

Aeration for Produced Water Management

As produced water management evolves in unconventional oil exploration and production, a transition is developing from waste product to beneficial, reusable product. During this transition the aggregation and storage of produced water become an important first step. Aggregation and storage have also evolved from frac tank storage to impoundments and above-ground storage tanks (ASTs). Aggregation and storage have led to other challenges, namely water quality management. Over time, produced water can foul quickly, leading to poor water quality and potential odor problems. These issues have created the need for regular pit treatment by adding oxidizers on a regular schedule. Insufficient mixing and UV degradation of commonly used oxidizers make this a potentially expensive process that isn't necessarily completely effective. A common alternative to pit treatments, utilized for years, is aeration.

Aeration is the process of increasing the oxygen saturation of the water by introducing air. This can take place naturally in flowing water and waterfalls or can be introduced through fountains. Oxygen acts as an oxidant, improving water quality while preventing bacterial growth. Aeration has been utilized for many years. An early paper by Dr. Stephen Hales, presented in 1755, extolled the virtues of water aeration. The first known large-scale application in the United States was the Water Works Company in 1861. Over the years, aeration has been applied using a variety of methods—from natural aeration, surface aeration and subsurface aeration.

Natural Aeration

Natural aeration can occur through waterfalls, flowing water and other disruptions of the surface tension to increase the contact between the water and air. Another type of natural aeration is through photosynthesis from subsurface plant life. Unfortunately, produced water's high salinity is not an environment for most aquatic plant life. Since produced water is mostly stored in static impoundments and ASTs, natural aeration is limited. As a result, natural aeration is unlikely to have any significant effect on the quality of produced water.

Surface Aeration

Surface aeration is typically conducted utilizing fountains or other surface agitation. Fountains typically pull water via a pump and spray it into the air. Increasing the surface area improves the air-to-water contact and increases dissolved oxygen (DO). Fountains also increase evaporation, which reduces water volume and can concentrate contaminants. If the ultimate goal is to dispose of the produced water, evaporation may be a benefit. If not, concentrating contaminants may make reuse more difficult.

Other floating surface aeration devices agitate surface water by improving the air-to-water contact to increase DO, while not having as significant an effect on evaporation as fountains. In either case, surface aeration affects only the top 1 to 2 ft of the water surface. This may improve odor concerns and provide

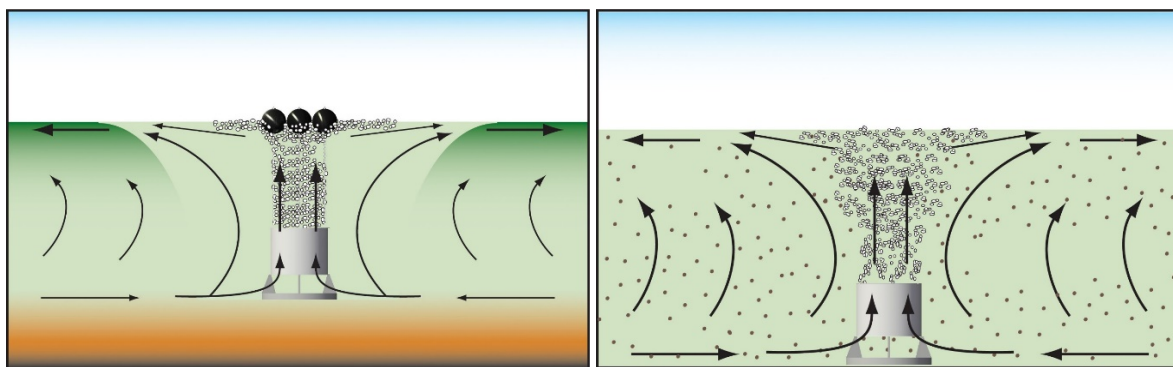
a barrier to help absorb odor and prevent its release, but it does little to improve overall water quality or prevent stratification. In produced water management, stratification leads to inconsistent water quality, which can make it more difficult for disinfection and reuse programs and have a negative effect on crosslink gel frags, where chloride concentration changes can affect gel quality.

Subsurface Aeration

Subsurface aeration can include jet aeration and coarse and fine bubble diffusion. Not only does subsurface aeration create more air-to-water contact, but it also improves circulation and mixing. The further from the surface the better the air-to-water contact is. Subsurface aeration creates an area of DO super-saturation (concentrations above saturation point) at the air discharge point, which ultimately diffuses throughout the water body. The idea behind subsurface aeration is to create circulation throughout the water volume, not just at the surface, while increasing DO to improve water quality. It's not the air in aeration that helps, but the oxygen in the air.

