LaserFocusWorld

SPECIAL REPORT: Optical sensors enhance oil and gas yields

With consumer demand on the rise, oil companies are scrambling to find new ways to tap into existing reserves.

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Pull up to a gas pump these days and you will quickly be reminded how emotional an issue the energy crisis can be. But behind the annoyance and even anger many feel when it comes to the price of gasoline or the monthly energy bill are some alarming facts:

- The world's 120 largest oil fields produce about 50% of the world's crude oil supply (33 million barrels per day); however, only 60 oil fields in the world produce more than 100,000 barrels/day (see Fig. 1).
- Only 20% to 30% of available reserves are currently extracted from existing wells.

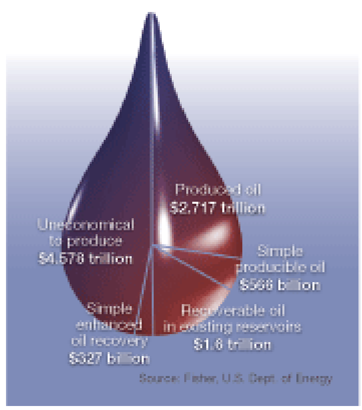

FIGURE 1. Currently only 20% to 30% of the world's available oil reserves are actually extracted from existing wells.

Given our ongoing dependency on fossil fuels, oil companies worldwide are clearly under the gun to implement more effective methods to tap into "hidden" reserves in existing oil fields. Fortunately, advances in optical sensing techniques are enabling them to do just that.

"Right now we only get about 30% of the reserves," said Paul Sanders, who oversees technology acquisitions at Weatherford International (Houston, TX), a leading systems integrator in the oil and gas industry. "Oil is mixed in with sand and you have to do a lot of things to 'herd' it toward the producing well. Eventually you hit water and other things where it becomes no longer viable and too costly to separate out. But optical technology promises to increase the yield. Maximizing reserves is a big deal today, even more so than just a few years ago because of the growing thirst for oil worldwide. New oil fields are billion-dollar projects, so there is also a value proposition; increasing the recovery factor even by a couple of percentage points can translate into huge profits."

In terms of production, the oil industry can be segmented into three main markets: deepwater (subsea), platform, and land. Subsea fields are the largest oil producers (100,000+ barrels per day) but have the fewest number of wells (in the hundreds). Platform wells number in the thousands worldwide and produce around 10,000 barrels per day. Land-based wells far outnumber the others (tens of thousands) but are the lowest producers (a few hundred barrels per day).

Contrary to popular perception, most oil is not obtained from single, vertically oriented production wells. Instead, most oil fields operate deep beneath the earth and sea, ultimately feeding dozens of production wells on the surface. With the advent of directional drilling 20 years ago, many fields are a series of horizontal wells that play off a single vertical well, much like a wagon wheel with spokes. The oil does not lie in large, easily accessible liquid pools; more often it is in near-solid form, tucked away in nooks and crannies spanning miles of dirt, sand, and rock. Locating these pockets with the use of seismic techniques and extracting this oil is what drives the high costs of oil production.[1]

"Two thirds of the world's oil reservoirs are heavy oil that is 'stuck' and has to be heated to get it out of the ground," said Clemens Pohl, business development manager for the Photonic Measurement Division of Agilent (Palo Alto, CA). "In a reservoir you might have several injection wells pumping in pressurized hot steam (200ºC to 300°C). Steam heats and liquefies the oil, which floats up to the production well and is pumped out. The key is to know where to inject the steam, the required flow volume per zone, and whether any cold-water breakthrough is cooling down the heated oil."

This is where optical sensors come in. By providing continuous multipoint pressure and temperature data, oil providers can better optimize well production and, theoretically, increase output and reduce costs. Optical components offer key advantages over electromechanical components in the field, including longer lifetimes, greater accuracy, lower cost, and the ability to withstand the often hot and wet conditions found in a production or injection well. This last feature alone opens up whole new oil-discovery and management applications such as towed arrays and sea-bottom monitoring systems.

"Offshore, when looking for reserves or trying to figure out what is going on in a field, they tow 16 to 20 cables with electromechanical sensors behind a boat and fire off an air gun to get pictures of what is going on underwater. The cables are very large, the risk of damage is high, and the cost is very expensive-$500,000 to $1 million a day to operate," said Pat Edsell, president and CEO of NP Photonics (Tucson, AZ), supplier of single-frequency fiber lasers (1550 nm, less than 3 kHz linewidth) for platform-, pipeline-, and boat-based monitoring systems. "So people are working to develop all-optical towed arrays where the only things in the water are passive devices. Same with sea-bottom monitoring; the goal is to put a grid of optical fibers and sensors on the ocean floor to cover an entire reservoir (10 to 20 wells) and monitor the reservoir on a real-time basis. With this kind of active monitoring, people in the oil industry believe they can double the amount of reserves that are recovered."

