SOLIDS FALLBACK PROTECTION TOOL FOR SUCKER ROD PUMPING

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INTRODUCTION

Sucker rod pumping can experience reliability challenges when produced fluids contain solids. Any sucker rod pumping system improvement for handling solids would be highly beneficial.

The sucker rod pump (SRP) is one component of a complex downhole system of components for sucker rod pumping. Other components of this system include a downhole gas separator, a downhole solids separator, a tubing anchor and sucker rods. To maximize the efficiency and performance of a sucker rod pump, all these components must act together systematically to effectively feed the pump on demand with liquid that has been gas and solids depleted – unfortunately, achieving this has been particularly challenging. Consequently, the sucker rod pump and sucker rods must still contend with gas and solids.

Solids that travel through a sucker rod pump can be transported or carried to surface only if the average liquid velocity inside the tubing exceeds the solids settling velocity. If the average liquid velocity is less than the solids settling velocity, solids that have travelled through the pump will accumulate inside the tubing. Inevitably, the well will need to be shut down and then the accumulated solids can freely settle on top of the pump and/or around the sucker rods. Upon restarting of the pump, the pump or sucker rods can be seized by the settled solids, forcing a costly workover. This is a common problem for wells that have been hydraulically fracced with sand.

Electrical Submersible Pumps (ESP's) have employed solids fallback protection tools in the tubing string above them. They have proven to be effective and are relatively simple designs. They prevent solids from settling inside the tubing and onto the ESP after a shut down event. Their designs include flow path staggered collection weirs or sand screens inside the tubing string to prevents solids from settling down to the ESP. Upon restarting of the ESP, the solids collected by the tool are flushed from the collection weirs or sand screens with design intent to carry the solids to surface and out of the tubing string. ESPs are more commonly used for higher production rates and there is often enough liquid velocity inside the tubing to efficiently carry the solids to surface and out of the well. Therefore, these existing ESP oriented tools are not designed to permanently contain or retain solids downhole.

For a SRP system, the liquid velocities in the tubing string are often inadequate for carrying solids to surface. Therefore, a solids fallback protection tool for SRP would require a permanent "out of harms way" downhole solids separation containment solution. Additional design challenges include the need for full tubing internal drift diameter to allow passage of the pump and rods, and that there are reciprocating sucker rods inside the tubing string.

A new patent pending system-based solids fallback prevention tool (trade named the SandShark^{TM}) was developed for sucker rod pumping. The tool's design features include:

- tubing conveyed with no moving parts,
- uses an external to the tubing eccentric solids collection chamber with multiple internal sub-chambers for permanent (larger volume) downhole containment of solids until the tubing string is retrieved,
- multiple tools can be run in series above a sucker rod pump for greater solids containment capacity,
- full unobstructed tubing internal diameter for passage of rod pumps,
- 10,000 psi (68.9 MPa) burst pressure rating,
- does not change the sucker rod pump's or rod string's design,
- does not interfere with the sucker rod string's reciprocal motion, and
- is cost effective.

Flow loop testing and initial field trials have indicated the system's operability.

This paper discusses and discloses how an engineered solids fallback protection tool for a SRP was developed, with the goal of improving production performance and failure frequencies associated with solids related stuck pumps.

FAILURE FREQUENCY RISKS WITH SOLIDS IN THE PUMP AND/OR IN THE TUBING ABOVE A PUMP

If solids entrained in produced fluids are not separated out before the sucker rod pump, they will enter the pump and the tubing string above, increasing the risk failure frequency risks.

Solids entering a sucker rod pump and into the tubing string above the pump can accumulate over time to the point where a failure occurs due to:

1. the pump's plunger sticking or seizing in its barrel, and/or
2. the pump's plunger and/or barrel and/or valves becomes excessively worn, and/or
3. solids impeding the sucker rod string movement to the point that maximum surface pumping unit loads are exceeded or the sucker rods part.

For when a sucker rod pump shuts down, solids inside tubing string can then gravity settle, and a failure occurs due to:

4. concentrated solids collecting on top of the pump or around pump's plunger, causing it to stick and prevent restarting, and/or
5. concentrated solids collecting above the pump and around the lowermost sucker rods, preventing sucker rod movement and restarting.

6. concentrated solids collecting above the pump and around the sucker rods, forming a bridge or barrier to fluid flow that hydraulically “locks” the pump and prevents restarting.

Figure 1 shows example pictures of solids accumulation in and above a failed sucker rod pump. The risk consequence of solids fallback is a costly major workover and production downtime. For example:

- must pull and replace pump,
- must pull the tubing string and bottomhole assembly (BHA) to retrieve a stuck pump and/or rods, and
- a stuck pump and/or rods often requires a costly tubing stripping operation.

<u>DOWNHOLE SOLIDS SEPARATION CHALLENGES</u>

Ideally, if downhole gas and solids separation is 100% efficient, pure liquid would feed the pump, and no solids would get trapped in the tubing string above the pump. Unfortunately, achieving this has been a considerable challenge. Consequently, some gas and solids will remain in the fluid stream as it enters the pump, and solids will accumulate in the tubing string above the pump. Therefore, sucker rod pumping systems must still contend with gas and solids.

Solids in the produced fluid risks have escalated considerably in horizontal wells, as multistage hydraulic fracturing practices have exponentially increased the number of frac stages, the amount of frac sand being pumped, the amount of lower quality of frac sand (namely, the amount lower quality frac sand that can crush into finer solids particles) and the amount of finer sized frac sand (for example, 100 mesh). Nystrom’s[i] research article noted that “horizontal well designs have become progressively longer and more intense in terms of proppant usage. Virtually, the entire industry has switched from high-permeability grade proppants like 30/50 to lower permeability grades such as 100 mesh.” Figure 2[ii] shows the finer frac sand solids particles and their typical size distribution range, noting 100 mesh frac sand particles are mostly larger than 120 microns and smaller than 200 microns is size.

Horizontal wells transport solids in concentrated accumulated masses due to multiphase flow slugging and this has also elevated the risks associated with handling solids entrained produced fluids. Kimery[iii] explained that it is very common for unconventional horizontal wells to posses inconsistent sluggy flows and its these sluggy inconsistent flows that transport solids to the separator in highly concentrated masses. This transport process is described as saltation. In other words, solids accumulate and form dunes along the horizontal wellbore and these dunes migrate in the direction of flow. When these concentrated masses of solids reach a downhole solids separator, they can be overwhelmed with solids carry-over to the sucker rod pump. How more solids concentration affects the efficiency of a downhole solids separator in sluggy transient flow conditions is not well studied in literature but should be apparent to the reader that a significant reduction in separation efficiency occurs as solids concentration in the fluid stream increases.

Figure 3 from Guzman's[iv] research showed that a SRP's plunger velocity profile during the pump's upstroke is highly variable and not constant. Correspondingly, the liquid rate into and out of the pump is therefore also highly variable and not constant. For example, the pump jack at surface can be one third the way up on its upstroke before the downhole pump's plunger starts moving (due to sucker rod string stretch and sucker rod friction). Then the plunger's velocity "slingshots" under extremely high acceleration to a peak plunger velocity. It is fundamental to understand that the plunger's velocity profile and intake liquid rate can vary from zero (0) to over four (4) times the average each pump stroke. This importantly points out, for example, that for a well with an SRP producing an average 200 bbls per day liquid, an instantaneous peak liquid rate entering the pump can be 800 barrels per day (each pump stroke). At six (6) strokes per minute, the pump's liquid intake rate goes for zero (0) to 800 barrels per day and then back to zero (0) in five (5) seconds. Such high variable rates amplify solids risks. To this end, the technical engineering consideration and challenge for downhole solids separation design is that the SRP intake liquid rates vary over an extensive rate range each pump stoke.

