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A supplement to E&P

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Water Management
The 2018 Techbook

A supplement to *E&P*

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Hart Energy's Techbook Series

The 2018 Water Management Techbook is the 15th in a series of techbooks in which Hart Energy will provide comprehensive coverage of effective and emerging technologies in the oil and gas industry. Each techbook includes a market overview, a sample of key technology providers, case studies of field applications and exclusive analysis of industry trends relative to specific technologies.

To learn more about E&P technology trends, ***visit EPmag.com.***

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On the cover: Oil and gas industry innovations in water management planning, treatment, technologies and services aim to optimize water resources for all stakeholders.

Taking Charge of Water Management

Enhanced practices emerge amid growth in production.

By Brian Walzel
Associate Editor, Production Technologies

The challenge of managing water—acquiring enough supply for massive fracturing jobs and safely and securely handling the growing amounts of produced water—has emerged as a task nearly equal to that of producing hydrocarbons themselves. Enhanced completions, sometimes more than 2 miles long, often result in high IPs, but what also arises are escalated amounts of produced water. Meanwhile, those same completions often are requiring hundreds of thousands of barrels of water for each fracturing job.

Layne Christensen operates two freshwater storage ponds just outside Pecos County in the Permian Basin, one holding 500,000 bbl and the other holding 250,000 bbl of water. *(Photo courtesy of Layne Christensen)*

In a study on water usage in North American hydraulic fracturing operations, the U.S. Geological Survey (USGS) found that "the amount of water [needed] to hydraulically fracture oil and gas wells varies widely across the country." The USGS reported that average water volumes for fracturing jobs ranged between 2,600 gal per well to as much as 9.7 MMgal per well. Meanwhile, according to the Produced Water Society, nearly 10 bbl of produced water are generated for each barrel of oil.

By most estimates, water management costs often account for about 40% of fracturing operations. According to Layne Christensen, a Houston-based water management company, the cost to acquire freshwater in the Delaware Basin ranges from $0.50/bbl to more than $2/bbl, while disposal costs range from $0.50/bbl to $1/bbl, an amount that does not include transportation costs.

With so much water going into and coming out of wells, and the costs of securing enough supply and managing produced water so high, both service companies and operators are investing in innovative approaches to moving, analyzing, supplying and disposing of water, while regulatory agencies work to stay ahead of this rapidly growing industry. According to Bluefield Research, spending on U.S. hydraulic fracturing water management and services will increase from a little more than $12 billion this year to nearly $15 billion in 2026, with disposal costs accounting for most of the increase in expenditures.

Layne Christensen's pump station operates four pumps running at 125 hp each and can pump more than 175,000 bbl/d of water through the company's Hermosa pipeline. *(Photo courtesy of Layne Christensen)*

Water supply and reuse

Acquiring enough water to fracture wells that feature the latest enhanced completion designs has given rise to an emerging midstream market, one that helps defray costs and ensures adequate supply. Additionally, both operators and service providers have worked to develop recycle and reuse operations to handle large amounts of produced water as an alternative to injecting it through disposal wells into deep underground reservoirs. These recycle and reuse operations are emerging options that reduce costs while also avoiding potential induced seismicity issues.

In July 2017 Layne Christensen announced the completion of its Hermosa project, a 20-mile water pipeline serving producers in the Delaware Basin. Five months later, in December 2017, Layne announced a 6-mile expansion of the pipeline.

Michael Anderson, president of the company's water midstream operations, said the Hermosa pipeline can deliver up to 175,000 bbl/d of water to producers operating in the Delaware Basin. Anderson said the water is sourced near the town of Pecos, where freshwater is more plentiful, and piped north and west, where the region is much dryer and the local aquifers are thinner.

"Along this 26 miles, we currently have 13 different delivery points, and we'll have 18 as we add the 6 miles, so it's really easy for a lot of producers to tap into the risers we have along the pipeline," Anderson said.

According to Layne Christensen, the system offers a long-term water source with enough aquifer resources to last more than 15 years.

With the demand for water increasing, Anderson said the company is looking to implement additional pipeline projects in other unconventional plays and that the Midland Basin and Scoop/Stack basins in Oklahoma are likely targets.

"The notion of building out big source water infrastructure is not going to be right for every single basin," Anderson said. "The big poster child for not doing this is the Marcellus, where water is pretty easy to come by."

Companies like Apache, Approach Resources and Continental Resources have invested in developing their own water midstream infrastructure, operations that include recycling capabilities that allow them to reuse produced water in fracturing operations.

Matador Resources has operated a recycling facility at its Rustler Breaks asset in Eddy County, N.M., since 2015. According to the company's third-quarter 2017 financial report, the facility has recycled more than 6.8 MMbbl of water with an estimated gross savings of $5.9 million. Since 2015 Matador

has stimulated 34 of its Delaware Basin wells with recycled water.

According to John Williams, executive director of technology for Bosque Systems LLC, only about 10% to 30% of water is being recycled for reuse, but he expects that amount to more than double over the next two years.

Williams said more companies may adopt water recycling and reuse operations if they were more willing to embrace change in their typical operations than they traditionally have.

"It's a challenge to get all of the people involved in the decision-making process in the same room to learn about new technologies that have emerged in the industry," he said. "That limits the ability to introduce new technologies and also the means to keep innovation from being commoditized before it is completely developed."

Bosque Systems' operations work to sterilize water by removing bacteria before injection for fracturing operations. *(Photo courtesy of Bosque Systems)*

Digitalization of water management

Like many other sectors in the oil and gas industry, water management is embracing digitalization. Its proponents and those who operate in this space—companies like Digital H2O and Veolia Water Technologies—say an analytics-based approach helps producers more easily find supply and streamline their water management operations.

"We see the power of Big Data in water treatment, just as in any other industry," said Veronique Bourgier, Internet of Things business development director for Veolia Water Technologies. "Technologies exist today that were not available even five years ago."

Veolia's primary digital offering in water management operations is its Aquavista suite. Its components feature a cloud-based monitoring and reporting tool, a performance optimization tool that applies algorithms and benchmarking metrics, and a suite of intelligent software and holistic systems that offer online control, monitoring and forecasting.

Bourgier said water systems already compile a significant amount of data that enable system automation and are available to onsite operators through digital control systems and human machine interfaces.

"The innovation is the cloud-based platform on which the data can be organized, monitored remotely and utilized in algorithms and benchmarking tools that are not available at the plant level," she said. "It is the comparison of data from multiple plants all over the world using the same processes that enables us to use the analytical and benchmarking tools for optimization. The data are already being collected; these new tools enable us to put it to use for the benefit of our customers."

Digital H2O's Water Asset Intelligent platform is an online cloud-based data system that leverages predictive analysis and interactive mapping to analyze publicly available oil and gas and water regulatory findings as well as completion and production information. The program allows users to identify oilfield water market opportunities to reduce costs.

Scott Rothbarth, Digital H2O data analyst, said although the oil and gas water industry produces large quantities of data, those data are often difficult to obtain. Digital analytics systems facilitate better access and understanding of those data, he said.

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"There's a huge lack of data and data availability in the marketplace, which is a shame, because when you're looking at the overall costs, 40% is water," Rothbarth said. "So just a little bit of intelligence on the water side could save companies a lot of money."

He also said that in many cases, such as in Texas, water information is not publicly available, and operators typically keep such information private. In those cases, Digital H2O implements machine-learning algorithms to estimate water production history based off well production data that are publicly available.

Bourgier said companies that implement an analytics approach to water management could likely see cost savings and risk mitigation in their operations.

"Finding reliable freshwater sources and managing the produced water from operations both involve costs," she said. "Minimizing operational costs for water management through process optimization using analytics will lower the overall operating costs of the company."

Seismicity issues

One of the effects of managing large amounts of the water produced during hydraulic fracturing has been induced seismicity events, particularly since 2008. The USGS has identified 17 areas in the central and eastern U.S. that have experienced induced seismicity events as a result of produced water injection into disposal wells, with Oklahoma being by far the most prevalent. According to the USGS, the number of earthquakes with a magnitude (m) of 2.7 or greater in Oklahoma increased from fewer than 500 in 2010 to more than 4,000 in 2016.

However, Mirko van der Baan, a professor at the University of Alberta in the Department of Physics, who spoke at a Society of Exploration Geophysicists event in Houston in December 2017, said, except for Oklahoma, areas with high produced water injection rates are not necessarily prone to earthquakes.

At the event, van der Baan cited the Bakken and Marcellus basins as regions that have seen substantial increases in production during the past several years but have experienced little to no seismic events. He said despite about a 700% increase in gas production in the Marcellus Basin since 2010, there has been "no significant increase" in seismic events measured above a 3 m.

In recent years, a few clustered locations in the Permian Basin have experienced increased seismic activity, particularly west of the Pecos River in Reeves County. According to TexNet, an online earthquake catalog run by the University of Texas at Austin's Bureau of Economic Geology, there were five 3 m to 3.5 m earthquakes in the Pecos region between Jan. 1, 2017, and March 5, 2018.

However, van der Baan said that even with an increased number of saltwater disposal wells in the Permian, no seismicity issues have been formally associated with them.

He said areas with lower seismic hazards are less prone to induced seismicity, but the opposite is not necessarily true.

"It's not as simple as 'I do disposal wells, therefore I will have seismicity,'" van der Baan said.

According to Laura Capper, president and CEO of EnergyMakers Advisory Group, seismicity issues are always locally defined, with each shale region featuring unique attributes that may interact with other local attributes. Capper said there are more than a dozen factors that must be in place to generate an induced seismic event (Figure 1).

In places like Oklahoma, regulators have put into place restrictions on produced water injection practices, which has led to a reduction in seismicity events in the state, according to the Oklahoma Water Resources Board (OWRB).

The challenge behind solving seismicity issues, Capper said, is that "the real action takes place miles underground, in most cases, where we have very limited access to good data."

She said there is ongoing debate among leading researchers on whether seismicity trends will continue, increase or decrease when drilling and production levels ramp up and when more produced water is injected into underground reservoirs.

"I personally do not believe we have learned how to completely eliminate induced seismicity, but I do believe it can be well-managed and mitigated with sound operational practices and local insights about high-risk zones," Capper said. "Transporting fluids farther or implementing local recycling to reduce injected volumes can impact operating margins, so a rationalized, balanced approach is required. But it is doable. I don't think we are completely out of the woods yet, but I do think we'll get there."

Trends in regulations

Since the tremendous growth in North American hydrocarbon production via hydraulic fracturing starting in 2010, federal and state regulatory agencies have worked to keep pace with a fast-moving industry. Mandates by agencies such as the U.S. Environmental Protection Agency, the Texas Railroad Commission (RRC) and OWRB have put into place regulations managing water practices,

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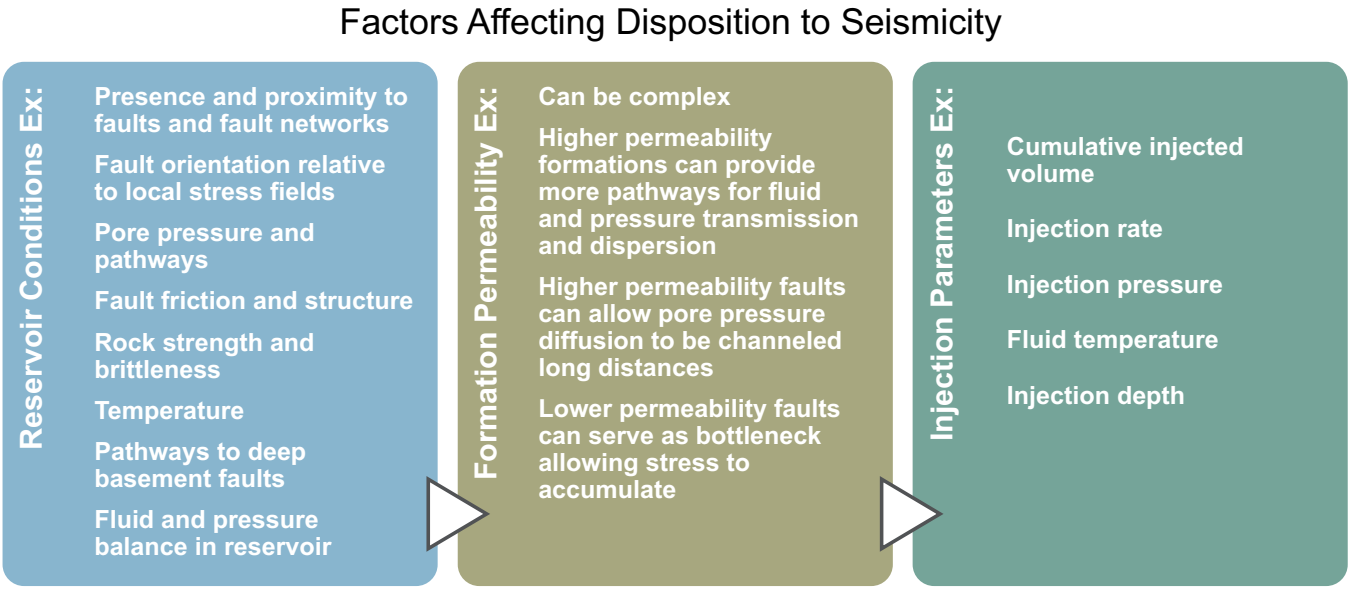

FIGURE 1. This graphic depicts factors that influence induced seismicity events in hydraulic fracturing operations. *(Image courtesy of EnergyMakers Advisory Group)*

including restrictions on disposal methods, guidelines on recycling produced water and directives on acquiring freshwater.

According to Kent Wilkins, planning and management division chief for the OWRB, and Brent Halldorson, chairman for the Texas Water Recycling Association board, agencies are primarily looking to fine-tune the regulations that have come into existence in recent years.

For instance, this session Wilkins said the Oklahoma Legislature will likely address marginal quality brackish water rights in the state for potential reuse for completions operations.

"We only have the authority to permit water for 0 to 5,000 ppm of TDS [total dissolvable solids]," he said. "What we're looking at is getting [the OWRB] authorization to regulate from 5,000 to at least 10,000 ppm of TDS."

Wilkins said the state's water use plan incentivizes the use of marginal quality brackish water for reuse in fracturing operations, but the state's rules do not allow it.

"[Oklahoma's] well drillers, when they encounter saltwater, they're supposed to plug that well back," he said. "So this would give [the OWRB] the framework to utilize that marginal quality water from 5,000 to 10,000 [ppm of TDS] and maybe even higher. The oil companies we've met with [have said] that if they can get 10,000 ppm of TDS to 15,000 ppm of TDS, they'd still like to use that water in lieu of the good freshwater, and we want them to."

