NOT ALL SPHERES ARE CREATED EQUAL

That's the lesson that producers have learned in the Permian basin. Traditionally, options for sand separators have been limited to using either low storage and flow-sensitive vertical cyclonics, or low efficiency generic spheres to manage sand. Functional differences in technology, design, innovation, and quality of material may not be apparent on the surface but ultimately impacts overall production in addition to bottom-line. Making it crucial for decision makers to understand the differences between separator technologies and how to manage produced sand most effectively.

SPHERICAL SAND SEPARATOR DESIGN COMPARISON

Spherical sand separators are a fast-growing market segment of sand separators used in flowback operations. Compared to traditional cyclonic sand separators, a spherical separator will hold more sand, have more accurate load scale measurements, and suffer less from turndown at low flowing velocities. Newer cyclonic systems often include filters to achieve higher efficiency, but these filters will typically increase back pressure. Increased back pressure across a sand separator can restrict the operation of the well and reduce the ultimate recovery volume. There has been a newer trend of multi-stage cyclonic sand separators to try to improve performance, but spherical sand separators are some of the most common, simplest, and most practical solutions to increasing sand volumes year over year which pose erosional risks to flowback equipment.

Among spherical sand separators, the two main designs on the market are Sandtinel's varied fleet (the Defender, the Maverick, and the General) and the Sand Hog. There are also other spherical units on the market which are functionally similar to the Sand Hog, including the NOV sphere. All of these non-Sandtinel spheres are similar in design to the Sand Hog and will be considered as "generic spheres". There are also a small handful of other spheres on the market such as the BBS, but these typically employ a filter system which introduces its own problems, such as cleaning, clogging, replacement, and increased greenhouse gas emissions and operator exposure when opened.

Computer fluid simulations of these generic spheres shows a lower efficiency than typically seen in Sandtinel's Vapor Lock spheres. Fluid modeling demonstrates the reasons behind this difference, which is backed up by head-to-head field trials. An estimated operating curve comparison is provided which showcases the lower performance of a generic sphere compared to a Sandtinel sphere with Vapor Lock. Generic spheres also restrict the well with higher back pressure compared to Sandtinel spheres with Vapor Lock. In a field trial in the Delaware basin, performing a flowback through two Sandtinels increased the overall liquid production by 2,000 BBL/d compared to flowback through two generic spheres. Sandtinel has also shown that it provides a reduction in fugitive emissions during dump operations compared to generic spheres.

Sandtinel can provide CFD simulations and performance estimates for specific well conditions upon request.

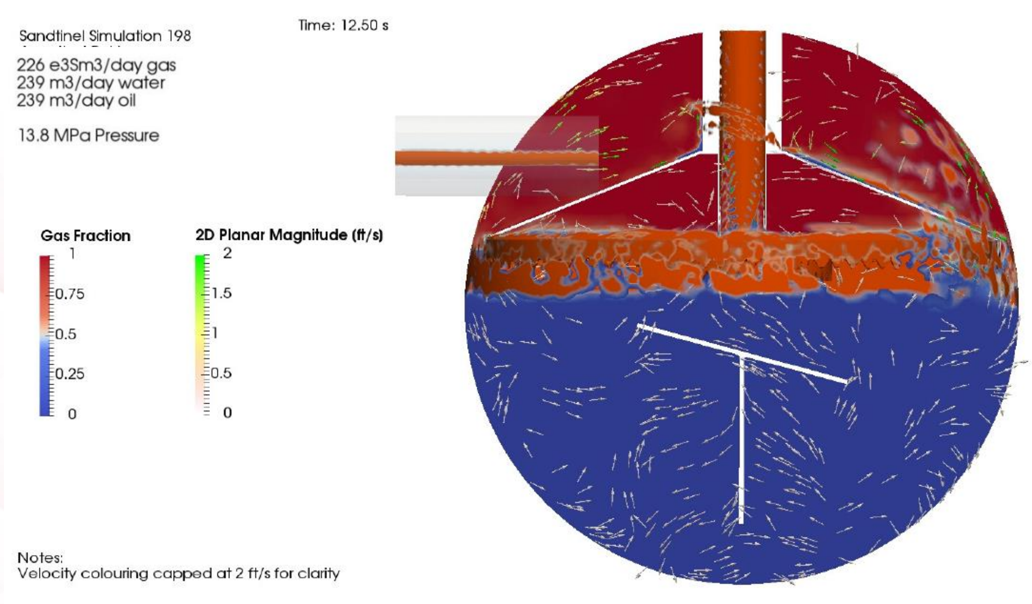
SANDTINEL G2 SEPARATOR

Sandtinel spherical separators use a method of fluid handling called the "Vapor Lock". A Vapor Lock design creates controlled separation of gas and liquid phases in the sand separator to slow down the incoming liquid so that sand can settle out of suspension. Sandtinel models the Vapor Lock effect using Computational Fluid Dynamics (CFD) to test the effectiveness of separation.