Downhole cyclonic solids separators can struggle to separate finer solid particles. Martins[v] research in Figure 4 showed that downhole cyclonic-gravity separators fail to efficiently separate solids smaller than 200 microns. Shaffee[vi] explained that downhole cyclonic separators designed for solid-liquid separation are unable to achieve their intended separation efficiency especially if any gas phase is present in the fluid stream. In other words, sizing of a cyclonic separator for solids-liquid separation is very challenging and will likely underperform if any gas volume fraction is present in the fluid stream – a condition that is highly likely during sucker rod pumping, as no downhole gas separator has proven able to separate all the gas from the liquid (especially foamy entrained gas). With respect to cyclonic separator handling of solids particle size distribution and range, Shaffee concluded that they will not be able to separate the entire range of sand in the hydrocarbon stream, especially smaller sized particles.

Shaffee further explained that cyclonic separators designed for solids-liquid separation underperformed during "varying inlet stream upstream conditions". In this respect, Shaffee observed that during a well flowrate decrease the required flow will fall below optimum cyclonic separation conditions leading to sand carryover to the outlet stream and flow stability (i.e., liquid slugging negatively affect cyclone efficiency). Such variable inlet conditions are obviously present during rod pumping. Shaffee showed that only 16% of their cyclonic separators were online and with a sand separation efficiency of "at best" around 50%. The root cause of this low efficiency being an inability for separators to handle varying inlet rates and lack adequate turn down ratio. A cyclonic separator needs threshold level of centrifugal force from the incoming feed flow velocity. If inlet rates are predictable and consistent, cyclonic separators should exhibit high performance for solids-liquid separation. If inlet rates into a cyclonic separator are too high, erosion (reduced reliability) and excessive turbulence (solids carry over into the overflow stream) risks arise. Langbauer in Figure 5 studied how limiting or narrow the flow rate operating envelope is for downhole cyclonic-gravity separators (using solids particles greater than 250 micron) and that they do not possess the ability to manage the flow rate range expected during a sucker rod pump intake stroke.

Gravity based downhole solids separators (typically poor-boy type) are challenged by smaller solids particles since they are more easily carried in a fluid stream. Figure 6 from Intermezzo[vii] shows solids terminal settling velocities as a function of solids particle size. Smaller solids particles settle at much slower velocities and therefore can be carried or suspended at lower liquid velocities than larger solids. Both the downward and upward liquid velocities outside and inside a poor-boy separator's dip tube ranges widely each pump stroke – from zero (0) feet per second to over sixteen (16) feet per second (500 millimetres per second), which is greater than the solids settling velocity of most particle sizes encountered in oil and gas wells. As such, some solids will always be carried through a poor-boy separator into and above the sucker rod pump.

Filtering screen solids separation solutions face the risk of plugging and/or scaling off. They often are designed with a bypass pressure differential valve that opens in the event the screen becomes plugged. Bypassing leads to solids carry-over in the fluid stream to the sucker rod pump.

In conclusion, sucker rod pumps and rods must still contend with gas and solids. There is a high likelihood that solids will accumulate in the tubing above a sucker rod pump.

PHYSICS FOR HOW SOLIDS ACCUMULATE IN THE TUBING ABOVE THE SRP

Solids that travel through a sucker rod pump can be transported or carried to surface only if the average liquid velocity inside the tubing exceeds the solids settling velocity (over an entire pump stroke). If the average liquid velocity is less than the solids settling velocity, solids that have travelled through the pump will then accumulate inside the tubing and will not be produced out of the tubing at surface. Inevitably, a SRP will need to be shut down and this is when the accumulated solids in the tubing string can freely settle on top of the pump and/or around the sucker rods. Upon restarting of the pump, the pump or sucker rods can be seized by the settled solids, forcing a costly workover. This is a common problem for wells that have been hydraulically fracced with sand.

Figure 6 shows solids settling velocities in water as a function of particle size. This figure can be used in a simple model to predict the minimum average pump rate required to lift solids (as a function of solids particle size) from the pump, up the tubing and out of the well.

Figure 7 shows calculated minimum average water pump rates to lift solids inside the tubing string. For 2-7/8 inch (73.0 mm) tubing and 1 inch (25.4 mm) diameter sucker rods, 100 mesh sized solids particles (sand) require at least 210 barrels per day to lift the solids from the well. Below this average liquid rate, solids of this size can accumulate in the tubing string. Larger solids particles settle faster, so for 20/40 mesh frac sand particles, an average pump rate of 956 barrels per day would be required to lift all the solids from the tubing string.

AS described above, it is known (Guzman) that a sucker rod pump's plunger velocity is highly variable during the pump's upstroke. The pump can have peak plunger velocities and instantaneous pump intake/discharge liquid rates that are four (4) times the average. An interesting condition can then arise during the pump's upstroke – the pump's liquid intake rate and associated velocity can be higher than solids settling velocity. In other words, there is a timeframe in the resultant liquid velocity profile generated by the pump's upstroke where the liquid velocities are high enough to efficiently lift solids. Consequently, high instantaneous liquid velocities formed by pump's upstroke can drag solids into the pump and onward into the tubing string above the pump. Further, as sluggy flows emanate from the horizontal wellbore and transport concentrated solids masses to the downhole separator, the volume of solids being dragged through the pump and into the tubing string can be significant.

Physics make this condition even more interesting. Near the sucker rod pump's discharge into tubing string, the instantaneous liquid rates closely approximate the pump's plunger velocity profile (and associated rate). But in the tubing string, closer to the surface, the liquid velocities and associated liquid rates become attenuated or damped due to compressibility of the fluid column in the tubing string. In other words, fluid compressibility flattens the liquid velocity profile closer to surface. As discussed previously, there is always some gas in the fluid stream going thorough a pump (gas is compressible) and the oil phase is also compressible. McCain[viii] revealed that crude oil can 5% to 10% volumetrically compressible at 3,000 psi (20.7 MPa) differential pressure (for example, from the downhole pump to surface). For all liquids, some degree of compressibility exists, often quantified by the bulk modulus of elasticity. Other factors[ix] attenuate or dampen a velocity profile, which include elasticity of the tubing string (expanding and contracting due to pressure changes) and damping from fluid flow frictional losses. Consequently, attenuation or damping out of the peak velocities and liquid rates in the tubing string's fluid column occurs throughout the tubing string. At some point or depth in the tubing string, the fluid velocity can eventually approximate a flat velocity profile of an average liquid pump rate.

Figure 8 illustrates a sucker rod pumping system and the liquid velocity profile inside the tubing near the pump and near the surface. There is a unique transition point somewhere up the tubing string where attenuation or damping of the fluid velocity profile (from the pump's discharge) results in a velocity profile where velocities are always less than the minimum velocity to lift solids. In the tubing string below this transition point, solids will be trapped in an equilibrium "cloud" of continuously suspended solids while the sucker rod pump is operating. When the sucker rod pump is eventually shut down, these trapped solids are then freely able to gravity settle back downwards.

These unique physics for how a sucker rod pumping system traps solids in the tubing string above the pump are not well understood or extensively studied in literature. The authors recommend a university or industry sponsored study group undertake this potentially valuable research.

EXISTING ARTIFICIAL LIFT DOWNHOLE SOLIDS FALLBACK PROTECTION TOOLS

There are existing and operability proven downhole solids fallback protection tools for artificial lift systems. Unfortunately, to the knowledge of the authors, none of these are compatible with or adaptable to a sucker rod pumping system.

Electrical Submersible Pumps (ESP's) have employed solids fallback protection tools in the tubing string above them. They have proven to be effective and are relatively simple designs. They prevent solids in the tubing from settling to the ESP after it is shut down.

ESP solids fallback protection tools mainly comprise two design approaches for preventing solids from settling onto or into an ESP after a shut-down:

1. flowpath staggered collection chamber weirs, and/or
2. sand screens with check valves.

Upon restarting of the ESP, these existing tools intentionally flush collected solids from their collection weirs or from their sand screens to carry the solids to surface and out of the tubing string. They are designed to not permanently contain or retain separated solids downhole. They simply prevent solids fallback onto or into an ESP after a shut down. They also do not manage, or control solids accumulated in the tubing during active pumping.