In November 2017 Texas' University Lands (UL) system, which manages the surface and mineral interests of 2.1 million acres across 19 counties in West Texas for the benefit of the state's Permanent University Fund, updated its requirements for building freshwater fracturing pits.

UL Executive Director Richard Brantley said the new requirements state that freshwater fracturing pits cannot contain more than 3,000 ppm of TDS. Brantley said that previously there were no restrictions on TDS containments on UL lands. The new regulations help ensure that any water that leaks out of a fracturing pit is safe for the land.

"Operators in about 2007 started building freshwater frack pits, and we saw the technology changes as the pits got larger and larger," he said. "We began to have a healthy concern for the sodium chloride in that produced water."

The 3,000 ppm of TDS mark is equivalent to that of Category 1 drinking water standards implemented by the Texas Commission on Environmental Quality but is also more restrictive than guidelines offered by the RRC.

"This focuses on the management, monitoring and controlling leak rates," Brantley said. "We believe this is in the best interest of the land." ■

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Water Management Solutions a Priority

These key players focus on providing valuable expertise and innovative technologies.

By Ariana Benavidez
Associate Managing Editor

Water management technologies and services provide a practical and reliable means of developing water resources, recycling/reusing fracturing flowback water, treating produced water and disposing of water.

While industry estimates vary, it is agreed that eight to 10 barrels of water are produced for every one barrel of oil.

The following is a sampling of the key players in water management and some of the offerings they provide in this space.

Key Players

Alfa Laval

Alfa Laval provides onshore and offshore technology, expertise and services.

The company supplies products and solutions for heat transfer, separation and fluid handling through its key products: heat exchangers, separators, pumps and valves.

Alfa Laval's compact heat exchangers have the capability to recycle heat, optimize customers' energy consumption, cut costs and reduce environmental impact, the company said on its website.

In addition to separators, the company's product line includes decanter centrifuges, filters, strainers and membranes.

Alfa Laval also offers tank cleaning equipment and installation material.

The company's DOLPHIN freshwater generators convert seawater into freshwater using vacuum distillation, ensuring freshwater with salinity levels below 2 ppm, according to the company's website.

The company also offers its PureBallast 3.1 large-flow ballast water treatment system, which was designed to have a small footprint and allows simple installation and ease of use, according to Anders Lindmark, head of Alfa Laval PureBallast. "No chemicals are needed to treat the ballast water or to neutralize residuals, which means there will be no chemical handling on the part of the crews. And just as importantly, there will be no risk of corrosion in the system components or ballast water tanks. Those things make a difference for any vessel, large or small," he stated on the company's website.

APATEQ

APATEQ engineers and manufactures turnkey, custom-designed oil-water separation systems, compact

An OilPaq container module facilitates redundant ultrafiltration. *(Photo courtesy of APATEQ)*

wastewater treatment plants and process water recycling systems. The company treats produced water, fracturing flowback and brine for reuse purposes such as EOR or irrigation.

OilPaq, APATEQ's proprietary oil-water separation system, "combines field-proven ultrafiltration and proprietary process technologies as a one-stop solution," a company press release stated. The system is designed to treat oilfield and other environmentally hazardous wastewaters for reuse or direct discharge into the environment. Either from onshore or offshore well sites, OilPaq can recover up to 99% of the oil from oil pad wastewaters, according to the company's website.

For compact wastewater treatment at remote locations such as oilfield or construction camps, APATEQ provides the WaterPaq, a turnkey and compact solution producing an effluent for direct discharge in accordance with the most demanding international regulations, even in environmentally sensitive landscapes such as environmental protection zones in Canada. Alternatively, the WaterPaq can be customized to produce effluent for irrigation or washing purposes. The system is flexible with regard to fluctuations in inlet volume as well as total suspended and dissolved solids. Wastewater treatment with the WaterPaq enables remote operation, surveillance and troubleshooting.

Aquatech International

Aquatech International provides water purification technology for industrial and infrastructure markets with a focus on desalination, water recycle/reuse, and zero liquid discharge. The company has successfully executed more than 1,000 water management projects in more than 60 countries worldwide, according to its website. Aquatech has offices throughout North America and subsidiaries in Europe, the Middle East, India and China.

Water management services include spare parts supply, build-own-operate and maintenance contracts, technical audits, leased water treatment systems, technical training and remote monitoring.

Water treatment and wastewater services for upstream oil and gas companies include recycle/reuse of produced water, industrial process water, deoiling, induced gas flotation, walnut shell filters/oil removal filters, warm line softening clarification, after filters, ion exchange softening, evaporation, crystallization for zero liquid discharge, brine neutralization and high-temperature membrane. These services can be applied to coal seam gas/coalbed methane associated water treatments, produced water deoiling, produced water treatments for boiled feedwater makeup, and evaporator brine treatments for discharge/deep well injection.

With treatment processes based on technology from Aquatech International, Aquatech Energy Services (AES) provides services on a turnkey basis to the unconventional shale and conventional oil and natural gas industry to manage and treat for beneficial reuse and to dispose drilling, flowback and produced water.

In addition, Fluid Recovery Services (FRS) operates within Appalachia providing turnkey water services to the unconventional and conventional oil and natural gas industry, providing the same management and treatment services as AES.

FRS and AES provide disinfection services using biocides and disinfectants to treat source water and produced water for sulfate-reducing bacteria, reduction of H_2S and prevention of biofilm formation within oil and water tank batteries.

The companies operate multiple merchant central water treatment facilities to treat and dispose of wastewater from E&P activities.

Baker Hughes, a GE company

Baker Hughes, a GE company (BHGE), provides well chemical products and services that are designed to help improve hydrocarbon production and reduce operating and water-related costs throughout the entire life cycle of the well.

The BHGE H2prO well chemical services use the industry's oldest problem—unwanted water production and flowback—to solve its newest challenge of getting enough water for oilfield operations. This technology is designed to allow operators to get the water needed in the right place, at the right time and with the right quality to perform hydraulic fracturing,

The H2prO well chemical services use proven treatment technologies designed to conserve water, reduce transportation and disposal costs, and ensure compliance with regulations. *(Photo courtesy of Baker Hughes, a GE company)*

waterflooding and other crucial downhole operations, the company stated on its website.

The H2prO SR service uses proven filtration technology in a highly mobile system to remove suspended solids from produced water and flowback water. The H2prO HD service uses chlorine dioxide, an environmentally preferred chemistry, for on-the-fly water treatments during hydraulic fracturing, treatment of source water in pits, tanks and surface vessels, and treatment of downhole production, injection and disposal wells.

In addition, BHGE's StimPlus flow assurance service provides a combination of hydraulic fracturing and production chemistry for years of ongoing active treatment to maximize post-fracture production and minimize post-fracture intervention costs, according to the company website.

Cudd Energy Services

Cudd Energy Services' Water Management Solutions Division (WMS) provides custom-engineered systems to address water management challenges. Offering water recycling, on-the-fly biocide services and well remediation solutions, WMS provides products and services for managing onsite fluid quality for a wide variety of oilfield operations. The technologies behind WMS systems are proprietary and provide a unique and proven solution to water treatment.

The WMS water recycling system restores any water for reuse in oilfield applications by eliminating the unwanted contaminants from fresh, brackish or recycled water sources. By incorporating the company's OxiFlo chemical pretreatment technology, the water recycling system breaks down emulsions, accelerates iron removal and destroys H_2S as well as other oxidizable species subsequently removing hydrocarbons and solid content to yield a sub 5 nephelometric-turbidity-unit clear brine ideal for completion operations. The system comprises compartmental units housed on individual trailers that can be rapidly mobilized to centralized pits, tank batteries and water collection/treatment facilities.

The WMS biocide treatment system treats produced and surface waters, surface vessels, pits and wells for bacterial control. The system utilizes oxidizing treatments to remove biomass and biofilm and additionally control iron sulfide, eliminate H_2S, break emulsions and degrade other oxidizable species. The system uses Cudd's Petro-Flo microbiocide, a fasting-acting biocide that effectively controls all types of bacteria including sulfate-reducing, acid-producing and biofilm-forming bacteria that contaminate water supplies. This proprietary chemistry affords dual efficacy by providing both the benefits of chlorine dioxide chemistry at surface as well as a built-in downhole extender to provide unmatched biocidal control.

Working together with other Cudd Energy Services groups, WMS can offer a complete array of well remediation solutions to address any downhole blockage issues affecting performance of either injection or production wells.

Digital H2O

Digital H2O is a digital oilfield technology company that delivers software-based insights and solutions for the end-to-end management of water in oil and gas production. The company deploys digital tools that use advanced data aggregation techniques, predictive decision analysis and in-house algorithms to help operators, service companies and investors reduce the life-cycle cost of managing water and identify new market opportunities.

The company's Water Asset Intelligence tool uses a proprietary data model and predictive algorithms to analyze tens of millions of publicly available water, oil and gas regulatory filings, completion and production observations. The platform's key datasets include disposal capacity and utilization, visibility into water logistics, and WOG production and consumption data. Water Asset Intelligence includes a water-transfer capability that leverages machine learning to provide a timeline view of where water travels after production to enable users to stay ahead of the oilfield water marketplace and reduce operating costs.

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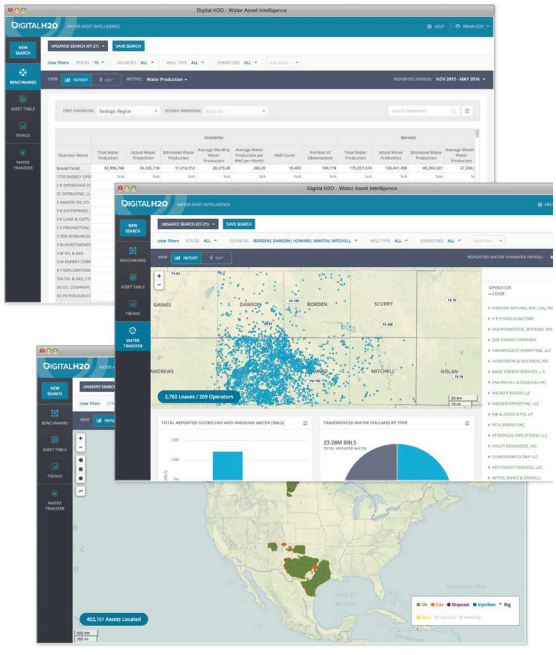

The Water Asset Intelligence dashboards offer visibility in the supply, demand and logistics of water in oil fields. *(Image courtesy of Digital H2O)*

Digital H2O is working on integrating international water data and developing water management tools for operators to more easily manage their assets.

DistributionNOW

DistributionNOW (DNOW) offers comprehensive engineering, design, fabrication and installation services for water management products and services through its Process Solutions Group. This group provides custom-designed solutions for saltwater disposal packages, pumps, filtration systems, freshwater and produced water transfer skids, chemical injection skids and waterflood packages. These packages feature integration technology that allows a unit's operation to be completely automated in the harshest and most variable environments, according to the company's website.

DNOW provides custom-designed solutions for saltwater disposal packages. *(Photo courtesy of DistributionNOW)*

DNOW Process Solutions, through its Power Service and Odessa Pumps brands, also operates service centers for repair, fabrication and machining needs. The company employs factory-trained service technicians who are certified to diagnose and repair complex water management systems, offering both field and in-shop service.

Dow Water & Process Solutions

Dow Water & Process Solutions, a business unit of The Dow Chemical Co., specializes in sustainable liquid purification and separation technologies. The company's water treatment technologies include ultrafiltration, polymeric adsorbents, selective ion exchange resins, reverse osmosis and sulfate-removal nanofiltration membranes.

In November 2017 the company released its WAVE (Water Application Value Engine) design software. The software integrates three of the industry's key technologies for water purification—ultrafiltration, reverse osmosis and ion exchange—into one comprehensive tool, providing accurate water quality and system design models for water and wastewater treatment systems, according to the company.

In 2016 the company released its DOW FILMTEC FORTILIFE product line, an addition to its reverse osmosis and nanofiltration portfolio. The technology elements transform wastewater into pure water and pure salts for reuse at about 60% lower cost than thermal treatment, according to the company.

In addition, the company's Water & Process Academies are a resource for building technical knowledge, learning new tactics for increasing efficiencies and developing best practices for enhancing performance at a facility, according to the company's website.

Fountain Quail Energy Services LLC

Fountain Quail Energy Services (FQES) was the pioneer of oilfield water management with the first permitted water recycling system in a U.S. shale play, according to the company's website.