Intelligent wells

For years the conventional approach to monitoring production wells has been to use a "slick line" with several electromechanical sensors and drop the line every 10 meters to create a profile of the well and its contents. But advances in optical technologies-including multipoint fiberoptic sensors and interferometric flow controls-are enabling the oil industry to take a more "intelligent" approach to well management. For example, Weatherford's initial optical product was a single-point optical pressure sensor that utilizes Bragg gratings operating at 1550 nm; today the company also sells a distributed temperature sensor and a multiphase in-well optical interferometric flow meter that measures the flow and constituency of the fluids at strategic points. Other optical pressure- and temperature-sensing technologies include evanescent field, fluorescence, intensity modulated, magneto-optic, and polarization.

"The ultimate is in-well seismic, which gives you an acoustic 'snapshot' of reservoirs in real time as they are being depleted," Sanders said. "Until recently we placed seismic systems on the surface, set off an acoustic charge, then measured the acoustic signal. But there is a lot of distortion with this approach. Permanently positioning optical sensors within the well and doing cross-well tomography is much more powerful, although this is in the early stages."

Nonlinear distributed temperature sensing (DTS) is proving to be one of the most attractive choices, especially for downhole monitoring. In a typical installation, a DTS system is located in the instrument area of the platform or subsea control module (no active components go downhole). A hydrogen-tolerant cable is then placed down inside the production tubing, and a passive optical system featuring a broadband light source with a tunable filter is lowered into the hole (see Fig. 2, p. 77). Light (1064 to 1550 nm) is then transmitted down the cable, with the resulting reflection spectrum detailing changes in pressure and temperature data inside the well.

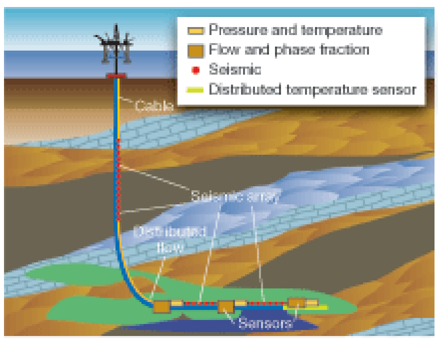

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FIGURE 2. In a typical downhole installation, a surface instrument containing all the active optical components and related computer and communications equipment is located in the instrument area of the platform or subsea control module. A hydrogen-tolerant cable is then placed down the production tubing, and a passive optical system featuring a broadband light source and a tunable filter is lowered into the hole.

Agilent is looking to capitalize on the growing interest in DTS via its new Fiber Sensing business segment combining its expertise in photonic-test and optical-time-domain-reflectometry technologies with a lower-cost plug-and-play approach. Combining standard 1064 nm diode lasers in an integrated "optoelectronic building block" eliminates the need for cooling.

"The hermetically sealed package is filled with inert gas, which protects the critical components so they can withstand shocks, vibration, and temperature changes," said Pohl. "So there are fewer components, fewer reasons for failure, and long-term stability. The oil industry is most interested in long-term comparable information, so we focused our efforts on extended operating conditions, low power consumption, reliability, and ruggedness."

Sabeus (Calabasas, CA) is taking a slightly different approach with its interferometric optical sensor system, using distributed-feedback diode lasers and a proprietary multivariable control system that improves the laser's frequency stability and reduces the phase noise, according to the company. "We produce fiberoptic pressure and temperature-monitoring systems for in-well deployment that enhance extraction from existing wells by providing the real-time data on downhole conditions that allow operators to make efficient decisions concerning steam injection, water flood, or CO_2 injection," said Al Garden, vice president of operations at Sabeus. "Real-time monitoring allows maximum reservoir exploitation while minimizing the risk of destabilizing the formation."

Distributed temperature sensing is also being used to optimize the electrical power grid in times of stress (see "Distributed temperature sensors find 'missing' power," p. 78).

REFERENCE

1. T. Knott, "Listening with Light," www.OilOnline.com, April 2003.

Distributed temperature sensors find 'missing' power

Whether due to global warming, cyclical weather patterns, or a combination thereof, 2006 saw record temperatures (highs and lows) around the world-a growing trend so far this decade. Peak usage of electronic appliances (air conditioners/heaters) can put significant stress on the electronic power grid in major metropolitan areas and entire regions.

Optical sensing systems are beginning to play an important role in enabling service providers to better manage the flow of electricity in peak usage situations. Distributed temperature sensing can provide continuous monitoring of high-power cable temperatures-detecting hot spots, delivering operational status, and providing power-circuit rating data to avert potential outages by ensuring the cables do not exceed the maximum allowable temperatures. The sensing fiber is either embedded in the power cable or deployed along the outside of the cable. It is intrinsically immune to electromagnetic interference and provides reliable temperature measurements.

"Power outages are due to the capacity of the power cables and the utility providers are limited by the temperature of the power cable," said Clemens Pohl, business development manager for the Photonic Measurement Division of Agilent (Palo Alto, CA). "They want to be able to consistently measure the cable temperature and increase the utilization as needed. This is especially important in the United States, China, India, and other countries where the power infrastructure is underdesigned."

Laser Focus World September, 2006
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