An ESP is more commonly used for the higher production rate phase of a well, where there is adequate liquid velocity inside the tubing string to efficiently carry or lift the solids to surface. Therefore, these existing ESP oriented tools are not designed to permanently contain or retain solids downhole.

Figure 9 illustrates a solids fallback protection tool for ESP's using a flowpath staggered collection weirs and the associated process sequence for how it functions.

ENGINEERING OF A SOLIDS FALLBACK PROTECTION TOOL FOR SUCKER ROD PUMPING USING A SYSTEM APPROACH

Sucker rod pumping liquid rates and associated tubing liquid velocities are often too low for carrying the solids to surface. Therefore, a permanent "out of harms way" downhole solids separation containment solution would be required for a solids fallback prevention tool. Additional design challenges include the need for full tubing internal drift diameter to allow passage of the pump and rods. Further, there are reciprocating sucker rods inside the tubing above the pump all the way to surface during pumping. Consequently, tubing internal staggard weir or sand screen approaches used for ESP's are not compatible or adaptable to sucker rod pumping.

Further, any solution that requires modifications to the sucker rod string will have a risk for increasing the failure frequency of the rod string. Near the sucker rod pump, the sucker rods are subject to cyclical compressional and tensional fatigue loadings, making it a challenging region for sucker rod reliability.

A system-based tool was hypothesized to be necessary for resolving solids accumulation in the tubing above a sucker rod pump, due to reciprocation, fluid flow complexities, and inability to transport solids to the surface. The tool and system embody the following design features:

- permanent separation and downhole containment of solids that have made it through the sucker rod pump,

- no impact to the rod string design or requirement for special/custom rod string components,
- absence of interference with the sucker rod string's reciprocal motion,
- does not require modifications to the sucker rod pump,
- does not restrict or limit the internal diameter of the tubing string,
- does not restrict or limit the annular flowby across sectional to the casing,
- does not limit the tubing string's pressure or temperature ratings, and
- is cost effective.

A new patent pending prototype system-based tool was developed, and was trade named the SandShark™. It was realized that a single tool by itself was not going to achieve all the required design features. In other words, a system of multiple tools or components working systemically together would provide the most effective solution. The SandShark was designed to continuously separate and permanent contain solids while pumping, thereby preventing the risk of stuck pumps.

To achieve the design features described above, the engineered system solution embodies the following design details:

1. continuously separates solids in the tubing above the pump <u>while the pump is operating</u>, such that for when a pump is shut down there are minimal solids to settling in the tubing string above the pump,
2. a tubing conveyed permanent solids collection and containment chamber system component with no moving parts, 10,000 psi (68.9 MPa) burst pressure rating and tensile rating equivalent to a 2-7/8" (73.0mm) L-80 tubing,
3. uses an external to the tubing eccentric solids collection "shroud over a tubing joint" chamber with multiple internal sub-chamber weirs for permanent downhole containment of solids (until the tubing string is retrieved),
4. systematically uses the sucker rod string's reciprocal motion during pumping to force flows into an external solids separation and containment chamber,
5. has full unobstructed tubing internal diameter for passage of sucker rod pumps and no interference to sucker rod design or motion,
6. does not change the sucker rod pump's or rod string's design, and
7. allows for multiple solids containment chamber to be run in series as part of the tubing string above a sucker rod pump for greater solids containment capacity.

Figure 10 illustrates and describes the SandShark's system solution and components.

A sucker rod pump's reciprocal action provides a beneficial process sequence for solids separation. Fluid flow is established in only one direction through the SandShark's eccentric solids separation weir chamber (i.e., upwards) and only during the sucker rod pump's downstroke. During the downstroke, the pump's travelling valve opens (with closed standing valve) to displace the volume inside the pump's chamber to above the travelling valve. As the pump chamber's fluid is displaced into the tubing, the pump's plunger and the sucker rods must fall through the fluid inside the tubing. If a section of guided sucker rods adjacent to the tool could act as a piston (resisting fluid flow), the flow could then be forced into and through the SandShark's eccentric solids separation and containment chamber.

For the initial prototype design, a section of the sucker rod string adjacent to the eccentric solids separation and containment chamber, included a "number" of specially configured rod guides with the design purpose to be fluid flow restrictive (i.e., would resist sucker rod fall and create a fluid piston effect). These commonly used rod guides beneficially restrict the fluid flow in the tubing as the sucker rods fall (during the sucker rod pump's downstroke), and therefore act as a fluid piston to force or push fluid into the bottom portion of the eccentric solids separation and containment chamber – the chamber's flow path becomes the path of least fluid flow resistance. Fluid (separated of solids) would then exit out the top of the eccentric solids separation and containment chamber back into the tubing string above the fully guided "piston" rod string section. The volume of fluid being forced into the SandShark's solids separation and containment chamber would be similar to a pump's stroke volume.

The following figures provide detailed information:

- Figure 11 – shows three-dimensional and transparent rendering of the eccentric solids separation and containment weir chamber. It also shows the location of intake ports (bottom) from the tubing and discharge ports (top) back into the tubing string.
- Figure 12 – shows three-dimensional and transparent of the SandShark tool's unique solids separation asymmetric weirs and channels.
- Figure 13 – shows engineering drawings of the side (cut-away) and an external top view.
- Figure 14 – shows engineering drawings of the multiple solids separation and containment weirs and with the eccentric external shroud removed. Each weir a has an engineered flow path channel for enhancing solids separation efficiency.
- Figure 15 – shows engineering drawings of the internal 2-7/8" (73.0mm) tubing joint with the top and bottom inlet and outlet ports' design.
- Figure 16 – shows pictures of the first manufactured prototype.

To affect fluid flow through the eccentric solids separation and containment chamber, RFG's Petro System's Stabilizer Bars guided with Long MP Polymer® Rod Guides (RFG's Long-Guided Stabilizer Bars) are positioned on the sucker rod string adjacent to the SandShark tool. RFG Petro Systems[x] has developed a successful and operability proven to help center the sucker rod string as it connects to the top of a sucker rod pump and at the base of a sucker rod string. It is industry common practice to run these guided stabilizer bars immediately above a sucker rod pump at the base of a sucker rod string to center the rod string, reduce tubing wear and improve sucker rod pump efficiency. Figure 17 shows RFG Long-Guided Stabilizer Bars and an RFG Box-Guide™, both of which can provide an effective fluid flow restriction during rod fall to force fluid through the SandShark' solids separation and containment chamber. This proven sucker rod technology provided a unique opportunity to integrate it as a component of a system solution for assisting the operability of the SandShark's solids separation and containment process.

Fluid does not flow through the SandShark's eccentric solids separation and containment chamber during the sucker rod pump's upstroke. During the pump's upstroke, the closed travelling valve lifts a fixed volume of liquid at the same velocity as the upward moving sucker rods (including the RFG Long-Guided Stabilizer Bars). This is a fixed volume between the RFG Long-Guided Stabilizer Bars and the plunger close travelling valve. Therefore, the RFG Long-Guided Stabilizer Bars do not have any pressure differential across them during the pump's upstroke. As result, no fluid enters the SandShark eccentric solids separation and containment chamber. With no fluid movement inside the eccentric solids separation and containment chamber, it can functionally allow any solids that have entered the chamber during the previous downstroke to settle into the multiple collection weirs for permanent downhole containment.

An embodiment to the design would be to consider use of a pump plunger (installed on the rod string above the pump and sealed off internally) instead of the RFG Long Guided Stabilizer Bars. This "piston" plunger could be custom sized for length and outside diameter to achieve the desired pressure loss as a function of pump stroke rate.

Figure 18, shows the system's operability process sequence over a full pump stroke:

1. pump upstroke with solids laden fluid drawn into tubing above pump and adjacent to the eccentric chamber,
2. start of pump downstroke, with solid laden fluid ready to be forced into the eccentric chamber,
3. pump downstroke, forcing solids laden fluid into the eccentric chamber,
4. pump upstroke, with no fluid movement in the eccentric chamber allowing solids to be separated and contain in the eccentric chamber, and
5. repeating the process for next upstroke.