FQES helps operators reduce water management costs by integrating its systems into operators' onsite operations. Those technologies include the company's

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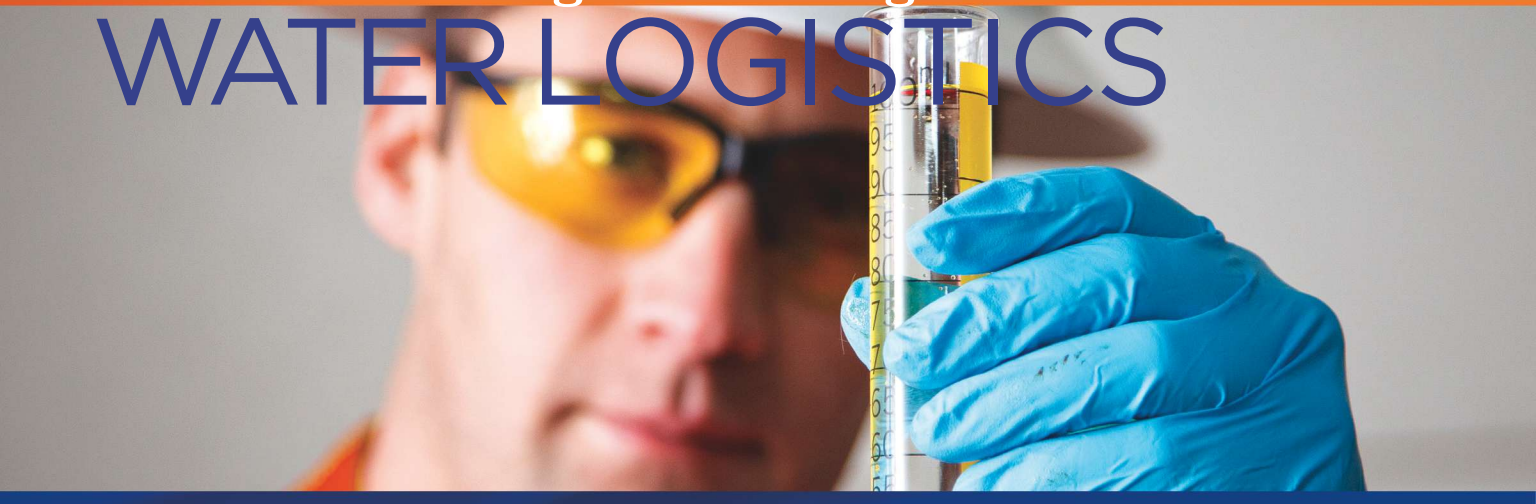

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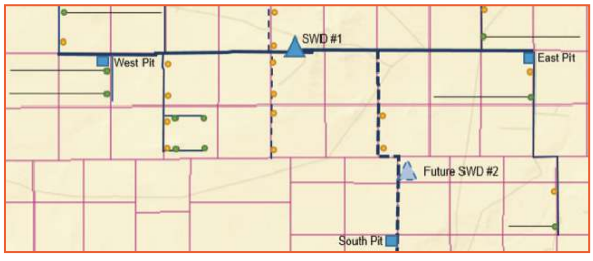
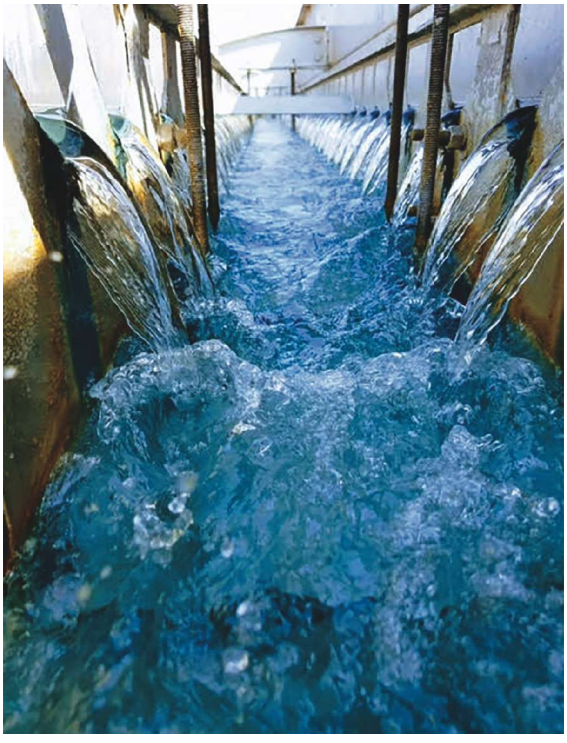
Basic Energy Services' (BAS) Water Logistics delivers integrated services that are tailored to address E&P companies' needs across the major basins in the US.

While keeping safety and the environment foremost in all operations, Basic supplies its customers with brine and fresh water, trucking and disposal, treating and recycling of produced water, and water midstream services.

Basic's Water Logistic team can provide flexible solutions to the construction of water midstream for the E&P company, freeing up capital for additional exploration and development, and lowering overall expenses at the capital expenditure and operating levels. Whether by offering a customized system that is engineered,



owned and operated by Basic, a joint-venture project or operated on a contractual basis; Basic has the technical expertise and resources to enable the client to succeed.



The ROVER mobile clarifier package is an in-field technology designed for primary treatment of shale gas flowback at or near the source. *(Photo courtesy of Fountain Quail Energy Solutions)*

MAVREX water treating system; the ROVER and NOMAD recycling systems to clean brine or freshwater; and the MAG Tank solution for containment as well as sourcing solutions, aboveground and below ground pipeline transfer, trucking and Class II saltwater disposal wells.

According to a company brochure, FQES' ROVER is "a safe, reliable and rugged system designed to convert produced and flowback water to clean saltwater for reuse during hydraulic fracturing." This flexible system that offers total suspended solids, iron and hydrocarbon removal is designed to result in pH-neutral clean brine for fracture supply.

The company's NOMAD system converts wastewater into surface discharge-quality freshwater, and the MAVREX is a bacteria disinfection system that provides on-the-fly active monitoring and dosing of chlorine dioxide. The MAVREX monitors pre- and post-treatment water in real time and self adjusts as water conditions change.

"Fountain Quail's ROVER, NOMAD and MAVREX can effectively eliminate the need for produced water transport and disposal and freshwater sourcing, allowing operators to save 30% and up to 80% on water management costs," FQES' website stated.

Gradiant Energy Services

Gradiant Energy Services (GES) is an energy technology company focused on providing innovations in water management and treatment to oil and gas operators. Launched out of the Massachusetts Institute of Technology in 2012 and owning multiple patents, the company can treat any influent water quality through its permanent and mobile treatment facilities. GES works with oil and gas operators in large activity shale play areas, such as the Marcellus Shale and Permian Basin.

The company's water treatment offerings include bacteria disinfection, reusable clean brine, evaporative disposal and desalination. GES is treating approximately 225,000 bbl/d across the four product lines (as of January). The four product lines offer not only varying levels of treatment but also cost-effective pricing for a variety of operators ranging from supermajors to small independents.

Gradiant Energy Services' SCE 2.0 recycling plant is operating in the Delaware Basin. *(Photo courtesy of Gradiant Energy Services)*

The company's pinnacle offering is its Carrier Gas Extraction (CGE) technology, which desalinates oilfield wastewaters to produce extremely freshwater (less than 500 ppm) and a highly concentrated brine solution that can be utilized for drilling, workovers and completions. "CGE reduces the high transpor-

tation costs of produced water by treating the wastewater onsite, producing freshwater and saturated brine, reducing any negative environmental footprint," the company stated on its website.

The company also offers its Selective Chemical Extraction (SCE) custom-engineered, mobile water treatment process to provide reusable clean brine as hydraulic fracturing fluid. "By cleaning water only to the needed level—and not beyond—our SCE solution enables the reuse of treated produced water for operations, saving customers both time and money," the company stated on its website.

H_2O Midstream LLC

H_2O Midstream LLC is a private-equity-funded midstream company focused exclusively on water. The company builds, owns and operates long-term water infrastructure that is designed to help producers improve the reliability, efficiency and safety of water operations while also lowering costs. The company is active in all major producing basins within North America.

The company's midstream services encompass the complete water life cycle including sourcing, transportation, storage, distribution and reuse of freshwater, brackish and produced water as well as the gathering and disposal of hydraulic fracturing flowback and formation water over the life of the lease.

"H_2O Midstream focuses on creating value for all customers and stakeholders through a proven third-party midstream approach to operating assets, structuring long-term contracts and managing risk," the company said.

In June 2017 H_2O Midstream acquired the produced water infrastructure from Encana Oil & Gas (USA) Inc., according to a company press release. "Under the agreement H_2O Midstream will gather, dispose and deliver for reuse produced water for a substantial portion of Encana's acreage position in Howard County, Texas," the release stated. "In connection with the acquisition, H_2O Midstream will assume ownership and operation of Encana's existing produced water gathering system consisting of over 100 miles of interconnected pipeline and five salt-

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water disposal wells totaling 80,000 barrels per day of permitted disposal capacity."

Halliburton

Halliburton provides technologies designed to minimize water costs and increase hydrocarbon production. The company addresses water management challenges from surface to subsurface with processes, tools and expertise.

Halliburton assists operators in capturing and treating complex fluids in agreement with local regulations. The company also helps operators repurpose produced waters for use in oil and gas operations and other applications.

Halliburton developed water-based polymer systems and sealants that have limited the flow of produced formation water into the wellbore. The company's relative permeability modifier technology provides water-oil separation in downhole conditions and has reduced water production, according to the company.

In addition, the simpler fluid chemistry and the nonrequirement for crosslinker is designed to make Halliburton's UniStim fluid practical and economical for use in a wide variety of produced water.

Hydrasep

Hydrasep treats fracture flowback water and produced water in-line and onsite. This results in zero oil releases into ponds or storage, less loading on post-treatment processes like desalination, less work on the backend and less time onsite.

Hydrasep technology helps with water process treatment and lowers operating cost. The company's separation units pretreat wastewater reducing downstream chemical consumption, filtering needs and system upsets. The technology will treat recirculation cooling water, extend the life of pumps and spray nozzles, maintain product integrity and reduce downtime, according to the company's website. The technology also recovers groundwater contaminants.

Hydrasep manufactures custom-designed oil/water separators. *(Photo courtesy of Hydrasep)*

Hydrozonix

Hydrozonix is a water management company that offers consulting, technology and services to reduce risk and operating cost by optimizing water quality and use throughout the fracturing water cycle. The company's crews, products and services are used by major and independent operators working in unconventional oil and gas throughout the U.S. Hydrozonix operates in North Dakota, Pennsylvania, Texas and Wyoming and has treated more than 100 MMbbl of water in five basins.

The company offers treatment and recycling of produced, brackish and freshwater either onsite or offsite as well as pit treatment and management. One of the company's latest products is the $Hydro_3Cide$ fully automated, unmanned oxidation system. The system can be purchased or leased. The system is normally used upstream of gun barrels, where the $Hydro_3Cide$ improves oil/water separation and produces a fracture ready water quality. When combined with the company's portable aeration systems, treated water can be stored without fear of bacteria growth or H_2S generation, according to Hydrozonix.

Hydrozonix also offers the combination of in-line treatment, aeration and final disinfection. This combination is referred to as H_ZO Trio.

Hydrozonix also released its HydroFlare produced water evaporator, while also offering gathering system optimization, membranes filtration and multiple solids control systems. The company said a constant in all of its services is real-time water quality testing and analysis.

ProSep

ProSep provides proprietary and conventional water treatment equipment, systems and services to assist operators in managing and treating their produced water streams and providing solutions that meet or exceed regulatory and/or other operational requirements, primarily focusing on effluent polishing technologies.

The company's CTour process removes dispersed oil and dissolved hydrocarbon contaminants in the produced water stream through injection of a hydrocarbon condensate stream. Not requiring any chem-

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icals, the process is easy to install in existing systems and has a very low operating cost. The CTour process has been used in Norway, having treated as much as 70% of all Norwegian offshore produced water. This equates to more than 2 MMbbl/d of water.

In addition, ProSep's Osorb Media is a regenerable, organically modified silica adsorbent used to treat oilfield, refinery and petrochemical effluent waters and gas streams. It adsorbs free, dispersed and water soluble hydrocarbons as well as many nonpolar oilfield chemicals from effluent water including benzene, toluene, ethyl-benzene and xylene (BTEX) components. Osorb also has successfully removed BTEX in a selective manner in natural gas wash water streams containing methanol yielding better than 45% IRR.

The company's scalable TORR coalescing technology addresses effluent excursions, particularly chemically induced emulsions, as well as increases in water cut for offshore operators. TORR systems reduce oil-in-water content from 1,000 ppm down to discharge regulation, often less than 5 ppm to 10 ppm and remove/recover oil droplets larger than 2 µ.

ProSep also offers mixers for water treatment applications demonstrating 25% to 60% reduction in chemical consumption as well as optimizing processes.

Schlumberger

Schlumberger offers many products and services for water treatment including oil removal and polishing of produced water, seawater conditioning for primary injection and controlled-salinity water injection for EOR.

For oil removal, the EPCON Dual compact flotation unit has an engineered design that incorporates residual flotation gas in a secondary separation stage to increase oil-in-water removal efficiency while fully degassing the clean water outlet. For polishing, the PETRECO HYDROMATION nutshell filter provides high throughput for purification of oily process water and industrial wastewater while delivering operational reliability with up to 99% annualized online performance history, according to the company.

The company's water injection technologies are used in the treatment of seawater for biofoulant control, dissolved oxygen removal, and suspended and dissolved solids removal.

Schlumberger's METROL SEA-CELL electrochlorinator generates hypochlorite from seawater *in situ*, which is used to prevent the growth of living organisms. The company's BFCC copper chlorine system uses low levels of copper and hypochlorite to control biological activity in water systems. The company's METROL SEA-SCREEN coarse strainer removes silt, plankton, algae and 98% of particles larger than 100 µm. It also can be used when space and weight are restricted.

For oxygen removal, Schlumberger supplies its VDX vacuum-stripping deaeration system and its GDX gas-strip deaeration system. The company also has developed the CDX compact deoxygenation system for more compact and lightweight equipment.

Developed to mitigate water management challenges, the xWATER Integrated Water-Flexible Fracturing Fluid Delivery Service allows operators to reuse 100% of produced water, thereby reducing or eliminating costs associated with water acquisition, conveyance, treatment and disposal.

As part of the company's newest endeavors into oilfield water treatment, Schlumberger can provide simultaneous three-way separation of oil, water and solids for onsite oilfield water treatment. The Voraxial

The EPCON DUAL compact flotation unit enables bulk oil removal through polishing of water in half the footprint of conventional technologies. *(Photo courtesy of Schlumberger)*

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impeller-induced cyclonics provides instantaneous separation of water, oil and solids at high flow rates through a single pass to bring new efficiencies to oilfield water sourcing and management.

Select Energy Services

Select Energy Services provides water services, well testing, fluid handling, disposal, oilfield chemicals, sand distribution, and wellsite completion and construction throughout the U.S. and Western Canada. The company's water-related services include water sourcing, water transfer, water storage and containment, and water treatment.

The company has developed AquaView, a telemetry system with the ability to remotely monitor and control water assets and provide real-time data. The system provides users with hydrographic mapping, remote monitoring of the volume and quality of water assets, reports and alerts. AquaView pump automation and proportioning systems respond to operator specifications and changing conditions in real time with the ability to remotely set and maintain operational parameters.

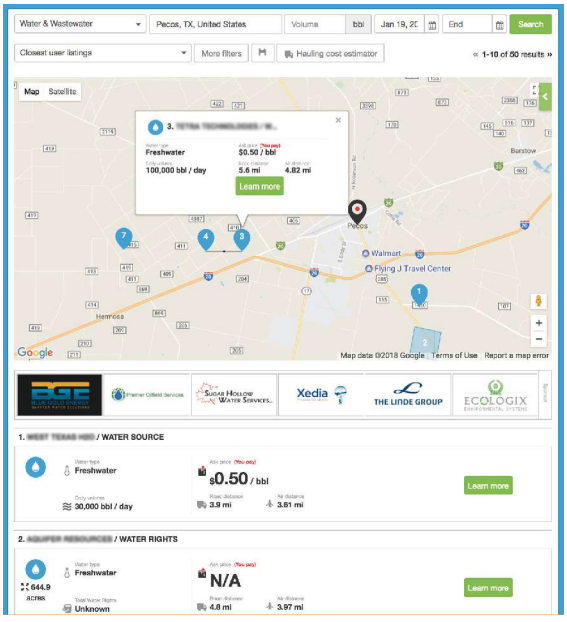
In November 2017 Select Energy Services completed a merger with Rockwater Energy Solutions, expanding the scale of its water management operations and asset base in key basins. The addition of technologies and services as a result of the transaction include an oilfield chemicals segment specializing in the development and distribution of chemical technologies used in completion, stimulation and production. This combined expertise allows Select Energy Services to provide operators with an optimal approach to fluid quality and logistics issues.

