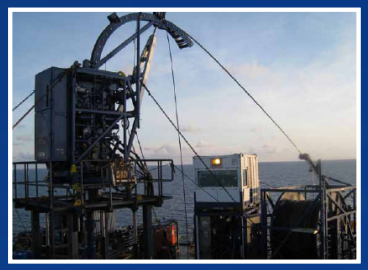
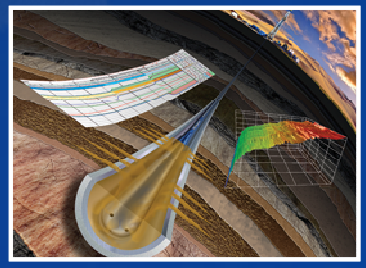
Wellbore Diagnostics & Evaluation Using Fiber-Optic Enabled Coiled Tubing

Leak Detection & Production Logging Case Studies







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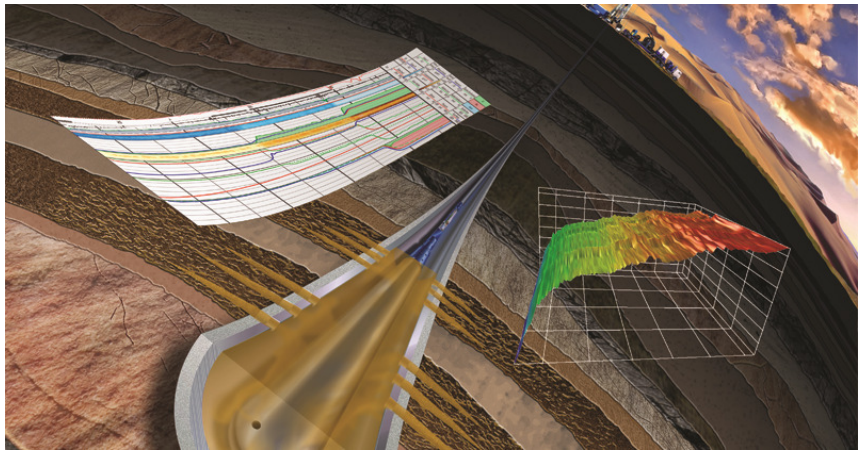
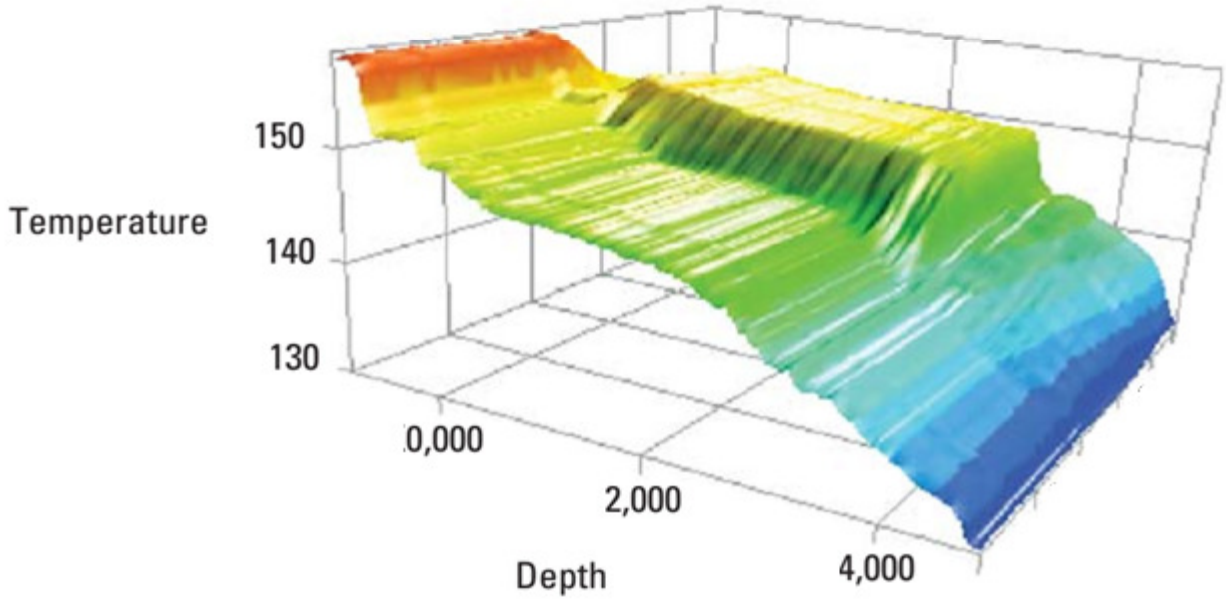
Agenda

