tank	4400	44
Transfer Pump	1690	9
Transfer Pump	1690	9
Vacuum Skid	2640	38
Vacuum Skid	2640	38
Totals:	**18010**	**261**

The footprint of the conventional example system described above vs. the example VCS can be visualized in Figure 9.

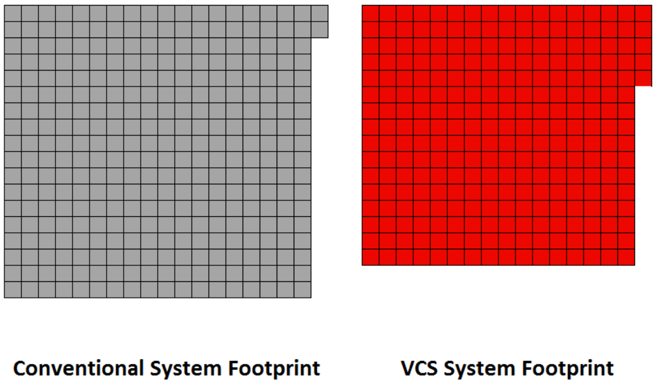

Figure 9 Conventional vs VCS Footprint Comparison

In this example, the VCS system can save approximately 65 ft^2 (6 m^2) of deck/pad space and 3515 lb (1594 kg) of equipment.

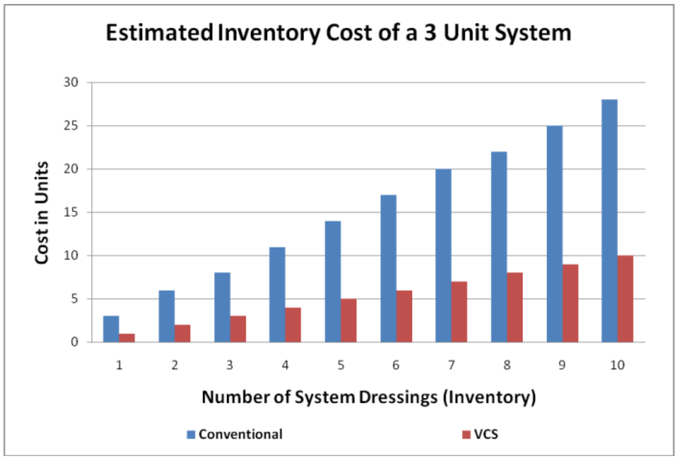

Figure 10 Shaker Screen Costs vs VCS Screen Costs in Normalized Units with Uniform Screen Life

Figure 10 shows the relative estimated cost of dressing a three VCS unit system compared to dressing a three double deck shaker system. This gives a cost savings of 64.4%. If the cost of dressing a conventional system over five years is $22.9m then comparatively the VCS would cost $8.15m. This would be a savings of $14.75m over the five-year term.

Assumptions:

- Three double deck shakers with five screens each unit
- Three VCS with one screen each
- VCS and shakers have the same screen life
- The VCS screen costs 3x more per screen

Health, Safety and Environment

Table 3 outlines some of the benefits of a VCS system from an HSE perspective, when comparing levels of risk with certain activities.

Table 3 Risk Comparison

Risks	Shakers	VCS
Fume Exposure	High	None/Low
Vibration Exposure	High	None/Low
Flash Point / Fire Risk	Low	None/Low
Noise Damage	High	Low
Fall Risk (From Height)	Med	None/Low
Slips / Trips / Falls	High	Low
Hand / Back Injuries (Twisting/Pinch/Lifting)	High	Low
Fluid / Chemical Exposure	Med	None/Low
Pressure Washing (Cuts/Eyes/Exposure)	Med	None/Low
Number of Workers Exposed	Med	None/Low

Fume exposure to the employee is minimized with the VCS unit. The only time an employee would be subject to fumes is if they open the cover during operation. In dangerous environments, such as H_2S exposure, the covers could be locked, or set to alarm if opened.