Sourcewater

Sourcewater was founded at the Massachusetts Institute of Technology and is based in Houston.

Launching in 2015, *Sourcewater.com* is the online marketplace for sourcing, recycling and disposing of water in the energy ecosystem. "Our platform ensures a reliable mission-critical supply chain, the lowest cost and the highest capacity utilization for the primary input and output of upstream energy production: water," according to founder and CEO Josh Adler.

Operator land and completions teams use *Sourcewater.com* to find the best available water sources and water rights when they are planning their drilling programs, including exclusive access to satellite data showing the location and ownership of all water pits in the Permian Basin and the ability to trade excess freshwater and produced water between operators.



Operator land and completions teams use *Sourcewater.com* to find the best available water sources and water rights when they are planning their drilling programs. *(Image courtesy of Sourcewater)*

In addition, service companies and water midstream companies can offer water sources and disposal capacity to operators, including through a unique real-time disposal capacity market that allows disposals to promote excess disposal capacity to dispatchers and allows production managers and hauling dispatchers to eliminate long standby times at busy disposals and get paid for more runs every day.

Moreover, landowners can list their water rights and rights of way to get the best offers.

TekSolv

TekSolv provides integrated safety, equipment and automation services. The company's technologies and safety services are designed to improve oilfield automation, life-safety and water management systems for drilling, completions, flowback, production and midstream operations. The company has offices in Delaware, Pennsylvania, Ohio, Illinois and West Virginia.

TekSolv's HydroWatch is a water management technology system that allows quick deployment of critical water tracking hardware with integration into real-time management software, the company stated on its website. The system uses existing field hardware such as flowmeters, level sensors and other monitoring equipment permits for integration into

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Water is a major challenge in the oilfield. Where get the large volumes you need to complete a what do you do with the produced water, and h you do it while keeping costs lo

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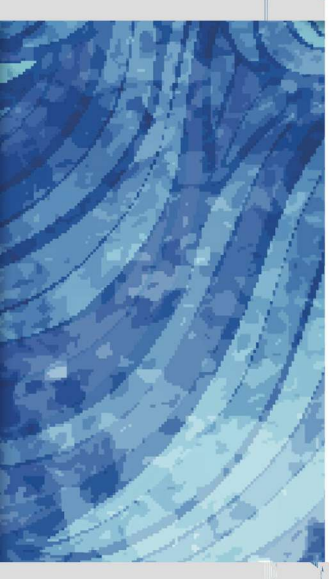

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HydroWatch is configurable for myriad of water transfer applications. *(Photo courtesy of TekSolv)*

existing infrastructures, and it provides a system that visualizes processes, analyzes system data, automates functionality and distributes real-time data to decision makers, operators and supervisors.

Water products and services include water tracking, pump/pipeline controls and transfer verification, production tank levels with leak detection, water treatment and storage, flow volumes and rate monitoring, and multiple tank support.

TETRA Technologies Inc.

With operations on six continents, TETRA Technologies provides water management, completion fluids and production well testing services to support land completion activity in all basins in the U.S. and Canada. The water management product line supports the upstream oil and gas industry, in particular hydraulic fracturing operations in which large volumes of water are required. The company's services support the transfer, storage and treatment of all water types including fresh, brackish, produced and flowback water. Each project is custom-designed using the company's proprietary planning and engineering software.

The company's services include planning, testing, filtration, blending and treatment chemistries to deliver water at the required specifications. TETRA's biocide and TETRAClean treatment additives are designed to be fast-acting, quick degrading, "green" biocides that kill bacteria as fracturing water moves through the tanks. The automated water blending controller and its patented blending manifold ensures that the water is consistent throughout the entire fracturing specification.

TETRA's new oil separator, the mobile Orapt system, removes sellable oil from produced water, which would normally incur disposal costs.

TETRA offers a variety of reusable aboveground storage options that are designed for easy assembly and relocation. The company's TETRA STEEL technology uses zero-discharge Storz Couplings and is mobilized using a patented rapid deployment system (TETRA STEEL RDV), which is designed to result in faster rigup and rigdown, shorter turnaround time between jobs and improved operational performance, the company stated on its website.

With potential throughput ranging from 25,000 bbl/d to 35,000 bbl/d, the TETRA Orapt helps pull out as much oil as possible prior to filtering and blending produced water—down to 50 ppm to 100 ppm. *(Photo courtesy of TETRA Technologies Inc.)*

Veolia

Veolia designs and provides water, waste and energy management solutions that contribute to the sustainable development of communities and industries, according to the company. Through its three complementary business activities, Veolia helps to develop access to resources, preserve available resources and replenish them.

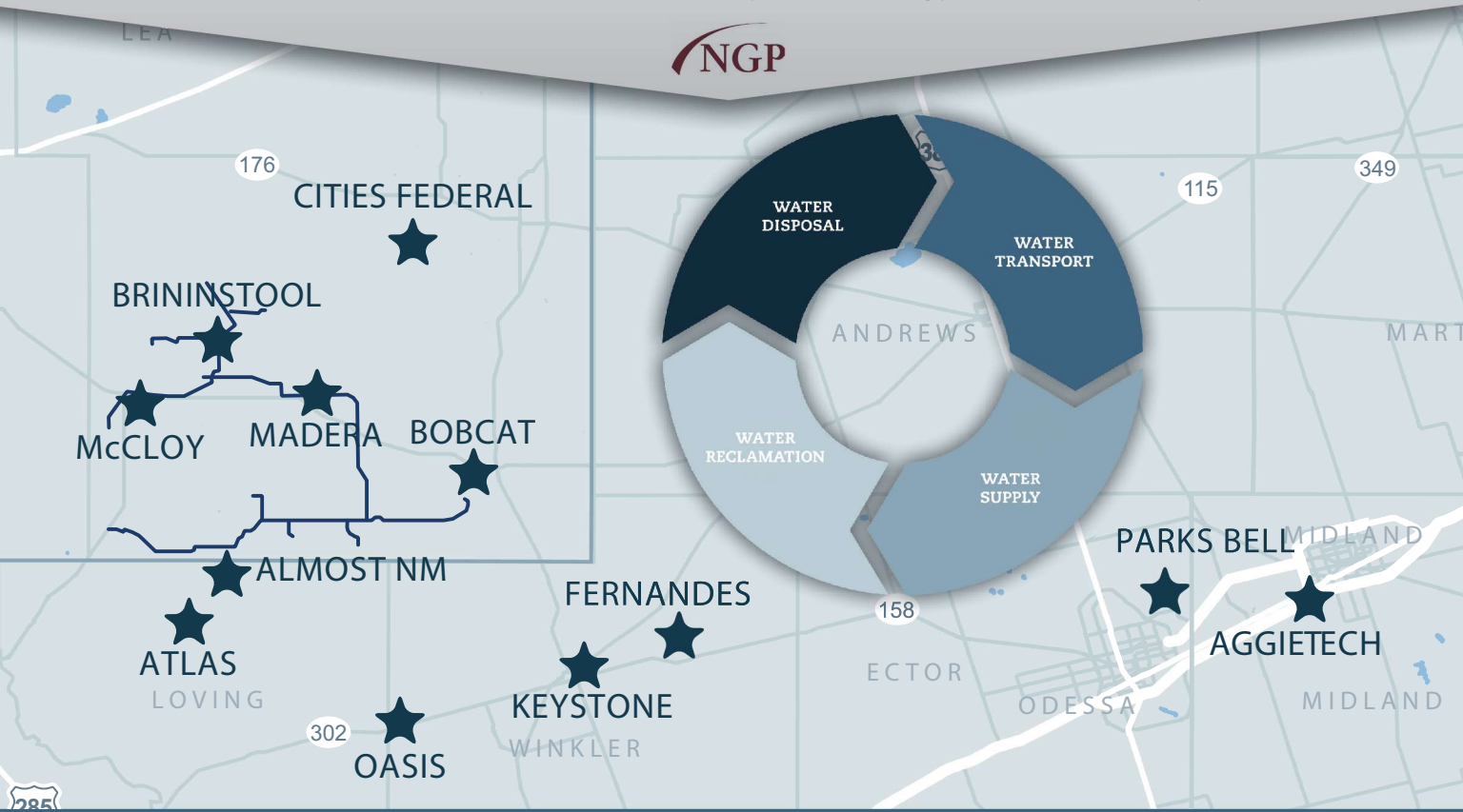
The company has more than 350 water technologies for physical/chemical processes, biological treatment, anaerobic wastewater treatment, filtration and separation, extraction, evaporation and crystallization, mobile water treatment, treatment chemicals and membrane-based solutions.

Oilfield Water Logistics

Watching Over Your Water Needs

Oilfield Water Logistics provides midstream water infrastructure and services to the energy industry in the Permian and Powder River basins. OWL currently operates over 25 saltwater disposal wells and facilities, and 200 miles of high capacity produced water gathering systems in the Delaware Basin. OWL is a portfolio company of NGP Natural Resources X, L.P. which is in the NGP family of energy private equity funds.

NGP



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Veolia's MBD (modular bulldozer design) evaporation/ crystallization system is designed to reduce installation time and cost. *(Photo courtesy of Veolia)*

The company uses its technologies to design, build and operate water treatment systems, including solutions custom-tailored to meet upstream and downstream needs from standard products to full-scale design-build options for water reuse, surface discharge or zero liquid discharge. According to the company's website, it provides "a consistent quality of reclaimed water that meets regulatory requirements, protects the environment and ensures long life of facility and system assets."

The company's latest oil and gas projects include a 60,000-bbl/d produced water treatment system for reuse or discharge and a supply water treatment system for an ethane cracker, both in the Marcellus region. New offerings include a mobile produced water treatment system, a degasifier, a modular evaporation/crystallization technology, a cloud-based platform for treatment optimization as well as a line of standard products that help reduce installation costs.

Water Standard

Water Standard provides water treatment products and services to the energy industry, specializing in compact modular systems and mobile onshore and offshore facilities. The company's products include environment-friendly produced water, flowback and oily water treatment equipment; waterflooding/IOR/EOR seawater treatment systems; and units for filtration, desalination, softening, sulphate removal, deaeration (membrane), and ultrapure and service water production.

Water Standard designs, engineers and manufactures various treatment and separation equipment using its Monarch Separators' facility for fabrication. Monarch Separators' produced water treatment equipment is "a mainstay in the industry with more than 3,000 units installed around the world," the company said.

Water Standard's compact H_2O Spectrum and H_2Ocean Spectrum waterflood products are designed to offer flexible and adaptable onshore and offshore solutions, which can maximize oil recovery over the course of a field's life while its Membrane Deaeration line of products is designed to reduce weight, footprint and costs for oxygen removal, according to the company. Water Standard also provides flowback and produced water treatment solutions to provide operators with mobile and fixed facility units to treat, recycle and/or discharge, applying its alginate flocculant to remove oil and solids.

The company also offers consulting, engineering, trouble shooting and operations services including feasibility, concept select and FEED design services; water management audits; troubleshooting and optimization of water treatment systems; membrane autopsies and related diagnostics; membrane cleaning, testing and analysis; filtration/ permeability reduction testing; cartridge filter deposit analysis; and onsite data collection. ■

A produced water treatment skid leaving Water Standard's Monarch fabrication facility was headed to an offshore platform in the Gulf of Mexico. *(Photo courtesy of Water Standard)*

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Automation, Modular Units Cut Water Management Costs

Regulations, reduced installation cost, lower operation cost and automation are driving new technology in the water management business.

By Scott Weeden
Contributing Editor

Consolidation in the water management business in 2017 has created several larger companies with the financial clout to continue investments in R&D. Much of the R&D to date has been focused on automation as a way to improve efficiencies and cut costs during operations, thereby allowing valuable labor resources to be redeployed elsewhere in the organization.

Select Energy Services and Rockwater Energy Solutions completed a stock-for-stock merger on Nov. 1, 2017, resulting in a post-merger market cap in excess of $2 billion.

"Both companies have really been at the forefront of developing the technology that supports our customers in what has proven to be a very fast-paced evolution of water management," said Holli Ladhani, president and CEO of the newly combined company.

Regionally there is not a lot of customer overlap. Select had a much larger presence in the Eagle Ford and Bakken. Rockwater had a much larger presence in the Midcontinent and Northeast. Both had large presences in the Permian. "We found that we were aligned quite well and strengthened our positioning in all major U.S. basins," she added.

According to Ladhani, the new company took the best of both old companies to create even better products. One example that benefits operators is monitoring the flow and levels of water to give a complete picture of the water in the impoundment, in the lines and available at the site.

"Another benefit is a little less tangible than the existing technology. I would say we're among the best capitalized service providers in the U.S. when you look at our balance sheet," Ladhani said. "That means we can afford to invest in technology and innovation. That's going to help our customers. That means not only bringing the best equipment and the latest technology to the table, but also allowing us to invest in our people who are actually creating and executing the advancements."

From recovery to growth

The recent industry downturn has had a significant impact on oilfield water treatment service providers. "As oil prices plunged in late 2014 and into 2015, we found that many water-focused energy service companies were struggling. By mid-2015 the Texas Water Recycling Association (TXWRA) had lost over half of its active membership. Thus 2016 was a survival year, 2017 was a gradual recovery year and 2018 is looking like it will be exceptional," said Brent Halldorson, CTO, Fountain Quail Energy Services, and TXWRA chairman.

This prolonged downturn has seen many changes in the water management business, both positive and negative, according to Halldorson. He listed four changes:

- There has been a "culling of the herd" among treatment companies. Many of the smaller "black-box" treatment companies are gone and those remaining generally focus on rugged, proven technology;
- Unconventional wells are developing ever-longer laterals with more stages. This means more water per completion. The biggest challenges now involve managing the treatment, transfer and storage logistics associated with these ever-larger fracture volumes (often well over 600,000 bbl/fracture);
- The industry is witnessing the advent of water midstream infrastructure. Several large players are investing in multimillion-dollar pipeline networks to help get the water (both fracture supply and wastewater) where it needs to go. This helps recycling as large volumes of produced water are now agglomerated to where they can be recycled at a low cost; and
- Produced water recycling is now widely accepted by the energy industry. When water needs are forecast it becomes apparent that recycling produced water is a no-brainer for lowering completions costs, especially as the cost of freshwater and disposal continues to increase.