This solids separation cycle repeats every pump stroke, with design intent to incrementally separate and contain, out of harms way, any solids that would have normally accumulated in the tubing string above the sucker rod pump.

The solids containment volume for the twenty-six (26) weirs in the external solids separation and containment chamber is approximately 50% of the volume of one mud joint of 2-7/8" (73.0mm) EUE tubing or approximately 0.5 barrels.

ENGINEERED PRESSURE LOSS AND FLOW LOOP TESTING

The first protype tool was built and flow loop tested. The flow loop test was conducted with water to assess the pressure loss through the eccentric solids separation and containment chamber at varying liquid rates. The internal diameter of the tool was fully isolated (i.e., blocked) to ensure allow flow was forced to go through the external chamber.

Figure 19 graphically shows a pressure loss at varying water rates, comparing flow through the SandShark's eccentric solids separation and containment chamber. Figure 19 also shows pressure loss past the RFG Long-Guided Stabilizer Bars between two (2) and eight (8) strokes per minute (for 2.0 inch and 1.5 inch pumps).

Key for the design is to not force all the flow through the tool's eccentric chamber during the downstroke. The system was engineered to have a higher percentage of the flow going through the SandShark solids separation and containment chamber versus through the RFG Long-Guided Stabilizer Bars. This engineered apportionment of flow was intended to prevent solids from impeding movement of the RFG Long-Guided Stabilizer Bars after a shut down (if, in the risk event, some solids have accumulated above the SandShark and settle downward).

This pressure loss data was important to compile for determining how many RFG Long-Guided Stabilizer Bars and/or Box-Guides would be needed for a specific well's application.

WELLBORE BOTTOMHOLE ASSEMBLY CONFIGURATIONS

Figure 20 shows some example and recommended BHA configurations for the SandShark solids fallback protection system for sucker rod pumping.

Figure 21 shows that multiple SandSharks can be stacked in series for increasing the downhole solids containment capacity.

FUTURE TOOL DESIGN ITERATIONS

Future design will include serviceability, both for when retrieved at surface (to allow re-running) or serviceable down hole with an ability to clean collected solids from the tool without the requirement to pull tubing.

CASE STUDIES

Field implementations have commenced effective April 2025. Prevention of stuck pumps from solids accumulation in the tubing above a pump is Statistically meaningful production performance results with these downhole separation system improvements are being compiled. These case studies will be updated by the authors as more time-based performance and reliability results are compiled.

Case Study 1 – placement of ten (10) systems in high failure frequency (pump sticking due to solids) North Dakota Bakken horizontal wells. Results reporting to following in future publications.

CONCLUSION

A patent pending solids fallback protection tool for sucker rod pumping was engineered and developed to address production challenges (primarily stuck pumps) associated with solids laden produced fluids.

This new design functions as a system with a sucker rod pump. It uses the reciprocation energy and the cyclical flow nature of the rod string to capture and retain solids out of harms way and therefore avoid solids accumulation in the tubing string above a pump.

It was engineered to continuously separate solids that have made their way through the pump while the sucker rod pump is operating. When a pump is shut down, solids are not able to fallback on top of the pump and therefore avoiding stuck pump risks. Although showing promise, compiling of multiple case histories over the next number of months will prove operability for improving upon stuck pump related failure frequencies.

FIGURES

FIGURE 1 – SOLIDS ACCUMULATION IN AND ABOVE A SUCKER ROD PUMP, CAUSING A STUCK PUMP EVENT

Southern Ohio Sand 100 Mesh Sand

Quick Chek ✓			ISO 13503-2	50/140 Frac Sand Public Values	100 mesh
Particle Size Distribution, mm		Mesh size			
	0.425	40	≤ 0.1	0	0
	0.300	50		0.1	2.8
	0.212	70		22.5	35.1
	0.180	80		36.2	24.4
	0.150	100		27.7	23.1
	0.125	120		9.4	11.0
	0.106	140		3.3	2.7
	0.075	200		0.7	0.8
	<0.075	Pan	≤ 1.0	0.1	0.1
		Total		100	100.0
		% In Size	≥ 90	64	96.3
Mean Particle Diameter, mm					0.195
Median Particle Diameter (MPD), mm					0.190

