



Weatherford

Joint Development Project Delivers Step Change to Drilling Efficiency by Breaking Temperature Barriers in the Gulf of Thailand

2015 SPE Thailand E&P Annual Awards, Document Submission

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And

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1.0 Innovative Features

Geothermal gradients from the producing reservoirs of the major Pattani Basin gas fields can be as high as 3.2°F/100 ft. Chevron Thailand Exploration & Production, LTD (CTEP) operates numerous fields with deep gas reserves; some with reservoir sands below 11,000 ft. TVDSS. The need for drilling into these high-temperature reservoirs has increased dramatically in recent years and is expected to continue this trend into the foreseeable future.

To reach these reservoirs, CTEP needs reliable Measurement While Drilling (MWD) and Logging While Drilling (LWD) tools that can withstand these harsh drilling environments. High formation temperatures are exacerbated by aggressive drilling practices, such as high RPM and very high penetration rates. It is these aggressive drilling practices which contribute to CTEP's top quartile drilling performance. Extreme HPHT LWD tools were needed to economically reach these deep gas reserves while maintaining the high well count and the current level of drilling efficiency.

Most commercial MWD/LWD tools are rated to 175°C (347°F), whereas circulating temperatures in CTEP's HT wells can exceed 200 °C (392 °F). When the circulating temperature reaches the limit, the options are:

- Continue drilling until the tool temperature reaches 174°C (345°F), trip out of the hole, lay down the MWD tools, run back in and drill "blind" to TD. This increases the well time and drilling is done without real-time well bore position data and petrophysical data as shown in Figure 1.
- Continue drilling to TD using drilling practices which mitigate temperature. i.e. Reduce drilling parameters and penetration rates and increase circulating time, as shown in Figure 2. This increases well construction time and is not always successful. LWD tools are exposed to higher temperature for a longer period; reducing life expectancy of the tools and significantly increasing the chance of a tool failure.
- Continue drilling until the tool temperature reaches 174°C (345°F), then call TD. This results in a missed objective and lost reserves.