An automated water proportioning system controls and blends the flow of multiple water sources based on incoming water quality and desired output parameters. *(Photo courtesy of Select Energy Services)*

Water management technology drivers

Mark Patton, president, Hydrozonix, said there are two drivers for technology in water management. "One is cost reduction and the second seems to be a movement to automation and data collecting, including water quality and water volumes. This data are critical to a successful water management program. Service companies are being forced to build in cost reductions while developing new approaches to water management," he said.

A few years ago customers were saying they needed to treat their water, but they didn't know what level to treat. "People were paying a lot more money than they needed to pay. Now people are actually starting to develop water specifications," Patton said. "We are seeing a kind of convergence where people are narrowly focusing on only what they need to take care of in the treatment."

Dirk Martin, chief sales officer at APATEQ, added a third major driver—regulations. "Some states [in the U.S.] have already prohibited the disposal of produced water and frack flowback into disposal wells as it is considered a risk to cause earthquakes," he said. "Oil and gas producers now need to find different ways to handle wastewater from oil and gas production, which accumulates in large quantities."

If these companies can no longer use disposal wells, they are looking for economically advantageous alternatives to remain competitive and attractive to their customers.

"Instead of discharging the water into disposal wells where it is lost and potentially hazardous, we decided to take another path and treat the water up to an effluent quality where it can be repurposed for various applications such as refracking, EOR or drilling, thus saving freshwater and costs. We can do that at a quite competitive cost level that is below $1/bbl for small installations and a few cents for large-sale units," he continued.

"There are always a number of drivers. Often the driver is regulation, especially when you're talking about wastewater," said Mark Nicholson, senior business development manager for oil and gas, Veolia Water Technologies. "Other drivers for our clients would be the minimization of capex and opex. Those three are probably the biggest drivers for the technologies we generally market in the U.S. Ideally product development will improve on all three facets—that is improved environmental performance while still yielding lower capex and opex for our clients."

Carla Robinson, Veolia's marketing manager for oil and gas, added, "The price of oil has been so depressed in the past few years; the cost of doing business has to be reduced for our clients so they can improve their

bottom lines. We see a push toward modularization not only in upstream but also in downstream oil and gas. It seems to be becoming more popular because it does help to reduce the installed cost of technology."

Fountain Quail's Halldorson said that right now one of the biggest drivers is logistics, more so than the actual treatment key performance indicators (KPIs). "What we're starting to see, especially in the Permian Basin, is fractures getting larger. We're talking about 600,000 bbls to 700,000 bbls per frack. Just a few years ago we were talking half that size."

He added, "Just managing the water inventory when you're talking about recycling and reuse, monitoring pits, monitoring the transfer and just getting the water where you need it with an ever-changing frack schedule is getting to be one of the industry's biggest headaches.

"As a treatment company, we're being asked for ever-higher volumes to be treated with lower costs, which is kind of a no-brainer. That's always the goal, and it is our job to keep pushing the envelope. We have to be very flexible and adaptable to handle those higher rates," he said.

Automated oxidation system

Pit management is starting to become a big part of water logistics. Attention is being paid to tracking and knowing where the water is and how much is there, said Hydrozonix's Patton.

"We developed a portable aeration system, and we're starting to see some growth in that area as well. People used to do conventional pit treatment by adding some chemicals to a pit periodically, but it was hard to mix the chemicals throughout the pit. This led to some very ineffective pit treatment programs. A properly sized aeration system can replace pit treatments at a fraction of the cost," he said.

The HydroFlare system is in the field in the Permian Basin awaiting commissioning. The system essentially converts the flare into an evaporator. *(Photo courtesy of Hydrozonix)*

According to Patton, in gathering systems they were adding oxidant before the gun barrels, which is where the oil/water separation takes place.

In a gun barrel, the water goes from flowing at a steady rate to slowing down to allow the oil to rise and separate. Hydrogen sulfide begins forming in those tanks and bacteria accumulates. In one specific case an operator was adding a chemical biocide at a cost of about 10 cents/bbl.

"We looked at that practice and realized they were injecting chemicals continuously, but the water quality was fluctuating wildly," Patton said. "They were not regulating it at all because they had no way of measuring the water quality. We said, 'Let's automate that system. Instead of using chemicals, let's use ozone."

Ozone is easier to use because it can be made from oxygen in the air, which means it is sustainable. The ozone is injected into the water and there is a monitoring system for water quality to know how much ozone is needed. "As the water quality worsens, more ozone is added, and when the quality is better, less ozone is added so you can monitor and maintain a consistent water quality," Patton said. "We ended up taking the old 10-cent/bbl chemical program and turned it into a 4-cent/bbl program while increasing the quality of the water."

This system created a new recycling model. The foundation of that model is what Hydrozonix calls $Hydro_3Cide$. "It is an in-line oxidation system that is fully automated," Patton added. "It fully regulates the injection of ozone based on the water quality you have. It allows us to optimize the water quality and maintain that there is no hydrogen sulfide in the gun barrel system, and no biofilm is growing."

According to Patton, each system is in two shipping containers. The first holds the chillers, air compressors and heat-generating components. The second container has the oxygen concentrator, which takes the air from the compressor, stripping out the oxygen and separating the other gases. It takes the oxygen into an ozone generator, and the ozone is then injected into the water stream.

The rejected gases—primarily nitrogen—are used as blanketing gases for safety on the gun barrel systems. Because operators spend money to generate blanket gas, they are saving money by getting that reject gas for free.

According to Patton, Hydrozonix also has another technology in the field in the Permian Basin, awaiting commissioning. The system, HydroFlare, consists

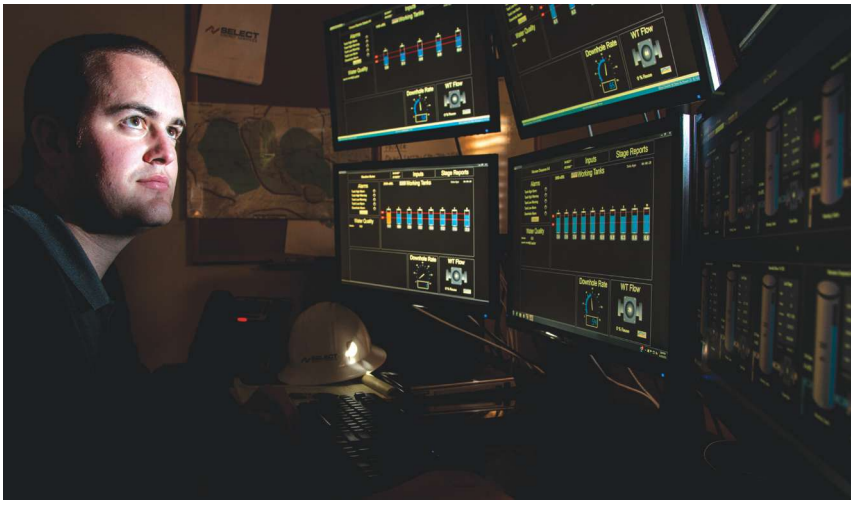
of an enclosed combustor to replace flare systems, but it also includes a scrubbing system that utilizes produced water, essentially converting the flare to an evaporator, he said.

Expanding pump automation

"As a service provider supporting our customers, we have to be able to drive costs out of the system for our services," Select's Ladhani said. "We need to help customers increase the productivity of their wells, and we need to remove human error from the process."

The company made good progress on its AquaView pump automation in 2017, which may have been slightly more in pilot mode. "In 2017 it was fully functioning and is now operating for customers," she said. "Pretty much all the pumps we've been able to automate are being utilized. Automating our pumps will be a continuing investment for us in 2018."

This is not remote control, according to Ladhani. "The pump truly detects pressure loss or gain. It modulates itself based on that data so it creates very efficient pumps with the ability to adjust the appropriate rate at which to move the water."



AquaView services monitor water at various stages of the completions process with real-time, wireless technology. *(Photo courtesy of Select Energy Services)*

Select takes the basic pump and refabricates it with the company's technology. "We'll put the brain on it, adjust it and tie that into the functionality," Ladhani said. "You can remove some of the labor cost from the equation because you don't have somebody driving the line checking the pumps and the actual water hoses."

In 2017 an operator in the Permian went out for bids to move produced water. Select won the bid because the other two providers did not have automated pumps.

"I think we're unique right now," she added. "It is something that customers are willing to speak out about. Our automated pumps are fully utilized because once a company gets comfortable with the automation, it wants to use it."

In high grading its technology the company made meaningful strides in its combinations in 2017. One such technology is in providing total visibility of water flows and levels to Select managers operating the jobs, and the technology is also available to customers.

"When you have large completions that sometimes have dozens of wells in a particular area with millions of barrels of water, this becomes very important. In our system it is monitoring tanks, wells and the flow of water through our pumps. They are also monitoring water quality," Ladhani said.

The modular MBD is designed to shorten project schedules and save installation costs. *(Photo courtesy of Veolia Water Technologies)*

The system provides alerts for pre-established minimum and maximum levels in a tank. There is an alert before there is a risk of overflowing. "It is almost a must with the volumes of water and the complexity of the water networks operators are dealing with," she added.

Another technology Ladhani mentioned was in regard to its chemical business. "We manufacture and deliver frack chemicals to the large service companies. Our delivery system is such that we can drop a tanker of product on location and then monitor the chemical usage by stage on each well, which is information the pressure pumping companies find useful," she said.

Select can also remotely monitor volume levels so that it knows when a customer is running low and can anticipate when a customer needs a refill. "It avoids last-minute antics or just the confusion that can come in trying to refill on a minute's notice," Ladhani said.

According to Ladhani, the company is emphasizing artificial intelligence. The automated pumps are programmed to respond on their own to changing operating conditions. "We have gathered enough data for the machine to know how to react and deal with the varying circumstances. There are ways to apply the technology we're using there into other parts of the business," she added.

Evaporation, crystallization cuts disposal costs

Veolia's evaporation and crystallization system, the Modularized Bulldozer Design (MBD), was developed to improve capex, opex and environmental performance for its clients. The technology is designed to handle difficult water chemistry from a wide array of industrial markets. The primary target markets are oil and gas, mining, power and chemical waste, Nicholson said.

The technology is also designed for rapid and economical installation in remote areas, thus reducing capex. The system is robust and highly automated, so expensive manpower in these remote areas can be minimized, according to the company. Finally, the technology is designed to reduce or eliminate liquid waste from client facilities, thus reducing high disposal costs and improving environmental performance, he continued.

In 2016 the company sold its first MBD unit in the oil and gas industry. "The site was remote where installation and operating manpower costs are high. The site was looking to reduce liquid waste volume that was being trucked off at considerable operating expense. The MBD unit recycles water, which improves the environmental performance of the plant, and the recycled water is used in the plant to improve the plant production," Nicholson said. "The technology was developed specifically for that type of application."

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The first sales were to the oil/gas and mining markets. But according to Nicholson any industry that produces high-strength waste brine or uses ponds for water remediation and retention is a good candidate. There are many ponds that have been utilized for decades and are now approaching full, he added.

"The regulators are not allowing additional ponds, so large volumes need to be dealt with," Nicholson said. "You have to figure out what to do with this water. Our concept was to make a very robust system that can really handle almost any kind of water you can give it."

Often these types of applications are in very remote areas with few inhabitants and a shortage of skilled labor. "We built it so that it can be easily put together in weeks, not months, which would be typical for this equipment. It is not what we call a mobile asset, but it is a relocatable asset," Nicholson continued.

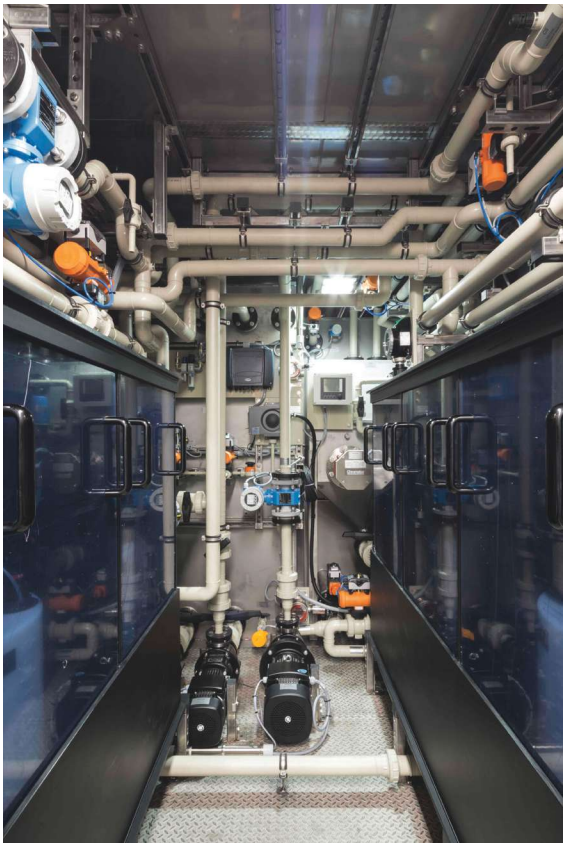
The core technology of this system is not new—forced circulation evaporators and crystallization are established and proven technologies. However, Veolia has added a few features that give it very high reliability. Many of these features have been developed from other challenging markets that operate on highly corrosive, viscous or fouling applications.

The technology takes in a highly contaminated, high-volume waste stream and converts it to a high-volume clean water stream and a small-volume waste stream. The waste stream that is discharged is either a highly concentrated slurry or waste salt cake. The clean water stream is usually returned to the client's facility for reuse, but it can be surface discharged on occasion when water is in excess. The process utilizes electricity to operate in a highly efficient process called mechanical vapor compression, Nicholson said.

Ceramic membranes for ultrafiltration

APATEQ's OilPaq is a system for the treatment of produced water, fracture flowback and brine based on a combination of proprietary process technologies and ultrafiltration membranes, which means the filters have very small pore sizes. "It is not intended to produce drinking water here, but to remove any impurities that are present in the water in a solid form," Martin said. "Suspended solids, free oil and pre-emulsified oil are taken out."

In the markets for clean brine, companies will add salt to freshwater as a certain weight is needed—10-lb brine for example—to be used for drilling purposes, supporting the control of the downhole pressure. According to Martin, rather than taking freshwater and adding salt, OilPaq operators can reuse the effluent from the system directly.



This detailed view shows the ultrafiltration module and piping in OilPaq's container. *(Photo courtesy of APATEQ)*

The core component of the equipment is the membrane technology. "An upfront pretreatment removes larger particles from the water ensuring that the membranes are not overstrained. We take out the majority of the suspended solids and the free oil in a first step before the water passes the ultrafiltration. The system is actually a combination of several processes," he added.