The G2/G2-S Defender is the most common Sandtinel sphere in operation in the field. The Defender is a side-entry 48" spherical separator with a top outlet. The vessel operates in steady state removing sand from the incoming fluid mixture of oil, gas, and water. Sand accumulates in the belly of the sphere, where it can be drained while the well is still online and still producing.

A Defender uses a Vapor Lock design to handle a wide range of operating conditions. The gas in the sphere is isolated into the upper region of the flow, creating a calm and controlled water flow in the lower hemisphere. This design handles oil and emulsions by creating a controlled layer of liquid buildup where sand can break through into the slow water reservoir below. An offset inlet pipe creates a slow and steady rotation of flow about the interface which increases retention time and promotes settling.

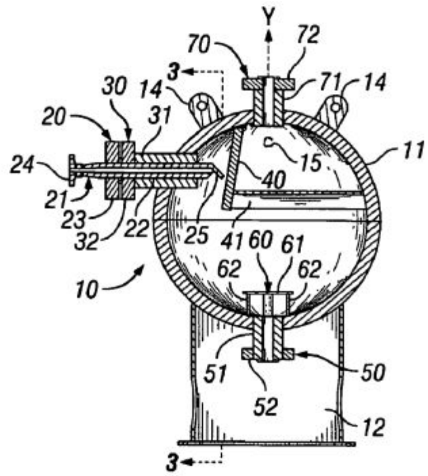
A typical condition is shown below in a CFD model for the G2-S Defender. Compared to the basic G2, the G2-S also includes Sandtinel's Sand Lock technology to maximize the storage capacity of sand, which reduces the necessary dumping frequency.

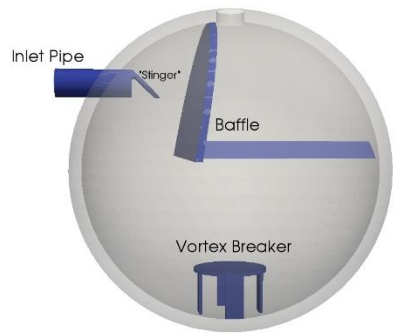


This CFD model allows Sandtinel to predict separation efficiency based on a wide range of criteria and to provide guidance on operational decisions about how to best use the equipment. Sandtinel's typical criteria for performance targets a minimum of 95% separation efficiency, which has been proven to be achievable in basins all across North America.

SAND HOG SPHERICAL SEPARATOR

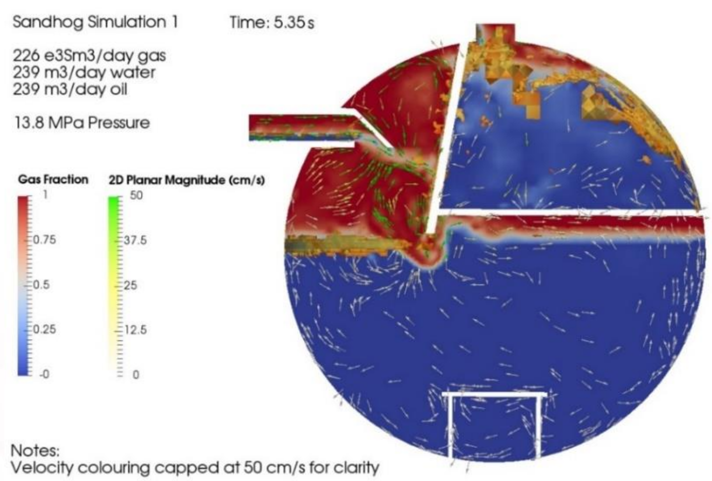
Sand Separators LLC filed the patent for the “Super Sand Hog” in June 2009. Sandtinel used publicly available patent information to create a model of the separator with Computational Fluid Dynamics (CFD) to better understand current spherical methods of sand removal. The Super Sand Hog internal design is shown below, first on the left from the patented embodiment, and on the right from Sandtinel’s interpretation of the patent for the purposes of CFD modeling.