In produced water applications, either submersible pump systems or bubble diffusion can achieve increased DO. Hydrozonix selected bubble diffusion to avoid running power into a body of water and potentially creating a safety concern. Air-driven mixing using diffusion requires only a compressed air hose be submerged, while the power and compressor remain above ground.

Unfortunately, most subsurface aeration systems are permanently installed into the water storage system, and most produced water storage systems are made to be nonpermanent and are not constructed to include subsurface aeration. This leads to the need for a portable subsurface aeration device. With subsurface aeration, the increased water-to-air contact improves circulation and mixing. Placing the aerating system near the bottom of the water source also agitates solids to prevent them from accumulating, or the height may be adjusted to prevent such agitation. A float system aids in the ability to adjust the distance from the surface. The further from the surface the better the circulation of the water source. The images below show how the flow pattern of the water changes as the distance from the surface changes.



Floating Aeration System

Completely Submerged Aeration System

This type of configuration only requires the device and an air line be submerged. The closer to the bottom, the better the circulation, but this configuration also agitates solids. Depending on the goal, agitating solids allows easier removal of solids as opposed to temporarily taking an impoundment out of service to have it drained and the solids removed. If the solids are not to be agitated, a floating design

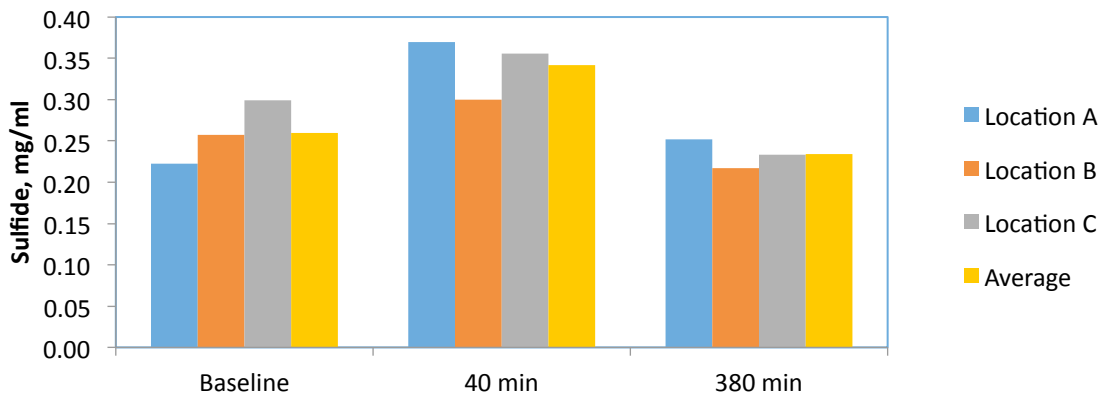
can help and provides the flexibility of adjusting the distance from the surface to maximize circulation. If the idea is to mimic surface aeration, the distance from the surface should be as short as possible, but this configuration causes a significant loss of circulation.