For now the company has developed a containerized system. The lowest offered capacity is 2,000 bbl/d, and there is such a unit operating in the Utica/Marcellus. "It is the smallest unit we have, but we see it more like a demonstration plant because it can be easily deployed and moved," Martin said.

"The attractiveness of the technology and processes is that these can be scaled up linearly. We have done extensive tests with customers, and they are in agreement that the technology can be scaled up. We developed the OilPaq in a modular design that can easily be adapted according to customer needs, and it is perfectly suited for large volumes," he added.

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"For larger capacities, if we go from 10,000- to 20,000-bbl/d units, then we would recommend deploying OilPaq modules in a purpose-made building," he noted.

APATEQ uses ceramic membranes for the OilPaq, so there is no real wear and tear on the components. "Members of our team developed installations with ceramic membranes over 12 years ago that are still running in the field today," he continued.

The smallest system is installed in one 40-ft shipping container and two 20-ft containers. The larger container holds the ultrafiltration membranes. One of the 20-ft containers holds the pretreatment, while the second 20-ft container holds the control cabinet, the office and a storage space.

The system is fully automated. It doesn't need an operator full time, and it can be remotely monitored and controlled. One person can operate several OilPaqs from multiple interface platforms (e.g., desktop, laptop and cellphone). On site the operator would check the levels, any leakages and the working of the pumps as well as anything that is electric and has moving parts. The system meets the highest international safety features, including IECEx. All critical operational subsystems are redundant to avoid process disruptions.

The new Generation II SCOUT will be completely containerized and everything shown on the Generation I (above) will be built into the automated system. The new Gen II system was expected to be operational by March 2018. *(Photo courtesy of Fountain Quail Energy Services)*

System pulled by single pickup truck

It used to be when 10 different people were asked what their treatment KPIs were, you would get 10 different answers, said Fountain Quail's Halldorson. "We're starting to see more commonality now in what the industry needs for a treatment specification.

"Typically they are wanting total suspended solids removal, oil removal and iron removal as well as making sure there is no hydrogen sulfide and that the product pH is neutral. We are starting to zero in on a common treatment specification and that makes our job a lot easier," he explained.

The company is developing a new mobile treatment platform called the SCOUT. It is a filtration system that is completely automated and has no disposable media such as filter bags.

This addresses one of the biggest costs for the company—manpower. "If I'm going to get to a very low threshold on costs, I need to remove or reduce the manpower part of the equation. So we started developing the SCOUT. We wanted something compact that would do a very good job of filtration," Halldorson explained.

One of the company's goals is to safely reduce the manpower. "We can make a system that's fail-safe in the middle of nowhere in the oil field. If there's an upset, it has to shutdown and do it without the potential for spilling," he emphasized.

Fountain Quail spent the better part of 2017 testing different technologies and now has a commercial system operating in West Texas.

"We're building a next-generation system with a higher capacity that is more containerized," Halldorson said. "Our real goal is to build a rugged system we can set up with a pickup truck that is capable of call-out type service. Our current generation is not that mobile yet."

According to Halldorson the next-gen system was to be available March 1.

The company is shooting for SCOUT to be a system in a 20-ft container capable of 10,000 bbl/d. "We have a lot of jobs where we may need 30,000 to 40,000 bbl/d," he said. "Four small containers in parallel would make sense. Most jobs need 10,000 bbl/d, but it sure is nice to have the flexibility to roll out mobile, modular systems.

"The reason Fountain Quail wants the SCOUT to be so flexible is it allows us to go into almost any situation where there might be an existing pit full of dirty water," Halldorson added. "We can rapidly deploy, get the job done and get back to the yard quickly, safely and efficiently." ■

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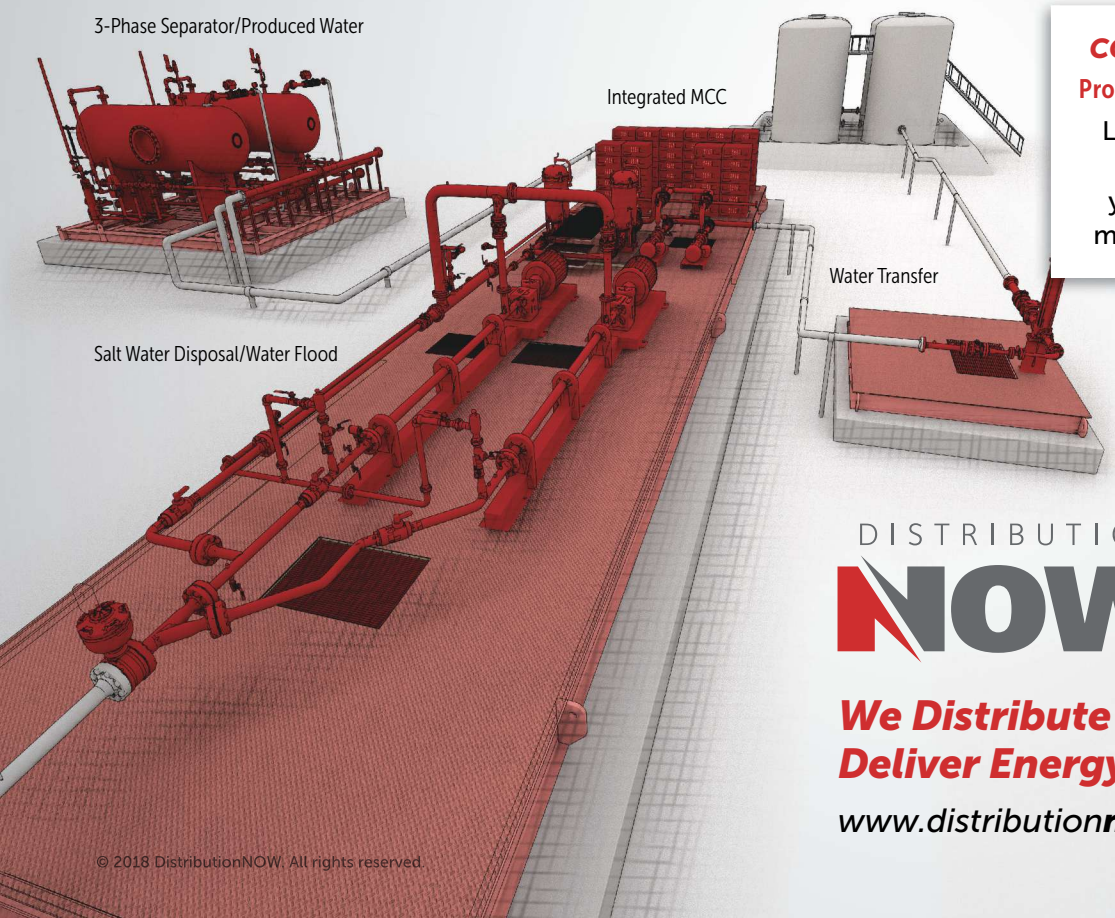

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Evolving Best Practices in Water Management

Tightening regulatory requirements, a changing financial landscape and decreasing supply are tipping the scales toward reusing and recycling water.

By Jennifer Pallanich
Contributing Editor

The sheer volume of water being produced to provide the world with fossil fuel energy is huge.

The Energy Information Administration (EIA) estimated U.S. crude production will increase by 1 MMbbl/d from 2017 with levels up to 10.3 MMbbl/d in 2018. This output would break the country's highest annual average record of 9.6 MMbbl/d, which was set in 1970. The EIA estimated the 2019 output will increase to 10.8 MMbbl/d. While an oil well may begin production with a 10% water cut, the output may be more along the lines of 10% oil and 90% water by the end of the well's life.

"We called them oil platforms in the Gulf of Mexico [GoM], but now they're water platforms," said Dr. Wally Georgie, principal consultant at Maxoil Process Consultancy.

Globally, the volume of produced water is only going to increase over time, said Lisa Henthorne, senior vice president and CTO at Water Standard.

"Having sufficient treatment for the volume is a global issue," Henthorne said. "Offshore, there's only so much water treatment capacity on the platform. It becomes a bottleneck, and you can't produce oil if you can't treat the water. You have to shut in."

The wastewater can contain high concentrations of salt as well as various organic chemicals, inorganic chemicals, metals and naturally occurring radioactive materials, according to the Environmental Protection Agency.

All that water and its constituent parts must be handled in some way.

Historically, produced water has been treated and discharged into existing bodies of water or injected back into the reservoir. But reusing and recycling the water are gaining in popularity.

"What I've seen and what clients are saying is that they're starting to reach critical mass with saltwater disposal wells, which are inexpensive. It costs much less to push it into ground than to treat it," said Georgianna Watson, produced water handling product champion at Schlumberger. "I'm

This seawater injection module is included in Schlumberger's line of water injection systems for diverse operating environments and water types, including ocean, river, aquifer and produced water for reinjection. *(Photo courtesy of Schlumberger)*

finding that the requirements aren't coming into play. Clients are being logical. They have all this water and they're saying, 'we need to use it instead of depositing it down a hole.'"

This trend has been readily apparent in the unconventional plays, Watson said, but inquiries about reusing produced water are coming in from around the world.

"That does my heart good," she said. "It's not necessarily the regulations. It's the clients looking at things and being pragmatic and saying, 'let's do something with this.'"

The need to source water for the number of unconventional wells being drilled and completed has driven some of the pragmatism.

"The smaller operators are being squeezed for getting freshwater, and they're really pursuing reusing every bit of produced water they have coming out of wells because they just can't get freshwater," Watson said. "You have to use your produced water. It can be challenging to get your hands on the water otherwise."

In the past operators were treating small volumes for reuse in completing wells, but now operators aim to treat and reuse nearly 60% of the estimated 800 Mbbl of water needed to complete a well, Watson said.

"It's hard to get to 100% unless it's a huge producing field" because it won't generate the full volume needed, Watson said.

This can result in multisourcing water.

"As you blend the waters, they react differently," she said. "Each field has its own water quality. Even if you mix this water with nonpotable water from the city, you wind up with elements dropping out. So there are treatment requirements."

Henthorne called water quality the biggest hurdle. "It varies drastically from site to site and region to region. It even changes day to day. When you start dealing with produced water, there are so many more variables and challenges to address," she said.

Offshore, there might be minimal treatment of the produced water before it is disposed of overboard. But onshore, a location without the destination to dispose of the water has cost implications for the project. Much of the produced water is too salty to be used for irrigation without treatment, and salt removal treatments are costly, Henthorne said.

"Much of the produced water is too saline to use a membrane for desalination, so you'd have to use [an] evaporative/thermal distillation process, which is energy- and capital cost-intensive to achieve that separation."

Brandon Kern, technical service specialist with Dow Water & Process Solutions, said treatment of the water differs by its planned use.

"Discharge usually has the most stringent requirements," he said, but for completion water, it may be "good enough to pull out hydrocarbons and any chemicals that may interfere."

From the outset

The need for handling produced water remains unchanged, as does the lack of operator enthusiasm for spending money on something that doesn't directly generate revenue.

"The biggest problem in this industry is the produced water is not a product that gives you revenue, so people don't prioritize it. They leave it to the last minute to deal with it. They're focused on oil and gas," Georgie said. "[Produced water] impacts revenue even if it doesn't give you your revenue."

According to Watson, designing an appropriate produced water system requires a great deal of data.

Merely pulling some gallons of water and sending it off to the laboratory only presents data from one brief period in the well's life, Watson said.

"One snapshot of analytical is not going to help me design a system that's going to fit a client's needs," she said. "That's just one spot in a 24-hour day that's supposed to be indicative of every change."

Watson said levels of measurable qualities like oil, water, iron, pH, particle size and solids data can change quite a lot and often throughout the course of a day, let alone the course of a well's design life.

"There is a wide gap between the people who design facilities and the people who manufacture the equipment and the people who deal with produced water," Georgie said.

In short, according to Georgie, design people go by the book, manufacturers tend to try to sell technology and the people actually dealing with the produced water see "it's not all lined up."

Often technology will work in one specific field, perhaps at a certain temperature or pressure or with a certain type of oil, but it may not work as well in other conditions, Georgie said. Technology that works in a black oil or crude system may not work for a gas condensate system.

"What is successful in one plant is not necessarily successful in another plant," Georgie added. "The problem that I see, being independent, is the people who design the facility do not talk to the people who operate the facilities, and they choose technology

that sounds good but may not be ideal for that kind of system. That can result in issues commissioning the produced water handling system."

Often when there's a problem with produced water, it manifests in the back end of the plant, Georgie said. The reality, though, is the issue could exist at any point in the process.

"A common belief is whenever you have a problem with the produced water, it's blamed on the chemicals. So they work with the chemical companies. But the reality is that a lot of your produced water problems are a result of the reservoir, the hardware, the this, the that. There are a lot of factors [from entry point to exit]," Georgie said. "Anything between here and there could have the potential for malfunction, so it's important not just to look at the back end of the plant but to look at it holistically."

For example, Georgie said he's been involved with a project in Australia where the focus has been on rooting out a problem chemical.

"But I don't think the chemicals are the problem," he said. "Believing something is the root cause doesn't make that the case."

Quality course

When water for injection isn't properly treated to the quality needed, it can damage the formation, Henthorne said.

"There are two groups of people," Georgie said. "There are the subsurface people who deal with the reservoir. They want to use the water for operations. They need it to be clean, with no solids—absolutely crystal-clear water. In reality, that is something that cannot be delivered with a high cost from the surface people. There's a balance where you can reuse your water for unconventionals."

According to Georgie, meeting the quality requirements of the subsurface experts is "very demanding," but with a "continuous dialog between the people working the subsurface and the surface, you'll find a compromise on what kind of water quality can be delivered."

Fracture-grade water—a benchmark set by the individual operators—is based on subsurface conditions. If a formation has fluoride, that fluoride would have to be removed from the fracture water along with the solids, Watson said.

"We can make a frack fluid with any water quality, but the subsurface engineers tell us not to put the solids downhole because of proppant issues," she said.

There's also the question of what to do with the waste removed from cleaning up the water. The objective is to minimize waste and have water quality good enough to do the work, Watson said.

Reusing produced water means having to handle the oil, solids, minerals and bacteria native to the water.

"All those things have to be handled in one way or another to effectively recycle it without causing additional problems," Georgie said. "People think they have answers, but if you go to conferences, there are some operational issues."

Georgie said the industry is working through how clean the water must be to be effective. There's a question of whether it's enough to remove only the big particles or remove most of the particles and reuse the water for use in completions. Some err on the side of maximizing the hygiene of the water, which can be cost-prohibitive, he said.