- Technology & Theory
- Application of the principles
- Case Studies
  - Leak Detection
  - Flow Analysis
- Summary



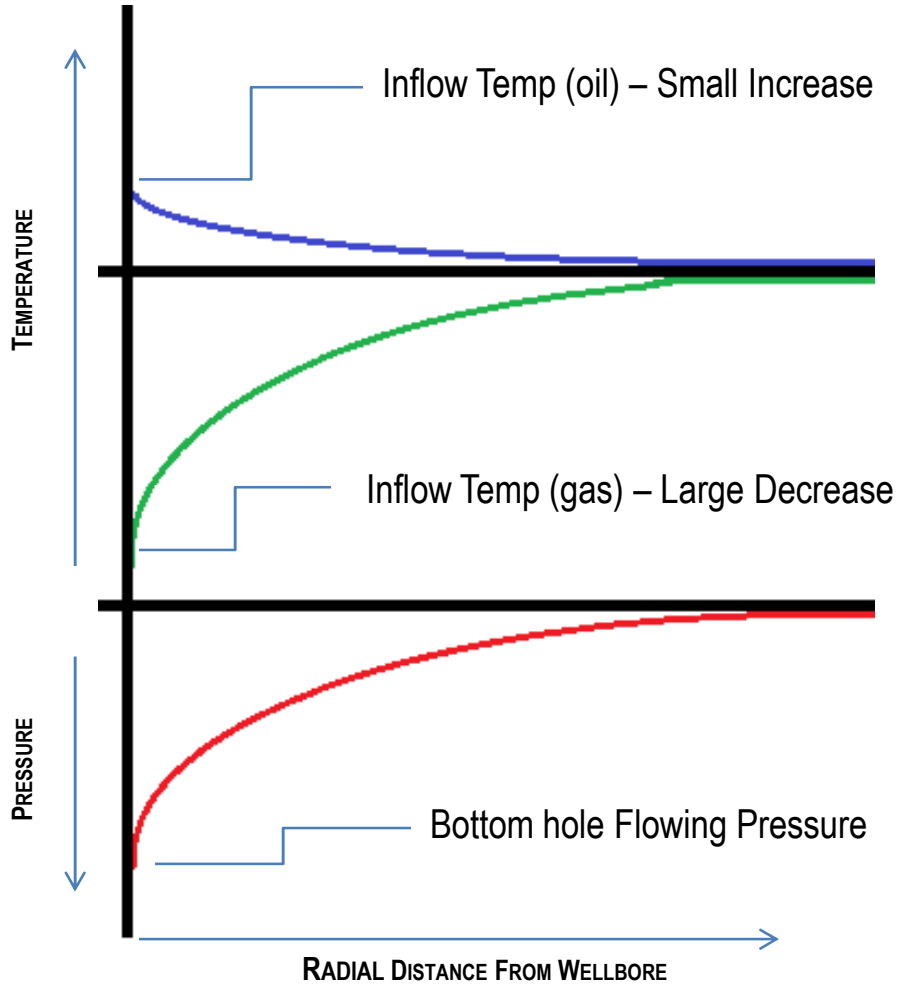
Distributive Temperature Sensing

- Fiber-optic enabled coiled tubing
- No moving parts, downhole electronics, external components, etc.
- Building a temperature profile of the entire wellbore over time
- Monitoring downhole temperature
- Interpretation of the temperature response allows correlation of the anomaly



Joule Thomson Effect

- Temperature of a liquid or gas changes as a function of its pressure (constant enthalpy)
- Temperature response of flowing fluid or gas allows interpretation of flow rates
- Important for interpretation in horizontal wellbores
- $\Delta T = \mu_{JT} \Delta P$



Applications of DTS

- Leak detection
- Flow analysis
  - Production
  - Injection
- Water detection
- Gas lift monitoring
- Matrix acidizing
- SAGD / Steam chamber monitoring
  - Well integrity

DTS Leak Detection

- Leaks are often very difficult to spot
  - Temperature alone is by no means the only/best solution
- To identify a leak, a temperature anomaly needs to be created
  - Typically by flowing fluid through the leak
- The larger the anomaly the better
  - High pressure drop with gas
  - Water/oil has smaller JT effect
  - Large leaks have smaller pressure drops across them