Exposure limits are in place in many countries. In the U.S. the OSHA (and MMS) safe working limits are up to 5 mg/m^3 TWA (40 hour workweek) for mineral oils. Diesel-based fluids have an exposure limit of 100 mg/m^3 TWA. It is important to note that diesel is classified as an OSHA Select Carcinogen, and fumes can be formed above temperatures as low as 52°F (11°C). In British Columbia, the exposure limit is 0.1 mg/m^3 TWA for 12 hours. In a recent study by WorkSafeBC it was noted that these exposures were exceeded even on an open shaker house (no roof). Employee exposure to oil-mist in the shaker house is removed with the VCS.

The VCS can have vibration, from the micro-vibrators, on a portion of the screen however these vibratory forces are isolated from the housing, and are not transmitted into the working area.

As noted in Figure 8 previously, the weight of the screen on the VCS is approximately 7 lbs (3.2 kg). To change a screen on the VCS, the unit is opened from the end, and the screen is rolled off of the unit in the fashion similar to rolling up a carpet. This is possible because the screen belt is not a continuous woven belt, but fastened together after installation. A new screen is installed in the reverse order. As many times as solids control equipment needs to be redressed in its lifetime, the reduction of weight, handling, lifts, twists and potential pinch points is substantial with the VCS. This minimizes risk for employees over time. Another benefit of the system is the minimization of waste when compared to pre-tensioned screens. Figure 8 clearly shows how much less weight an employee has to handle, and how that is directly related to the amount of waste generated when screen life expires.

The air-knives in the VCS keep the screen clean. In all testing to-date, the air-knives eliminated the need to pressure wash any shale blinding or particles from the screen.

The way to make an activity risk free is to completely remove the employee from the activity. With no pressure washing needed, automated screen failure detection, automated density and viscosity measurement, the employee duties required with a VCS when compared to a conventional system are dramatically reduced, and in some cases remove risk completely.

Oil on Cuttings Data

The field data for ROC is currently being collected. To date, all cuttings off of the VCS appear visually drier than the shale shaker cuttings on the same location. Finalized field results were not available at the time this paper was written and will be presented at a later date.

However, under laboratory conditions, the OOC was reduced by 54-69% from its original value after processing through the VCS unit. The MOBM cuttings were shipped to shore, homogenized, and then pumped over the VCS utilizing API 120 (API13C designation) screens, with the air-knives functioning. Table 4 displays the retort and weight analysis before and after processing.

Table 4 Retort Analysis of Cuttings

MOBM Cuttings Analysis	Start	VCS1	VCS2	VCS3	VCS4
Mass of oil per kg of wet cuttings	188.41	57.23	73.08	66.45	85.9
Mass of oil per kg of dry cuttings	299.93	75.47	95.93	86.53	118.84
Oil %	18.84	5.72	7.31	6.64	8.59
Water %	18.34	18.45	16.51	16.56	19.13
Oil Reduction	-	69.6%	61.2%	64.7%	54.4%

In Figures 11 and 12, the initial volume was 166 gallons (630 litres) and the final processing volume was 82 gallons (310 litres). This shows a volume reduction of 51% overall. While more testing is required, this could open the possibilities of utilizing a VCS as an offline unit to reduce cuttings haul-off or disposal for many areas.

Figure 11 Cuttings as Received

Figure 12 Cuttings after VCS Processing

Separation Technology

The preliminary test data points toward the potential of the VCS to provide a different cut-point with similar API13C designated screens when compared to conventional shaker technology.

Testing to date was performed with the following:

- MOBM – 1.55 sg
    - PV –29.5 cP
    - YP – 6.1 Pa
    - LSYP – 2.1 Pa
    - Solids – 22%
    - OWR – 77/23
    - Temp – 90°F (35°C)

The shale shaker was dressed with an API 140 (API13C designation) screen and the fluid was circulated through the shale shaker for 30 minutes. The shaker was visually no longer removing solids from the system. The fluid was tested, and had a d50 of 9µ.