FIGURE 2 – TYPICAL 100 MESH FRAC SAND PARTICLE SIZE DISTRIBUTION

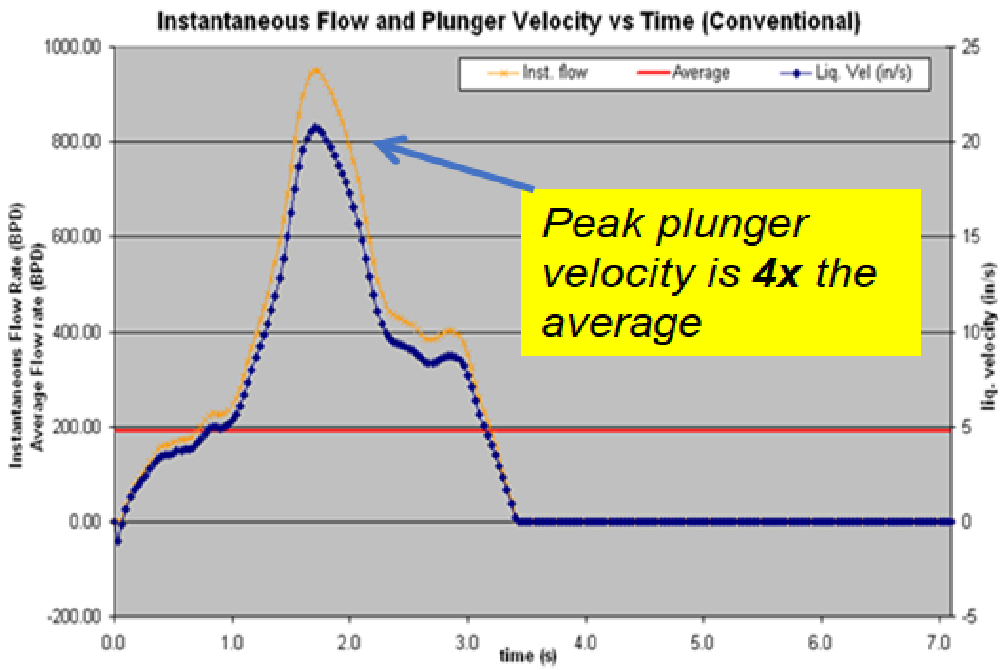

FIGURE 3 – INSTANTANEOUS LIQUID FLOW RATE INTO A PUMP DUE TO UPSTROKE PLUNGER VELOCITY

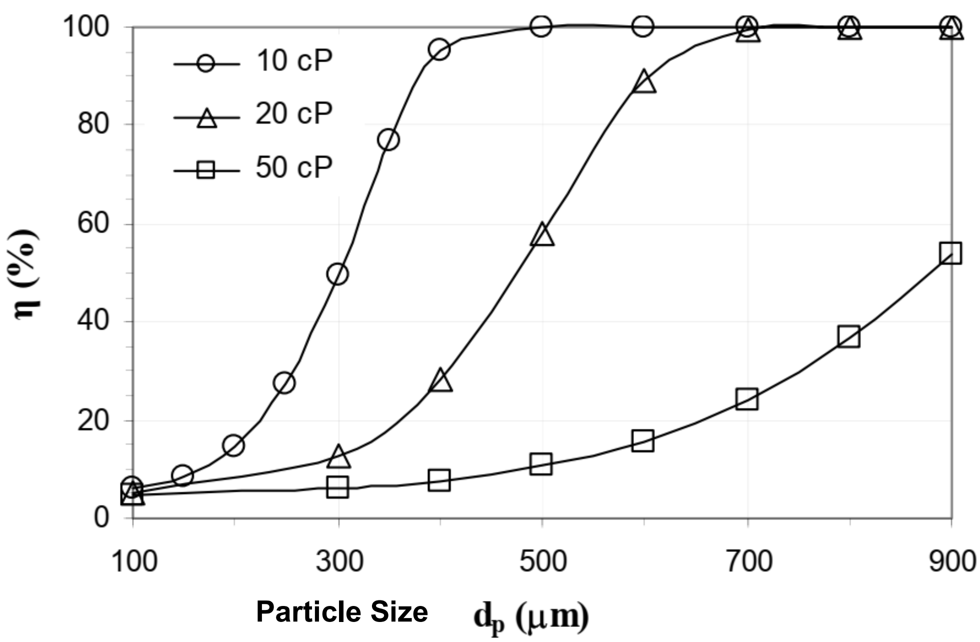

FIGURE 4 – DOWNHOLE CYCLONIC-GRAVITY SEPARATOR EFFICIENCY AS A FUNCTION OF PARTICLE SIZE

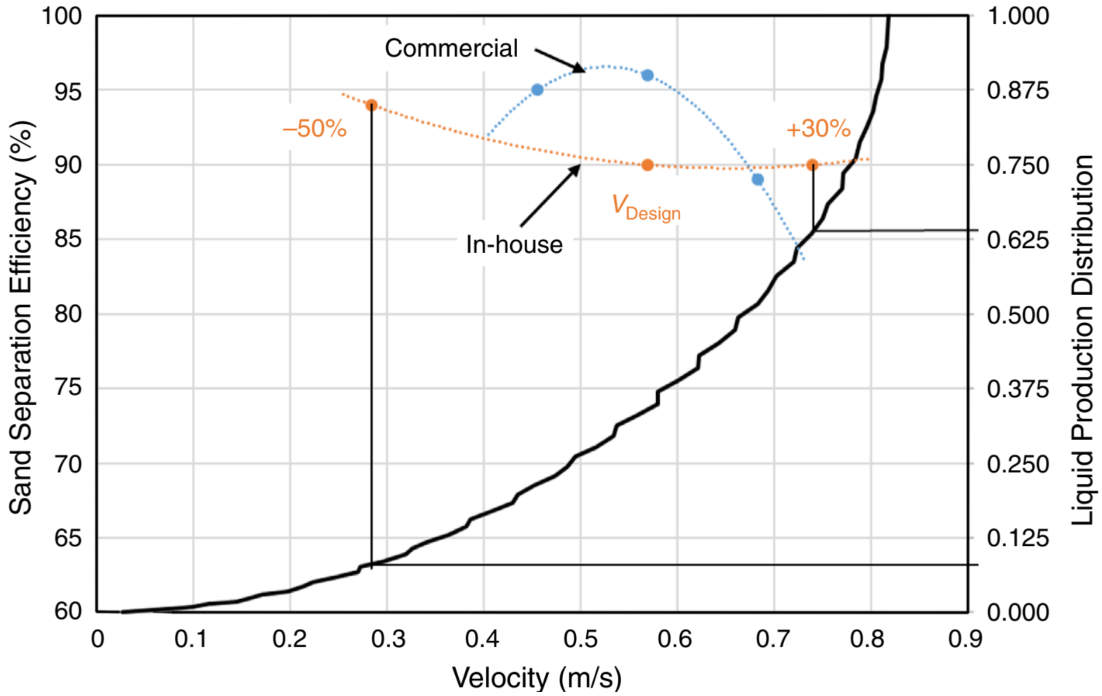

FIGURE 5 – DOWNHOLE CYCLONIC-GRAVITY DESANDER'S LIMITED SOLIDS SEPARATION (GREATER THAN 250 MICRON) LIQUID RATE ENVELOPE

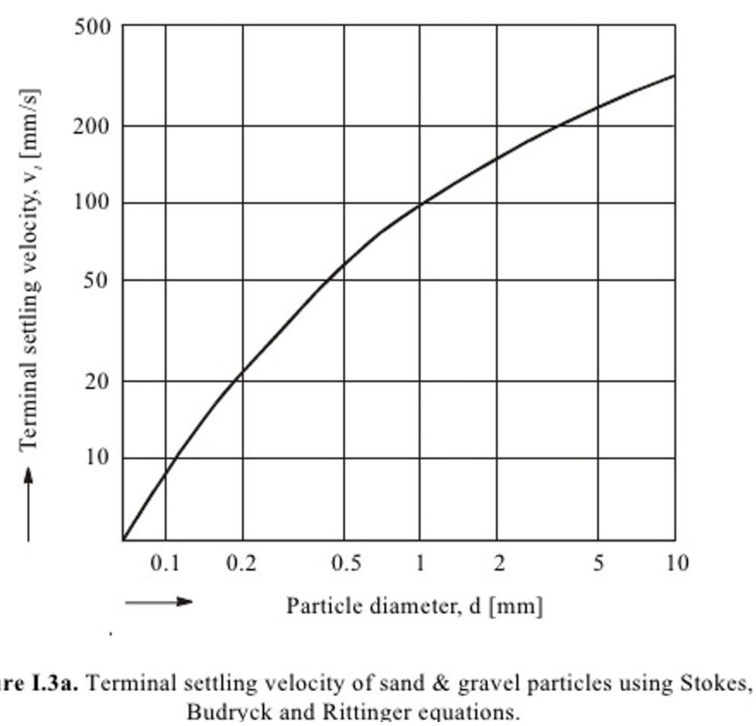

FIGURE 6 – SOLIDS SETTLING VELOCITIES A FUNCTION OF PARTICLE SIZE

Solids Transport in Tubing Calculator

Tubing Size	2.875	in	2.875	in
Tubing ID	2.441	in	2.441	in
Sucker Rod OD	1	in	1	in
Pump Rate	210	bbls/day	956	bbls/day
Solids/Sand Diameter	0.005	in	0.03	in
Solids/Sand Density	15.0	ppg	15.0	ppg
Liquid Velocity	**0.50**	**ft/sec**	**2.30**	**ft/sec**
Solids Lifting Minimum (vertical velocity)	0.50	ft/sec	2.30	ft/sec
	100 mesh		20/40 mesh	