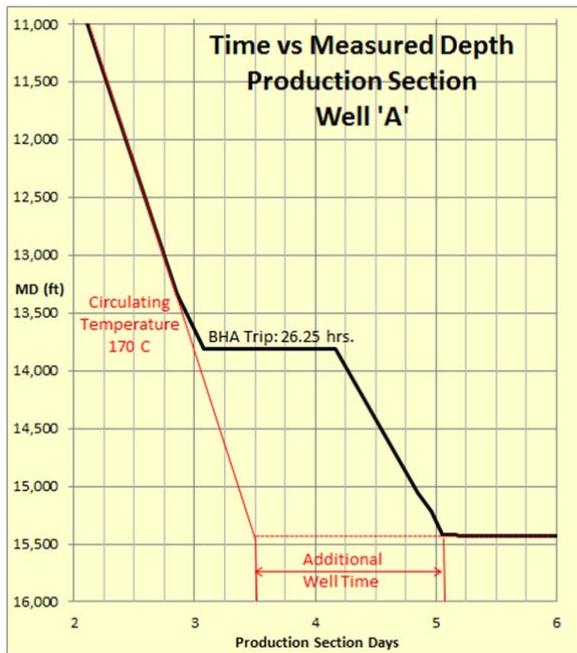


Figure 1: Well 'A' Time vs Depth

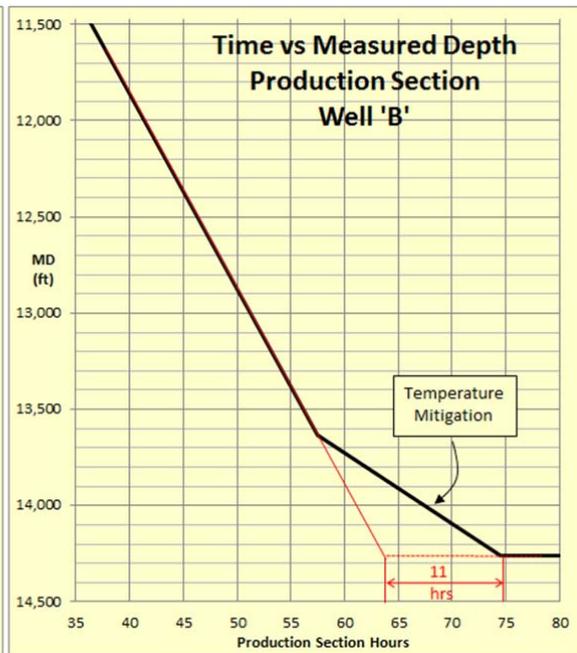


Figure 2: Well 'B' Time vs Depth

In May 2014, CTEP and Weatherford entered into a two phase Joint Development Agreement (JDA) to collaboratively develop High Temperature MWD & LWD sensors, operationally rated for 200 °C (392 °F) with a survival temperature of 210°C (410°F) for four hours. The CTEP's business case justification for the joint development was rig time savings, ranging between 6 and 24 hours per well, depending on the well depth.

The first phase of the project had a nine month timeline with four major Milestones and developed the following sensors:

- 1.) Mud Pulse Telemetry
- 2.) Directional Sensors
- 3.) Thermal Neutron Porosity
- 4.) Pressure While Drilling (PWD)
- 5.) Gamma Ray

A total of 11 high temperature Printed Circuit Boards (PCBs) were engineered, built (Milestone 1) and tested at Weatherford's R&D facility in Houston with support from the Petrophysics specialist sourced from Chevron's Energy Technology Center (ETC).

In order to handle the hostile downhole drilling environment, sensors and boards were rigorously temperature and vibration tested before they were deployed to Thailand for field testing.

All 11 boards were thermally qualified (Milestone 2) in the R&D ovens at 205°C (401°F) for 250 hours and tested to 210°C (410°F) and -10°C (14°F) during the temperature cycles. All the electronic boards were then vibration tested at 15 G random frequency vibration at 200°C (392°F) for a total of twelve (12) hours on each of the three axis' X, Y and Z (Milestone 3). The boards continuously monitored throughout the duration of both the oven testing and thermal vibration qualification testing.

The first phase of the project was delivered on time and budget. Five prototype HT tools were mobilized to Thailand (Milestone 4) in January 2015 for extensive field trials.

After the successful development of the first phase of the project, CTEP's Decision Review Board approved the second phase of the joint development. Phase 2 will deliver Extreme High Temperature Density and Resistivity sensors. This will provide the full suite of LWD petrophysical data required by CTEP.

Phase 2 of the joint development was kicked off in March 2015. The first five prototype tools will undergo field trials in Q3 2016. The second phase of the joint development will eliminate the requirement to run the wireline triple combo log. CTEP's well factory system, drilling practices and the implementation of this new technology will maintain CTEP's position as the clear leader in drilling performance well into the future.

2.0 Thailand Industry Impact and Value

The deployment of these tools is a major step change in drilling efficiency in the Gulf of Thailand. It is possible to access the deep gas reserves with the same high level of drilling efficiency as the lower temperature wells. This will save millions of dollars in CAPEX well costs on future projects at the same time providing reliable Petrophysical data. Economics for the high temperature Pattani Basin gas fields are significantly increased due to the decreased drilling costs for the following reasons:

1. Previously uneconomical deep gas reserves can now be drilled and evaluated more cost effectively with the new generation extreme high temperature LWD tools. There is significant value in utilizing the existing infrastructure in areas which have deep gas potential.
2. New deep reserves could potentially be discovered in the Gulf of Thailand that are economically accessible with extreme high temperature tools.
3. The cost of evaluating a well that is drilled deeper than planned is significantly reduced if the drilling assembly does not need to be changed. In other words, the “exploration tail” on a development well becomes cost effective. A good example of this is a recent well drilled with the Phase 1 high temperature tool. The well was planned to TD at 11,482’ TVD. A decision was made to deepen the well to 11,566 ft TVD. A new sand was encountered in the deepened section. The circulating temperature at TD on this well was 193°C (379°F). The cost of discovering the new sand was an additional three hours of rig time.

Cost savings for deep gas wells is due to the high level of drilling efficiency that can be realized using the new generation of high temperature LWD tools. Figure 3 shows the production section penetration rates for CTEP’s top ten deepest three string wells. The wells shown in red were drilled with the Phase 1 Joint development tools.

Figure 4 shows days per well for the same ten wells. These are CTEP’s most challenging wells. The three fastest wells were drilled with the Joint Development tools.

On average, the cost savings per well is conservatively estimated to be 120,000 USD/well.