In CFD analysis of the Super Sand Hog, Sandtinel found that the main features for sand removal were a “stinger” on the inlet pipe and a slanted baffle which acts as a barrier to the flow. Fluid and sand are pushed down into the bottom of the vessel; the fluid circulates back up to the outlet pipe at the top, while some sand is retained in the lower hemisphere.

A representation of the flow pattern inside of a generic sphere is shown from a typical CFD simulation, identical to the previous case shown for Sandtinel. The conditions for this simulation were chosen based on a typical US Permian application.



Compared with the design of the Sandtinel, which uses the “Vapor Lock” separation concept, there are several important differences in the Super Sand Hog:

- In the Super Sand Hog, gas is directed downwards into the bottom of the vessel to push the sand down. At high gas rates (lower pressure), this means that the gas will agitate and lift sand back up with it. Sandtinel uses a “Vapor Lock” design which separates the gas and liquid temporarily inside of the vessel, and maintains an even liquid interface across the entire vessel. This stops gas agitation from causing recirculation in the bottom of the sphere.

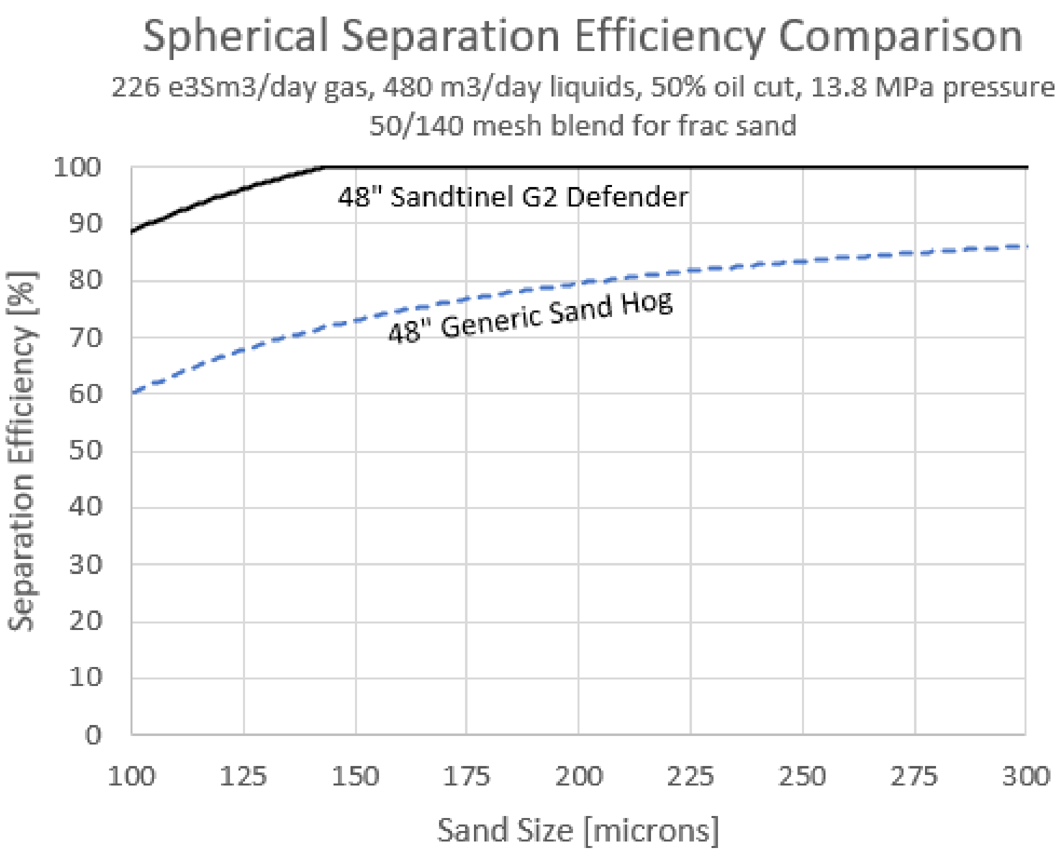
- The Super Sand Hog does not develop any kind of rotation in the flow, which means that there is only one chance to remove sand — when it is initially propelled into the bottom hemisphere. If the sand is buoyed back up or dragged up by high liquid rates, then it will never be able to settle out. Sandtinel uses the cross-section of the separator at the central plane as a spiral travel path for the sand. This provides a long distance of travel for the sand, which may drop out of suspension due to gravity. In this manner, Sandtinel provides a second chance or second pass at separation for sand which is not immediately propelled down into the collection area.