FIGURE 7 – AVERAGE WATER PUMP RATE FOR LIFTING SOLIDS IN 2-7/8 INCH TUBING AS A FUNCTION OF PARTICLE SIZE

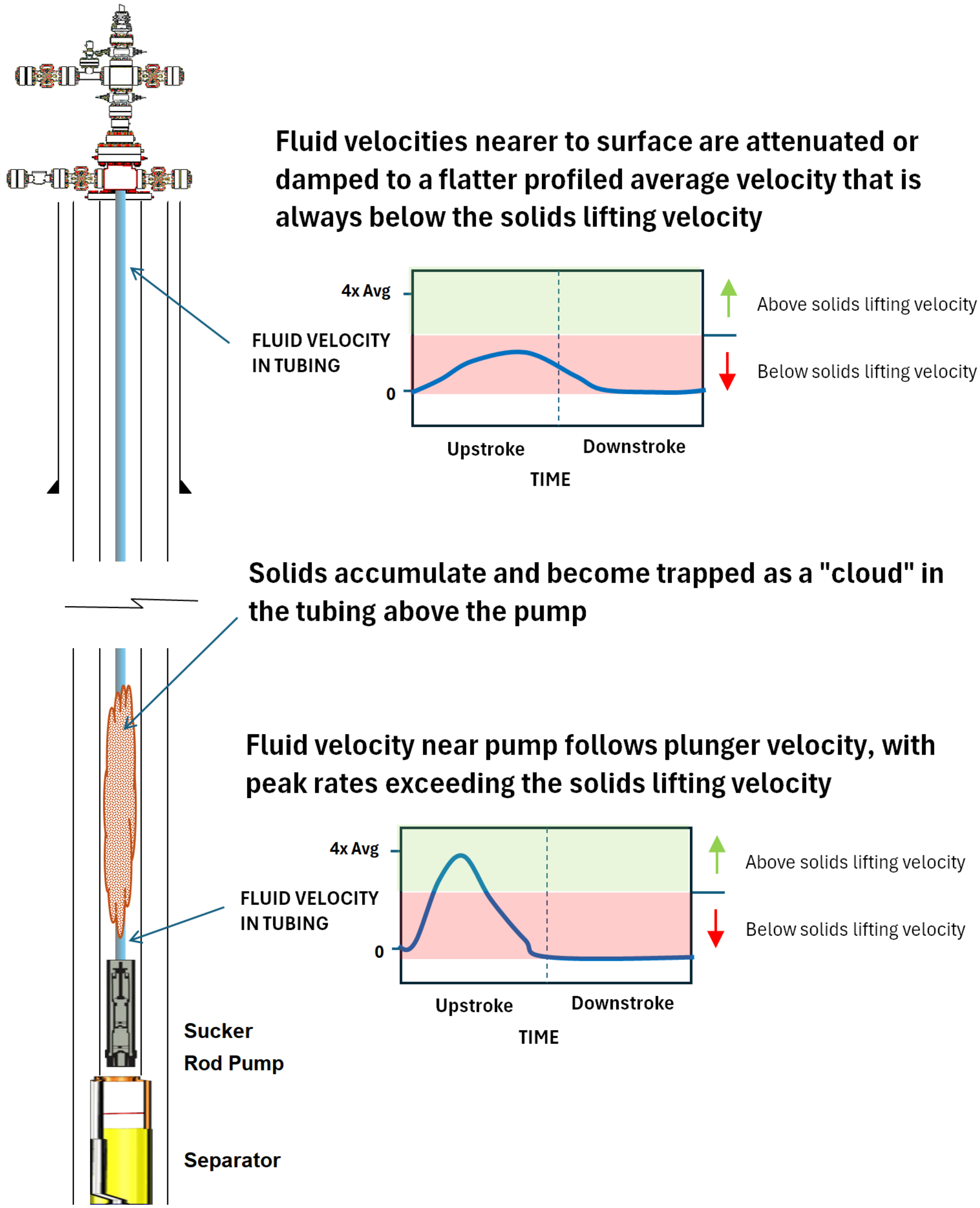

FIGURE 8 – HOW SOLIDS ACCUMULATE AND GET TRAPPED IN THE TUBING ABOVE A SUCKER ROD PUMP

FIGURE 9 – EXISTING TOOL FOR ESP SAND FALLBACK PROTECTION WHEN ESP SHUTS DOWN; NO DOWNHOLE PERMANENT CONTAINMENT OF SOLIDS

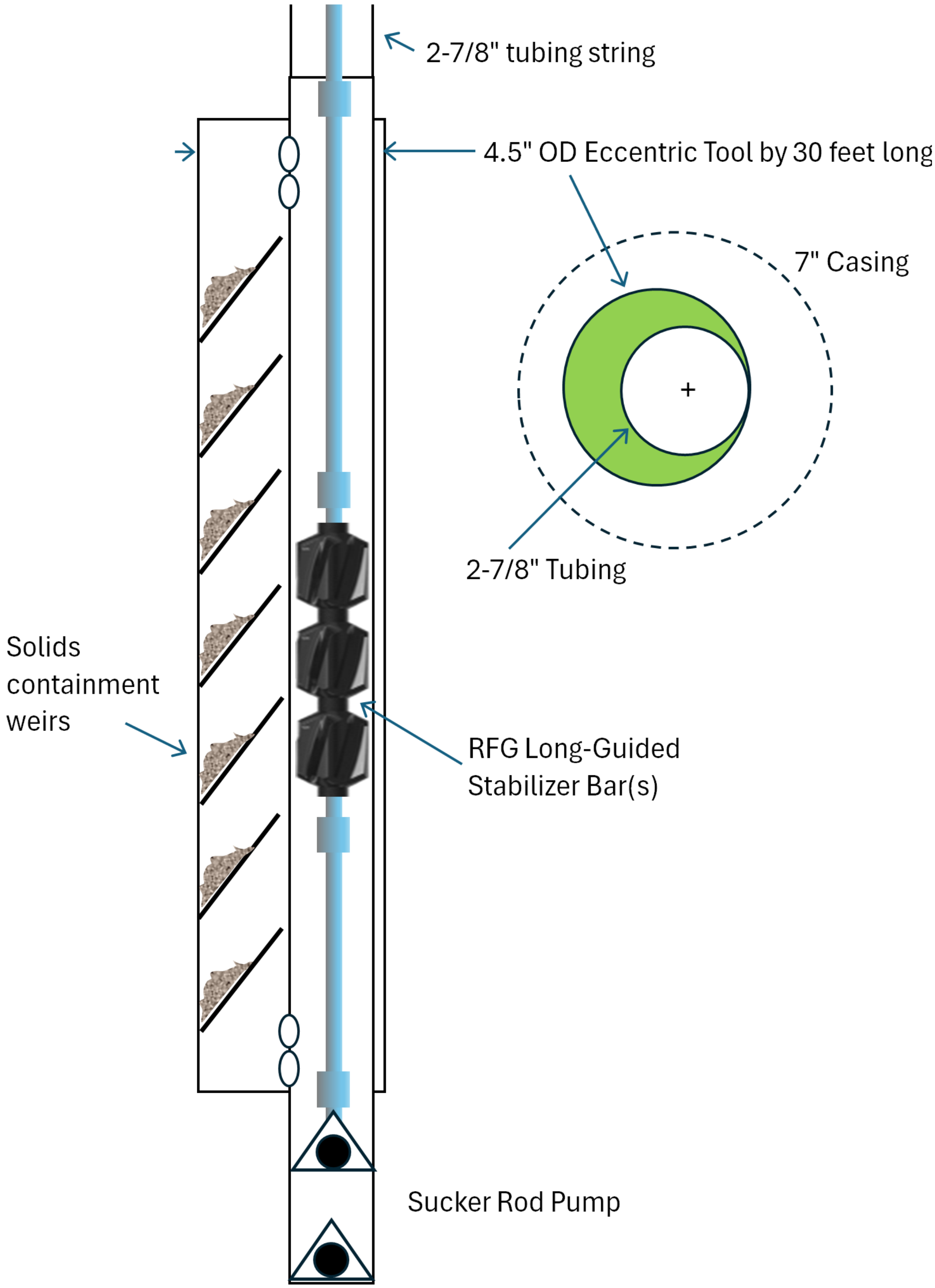

FIGURE 10 – SANDSHARK TOOL CONTINUOUSLY SEPARATES AND PERMANENTLY CONTAINS SOLIDS DOWNHOLE WHILE PUMPING, PREVENTING STUCK PUMPS