Case Study 1: Leak Detection

- Horizontal +/- 3500m
- Multi-stage open hole completion with debris subs and stage tool
- Multiple ball activated seats
- During fracturing operation
  - Drop ball to open the next sleeve
  - No pressure response
  - Drop a second ball
  - Still no pressure response
  - Attempt to pressure up the wellbore with no success
  - Suspected stage tool open/leaking

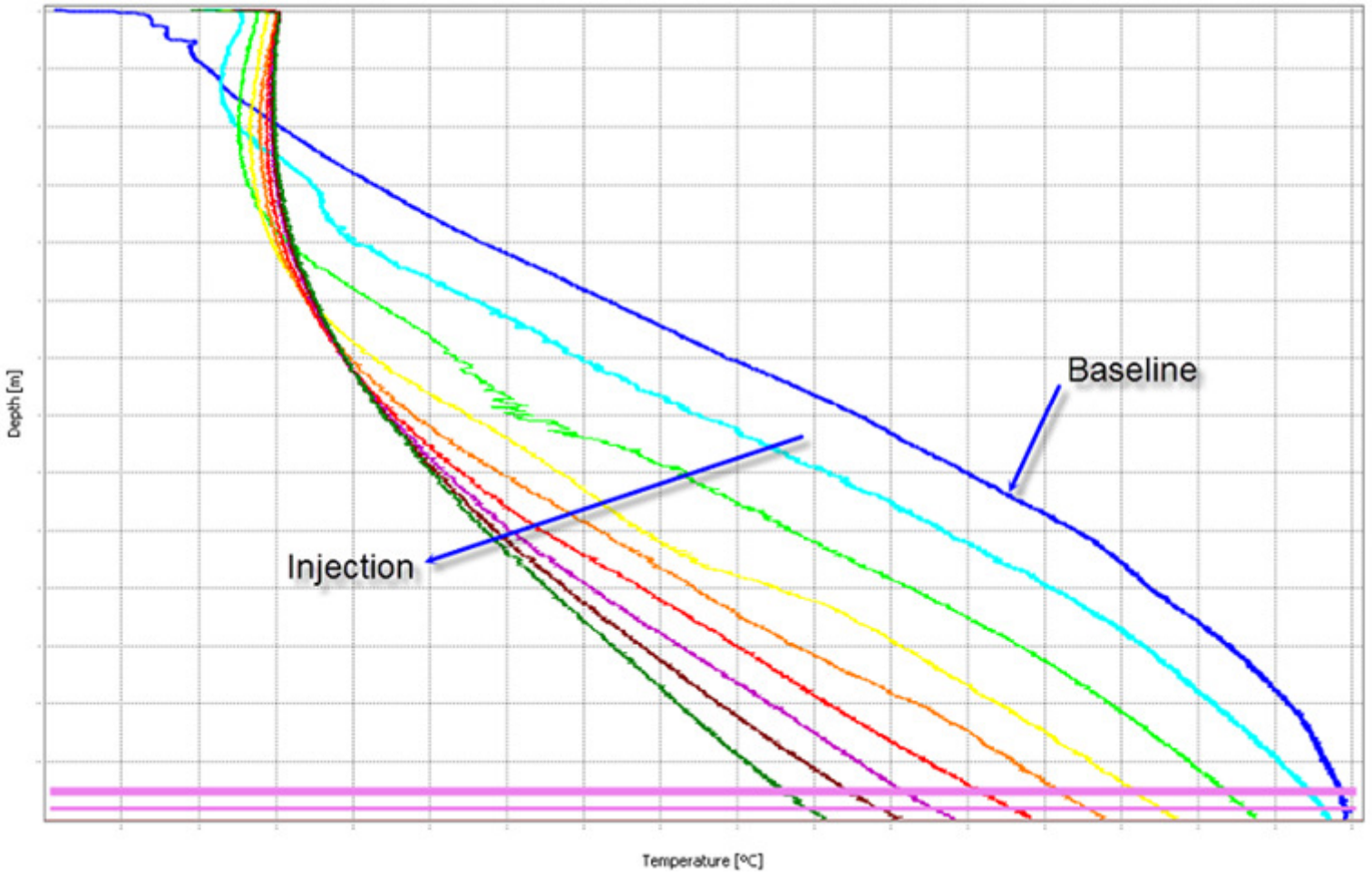
Case Study 1: Proposed Solution

- Run 1: Venturi & DTS
  - Attempt to capture the 2 unseated balls
  - Inject fluid and perform DTS log
  - Identify any temperature anomalies