"Both are manageable and sustainable, but people in the industry will take a long time to understand whether overdoing it gives you better results," Georgie said.

A blend of produced and flowback water undergo treatment via Water Standard's mobile system. These water samples demonstrate the before and after treatment. *(Photo courtesy of Water Standard)*

There is no current standardization in the criteria for reuse of water, according to Georgie.

"Everyone's doing different things," he said.

If regulations aren't an issue, it will likely come down to economics. Cleaning to 50% of solids may cost 30 cents per barrel while cleaning to 99% removal of solids may cost twice that or more.

"When you're using hundreds of thousands of barrels of water, it makes a huge difference to your costs," Georgie said.

Some suggest that disposing of water by reinjecting it into the reservoir and buying freshwater is cheaper than treating produced water, he said. However, Georgie said they may not factor in all expenses such as the cost of handling the water at the injection site and the financial and community cost of transporting water by truck.

Given the vast quantity of water produced each day, and the need for water in operations like fracturing, some companies are seeking ways to better move around water. This is particularly evident in the Permian Basin, Henthorne said.

Midstream water management is "a burgeoning area," she said. "A number of companies are thinking strategically about water. They're looking at pipelines to move the water volumes around. The goal is to get away from trucking."

In some locations it's necessary to minimize the impact of trucks carrying water. These trucks don't just contribute to congestion. The water transport trucks are heavy and can eventually damage roads.

Getting pipeline infrastructure into place to move produced water requires many of the same hurdles other pipelines must clear, such as acquiring rights of way.

"It's quite a complicated puzzle they're trying to put the pieces together for," Henthorne said. "The Permian will be a great case study about how to do this economically and cost effectively, and the other basins could adopt it."

Unconventional variables

Unconventional fields differ from conventional fields in more than just the fact that unconventionals produce from the source rock.

"When you deal with a conventional field, you are dealing with a consistent water composition," Georgie said. "In unconventional fields, all of them have a variation in the water. When you have inconsistency, you have different challenges. When you have inconsistency, it changes from day to day, and it makes it much more challenging for how to deal with it, such as flow assurance issues."

While a lot of operators use freshwater for fracturing jobs, that approach is not sustainable. As such, some operators have begun using the produced water for fracturing jobs, which offers some cost benefits, Georgie said.

When an operator wants to reuse water produced from an unconventional well to fracture a well, the daily produced water from the lease may not be enough. One option is to store up the water volume, which requires infrastructure. Many are opting to use whatever treated produced water they have from the field and supplement it with freshwater or treated sewage water. The problem with using treated sewage water is the potential for biological activities that are a far cry from those native to the reservoir.

"Putting the two together can be challenging," Georgie said. "To be frank, I don't think we have a clear answer for that. Are we treating it effectively? I don't believe so. When using water and recycling, every time you take it through a cycle, you are increasing the activity."

One of the chief challenges Georgie foresees is finding a good best practice for reusing produced water that must be mixed with other water sources.

"That's probably going to be the future normal," Georgie said. "But we need to find a way to treat that water effectively because if we don't, the problem is going to be exacerbated."

Tightening regulations

Regulations for treating and disposing of produced water vary by location.

"These regulations are constant moving targets for what people need in terms of treatment," Henthorne said.

For instance, it is possible to obtain disposal well permits in Texas while other states don't permit disposal wells.

Adaptable systems with the ability to effectively treat varying inlet water quality is crucial in successful treatment of produced and flowback water. *(Photo courtesy of Water Standard)*

The major downside of disposal wells is "once water goes in, you lose that water forever. It won't be available for generations," Henthorne said.

If the water is to be discharged into an existing body of water, those regulations can vary as well. For instance, in Colorado the specifications for discharging water into rivers are different from discharging into a stream that primarily has snowmelt going into it.

"It's a function of what the marine environment can tolerate and other discharges into the rivers," Henthorne said. "The lucky operators have access to some of the bigger rivers that don't have as stringent requirements in most cases."

Technology focus

Georgie said it's crucial to consider why certain technologies work in one region and not another.

"The belief was, and a lot of people still think about it [this] way, was the technology used for the North Sea was only good for the North Sea and doesn't work in the Gulf of Mexico. This is rubbish. The reasons some work in the North Sea and don't work in the Gulf of Mexico is because the way we develop things in the Gulf is slightly different than the North Sea, so those designs are not favorable," Georgie said.

In other words, the technology could be effective, but the lineup and configuration could be problematic and limit the efficacy of the technology, he said. One example was the attempt to bring de-oiler hydrocyclones from the North Sea to the GoM. Many of the units failed to provide the desired results in the GoM. According to Georgie, the problem was that pressures and temperatures were different and therefore caused problems with the units.

Keeping the treatment technologies affordable is critical, Henthorne said, and those technologies must be able to adapt to incoming water quality variations. One of the technologies Water Standard recommends for treatment is an alginate or a seaweed that flocculates contaminants such as suspended solids, oils and iron to remove them from the water. The biodegradable alginate is a natural ingredient that also is used in the food industry.

"This alginate works to flocculate and easily remove the contaminants," Henthorne said. "It scrubs the water and collects the stuff and removes it. That's been a cornerstone of a lot of this treatment for reuse and recycle."

Beyond that, Henthorne said Water Standard uses hardware in conjunction with the seaweed-based alginate to enhance the contaminant removal.

"There are checks and balances in the system to allow us to adapt to the changing quality in the water," Henthorne said. "If one system is not working as well as it can because a slug of oil has come into the system, the second unit would pick that up and remove it."

Water Standard has developed a mobile water treatment system for fracturing operations, which can be deployed to multiple wellsite areas. Henthorne said using mobile water treatment designed to reuse or recycle produced water or to safely discharge mitigates many challenges traditionally associated with transporting water to stationary facilities.

Kern said Dow is actively looking at technologies that answer the oil industry's produced water challenges.

When it comes to treatment for water intended for fracturing or other types of reuse, Kern said one of the first steps would be to remove any emulsified or soluble hydrocarbons in the water. Most produced water holds an estimated 1% to 3% of hydrocarbons. As such, at $50/bbl of oil, each barrel of produced water could represent 50 cents to $1.50 of additional value for the operator.

The mobile produced and flowback water treatment system is operating to treat water for reuse in fracturing operations and to meet stringent regulations for safe discharge into a nearby river. The system is designed to remove total suspended solids, benzene, toluene, ethylbenzene and xylene, oil, iron, manganese, H_2S and ammonia. *(Photo courtesy of Water Standard)*

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Voraxial impeller-induced cyclonics provide a robust, flexible, onsite separation method in a compact, self-contained unit for high-rate water treatment. *(Photo courtesy of Schlumberger)*

"Otherwise that is lost revenue," Kern said. "That is saleable product that is stuck in the water as a carrier."

Kern said Dow uses a two-step process to remove hydrocarbons from produced water. The first step is a coalescing technology Dow calls AMBERLITE ROC 110. It is a surface-modified media that causes the oil to form larger droplets, slough off and separate out, thereby breaking the emulsion. However, Kern said some soluble hydrocarbons often still remain, requiring a different technology for removal. An adsorbent resin called DOWEX OPTIPORE can adsorb the hydrocarbon out of the water to the 1 parts per billion range. Together, the technologies are designed to treat water economically.

The products and technology have been used in chemical process settings, such as ethylene crackers, for years, but they are just starting to gain traction in the oil and gas sector. DOWEX OPTIPORE is being used in tandem with a project in Wyoming that is producing 25 Mbbl/d of water. "It's effectively treating that," Kern said.

Water intended for reinjection might be softened to remove hardness. Highly saline water may go through a reverse osmosis process to reduce the amount of salts.

One of Schlumberger's water treatment technologies is Voraxial impeller-induced cyclonics, which provides simultaneous three-way separation of oil, water and solids for onsite oilfield water treatment. Voraxial uses impeller-induced cyclonics to provide instantaneous, continuous and concurrent separation of water, oil and solids at very high flow rates. The water can then be subject to further treatments, such as ultraviolet lights, oxidation and biocides. These treatments destroy polymer content for frack water recycling, sterilize microbes for pit and pond maintenance and reduce select ions for protection of tanks, pipelines and saltwater disposal wells.

According to Schlumberger, the mobile in-line treatment system has a wide operating window that can accommodate changing influent water quality and flow rates without interrupting operations for reconfiguration. Produced water is then treated to augment freshwater inflow.

Revenue source?

If operators can find a way to turn produced water into a revenue stream, the matter may garner more attention. Produced water that has been treated to reduce the salt can be sold for use in irrigation. Henthorne said she is aware of some companies that are actually mining those salts to some degree of success. She said some companies are looking at mining a specific mineral that appears in some produced water to sell for use in certain batteries.

According to Georgie, perhaps the best way to turn produced water into a revenue stream is to reduce the overall operating costs.

It has been reported that in 2016 the U.S. shale industry paid $20 billion to dispose of produced water. Of that outlay, more than half went to transportation and disposal. The 2018 spend on dealing with produced water is projected to be high as well.

"If we accept that we could reuse that water and we don't dispose of it, there will be a significant amount of that $20 billion saved. So it's not a revenue but a cost savings," Georgie said. ■

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A New Approach to Reuse

Water recycling system replaces disposal with reuse in the water chain.

By Sandy McDonald
Kaizen Fluid Systems

Kaizen Fluid Systems has combined modern technologies to create an electromechanical water recycling system. An electromechanical system converts extracted solids, liquids and/or gases into useful commodities, virtually eliminating the need for any type of disposal. The process removes or destroys all chemicals, silts, clays, chlorides, bacteria, fungi and parasites, all of which are total dissolved solids (TDS) and total suspended solids (TSS). The system returns pure, clean and clear water that is very close to distilled quality, which may be used for many additional purposes.

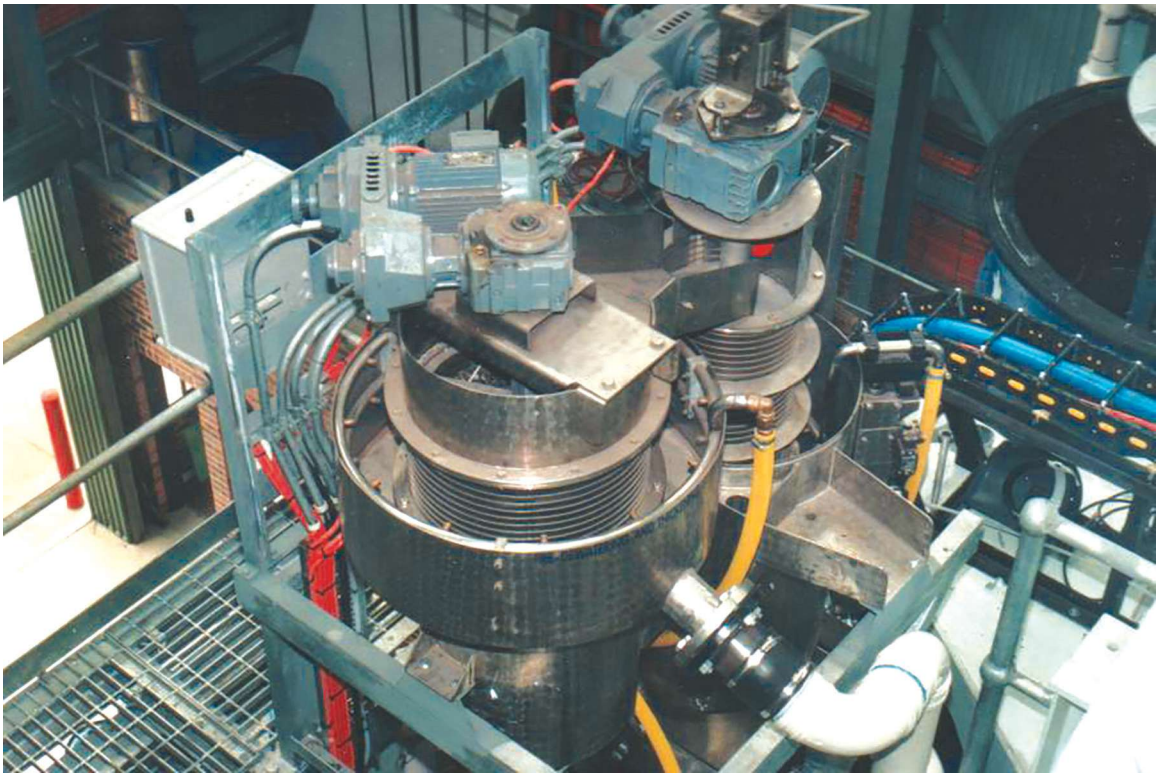
The process resulted in pure water that was near-distilled water quality and was ideal for fracturing, drilling use or discharge into the environment without any worry of discharge violations.

A producer in the oil and gas industry approached Kaizen asking for a solution to purify the mass volumes of its produced and flowback water. The producer had worked previously with at least 16 water management companies without success in search of not only an economical solution but one that would allow it to maintain compliance with all state and Environmental Protection Agency (EPA) guidelines. The solution for the producer also would need to reduce and/or eliminate the costly expense of storage and transporting the water for disposal.

The producer's corporate mandate was to procure a system whereby it would have the option to use the clean water for fracturing or drilling operations as needed, and either discharge or evaporate the balance into the environment well within current and proposed state and EPA guidelines. To meet state and EPA guidelines, the water needed to be free of chemicals, metals, salts and virtually all TDS and TSS. Solids extracted needed to meet state and EPA guidelines for disposal or reuse, and the operator needed to ensure naturally occurring radioactive materials concentrations remained within guidelines for conventional disposal wells.

Kaizen had a system in place for other producers that delivered results that were significantly lower than the EPA and state guidelines. After further discussions with the operator, Kaizen agreed to perform a site visit to evaluate the operator's specific needs, pull produced water samples and complete the laboratory analysis to determine the best practice to meet the requirements. The producer's water sample had a TDS of 318,000 mg/l, a TSS of 297 mg/l, a turbidity of 226 mg/l, a pH of 4.4 mg/l with barium at 11,600 mg/l, iron at 102 mg/l, magnesium at 1,820 mg/l, strontium at 7,270 mg/l and zinc at 6.7 mg/l. All other constituents were within reasonable concentrations for produced water.

Kaizen determined that to provide water pure enough for discharge into the environment while complying with the state and EPA guidelines, it would process the water in a systematic order using nine of its portfolio technologies. By following a systematic procedure, Kaizen extracted the solids, which are all benign and usable and therefore have no disposal costs. This procedure included destroying all chemicals and changing the ionic metals back into their oxide form, thus rendering them benign. Then, all of the chlorides were extracted from the brine stream in either a concentrated heavy brine form for drilling operations or as high-quality dry salts ready for other commercial or industrial use. The process resulted in pure water that was near-



Kaizen's dewatering cylinder works as part of the separation process for produced water. *(Photo courtesy of Kaizen Fluid Systems)*

distilled water quality and was ideal for fracturing, drilling use or discharge into the environment without any worry of discharge violations.