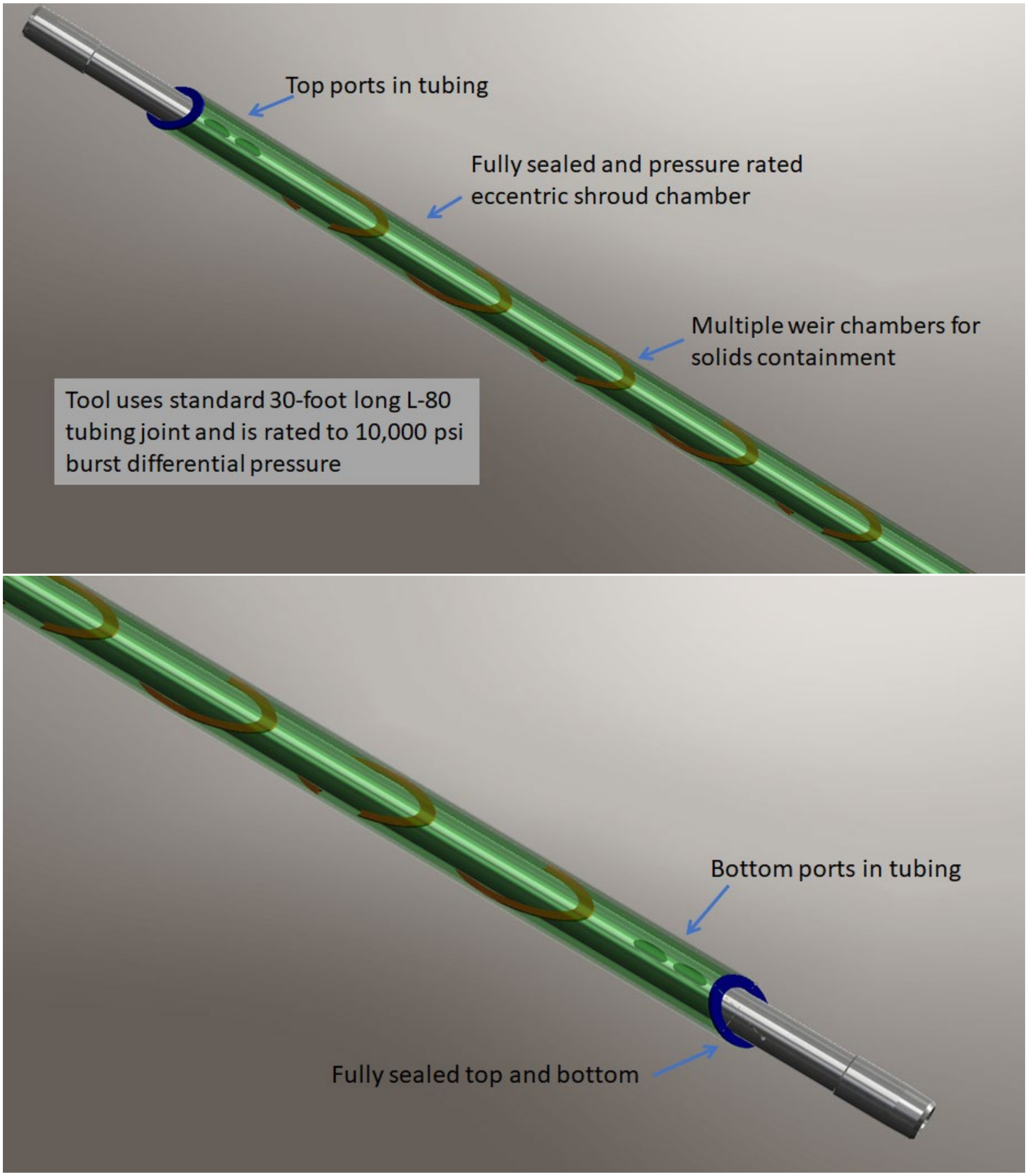

FIGURE 11 – SANDSHARK TOOL THREE DIMENSIONAL RENDERINGS

FIGURE 12 – SANDSHARK TOOL'S SOLIDS SEPARATION ASYMMETRIC WEIRS AND CHANNELS THREE DIMENSIONAL RENDERINGS

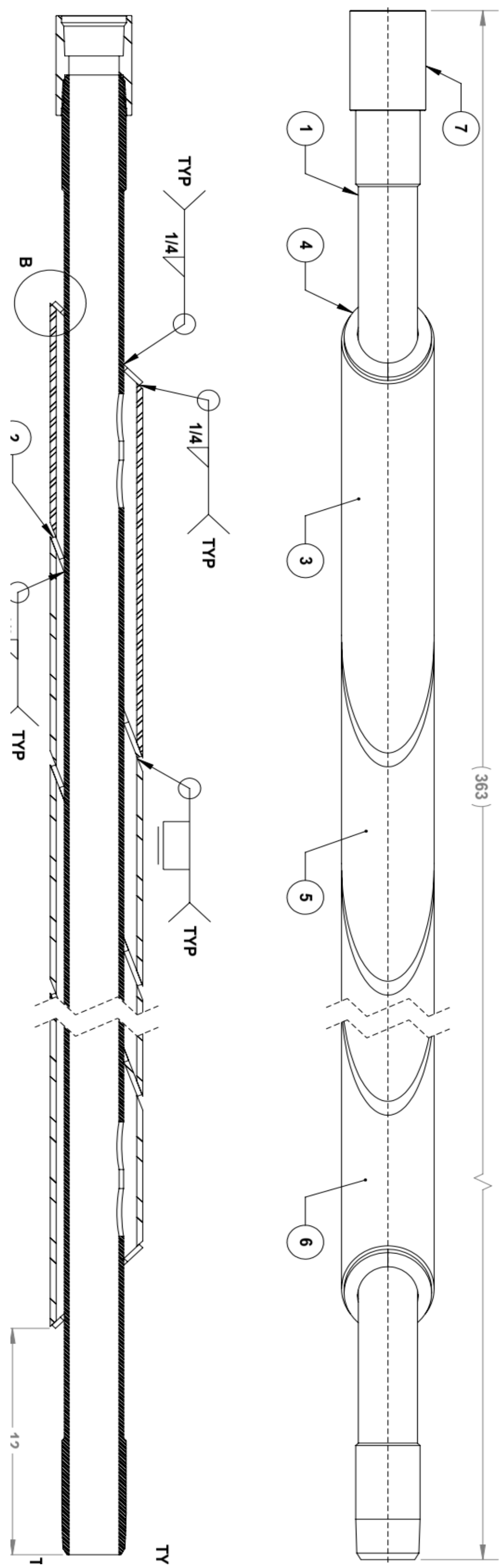

FIGURE 13 – ENGINEERING DRAWINGS, CUTAWAY SIDE AND TOP VIEW

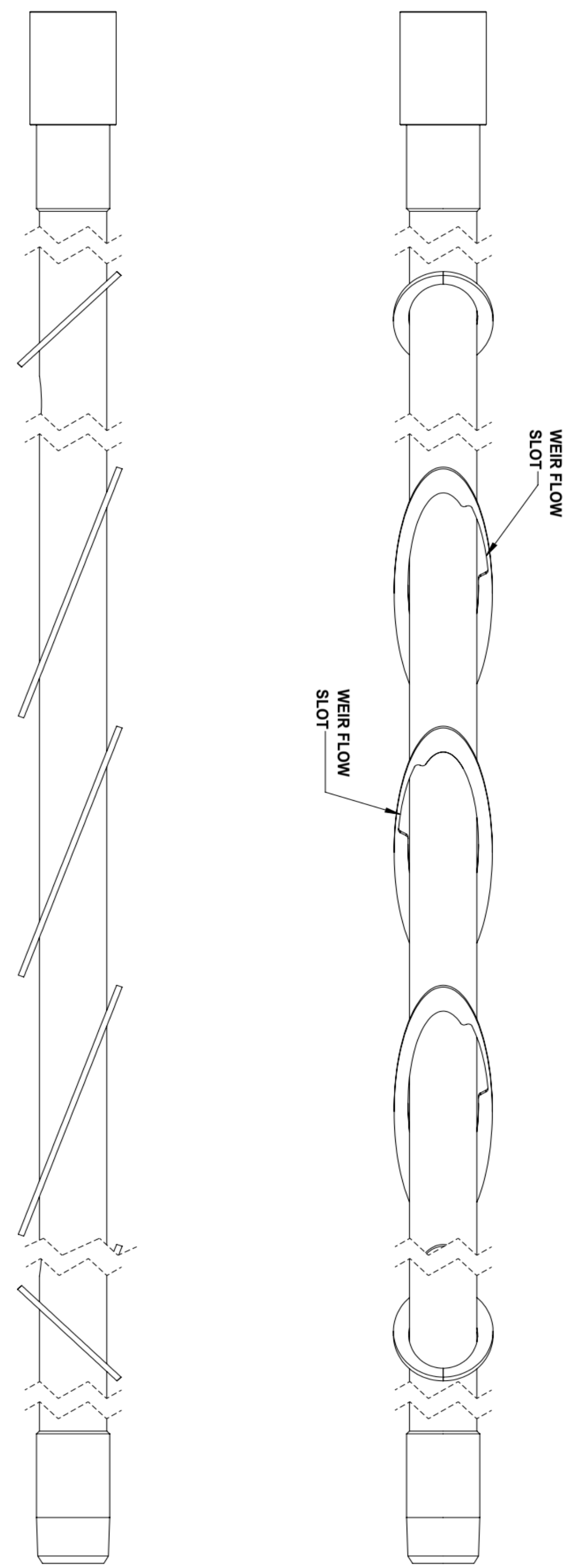

FIGURE 14 – ENGINEERING DRAWINGS, SHROUD REMOVED

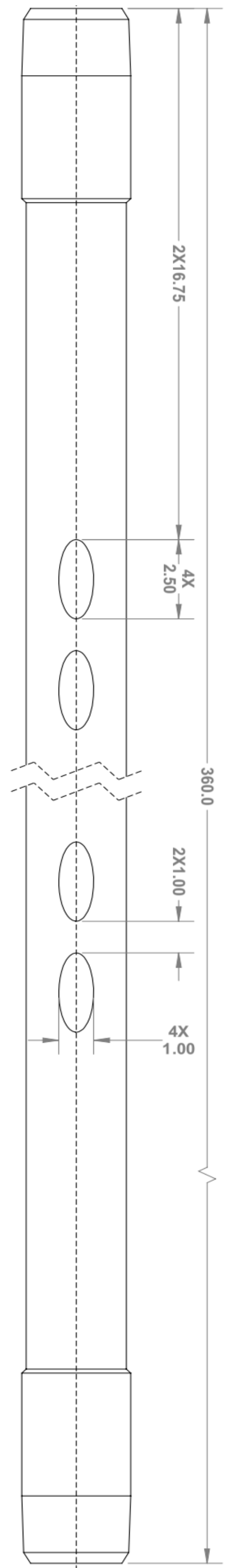

FIGURE 15 – ENGINEERING DRAWINGS, 2-7/8" TUBING JOINT WITH ENTRY AND EXIT PORTS TO SOLIDS SEPARATION CHAMBER

FIGURE 16 – SANDSHARK TOOL PROTOTYPE MANUFACTURING PICTURE

RFG PETRO SYSTEMS