The VCS was dressed with an API 120 (API13C designation) screen and the fluid run through the VCS for 30 minutes. The VCS removed a considerable amount of solids visually. The fluid was tested, and had a d50 of 5.7µ.

The early theory is that shale shakers give the near mesh sized solids in the system many opportunities to lodge in or fall through the openings in the screen mesh, whereas the VCS technology conveys up to 5.9 ft^2 (0.55 m^2) per second, giving very little time for the near mesh sized solids to travel through the screen. Figure 13 demonstrates how solids travel on a shaker screen, potentially giving near mesh sized solids, hundreds, if not thousands of chances to penetrate the cloth.

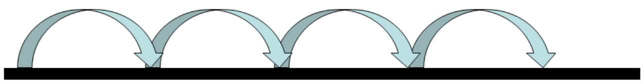

Figure 13 Demonstration of Solids Travel on a Shaker Screen

While the data is still in the early stages, if this proves to be correct, then a lower API13C designated mesh size on a VCS could be used to achieve similar filtration rates with higher API13C designated screens on a shaker. This would increase the conductance of the VCS, increasing maximum flow capacity.

Specifications

The VCS system has been utilized offshore and is undergoing continuous side-by-side comparison testing with conventional technology at the Cubility Test Center in Sandnes, Norway. The test center includes a complete circulating flow loop which can utilize water-based, oil-based, and completion fluids. The current configuration at the test center has a maximum flow rate of 475 gpm (1800 l/min) per unit. The circulating temperature can be adjusted up to a maximum of 185°F (85°C). It is also valuable to note that while the test center is currently limted to 475 gpm (1800 l/min), early testing of the VCS achieved flow rates of over 630 gpm (2400 l/min) on low solids polymer WBM.

As this is a relatively new system, the field data is limited at this time. Additional offshore data being collected at the time of the writing of this paper will be presented in 2010/2011.

The VCS known capabilities and capacities include the following:

- Figure 14 shows the VCS while drilling 65-82 ft (20-25 m) per hour surface 17 ½" surface hole (sticky shale) with 1.25 sg water-based fluid, maximum flow was 475 gpm (1800 l/min) with an API 80 (API13C designation) screen (per cube). Additional offshore test data collection is ongoing and this will be made available in the future.

Figure 14 VCS Resisting Blinding

- At the test center >475 gpm (1800 l/min, as this is the test center pipe limitation not the VCS limitation) tested up to API 170 (API13C designation) mesh screen up to 1.55 sg fluid, both OBM and WBM tested.
- Screen life has limited data to date, when compared to the data available for shale shaker performance, but preliminary test data shows that the non-tensioned VCS screens can have lives over 35 hours with the micro-vibrators engaged, and in many scenarios double or triple that life without the micro-vibrators engaged.
- Rotational feed from zero to 1.5 feet per second (0.48 m/s). The screen belt is 16.1 ft long by 3.94 ft wide (4.9 m x 1.2 m). This gives an equivalent screen area of up to 5.9 ft^2 (0.55 m^2) per second.
- Vacuum capacity can be sized as needed per system. Each vacuum skid can vacuum 11095 gpm (1480 cfm or 42000 l/min).
- Transfer pump capacity is 713 gpm (2700 l/min).
- Vacuum tank is 12 m^3, but will be sized based on rig application.
- Limited mud weight tested to date (13.9 ppg / 1.69 sg), but solids concentrations have been tested up to 40% v/v with low gravity solids, which should be indicative that high mud weights can be tolerated.
- Equipment noise levels are in the 65-75 decibel range depending on the operation of the micro-vibrators.
- The VCS is controlled with touch screen (Figure 15) software automation (and can be manually controlled if necessary).
    - The touch screen and information display can be remote mounted anywhere on the rig including the drillers shack, eliminating a need to staff the shaker house.
    - Real-time screen condition monitoring provides an alarm when the unit requires service.
    - Real-time loss / kick detection is monitored via the transfer pump to the active system. The transfer pump is a known displacement volume pump which can correlate to the downhole pump

volumes.

