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Permanent Reservoir Monitoring Using Fiber Optic Distributed Temperature Measurements

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Topics

- How the measurement works
- How the system is installed in the reservoir
- Steam Flood and SAGD
- Producing Wells
- Water Injectors
- Gas lift valves
- Conclusions
The distributed temperature measurement

Laser

10 ns Pulses of Laser Light

Fiber

Back-Scattered Light

Analyser

Spectrum of Back-Scattered Light

Incident Raleigh Light

Brillouin

Anti-Stokes Raman Band

Stokes Raman Band

Wavelength
The DTS temperature calculation

\[
\frac{1}{\text{Temperature}} = \frac{1}{\text{Tref}} - \frac{\ln(\text{Stokes/Anti-Stokes})}{\text{Sens}}
\]

Constants

\textbf{Temperature} = Calculated temperature °K
\textbf{Tref} = Reference Coil Temperature °K
\textbf{Sens} = Temperature Sensitivity
Temperature installation options

Single ended

Double ended

Check Valve

Hydraulic Wet-connect

Turn around Sub
Sand control systems

Control line for fiber installation can be installed on the outside of sand-screens.
Steam Flood and SAGD Monitoring
Bi-weekly monitoring of steam observation wells
Showing steam front breakthrough in upper reservoir

Steam Breakthrough @ 900ft after 15 months

Permeable Zones
Steam assisted gravity drainage (SAGD)
Upper steam injection well and lower producer
SAGD temperature monitoring
Showing incomplete steam chamber development

- Injector Temperature
- Producer Steam Soak
- SAGD Steam Chamber
- Geothermal

Temperature (Deg C) vs. Depth (m)
Value

- “Slick-line” or pre-installed monitoring of steam observation wells enables the steam flood front to be tracked over time.
- Permanently installed SAGD producer monitoring allows early identification of problems and confirmation of the steam chamber development.
Producing Wells
Flow rate and the temperature profile
(300 days of production)
Well bore heat transmission – H.J Ramey Mobil Oil  
(SPE 096, 1961)

\[ f(t) = -\ln\left(\frac{r_{ce}}{2(\kappa t)^{1/2}}\right) - 0.290 \]

\[ A = 1.66Q\rho_f C_f f(t) \]

\[ T(z,t) = T_{ge} - g_G z + g_G A + (-g_G A)e^{-\frac{z}{A}} \]

Where:

- \( A \) = Relaxation Distance (ft)
- \( C_f \) = Fluid specific heat (Btu/lb. Deg F)
- \( \kappa \) = Thermal diffusivity (sq ft/day)
- \( t \) = time (days)
- \( Q \) = Flow rate (bbl/d)
- \( \rho_f \) = Fluid density (gm/cc)
- \( r_{ce} \) = Casing outer radius (ft)
Upward flow – from 2 reservoirs
(Lower 500 bbl/d, Upper 500 bbl/d)

\[
\frac{\text{Lower flow}}{\text{Total flow}} = \frac{T_t - T_g}{T_l - T_g}
\]
ESP multi-zone reservoir – SPE 92962
Geothermal Gradient

ESP oil producer well start-up
ESP oil producer well start-up

Warm-up with time

Significant inflows

Geothermal

Well Start-up

Start-up +2 Days

Start-up +4 Days

Start-up +6 Days

Temperature (Deg C)

Resistivity
Thermal analysis March 6th 1,775 bbl/d
(permeability fit)
DTS estimated reservoir pressures

March 6

November 8
November shut-in

Cross flow

Initial Flow Profile
Geothermal
8 Months Production
Shut-in after 8 months
Value

- Installed with the completion – shifts major costs to CAPEX and reduces the risk of monitoring with PLT

- Allowed the operator to save on a Y tool, reduce casing size – and monitor regularly the well

- Identified zones where production changes over time - confirming pressure support - and locating isolated sand lenses
Example - a WAG tertiary recovery project
CO$_2$/Water Injector

20/11/2003 Water Injection
19/11/2003 Gas Injection
Geothermal

Reservoir
Water Injection
and shut-in data

Major Inflow

Minor Inflows
Breakthrough of CO$_2$ WAG flood

Temperature (Deg F)

Depth (ft)

Annulus Liquid Level

ESP

Increase in GOR

Flowing zones

26/06/2003
21/09/2003
Breakthrough of CO₂ WAG flood #3

Increased cooling at the upper perforations as CO₂ and oil break through

Zone stops flowing when water injection started
Breakthrough of CO$_2$ WAG flood #4

Increased cooling at the upper perforations as CO$_2$ and oil break through
6 Spot WAG injection pattern

- Down-dip Producer
- WAG Injector
- Up-dip Producer
Value

- Installed with the completion – shifts major costs to CAPEX – wells cannot be logged with a PLT

- Identified zones where the WAG flood breaks through - confirming WAG support - and flow through the reservoir

- Confirms reservoir model and allows options to be tried

- Monitor changes with time as the WAG flood progresses
Water Injector Wells
Thermal model of 10 day shut-in

Note that reservoir warm-back is a function of permeability.
Horizontal open hole injector - SPE 84379

Gas lift mandrels (in producers)

3 ½ inch production tubing

¼ inch control line containing fiber

2 7/8th inch stinger

6 ¼ inch open hole

Shuaiba Formation
2 weeks injection + 24 hours shut-in
Hot slug created at the tubing shoe

Hot slug of water in the tubing
Well shut-in

Temperature (Deg F)

Depth (ft)
Injection is switched on @ 4,500 bwpd
Hot slug at tubing shoe is tracked along the reservoir using DTS
Hot slug velocity injection profile

Inflow Distribution

Distribution March
Distribution October

Casing Shoe

Depth (ft)

6000.00 7000.00 8000.00 9000.00 10000.00 11000.00
Value

- Installed with the completion – shifts major costs to CAPEX – costs less than 2 coiled tubing PLT’s
- Allowed the operator to monitor the well regularly to ensure the long reservoir interval was completely flooded – thus justifying the completion
- Injection profile can be observe over time, with little cost or risk, to monitor changes
Gas Lift Valves
Gas Lift Valve Monitoring

![Graph showing depth, temperature, and operating GLV data with dates and times labeled on the graph.]

- Depth [ft]
- Temperature [Deg F]
- Operating GLV

Geothermal

GLV’s

Dates and times indicated on the graph:
- 15/05/2005 13:17
- 15/05/2005 12:51
- 15/05/2005 12:25
- 15/05/2005 11:59
- 15/05/2005 11:33
Horizontal open hole producer start-up

- Geothermal
- Well flowing
- GLV @ 3600ft operating
- GLV @ 6200ft operating
- Open hole

Graph showing depth (ft) vs. temperature (Deg C) with data points for different dates and times, indicating start-up dates:
- 25/08/2002 22:01:08
- 26/08/2002 10:29:08
- 28/08/2002 02:45:42
Value

- Additional data if installed with the completion
- Can also be run as a slick-line intervention service
- Identifies operating GLV’s and tubing gas leaks
- Enables rapid identification of problem valves reducing service company standby costs and optimising production
Conclusions

- Fiber optic temperature monitoring was originally installed in steam flood wells.

- It can monitor flow in producers – and even horizontal wells under certain conditions.

- It can also be used to monitor water injectors following a shut-in.

- An additional benefit is GLV monitoring.

- The system is ideally suited for wells where conventional PLT monitoring is not possible.