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Oil in water—good to the last microdrop

Oil and water don't like to mix. It is not because of their relative densities—substances with different densities can mix readily as long as they are miscible, or capable of being mixed in any proportion. (Miscible liquids of different densities just mix to form a substance with an intermediate density.) The enmity between water and oil stems from the fact that water molecules are dipolar, with positive and negative charges on opposite sides, while the long hydrocarbon chains that make up oil are nonpolar, attracted to each other by the weak van der Waals force. They don't actually repel water molecules, they ignore them—while water is attracted to its own kind through much stronger hydrogen bonding and moves away from oil because of density differences. That is lucky for us, because it makes petroleum production possible.

This is probably elementary to most, but I'm really just explaining this to myself. (I'm many, many years removed from college chemistry.) In reality, water and oil are virtually always associated in underground reservoirs, and almost all oil production involves at least some water production—sometimes a great deal of water.

When a well is completed by hydraulic fracturing, the water cut will start off high, then fall off rapidly as the frac water is removed. Over the course of a well's life, the percentage of produced water will usually climb again, until the inevitable time when the cost of handling the water makes the well uneconomical, and it is shut in.

Water, water everywhere. The most abundant product that the U.S. oil and gas industry pumps out of the ground is water, not oil or gas. The great majority of this water is contaminated with salt, naturally occurring minerals (some radioactive), acids and CO_2, and, of course, stray hydrocarbons. Quantifying the total is a difficult problem, because neither industry nor government keeps reliable records.

A study produced for the DOE's National Energy Technology Laboratory in 2009 (*Produced Water Volumes and Management Practices in the United States*) estimated that 21 Bbbl of produced water found its way to the surface every year. As this figure predates the shale revolution and the boom in U.S. onshore production, it is safe to assume the figure is considerably higher today, with totals thought to exceed 60 MMbpd. On average, 7.7 bbl of water are produced for each barrel of crude oil (and 260 bbl for each MMcf of natural gas), most of that onshore.

The water-oil ratio (WOR) varies widely from region to region. In general, the more mature the producing area, the more water is produced, relatively speaking. While the Bakken shale of North Dakota produced a mere 3 bbl of water per barrel of crude (keeping in mind these estimates are over five years old), Illinois wells yielded water at a ratio of 43:1 over oil. WORs in most states fall somewhere in-between.

Again, it is not oil production that determines a well's economic viability, but the cost of that production, and water management is a cost that grows steadily as the water cut grows. After primary separation via settling tanks, coalescers or whatever, the produced water usually ends up in saltwater tanks, where they await removal by truck for disposal. The more water there is, the less efficient the system is.

The real "left-behind" oil. The water, itself, still contains a measurable amount of oil, sometimes as much as 100 to 1,000 parts per million (ppm), in the form of microdroplets. This remnant is trickier to remove, but it has market value when you consider the amount of water a mature field can produce. Additionally, the aforementioned solid particles can be problematic when the water is reinjected, and dissolved gasses, such as CO_2 and H_2S, that are released can pose environmental hazards.

Secondary oil recovery systems have been developed to address these problems and remove this form of left-behind oil, such as skim tanks with gas flotation cells and filters. Last year, National Oilwell Varco (NOV) introduced a treatment system to remove oil and solids from produced water in a single stage. Named the WaterWolf Dynamic Oil Recovery (DOR) system, the technology uses a combination of hydrocyclones and progressing cavity pumps to remove solids and oil without chemical treatment or filters.

Hydrocyclones have been used successfully offshore for many years. Hydrocyclone separators, or enhanced gravity separators, use centrifugal force to remove oil from produced water. Water from separators enters a cylindrical swirl chamber through a tangential inlet. The water accelerates as it flows through a concentric reducing section and a fine tapered section, where larger oil droplets are separated. The water continues through a cylindrical tail section, where smaller oil droplets are removed. Centripetal force causes the lower-density oil to move toward the central core.

One inherent problem with conventional pumps is oil droplet shearing. When pump-induced turbulence breaks up the oil into smaller and smaller droplets, they become much more difficult to recover. The use of low-shear progressing-cavity pumps results in larger particles of oil, hence less energy required for recovery.

The WaterWolf system is closed-loop and pressurized, eliminating air emissions by keeping pollutants and greenhouse gases dissolved in the water. The entire package is comparatively light and compact, and it can treat up to 16,000 bpd of water, per unit.

End-of-life decisions can be tough, with both favorite pets and long-producing oil wells. The call to shut in the latter has to depend on economics, and there are many factors affecting the estimated ultimate recovery (EUR) of a well. With crude in the $100/bbl range, there is more room to make money on a watered-out field. When you start looking at $50 or less, every drop, and every microdroplet, counts. WO

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