Fiber-Optic Sensors for the Exploration of Oil and Gas

Tsutomu Yamate
Schlumberger K.K., 2-2-1 Fuchinobe Sagamihara, Kanagawa, 229-0006 JAPAN
Phone: +81 42 759 2111, Fax: + 81 42 759 5398, Email: yamate1@slb.com

Abstract
Fiber-optic sensors for exploration for oil and gas will be reviewed. Technical superiority with high-reliability and cost-effectiveness is the key to success for expanding oil field applications.

Keywords: Oilfield, Spectroscopy, Downhole Fluid Analysis, DTS

Introduction

A large variety of sensors are used in the oil service industry for the exploration for and development of oil and gas. These sensors should operate under severe conditions of high pressure, up to 20,000 psi [1 atmospheric pressure = 14.7 psi], and high temperature, up to 175 degC. Owing to exploration activity in increasingly deeper wells, sensors that can function in higher-temperature and other hostile environments are required. Fiber-optic technology is a key enabler with its higher temperature capacity, multiplexing and distributed sensing capability, and small space requirements to meet these demanding applications. In this paper, fiber-optic sensors for the exploration of oil and gas will be reviewed.

Downhole optical spectroscopy[1]

Understanding crude oil composition early in a development process helps optimize resource exploitation. Such information is now available from a fluid analyzer using data from a formation dynamic tester tool to determine formation properties in open holes (Figure 1). Fluid analysis provides real-time information to optimize fluid sampling based on the measured in-situ composition. An absorption spectrometer and a fluorescence and gas detector are used. Downhole fluid is introduced into the flowline through the formation probe, and optical sensors analyze the fluid in the flowline. Figure 2 shows the fluid analysis spectrometer. The light path passes through a flowline into a series of optical filters to detect absorption through a spectral distributor. The light source for the spectrometer is a tungsten halogen lamp. Light from the lamp is split into two separate paths, the source path and the measure path, with shutters. The source path, which provides a reference measurement, routes the light directly from the lamp to the spectral distributor. The distributor and optical paths are composed of fiber bundles. The measure path routes the light from the lamp through the fluid stream in the flowline and to the spectral distributor, where it recombines with the source path. The absorption cell is constructed with thick sapphire windows to withstand up to 20,000 psi of flowline pressure. All the optical sensors and electronics have been designed to meet the extreme environmental specifications and function at temperatures up to 175 degC.

Figure 1. The formation tester tool in single-prove module

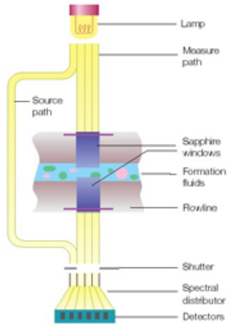

Figure 2. Fluid analysis spectrometer

Figure 3 shows an example of downhole composition analysis with fluid analysis. The change in fluid composition with depth in a thick sand reservoir yields information that is difficult to obtain with any other technique. By combining this information with fluid density data from a pressure gradient survey, a superior evaluation of fluid in place is obtained.

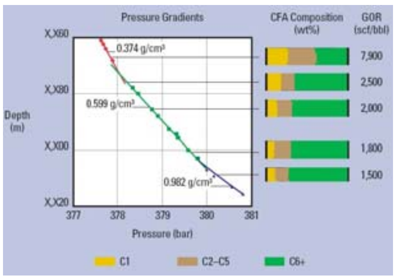

Figure 3. Fluid analysis to provide fluid composition at each depth

Distributed Temperature sensor[2], [3]

A fiber-optic sensing system offers many advantages for monitoring fluid movement in the larger reservoir-scale level through its capabilities in distributed sensing, multiplexing, and high-temperature operations. A fiber-optic distributed temperature sensor (DTS) is the most popular fiber-optic sensor for downhole applications.