- As sand build-up starts to occur in a spherical vessel, the region of the sphere available for flow starts to shrink due to the sand layer height. This means that the same amount of flow is being pushed through a smaller area or volume, and thus the vessel will see higher flow speed. Faster flow is more likely to pick up sand that has settled to the bottom. To increase the size of the storage region, Sandtinel uses a vortex breaker feature as well as "Sand Lock" technology to create a region of slow flow in the bottom hemisphere. This results in improved storage capacity compared to a generic sphere, where up to 20-30% of the sphere can be holding sand without any effect on performance (exact retention depends on flow rates and conditions).

Typical sand behaviour inside of the Sand Hog is shown below, modeled with Discrete Element Method (DEM) techniques. The flow pattern has been removed here for clarity.

Heavier and larger sand is able to settle into the bottom of the Sand Hog, but a large fraction of the smaller sand is pulled straight up and out of the outlet pipe.

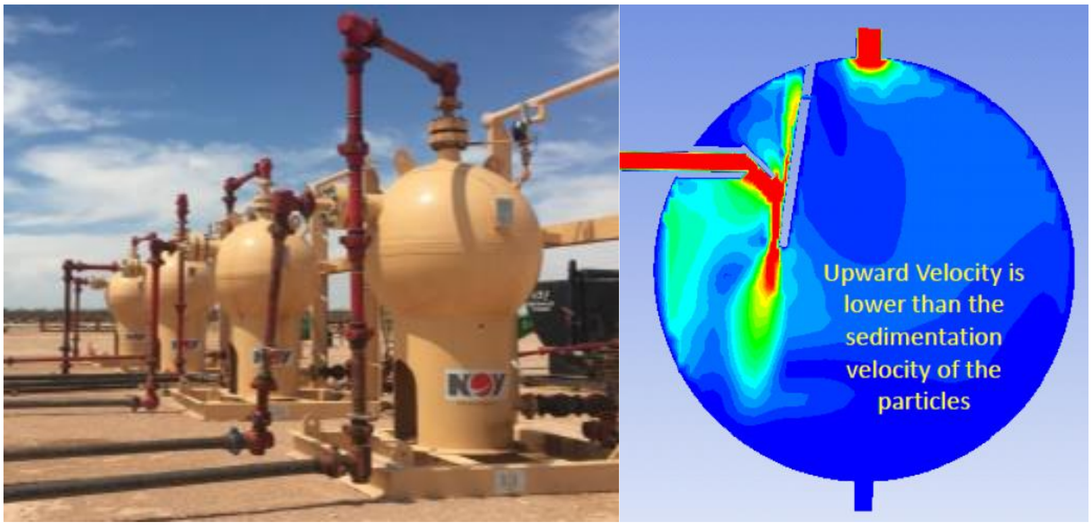
These results were combined with the Sandtinel G2 results discussed in the previous section. For a typical 50/140 mesh blend of frac sand, the chart below shows the performance difference between the two spheres.



This condition is representative of Sandtinel's typical findings, which is that even at the conditions where generic spheres perform well (eg. at 200 microns and above in this chart) they rarely ever see better than 85% efficiency. Sandtinel's typical target for performance is a **minimum** of 95% separation efficiency, but in general Sandtinel spheres have the **highest efficiency which is mechanically possible without using filters**.

NOV SPHERICAL SEPARATOR

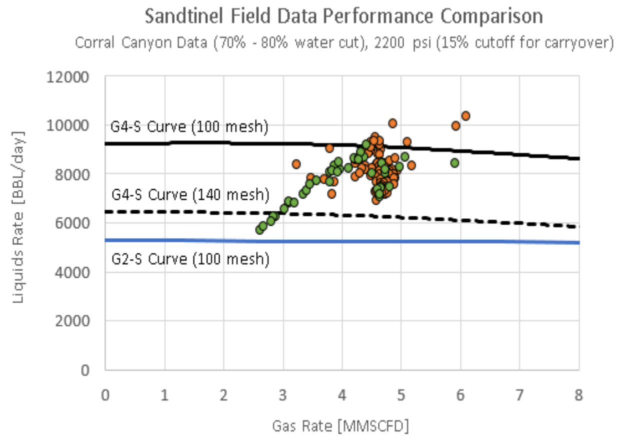
Although the CFD analysis above was based on the Super Sand Hog, another similar sphere is the NOV sand separator. Little information is publicly available on this device, but some information was taken from a presentation NOV delivered on their solids handling ("Flowback and Early Production Solids Handling"). This presentation shows the following images:



The main features from the Sand Hog, including the inlet pipe stinger and the angled baffle plate, are both present. Although Sandtinel has not modeled NOV spheres in detail, it is expected that the behavior would be very similar to a Sand Hog on the basis of these features. There are no components to develop an effective Vapor Lock, nor to create a secondary pass at sand removal through retention time. Storage in the bottom hemisphere will also be limited.

Sandtinel has had several field trials going head-to-head against NOV spherical separators. The most extensive was described in a recent field trial report on Sandtinel's website from the Delaware Wolfcamp region. In this trial, separators were placed in series, allowing an estimate of the upstream unit's efficiency from high efficiency downstream capture.

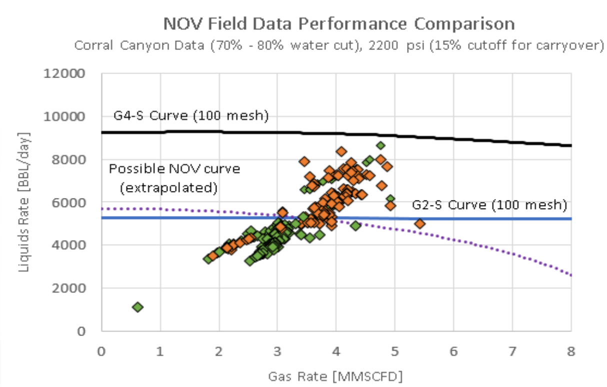
The chart below shows hourly data taken from a Sandtinel G4-S Maverick. The sand was between 100 and 140 mesh in size (between 100 and 150 microns in diameter on average).



On this figure, the green dots indicate hourly measurements of flow rates where a minimum of 85% separation efficiency was seen in the upstream G4-S Maverick sand separator. Orange dots indicate hourly measurements where less than 85% efficiency was seen.

Note that Sandtinel targets a minimum efficiency of 95% removal. In this chart an 85% threshold is used, in consideration of the NOV sphere — because the NOV never saw an efficiency of 95% in this trial. The Sandtinel saw a gradual reduction in efficiency as flow rates increased, from 99%+ at the lower flow rates around 6,000 BBL/day, down to ~70% efficiency at 10,000 BBL/day.

As shown in this chart, Sandtinel saw no noticeable carryover below 7,000 BBL/day of liquids. There was very high efficiency up to approximately 8,000 BBL/day, and often above. There were multiple NOV spheres installed in on a parallel well. The chart from that well is shown below:

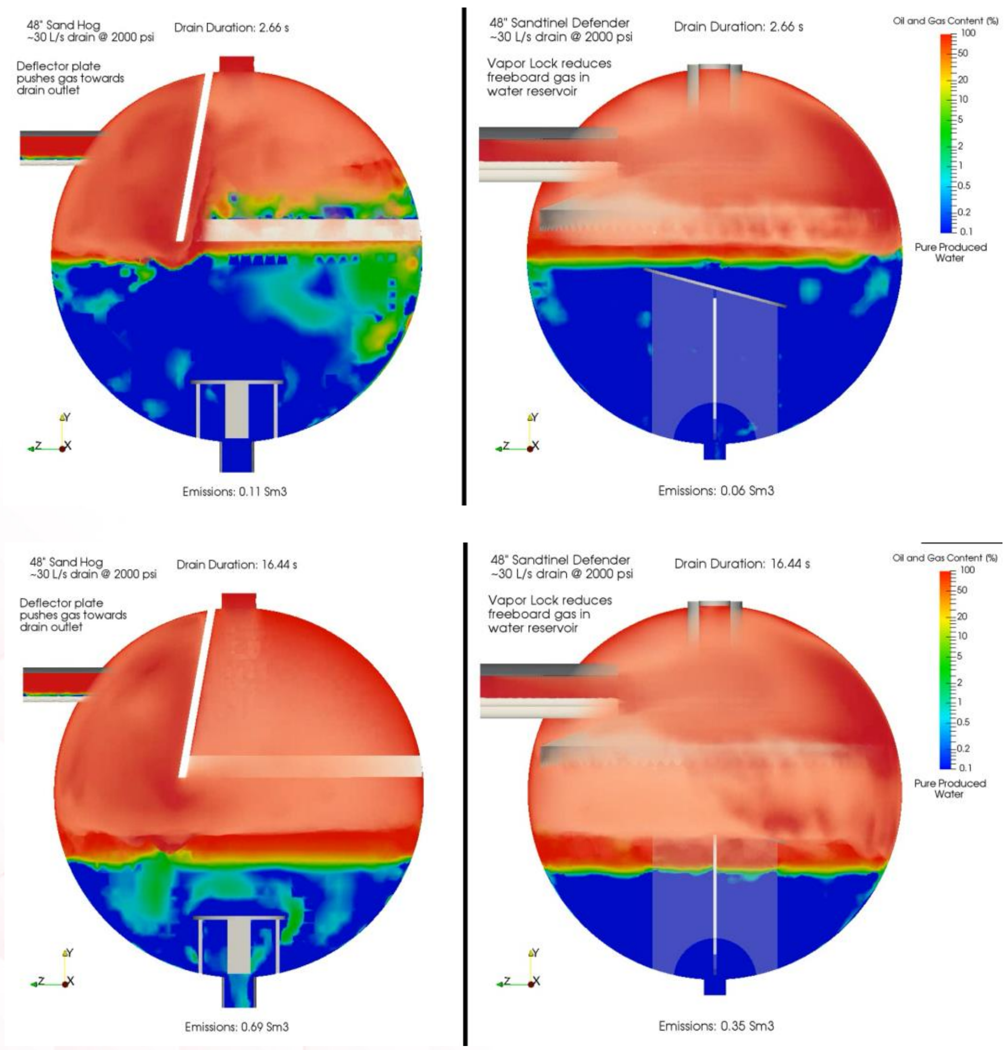


Compared to the Sandtinel separators, there was a sharp increase in carryover on the NOV spheres as soon as they exceeded approximately 5,000 BBL/day. Carryover rose quickly above that point, and at the highest flow rates of 8,000 BBL/day the efficiency was less than 50%. The use of NOV spheres compared to Sandtinel spheres also resulted in lower overall liquid volume from the parallel well. The production difference was approximately 2,000 BBL/day less compared to each Sandtinel train of two spheres. This reduction in liquid is due to the higher back pressure across NOV spheres which creates restrictions on the well.

EMISSIONS COMPARISON

One last comparison which must be mentioned is the propensity of generic spherical separators for fugitive emissions. When dumps of sand are performed from spherical separators, it is typical to have some gas release along with the liquid and sand slurry. This gas must typically be vented or flared. Sandtinel's Vapor Lock technology has shown that it is able to substantially reduce the volume of fugitive emissions with each dump cycle. In addition, Sandtinel separators hold more sand than generic spheres for reasons previously discussed, which means that they do not need to be dumped as often to begin with. The higher fugitive emissions are due to increased agitation of gas into the bottom of the sphere, whereas the Vapor Lock isolates gas in the top of the vessel.

The figures below demonstrate a typical dump scenario of up to 16 seconds, where a generic sphere saw approximately 200% of the fugitive emissions compared to the Sandtinel sphere.



The operating condition modeled in the sphere above was the same flow rates and pressure as was modeled in previous sections for efficiency comparison.

CONCLUSIONS

Overall, Sandtinel spherical separators have several key advantages over generic spheres (which include both Sand Hog and NOV spheres):

- Vapor Lock technology increases the peak efficiency from 85% separation to 100% separation (Sandtinel typically targets a minimum 95% separation efficiency)
- Improved design reduces back pressure, resulting in higher overall well production
- Improved performance at high gas rates, high oil rates, and with smaller sand
- Sandtinel provides a long retention time for sand settling; generic spheres have one opportunity to remove sand, or it is lost as carryover
- Increased storage capacity of sand, implying fewer dumps are required to deal with the same volume of sand in the fluid
- Dramatically reduced fugitive emissions from the bottom drain during dump operations, of approximately 50% from a generic sphere. Emissions reduction compared to vertical cyclonic separators is even more extreme, up to a 98% reduction or more.

Sandtinel can provide CFD simulations, performance estimates, emissions comparisons, and more upon request for specified operating conditions. Advanced Sandtinel units are also available to tackle tougher challenges, including the Maverick and General lineup, whereas this report only discussed the G2 Defender series.