Cost savings is primarily dependent on the vertical depth of the well, penetration rate and rotary speed. For every 100 high temperature wells drilled in the Gulf of Thailand, on average, 12 million \$US in CAPEX will be realized through increased drilling efficiency and the elimination of wireline logs. This does not take into account the value of undiscovered or accelerated reserves.

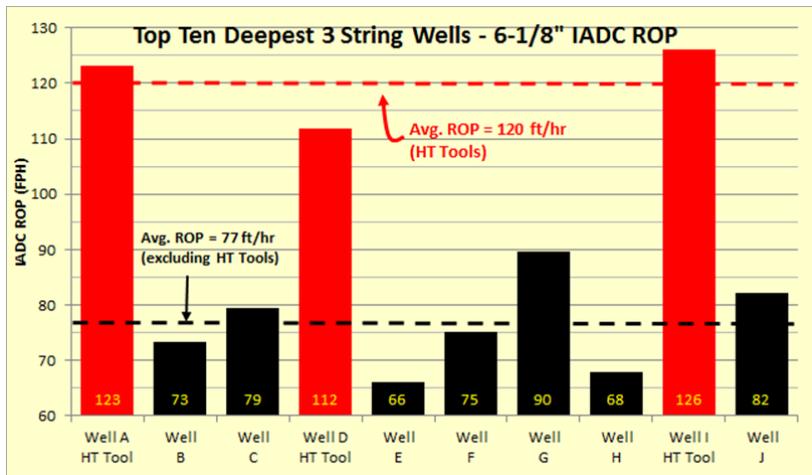


Figure 3: Penetration Rates, CTEP’s Deepest 3 String Wells

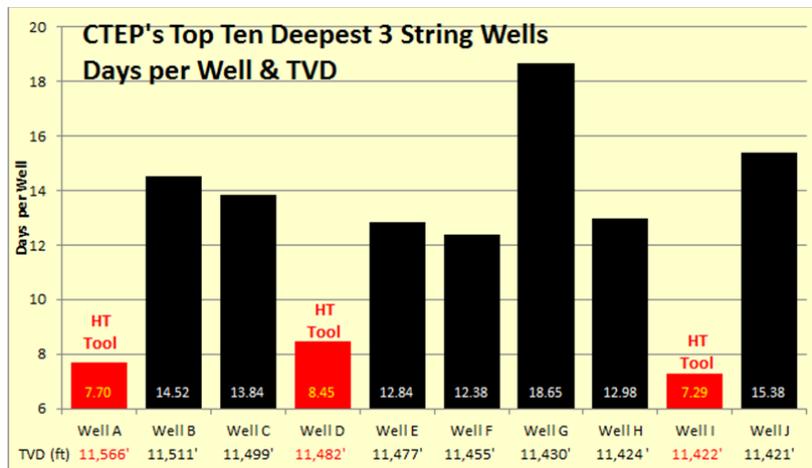


Figure 4: Well Times, CTEP’s Deepest 3 String Wells

It is very difficult to predict what ultimate value of this new technology will be in the coming years. CTEP has long term plans to drill many more wells in fields with deep gas and high temperatures. New fields could be discovered and new discoveries in existing fields could be made. Marginal or sub-economic resources move into reserves and production with reduced drilling costs. Current wellhead platforms may be brought back to production when considering the deep pay potential combined with not fully depleted existing pay.

Clearly, this technology will contribute to the Kingdom of Thailand’s economy by helping to ensure a long term, reliable supply of gas well into the future.

3.0 Why this Project should win the Award

The first phase of this project has been highly successful in saving drilling time and cost on high temperature wells. Five 200°C (392°F) rated LWD tools were delivered to Thailand in Q1 2015. To date, the highlights of the Phase 1 field trials include, but are not limited to, the following:

1. 22 wells drilled. No failures or service interrupts. 100% success rate to date.
2. The maximum circulating temperature while drilling was 195°C (383°F).
3. The maximum recorded temperature by the tools was 213°C (415°F).
4. 150,282 ft. (45,806 m) of production hole drilled without service interrupt.
5. CTEP's deepest 3-string Production well to date, 11,566 ft. TVD
6. 1,652 Operating hours without a failure.
7. CTEP's first well greater than 10,500' TVD drilled in less than 4 days: 10,552 ft. TVD in 3.88 days.
8. CTEP's fastest well deeper than 11,000' TVD: 11,316 ft. TVD in 5.31 days.
9. To date, tools have saved approximately \$4 million USD in drilling costs by eliminating bottom hole assembly (BHA) trips, gyro survey costs and have significantly increased drilling efficiency on high temperature wells.