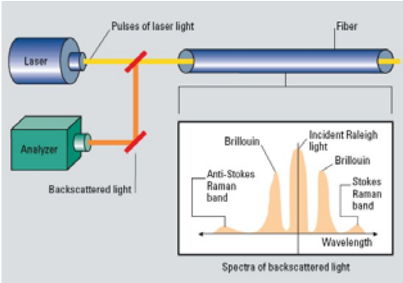

Figure 4. Fiber-optic distributed temperature sensor principle

Figure 4 shows the principle of fiber-optic DTS. A fiber-optic line functions as both the sensing element and the data-transmission medium. The fiber-optic DTS system uses a laser to send pulses of light through a directional optical coupler and down the fiber. Light from each pulse is scattered by several mechanisms, including Raman scattering. The ratio of the Stokes Raman bands to the anti-Stokes Raman bands is directly proportional to the temperature of the length of fiber from which it is generated. By using time sampling and applying a constant speed for light, distances along the fiber can be estimated. Fiber-optic DTS can provide a continuous temperature profile along the entire length of an optical fiber.

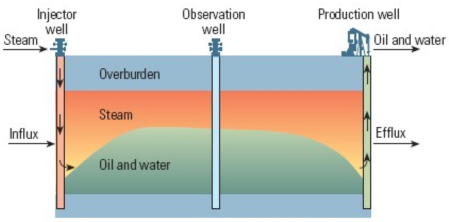

Figure 5a. Ideal scenarios for movement of injected steam

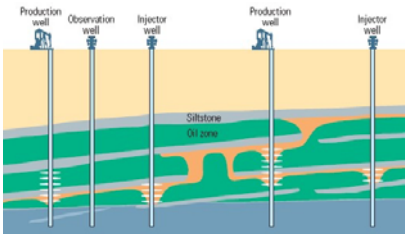

Figure 5b. Realistic scenarios for movement of injected steam

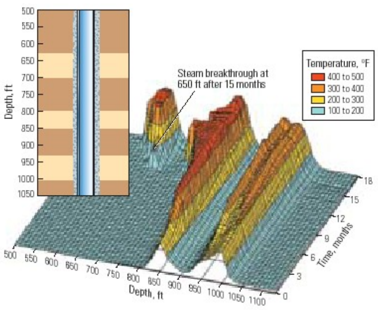

Figure. 6. Fiber-optic temperature monitoring in steamflood observation well

One example of fiber-optic DTS application is temperature profile monitoring for a steam-injected heavy-oil recovery system. Steam is injected into the heavy-oil reservoir to reduce the viscosity of oil, resulting in mobilizing viscous oils. Steam temperature downhole can exceed 250 degC.

Figure 5a shows an ideal case of steam flow. Steam rises from perforations in the injection well and reaches a barrier followed by lateral spreading and breakout at the producing wells. Figure 5b shows a more likely case of steam flow through unpredictable paths from reservoir and borehole complexities.

Figure 6 is an example of fiber-optic temperature monitoring in a steamflood observation well. Steam was injected into three sands, and by the beginning of this monitoring period had reached the lower two sands at the location of the observation well. The fiber-optic DTS detected steam breakthrough in the top sand after 15 months.

Conclusions

Downhole optical spectroscopy provides in-situ downhole fluid analysis and gives an improved evaluation of the fluid in place. Fiber-optic DTS makes a key role of temperature profile monitoring of steam injection well. There are other commercial products based on optical fiber sensors. For example, optical probes for multiphase flows[4] and distributed dynamic strain measurement with Fiber Bragg gratings or integrity monitoring of risers[5]. Technical superiority with high reliability and cost-effectiveness is the key to success for oil field applications.

References

1. S. Betancourt, G. Fujisawa, O. C. Mullins, A.Carnegie, C. Dong, A. Kurkjian, K. O. Eriksen, M. Haggag, A. R. Jaramillo and H. Terabayashi, “Analyzing hydrocarbon downhole,” Oilfield Review Autumn, 54-61 (2003).
2. C. Curtis, R. Kopper, E. Decoster, A. Guzmán-Garcia, C. Huggins, L. Knauer, M. Minner, N. Kupsch, L. Linares, H. Rough and M. Waite, “Heavy-Oil Reservoirs,” Oilfield Review Autumn, 30-51 (2002).
3. Sensa Fiber Optic Monitoring System, www.slb.com/sensa
4. R. Schroeder, R. Ramos, T. Yamate and E. Udd, [Handbook of Optical Fiber Sensing Technology], John Wiley & Sons, 671 – 686 (2002)
5. Subsea Surveillance, http://www.slb.com//content/services/subsea/surveillance/index.asp