March 2010

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Biological Treatment of Produced Water

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What is produced water?

Produced water, also known as drilling water, is waste water formed during the process of petroleum extraction from underground reservoirs. To better understand what produced water is, it is important to take a closer look at the actual oil drilling process. Drilling for oil, referred to in the industry as the 'upstream mining process' frequently involves pumping large quantities of high pressure, extremely hot water into the petroleum reservoir beneath the ground. The water pressure forces the petroleum upwards, and the heat of the forced water lowers the viscosity of the petroleum. The fluid that returns to the surface is known as produced water and is comprised of hot petroleum, water that was trapped underground, as well as the pumped water, along with earth and debris.

After cooling the produced water and extracting as much of the oil as possible for use, the remaining wastewater requires cleaning, to eliminate all of the additional oils and other compounds. This is necessary before it can be discharged into the environment or re-used through the pressure pumps for repeated cycles of petroleum extraction.

Produced water characteristics

Produced water characteristics and physical properties vary considerably depending on the geographic location of the field, the geological formations with which the produced water has been in contact and the type of hydrocarbon product being extracted. Produced water properties and volume from one location, can even vary over time.

While oil and grease components of produced water receive the most attention in both onshore and offshore operations, produced water contains various toxic organic and inorganic compounds. Some of these are naturally occurring in the produced water while others are related to chemicals that have been added for 'cleaning' purposes. As the various components need to be treated, whether due to discharge laws, or because of the damage they cause to drilling equipment and oil-well quality, we will briefly review some of them in order to provide a more complete picture of the challenges of treating produced water.

- *Dispersed oil consists of small oil droplets suspended in the aqueous phase*
- *Dissolved or soluble organic components include hydrocarbons that occur naturally in produced water such as organic acids, polycyclic aromatic hydrocarbons (PAHs), phenols, and volatiles*
- *Treatment chemicals include biocides, reverse emulsion breakers, and corrosion inhibitors*
- *Produced solids include precipitated solids, sand and silt, carbonates, clays, proppant, corrosion products, and other suspended solids derived from the producing formation and from wellbore operations*
- *Scales can form when ions in supersaturated produced water react to form precipitates when pressures and temperatures are decreased during production. Common scales include calcium carbonate, calcium sulfate, barium sulfate, strontium sulfate, and iron sulfate*
- *Metals typically found in produced waters include zinc, lead, manganese, iron, and barium*

Clearly, all of these substances are highly problematic as toxins affecting the environment or because they hamper efficient drilling and production. As such, produced water treatment is no longer an option, but an integral part of any oil-drilling operation.

> "while oil and grease components receive the most attention in both onshore and offshore operations, produced water contains various toxic organic and inorganic compounds"

How much produced water exists?

Most sources estimate the total volume of produced water to be minimally about 77 billion bbl per year. As oil excavation sites age and their reservoirs become depleted, water can constitute as much as 98% of the material brought to the surface. It is important to note that the volume of produced water from an oil well does not remain constant over time. The water-to-oil ratio increases over the life of a conventional oil well. In the case of a new well, water makes up a small percentage of produced fluids. Over time, the percentage of water increases and the percentage of petroleum product declines. As such, the volume of produced water can be expected to grow exponentially.

The importance of properly treating produced water

Regarding produced water, the disposal of untreated effluent into the surrounding environment is strictly forbidden and regulated by governments around the world. A lack of compliance is often met with stringent penalties. Furthermore, re-injection of untreated produced water into the reservoir can result in costly damage to pumping and drilling equipment. Additionally, adverse chemical reactions with various contents of the underground reservoir can be precipitated by untreated water. This can cause complications arising in the subsequent oil extraction. As a result, more oil companies are searching for effective and efficient means of managing their produced water.

Common methods of treating produced water

Typically, produced water is treated with physical and chemical methods prior to its discharge or re-injection. The methods employed vary depending on whether the water is intended for re-injection or discharge, as well as whether the drilling site is offshore or onshore. As a first step, the water is treated with a gravitational separation device (API). Due to variations in density, free oil is separated from the water and forms an oily upper layer which is then skimmed off. Heavy components such as sand or other particles are collected from the bottom of the tank, and the water flows to the next separation step.