The scatter plot on the right shows TVD vs days per well for the wells drilled with HT tools (red) and for historical Gulf of Thailand data (blue). The trend lines show the best fit curve for both data sets. When the Phase 2 Triple Combo tools are deployed in Q3 2016, there will be further improvement in the well times by eliminating the wireline logging run and all the problems associated with getting wireline logs to bottom in high temperature wells.

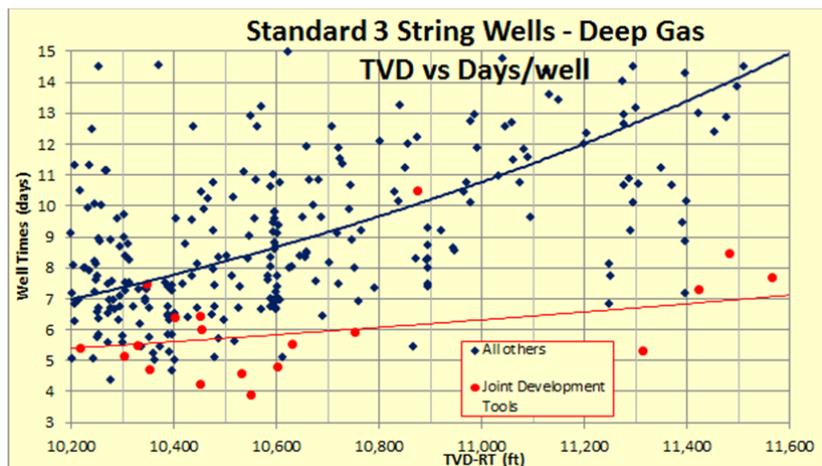


Figure 5: TVD vs Days per well

The tools have been successfully tested under very hostile drilling and temperature conditions. On one well, the tools were ran outside of their operating window. The HT LWD tool was used to make a wiper trip after wireline logs failed to reach TD. The tool was run in hole without breaking circulation. Close to bottom, circulation was initiated. A tool temperature of 212°C (414°F) was transmitted to the surface.

All of the sensors and batteries were operational except for the Neutron sensor. Further detailed analysis of the electronics showed that the Neutron tool had thermally shutdown at 212°C (414°F). The maximum temperature recorded for the run was 213°C (415°F). The Neutron sensor survived and was functioning normally after being cooled.

This is an extreme example that proves the tool is capable of operating under the most extreme environmental conditions that can be encountered in the Gulf of Thailand.

This project deserves to win the 2015 SPE Thailand E&P Award primarily for the following reasons:

1. Joint collaboration between a major operator and oil service company engineered, designed and implemented new technology specifically for creating value to Gulf of Thailand operations.
2. This new technology is a step change in drilling efficiency for high temperature Gulf of Thailand wells, improving the economics of accessing and producing deep reserves in the Gulf of Thailand.
3. The tools have operated under the most extreme and hostile environmental conditions and have proven to be very robust and reliable, while still delivering high quality directional and petrophysical data.
4. These tools have enhanced well site safety by eliminating unnecessary BHA trips and BHA handling.
5. This project has created a new industry standard for efficiently delivering high temperature wells in Thailand.
6. This joint development is a multi-discipline collaboration with input, support and expertise supplied from Drilling, Petrophysics, Earth Science, Petroleum Engineering, Legal and Finance.
7. Current wellhead platforms could be brought back into production when considering the deep pay potential combined with not fully depleted existing pay. Many wells have been abandoned for mechanical reasons or lack of compression. To drill for the remaining reserves alone would not be economical. But by combining these unproduced reserves with additional deep pay, wells will go from uneconomic to economic.
8. This project is beneficial to Thailand by contributing the Kingdom's energy security and future prosperity by economically accessing deep gas; moving marginal and sub-economic reserves into resources and production by increasing drilling efficiency.

4.0 Project Team

- Doug Ellis, Author, Drilling Engineer, CTEP Project Manager : SPE Member 4403966
- Steve McBride, Weatherford Thailand Country Manager: SPE Member 1675222
- Keith Ormston, CTEP Special Projects Team Leader, SPE Member 4497087
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- Marco Goense, CTEP Production Optimization Team Lead - Thailand: SPE Member 3010378