FIGURE 17 – SANDSHARK TOOL'S USES RFG PETRO SYSTEMS LONG-GUIDED STABILIZER BARS AND BOX-GUIDES TO FORCE FLOW THROUGH THE TOOL DURING THE PUMP'S DOWNSTROKE

FIGURE 18 – SYSTEM PROCESS SEQUENCE OVER A FULL PUMP STROKE

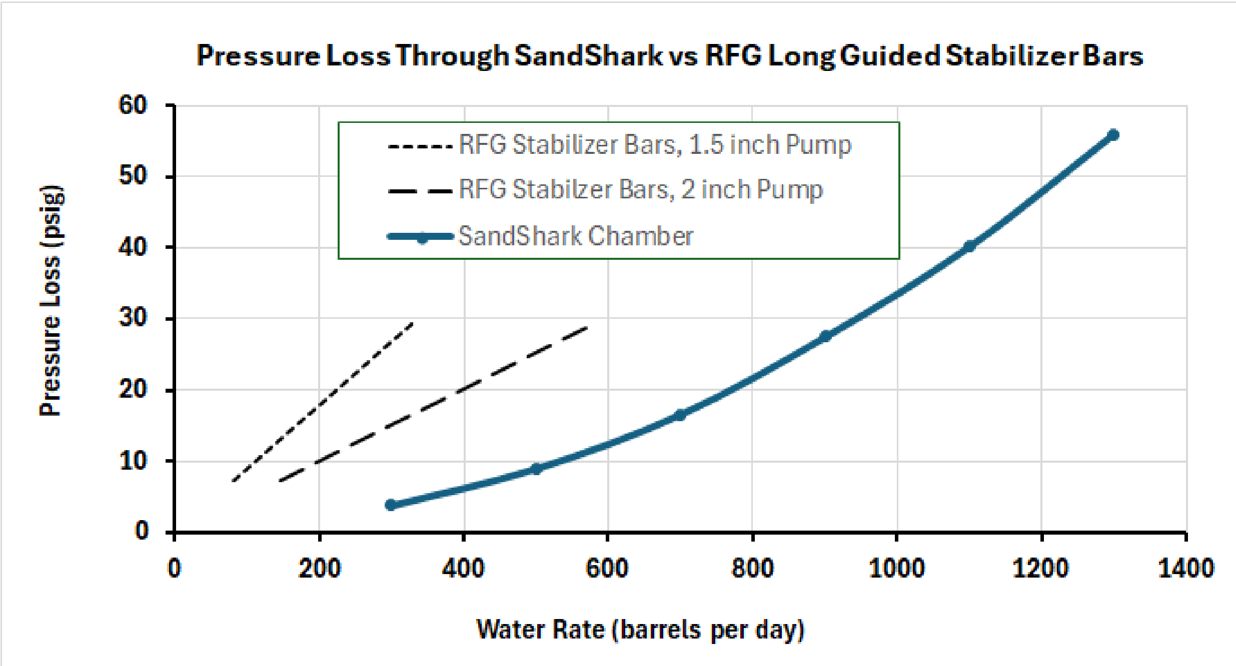

FIGURE 19 – PRESSURE LOSS AT VARYING LIQUID RATES THROUGH SANDSHARK TOOL'S SOLIDS SEPARATION CHAMBER VERSUS RFG STABILIZER BARS

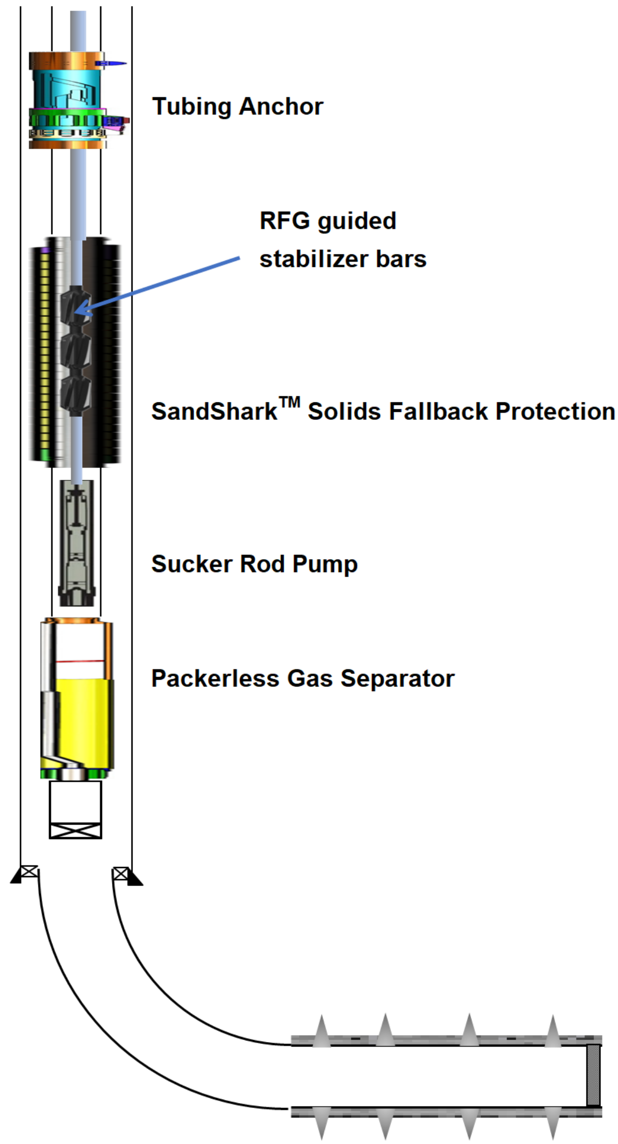

FIGURE 20 – WELLBORE BOTTOMHOLE ASSEMBLY CONFIGURATION

FIGURE 21 – SANDSHARK’S STACKED IN SERIES FOR INCREASED DOWNHOLE SOLIDS CONTAINMENT CAPACITY

ENDNOTES

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