Centrifugal methods are used when efficient separation is needed and residence time must be low, for example aboard ships and offshore oil rigs. They are rarely used on land, since the effluent quality does not meet the desired parameters set by local governments. The most common centrifugal devices are the separator and the decanter. These separators can only be used for wastewater treatment when the desired discharge levels are not too restrictive. This method is commonly used aboard ships as a substitute to API, where low residence time is required. An example is a centrifugal decanter which is a horizontal, solids-oriented, solid-wall scroll centrifuge. Generally, separators are used for the clarification of suspensions and sludge with relatively high solids concentrations. However, they can also be used for the separation of liquids (oil and water) with the simultaneous removal of any solids that are mixed in.

Dissolved Air Flotation (DAF) or Dissolved Gas Flotation (DGF) technologies primarily allow separation of dispersed oil from the water. This separation is achieved by forcing air into a solution within the >

wastewater through a high pressure system. The pressure is then released, causing the air to form tiny bubbles which adhere to the oil globules. This process elevates the oil globules which can be easily extracted by skimming or filtration. Added chemical treatments also ensure that the chemical makeup of the produced water is compatible for re-injection into the reservoir.

Bioremediation of produced water

Typically physical and chemical methods for wastewater treatment are efficient in the elimination of solids, as well as free and dispersed oil. These methods, however do not achieve a high level of efficiency for the elimination of dissolved pollutants. Microbial biodegradation is extremely effective in treating various types of dissolved molecules, including petroleum hydrocarbons, and therefore are very useful in lowering the organic contamination levels in produced water.

Biological treatments of wastewater are very well known and implemented in oily water treatment in other fields (such as refineries, storage farms etc.). The most common biological method is known as activated sludge. Treating produced water with activated sludge works because the dissolved contaminants are consumed by the microorganisms within the tank to form additional bio-mass (sludge). Next, water and sludge are washed out of the bioreactor and into a clarifier. The solid waste (sludge) that settles on the bottom of the clarifier is composed of both live and dead bacteria. Approximately 50-70% of this sludge is transported back into the bioreactor in order to continually re-activate the biological process. The other half of the sludge is fed into a de-watering system for removing additional water and is then disposed of in a landfill. The effluent from the clarifier passes through a filtration unit (usually ultra-filter) into a settling pond and only then is it ready for discharge or re-use.

Challenges in biological treatment of produced water

The contamination levels and composition in produced water can vary through time or from one oil well to another. This may cause upsets during the biological treatment process as such biological treatments are often very sensitive to fluctuating conditions. The upsets can ultimately lead to complete site shut downs, costing exorbitant amounts of money and people resources to bring back online. Furthermore, common biological systems such as activated sludge or membrane bioreactors (MBR) usually include very cumbersome systems that require highly skilled management.

Common biological processes, such as activated sludge or membrane bioreactors are based on the concept of maintaining a high cell concentration throughout the process. This leads to high final sludge levels that translate directly into higher disposal costs. In addition, the infrastructure of the common biological methods is stationary, requiring a long time for assembly and operation.

> "more effective ways of wastewater treatment are being explored due to stricter standards, environmental awareness, and the damages untreated water has on drilling equipment"

Such systems are not suitable for handling produced water of multiple wells within short time frames and at low cost. Since these systems cannot be moved from one drilling site to another, the only option in these cases is to transport the produced water from the various wells (sometimes from a significant distance) to the stationary wastewater plant. In addition to standard shipping expense, the transportation >