Dissolved Oxygen: Friend or Foe

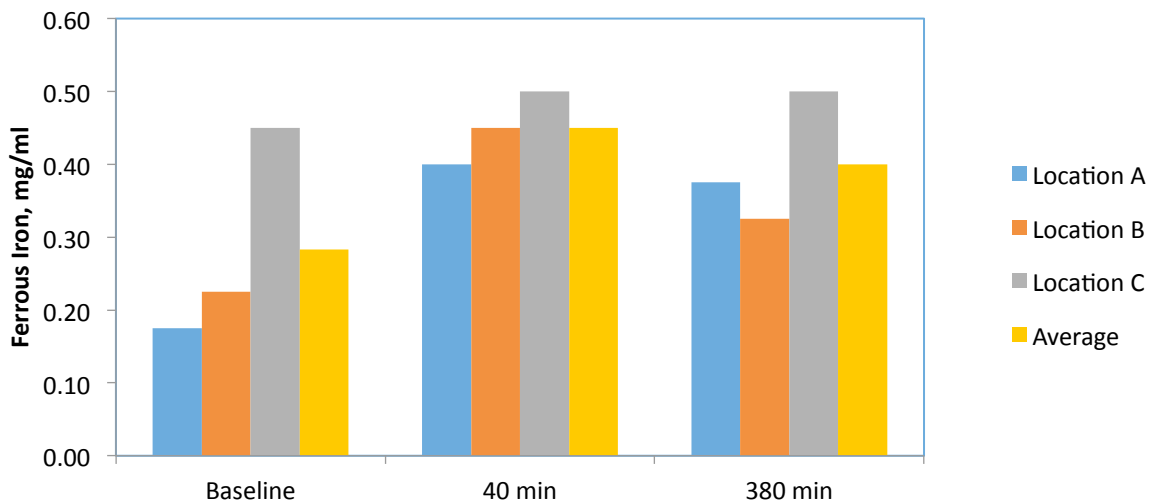
DO in the air acts as a mild oxidizer that reduces bacteria, iron and sulfides, as well as other reducers that may be in the water. Using finer bubbles also increases the surface area of the air, leading to better water-to-air contact. Typically, the saturation point for water is just over 8 ppm at 70°F. Saturation point, unfortunately, decreases with an increasing chloride level. For example, the saturation point of seawater is 20% lower. Saturation point is also affected by temperature and pressure. Saturation point increases with increasing pressure and decreases with increasing temperature. This is important to understand so that a target can be established for aeration. However, the problem with using a saturation point as a target in produced water management is that new oxygen-deficient water is added to the pit. This makes reaching the saturation point difficult. Establishing a goal of 2 to 4 ppm for DO means at least DO is readily available. If a 2- to 4-ppm level is maintained in an active pit, bacterial growth is prevented and reduced over time. Higher levels are preferable if they can be maintained. One common concern is the role DO has in corrosion. DO can accelerate corrosion, and as a result, adding oxygen scavengers is not uncommon in waterflood applications. In frac reuse, this is not as big an issue. Typically, DO is highest at the blender, where vortex mixing adds significant air and provides little in the way of a release point for super-saturated fluid. Adding a little DO in storage usually declines in the working tanks and doesn't compare to what is added at the blender. As a result, increasing DO while in storage has an insignificant effect on corrosion because of the release points available to avoid super-saturation, and DO in aerated water is always much lower than post-blender results.

Circulation with Aeration

All aeration, as mentioned earlier, does not create good circulation. Circulation has many benefits on its own. Bacteria can be either sessile (growing on a surface) or planktonic (floating in the water). Sessile bacteria populations like biofilms grow much faster than planktonic, in most cases. That is one reason flowing water and waterfalls have better water quality than a static pond. Good circulation helps inhibit bacterial growth by keeping bacteria planktonic. Another concern with static water is stratification. Stratification is common with produced water because chloride content increases with depth and temperature decreases with depth. Compounds heavier than water settle and lighter ones float. Circulation prevents stratification and keeps a more consistent water quality throughout the water volume. By combining circulation and aeration, water quality is improved by increasing DO, and by circulating DO throughout the water volume, a uniform water quality can be maintained.