- Real-time viscosity and density are measured for trends from an off-the-shelf harmonic sensor, potentially eliminating the need to constantly check and call out funnel viscosity and density.
- Real-time sensors of any kind can be added to the system, such as pH, rheology, pit levels, temperature, etc.
- All data can be logged and then transmitted via WITSML to the drilling console, or logging companies on-site.
- Future plans include offering data analysis beyond the above, utilizing the information for real-time barite or chemical additions to the system, ensuring a homogenous fluid going downhole.

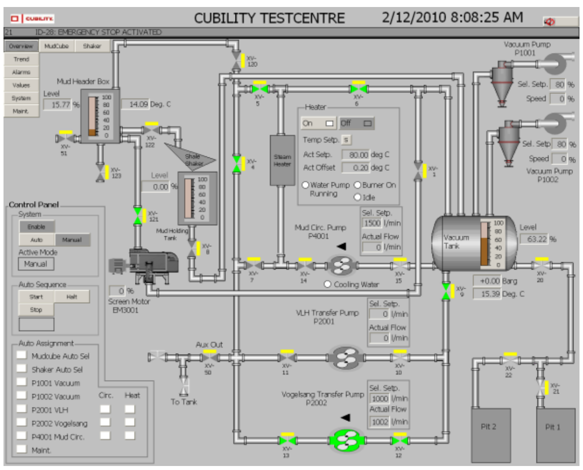

Figure 15 Screen Capture of VCS Touch Screen Display

Conclusions

The VCS system is a step-change technology that can supplement, or replace conventional solids control equipment at the rigsite. It offers the following potential cost and operational advantages:

- Can provide construction cost savings during initial rig builds.
- Provides footprint savings on many operations.
- Provides savings in inventory weights, employee exposure to lifting screens and waste generation.
- Provides unique benefits when drilling high-pressure high-temperature wells in regards to mist and exposure.
- Helps minimize risk of exposure to H_2S.
- Reduces or eliminates the need for employees to handle pressure washing equipment routinely for screen cleaning.
- Could be utilized as an offline device to reduce volumes of waste or offline filtration.
- Could be utilized as a scalping device in current solids control systems to help increase flow and safely degas the fluid.

To confirm the capability of the VCS to deliver the wide range of processes and features included in its design, additional testing and data collection are ongoing as follows:

- Additional data points for ROC.
- Additional data points for heavy weight fluids.
- Additional data points for screen life expectancy.
- Additional data points for brine filtration.

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Nomenclature

API = American Petroleum Institue
cP = Centipoise
ft^2 = Square Feet
gpm = Gallons per Minute
H_2S = Hydrogen Sulfide
hp = Horse Power
HVAC = Heating, Venting and/or Air Conditioning
l/min = Liters per Minute
lbs = pounds
*LSYP = Low Shear Yield Point = (2 * θ3 – θ6), where θ3 and θ6 are the 3- and 6-rpm Fann 35*
m/s =Meters per Second
mg/m^3 = Milligrams per Cubic Meter
MMS = Minerals Management Services
MOBM = Mineral Oil-based Mud
NTU =Nephelometric Turbidity Unit
OBM = Oil-based Mud
OSHA = Occupational Safety and Health Administration
Pa=Pascals
ppg = Pounds per Gallon
PV = Plastic Viscosity
ROC =Retention on Cuttings
sg = Specific Gravity
TWA = Time Weighted Average
VCS = Vacuum Conveyor Separator / Separation
WBM = Water-based Mud
WITSML =Wellsite Information Transfer Standard Markup Language
YP = Yield Point

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