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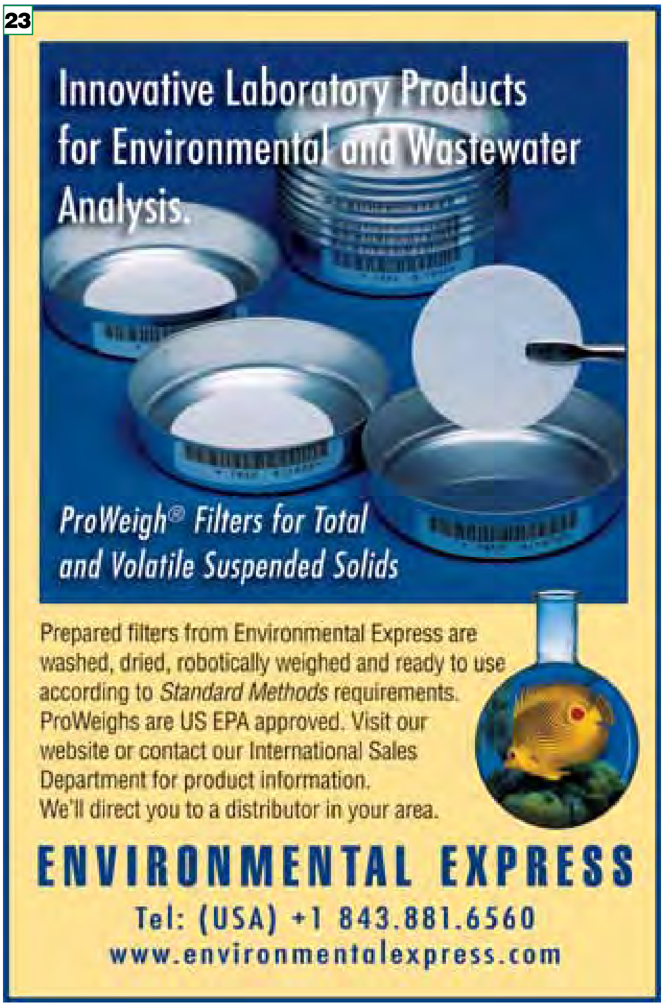
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of hazardous materials such as produced water can be very costly. For these reasons, biological treatment methods are not always ideal for cleaning produced water. However, despite the costs and logistical challenges, companies in the oil industry are starting to explore more efficient and effective ways of wastewater treatment. This is due in large part to the combined effects of stricter governmental discharge standards, increasing environmental awareness, and a growing understanding of how re-using untreated water damages both drilling and pumping equipment as well as oil-well quality.

Alternative biological approach as a solution

A recently developed biological method for wastewater treatment, known as the Automated Chemostat Treatment™ (ACT) appears to provide a potent solution for the existing challenges in the field of produced water treatment. This new biological concept is based on maintaining a pre-selected bacterial "cocktail" at a stable, low concentration while monitoring the system with a fully automated control unit.

The first essential aspect of this biological method lies in the meticulous selection and culturing of bacteria from pre-treated water that are specifically designed for any given wastewater type. These bacteria are naturally occurring, without alteration or genetic engineering. The more homogeneous nature of the cocktail ensures a more targeted and effective bio-degradation of the polluted water content. The tailor-made bacterial cocktail is so specifically designed for the water-type and the on-site environmental conditions, that some designs can even yield a bacterial cocktail that is tolerant to extreme environments such as high temperatures (up to 45 ºC) or high salinity (up to 4%).

Additionally, as the bacteria concentration is kept at a minimum throughout the process, aggregate formation is prevented. This approach increases the surface area available for the bacterial bio-degradation process, with a resultant higher quality of effluence. Moreover, the low cell concentration ensures that a young cell population is maintained, keeping sludge-buildup at a minimum and cell efficiency at a maximum. This biological system is also characterised in a relatively low recovery time when various upsets occur.

Such short "lag periods" is made possible by the high competence of logarithmic phased bacteria (as compared to the stationary phased bacteria, that characterise other common biological methods) to adjust to changing environments and perform under stressful conditions.