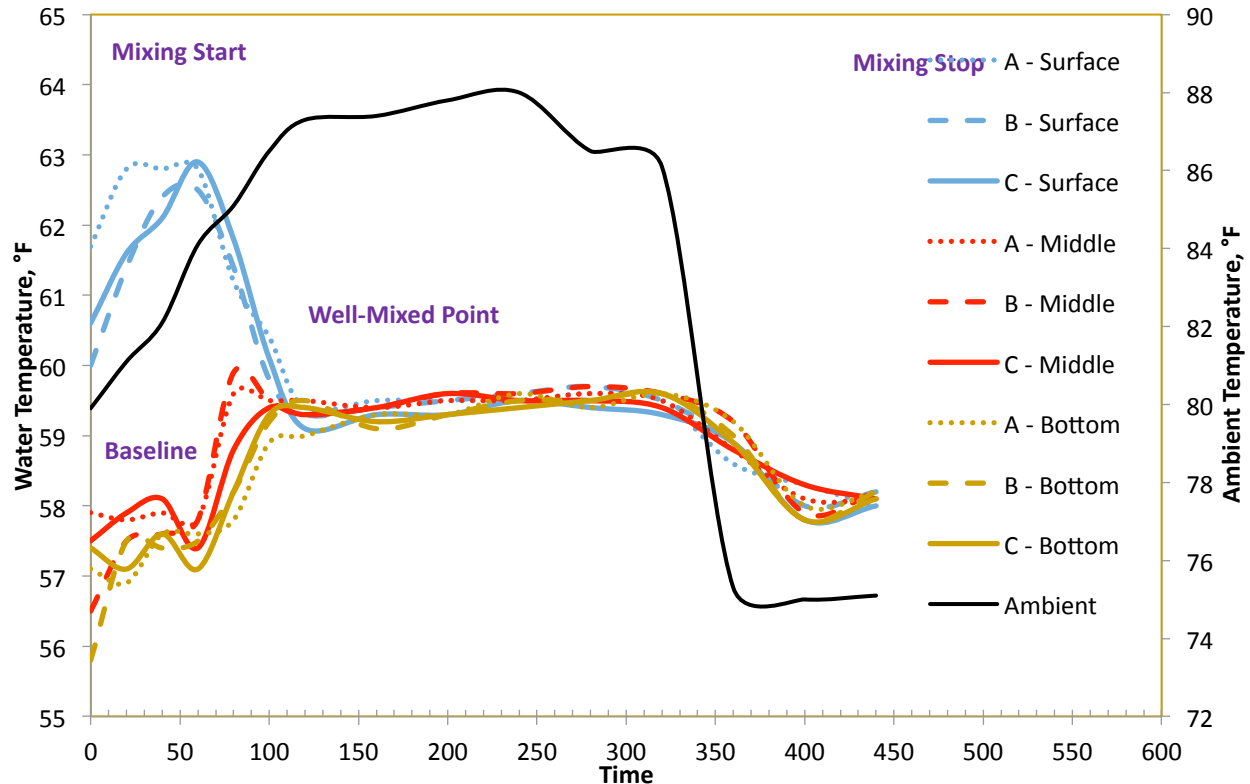
Sulfide Reduction from Aeration



Iron Reduction from Aeration

The above examples are taken from a pit where some stratification had begun. Sulfide and iron levels are inconsistent when taking surface samples at different locations. After a short time of mixing and circulation, sulfides and iron increase. Since sulfides and iron weren't being introduced, it appears that stratification caused higher sulfide levels at depth and circulating the water caused a temporary increase. Over time, the concentration was reduced and became more stable. This initial increase can be repeated for most parameters, including bacteria, total dissolved solids (TDS) and chlorides in a stratified body of water. It is important to circulate first in order to get accurate data representing a body of water. Without circulation, water quality is grossly underestimated.

So how can one determine that a body of water has been sufficiently circulated in order to have consistent quality? Several methods may be used. Hydrozonix compared temperature and TDS, and both gave similar results. Because temperature can be measured much more quickly, Hydrozonix uses temperature to determine whether mixing/circulation of a water volume is adequate.



Temperature Readings in Pit to Determine the Well-Mixed Point

Measuring temperature at different depths and different locations results in dramatic differences and signs of temperature stratification. Monitoring this over time indicates a convergence of the temperature, and this is the “well-mixed point.” This occurred in the above example in about 110 to 120 minutes. The time to reach the well-mixed point varies based on the amount of circulation and volume of water, but monitoring temperature at different depths and locations will indicate the time required. The well-mixed point is the best time to take a sample and provides the most accurate picture of overall water quality. For planning purposes, especially reuse on crosslink gel fracs, sampling at the well-mixed point ensures that frac fluid consistency does not change and the gel is stabilized, provided circulation continues.

As mentioned earlier in pit treatments, adding an oxidizer to the pit is a common practice to inhibit bacterial growth and odor, but applying it becomes problematic. Adding it to a pump and injecting it into the water source provides uneven treatment. Over time, the oxidizer diffuses to try to reach equilibrium, but decay and degradation from sunlight can occur before the oxidizer reaches the depth and width of the pit. Aeration and circulation are a good alternative but can take time to achieve a specific bacteria level. Adding biocide with circulation and aeration provides the mixing and mass transfer to make it more effective and speed up the bacterial disinfection process.

Mixing/aeration systems have many benefits. They can homogenize a pit for consistent water quality, they can improve water quality by mildly oxidizing contaminants such as iron and sulfides with oxygen, they can control odor, and they can be used for mixing efficiency to improve pit treatments when a

quick result is needed. More importantly mixing/aeration systems are a relatively inexpensive water management strategy, which is important in the current price-sensitive market.

For information about Hydrozonix portable aeration solutions to control bacteria, iron and hydrogen sulfide, visit www.hydrozonix.com or call us at 936.441.0071.