Having completed the process, the produced water underwent substantial improvement in quality. An industry-respected third-party laboratory report showed the following results:

- Barium reduced to 0.115 mg/l from the original 11,600 mg/l;
- Iron reduced to 0.01 mg/l from 102 mg/l;
- Magnesium reduced to 0.1 mg/l from 1,820 mg/l;
- Strontium reduced to 0.113 mg/l from 7,270 mg/l;
- Zinc reduced to 0.0039 mg/l from 6.7 mg/l;
- Aluminum reduced to 0.0031 mg/l from 3 mg/l; and
- All other metals were at a fraction from their start point;
- Turbidity reduced to 0.18 mg/l from 226 mg/l;
- TDS reduced to 144 from 318,000 mg/l
- Chlorides reduced to 3.98 mg/l from 181,000 mg/l; and
- TSS reduced to 5.4 mg/l from 297 mg/l.

The pH can be adjusted with accuracy to any level specified to meet the producer's specific needs.

To accomplish these results, Kaizen has developed a protocol whereby all water is processed in real time, except for buffer capacity, before entering the company's equipment at certain intervals in the equipment and at the discharge stage. Therefore, the process greatly reduces the need for any large volume storage or transportation (thus reducing producer costs and environmental concerns) while processing any volume of water at a site. This also allows Kaizen to monitor and control each phase to ensure each step is meeting predetermined process standards.

The Kaizen process is completed in two stages, with pH adjustment, solids removal, chemical destruction and metals removal completed using eight of the company's technologies in the first stage and nonconventional desalination in the second stage. The first stage is designed to remove all impurities from the produced water input stream, creating a pure brine for the second stage feedstock. This process allows Kaizen to keep all resultant fluids and solids pure, clean, nontoxic and nonhazardous.

The water discharged is high grade and close to distilled quality, suitable for reuse in operations,

Kaizen Fluid Systems' separation equipment works to eliminate TDS and TSS from produced water. *(Photo courtesy of Kaizen Fluid Systems)*

agriculture or discharge into the environment and completely mitigates the need for any use of imported potable water by the producer. Vaporization can be used if wanted as there is no risk of any chemical discharge into the environment due to the water's purity.

The company's process can handle any concentration of TDS from 1,000 mg/l to 500,000 mg/l entrained in the water column as long as the column can be pumped, is somewhat fluidic and will flow. The concentration of the contaminants will affect the speed at which any specific treatment train can process; however, there is no limitation on the chemical toxicity or TDS concentration with the process. This is a unique feature as all other systems are restricted in most cases by TDS levels.

Water with lower TDS or chemical properties may require a simpler process. Kaizen's technologies are customizable and can function independently for specific tasks or be placed in sequence for complex water purification needs.

Systems are fully scalable and have the capability of purifying virtually any discharge stream of fracture fluid or produced water as generated within the oil and gas industry with a minimum size of 50 gal/min.

In many cases there is no need to remove TDS or other components found in produced or fracture water. For this reason Kaizen can deploy only the required pieces of equipment to the site for the specific needs of the producer. The company also can supply complete systems capable of purifying high (more than 400,000 ppm) TDS produced water to potable standards. The system also can precondition water before, after and during fracture operations or process a fixed volume of produced water at any site and make it suitable for its designated use. The electromechanical process typically reconfigures undesirable compounds into useful products and does not generate a toxic waste stream. ■

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E&P

Produced Water Management: The Role of Aeration

As practices move from disposal to reuse and recycle, aeration could provide a cost-effective solution.

By Mark Patton
Hydrozonix

Produced water, a byproduct of oil and gas wells, has grown in importance as discussion has moved from waste product to valuable resource. As shale activity increases, so does water demand for completions and produced water disposal capacity from producing wells. A natural solution is to consolidate a produced water management program into a water supply program for completion activities.

This has pushed produced water management from disposal in injection wells to recycle/reuse programs. Induced seismicity has accelerated the recycle/reuse movement in some areas. Other factors moving produced water from disposal to reuse vary from area to area but include water scarcity/drought, disposal capacity and the cost of recycling.

Over the last few years, the industry has seen produced water treatment costs for reuse increase from $0.40/bbl to $0.65/bbl and decrease to less than $0.30/bbl. This reduced cost is primarily a result of improved fracture chemistry and a better understanding of what needs to be treated. The idea of "just enough" treatment has narrowed the focus to bacteria, iron, sulfides and some solids control. This narrowed focus has significantly reduced the need for total dissolved solids control and eliminated pit treatments for a much lower cost aeration approach.

Aeration has been used for water quality management as early as the late 1800s and is a part of most all municipal treatment plants across the country, but it is a relatively new concept for produced water. Produced water aeration allows oxygen from the air to provide oxidation of iron and sulfides, while oxygenating the water to mitigate anaerobic bacteria. This system addresses many of the items on the narrowed list of constituents needed to address as part of a produced water reuse program. Aeration is also a fraction of the cost of conventional pit treatments. So why is aeration just getting noticed?

As produced water reuse has grown, the need to aggregate and store produced water has grown. Storage has evolved from multiple fracture tanks to larger aboveground storage tanks to large in-ground pits. This evolution has increased the storage time for produced water, which allows bacteria to grow and H_2S to generate and make reuse more difficult. This concern was addressed initially with chemical pit treatments but has evolved into an aeration solution. Aeration takes longer to work as oxygen is a slower acting oxidizer, so the longer storage time made aeration a more viable solution and much more cost-effective than chemical treatments.

Floating versus submersible

As companies accept aeration as a cost-effective solution, then comes the choice of what type of aeration. To simplify, consider aeration systems as two categories: floating and submersible. Floating systems are easy to deploy when water is already present, but they typically only aerate the top few feet of water leaving a significant amount of water with inadequate quality. Some floating systems add

Water aeration processes could result in cost savings for handling produced water compared to conventional pit treatments. *(Photo courtesy of Hydrozonix)*

more horsepower to push air deeper, but air wants to return to the surface, and the additional power increases the cost, while the operation still suffers from poor distribution of oxygen.

Another concern for floating systems is the running of electrical power into a pit creating a potential electrical safety concern. This is when submersible systems become a viable option. Submersible aeration provides the distribution of oxygen needed throughout the water volume, doesn't pose the electrical shock concerns and uses far less energy, but it typically requires an empty pit or tank to deploy, which can pose a concern for deployment. Nobody wants to drain and take a pit out of service.

Case study: Permian Basin produced water pit

This case study explores the advantages of a portable, submersible aeration system that allows submersible aeration to be deployed into water. The case study also evaluates performance and discusses metrics that should be monitored to evaluate performance of aeration systems.

The most common failure in the application of aeration for produced water is the sizing of the system. It is not uncommon for an operator to simply base the size of an aeration system on water volume, which is wrong. The water quality and its oxygen demand must also be taken into account. It is this missing piece that creates failed aeration programs, which unfortunately happen more often than expected—consider not only biological oxygen demand but other reducers in the water that will consume oxygen like sulfides and iron. Once enough data are acquired and water quality changes over time have been considered, the system is sizable.

In this specific case study, about 1,000 cf/m of air for a 450,000-bbl pit was needed. Once sized, the blower and aeration system were deployed, taking initial tests of the pit before and after deployment. Using oxidation reduction potential (ORP), general water quality was determined and, as expected, the

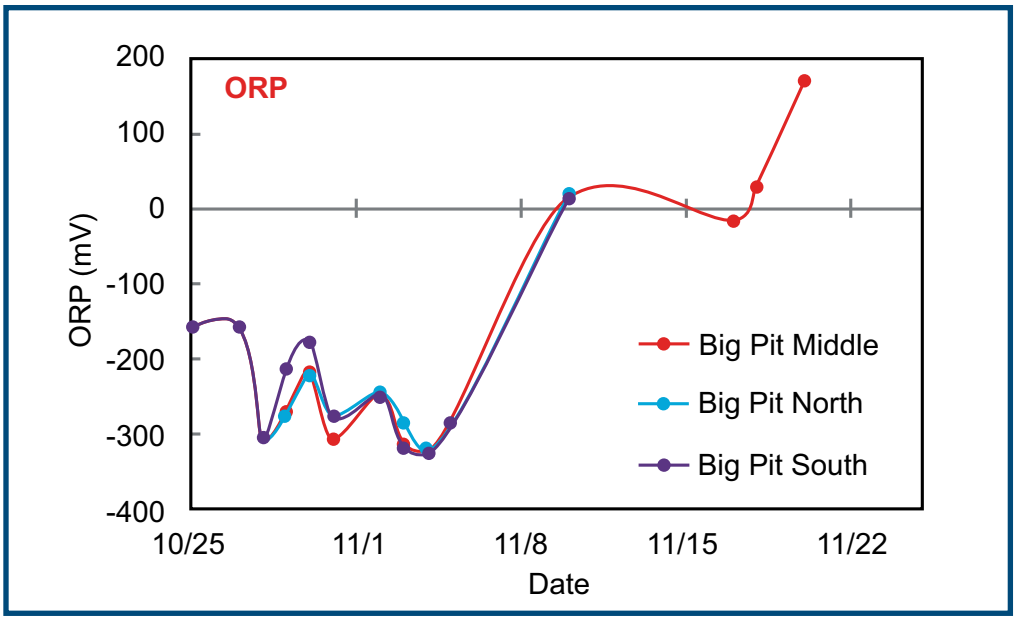

Figure 1. The general water quality in a Permian Basin produced water pit using ORP was tested in a 2016 study. *(Data courtesy of Hydrozonix)*

water quality continued to worsen while in storage and began improving once the aeration system was installed. It took about five to seven days to get the water to an adequate quality (slightly positive ORP) and 14 days to get the water to a good quality (more than 100 ORP) (Figure 1).

ORP is just one parameter to consider. Dissolved oxygen, iron and sulfides are just as important to evaluate the overall performance of the aeration system. Measuring these parameters also help verify if ORP is a good indicator of overall water quality. A review of the results for iron, sulfides and dissolved oxygen shows they are consistent with the changes in ORP. It can be verified that ORP provides a good indication of overall water quality and aeration system performance.

In sampling a pit or tank, it is important that samples are taken from multiple locations and different depths. It is also important to evaluate the deviation between these results. Significant deviations can be a sign of dead zones or stratification. A review of the data shows the results are consistent, which is an indication of good mixing. Another technique to evaluate mixing is the use of temperature. A line of thermocouples for temperature measurement can be put into the water. There should be very little deviation from the top to the bottom. If there is a deviation, this is a sign of poor mixing or stratification. The portable aeration system being evaluated here is designed to provide mixing with aeration.

Why is stratification a concern? Poor mixing can result in chlorides concentrating at the bottom of the pit. In a reuse program, increasing chlorides will increase the friction factor of the produced water, requiring an increase in friction reducer in completion fluids. To avoid this, a consistent fluid should be maintained by monitoring mixing.

In this case study, a portable aeration system was evaluated. It was deployed in a 450,000-bbl pit and tested the water over four days. A deployment barge with a small crane attached was developed to deploy each mixer, while complying with confined space entry requirements. Produced water pits, although open, can meet the requirements for confined space entry. As a result, the deployment barge had to be outfitted with safety harnesses, communication and multiple self-contained breathing apparatus.

Baseline testing was conducted to evaluate water quality changes before and after deployment. As expected, water quality improved and was maintained. Pit water was regularly removed for a reuse program. Secondarily, mixing was evaluated, which also was found to be effective. Ultimately the portability allowed the submersible aeration system to be removed and relocated without concerns requiring the pits to be empty. The key to the success of this aeration system was sizing it to account for water quality and its oxygen demand. ■

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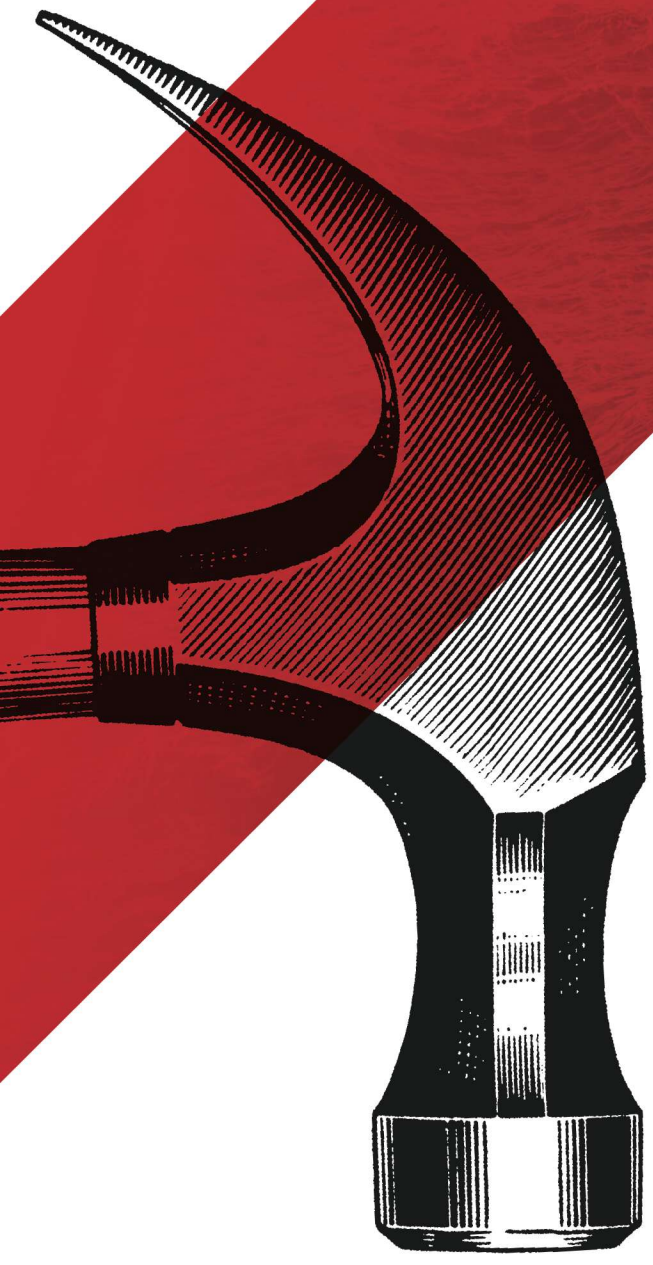

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