> "short "lag periods" is made possible by the high competence of logarithmic phased bacteria to adjust to changing environments and perform under stressful conditions"

Lastly, the process is continuously monitored by a control system designed to overcome system fluctuations. The monitoring occurs both in pre-treated influent as well as within the bioreactor. The fully-automated control system maintains a permanent homeostatic state, and can handle a variety of contaminants and waste capacities. The control system is a computerised network connected to sensors that consistently measure the environmental variables of the wastewater. It is also connected to a series of valves that can modify each of the measured variables as needed. In this way, the system continuously ensures the best possible environmental conditions for the bacteria. The control system is able to communicate data (automated alerts) to a specific cell phone number(s) or to selected personnel when one or more of the measured parameters breaches the tolerance range. This maintains the integrity of the processing system at all times, and significantly reduces the time and attention required to maintain the system at full operation capacity.

This type of custom-designed solution effectively decreases the issues surrounding the produced water treatment process. The sludge levels that are produced throughout the biological processes are significantly lower in comparison to sludge levels produced by traditional treatments. This directly translates into a cost reduction, as less handling of by-products is required. The modular approach provided by this solution allows for a fast and easy on-site implementation, leveraging the site's existing infrastructure. In the case of treating produced water streams, the modularity of the ACT system is >

parameter	Raw Produced Water	ACT-Treated Produced Water	Desired Values
COD	1542	165.7	250
TPH	117.4	1	10
TOC	340	41.2	****
NH_4^+	18	4.6	****
Turbidity [NTU]	181	0.33	<0.5
Filterability [Lit/600min]	4	101.8	>100
TSS [ppm]	86.5	0.5	<2.5
SRB Counts/100ml	103	<1	Nil

Table 1: The contamination level of produced water before and after the ACT biological treatment

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specifically advantageous as the system can be moved from one site to the other.

To clearly illustrate, the ACT control system can be assembled in the short period of one week. Additionally, there is no need to add storage tanks or reactors, as the control system can be directly integrated with the existing facilities. Once the produced water has been treated, the control system can be disassembled also in the short period of one week. After disassembling the system, it can be easily and economically transported (both on-shore and off-shore) in a 20 foot container. The ease of assembly and transportation allows operators of multiple drilling sites to stagger treatment at different sites in an affordable and efficient manner.

Recent pilot of produced water bioremediation

The potency of the ACT technology in treatment of produced water was recently demonstrated by BioPetroClean™ (BPC), developer of ACT, in a drilling site in India. Ordinarily, the accumulated produced water in this site is treated with conventional chemo-physical methods. The goal of this project was to build a cascade system which produces clean water according to the client's dictation. During the treatment process, the water was analyzed for COD, TPH and TOC reduction, as well as ammonium, turbidity, filterability and total dissolved solids. The measured parameters are summarised in Table 1.

The water in the reactor was kept at room temperature, and at a constant DO and pH. As demonstrated in the table, the carbon uptake was very high. During the process, the total organic carbons were consumed at an efficiency of 88%. In correlation the COD was consumed at an efficiency of 89% and the TPH was consumed at an efficiency of 99%. In addition, the ammonium was also reduced by 74%. The TSS, turbidity and filterability levels met with the client's requirements. Following the biological treatment biocides were added to the treated water in order to reduce the total bacterial count and especially the Sulfate Reducing Bacteria (SRB). It is shown in the table that the final SRB level also met with the client's desired values.

In summary

Produced water is a by-product of the oil and gas drilling process. This water is characterised by high contamination levels and requires several purification steps prior to re-use or discharge. Traditionally, biological treatment methods are not preferable due to their high complexity and sensitivity. However, the growing standards for water purification levels has increased the need for methods that can treat dissolved contaminants in addition to existing methods that primarily treat free and dispersed oil. This article describes an innovative biological concept that can be specifically advantageous in produced water treatment. The Automated Chemostat Treatment™ allows an efficient, portable and cost effective solution for produced water treatment. ■

Author

Yael Barash has received her MSc. degree in Microbiology and Biotechnology at the University of Tel Aviv, and her MBA at the Collage of Management in Israel.

For the last 8 years Yael has dedicated herself to Environmental projects, working in both the regulatory aspect, as an industrial wastewater regulator in the Israeli EPA and the industrial sector as a technologist in one of the biggest international water corporation.

In her career she gained experience working at the interphase between waste water technologies and business management in various projects in this field. Yael Barash is currently the director of business development at BioPetroClean.

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