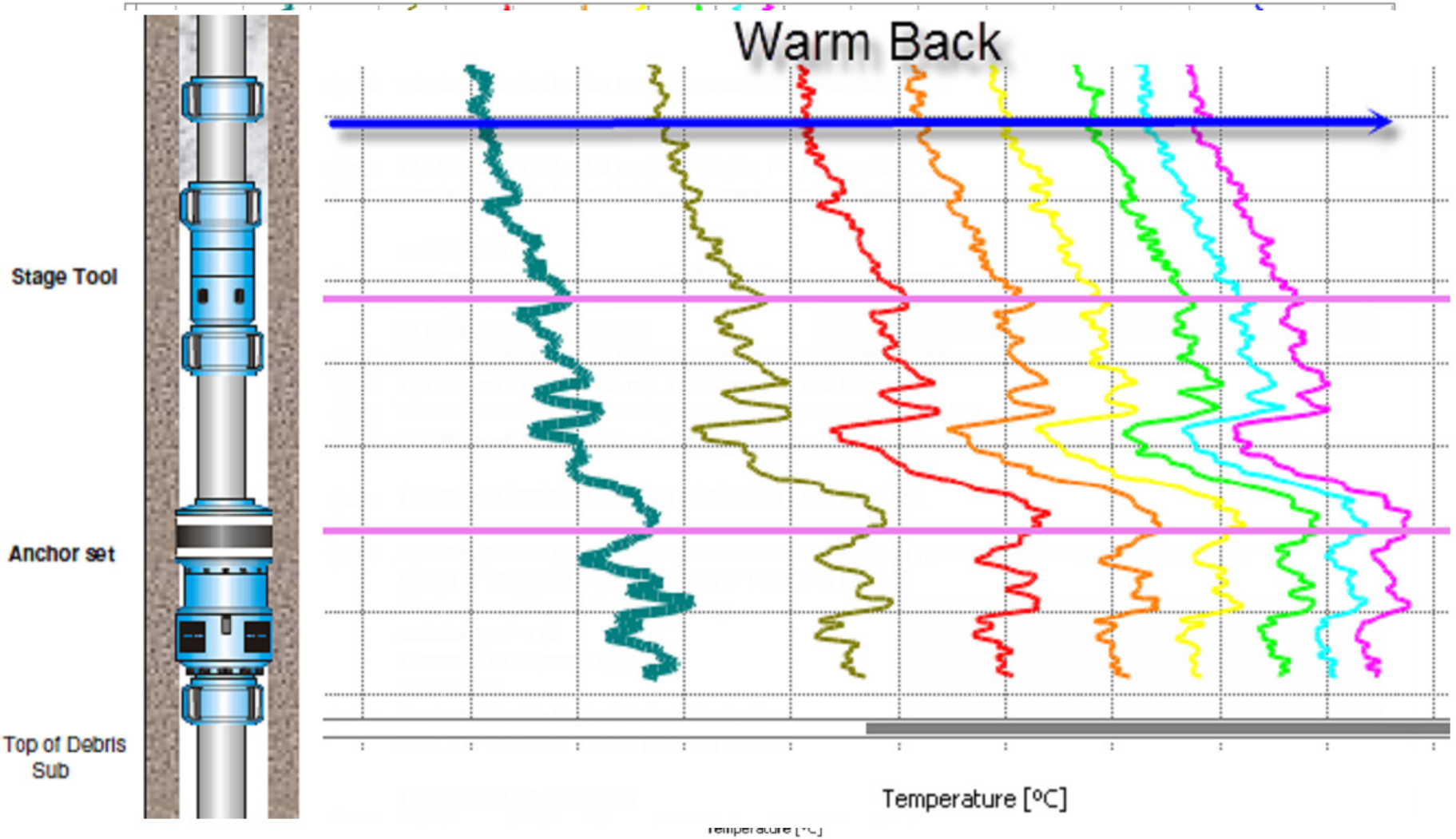
- Run 2: Manually confirm stage tool is closed
  - Eliminate possibility of leaks through stage tool

- Run 3: DTS
  - Manually seal the ball seat that would not pressure up (seat # 9)
  - Inject fluid and perform DTS log
  - Identify any temperature anomalies

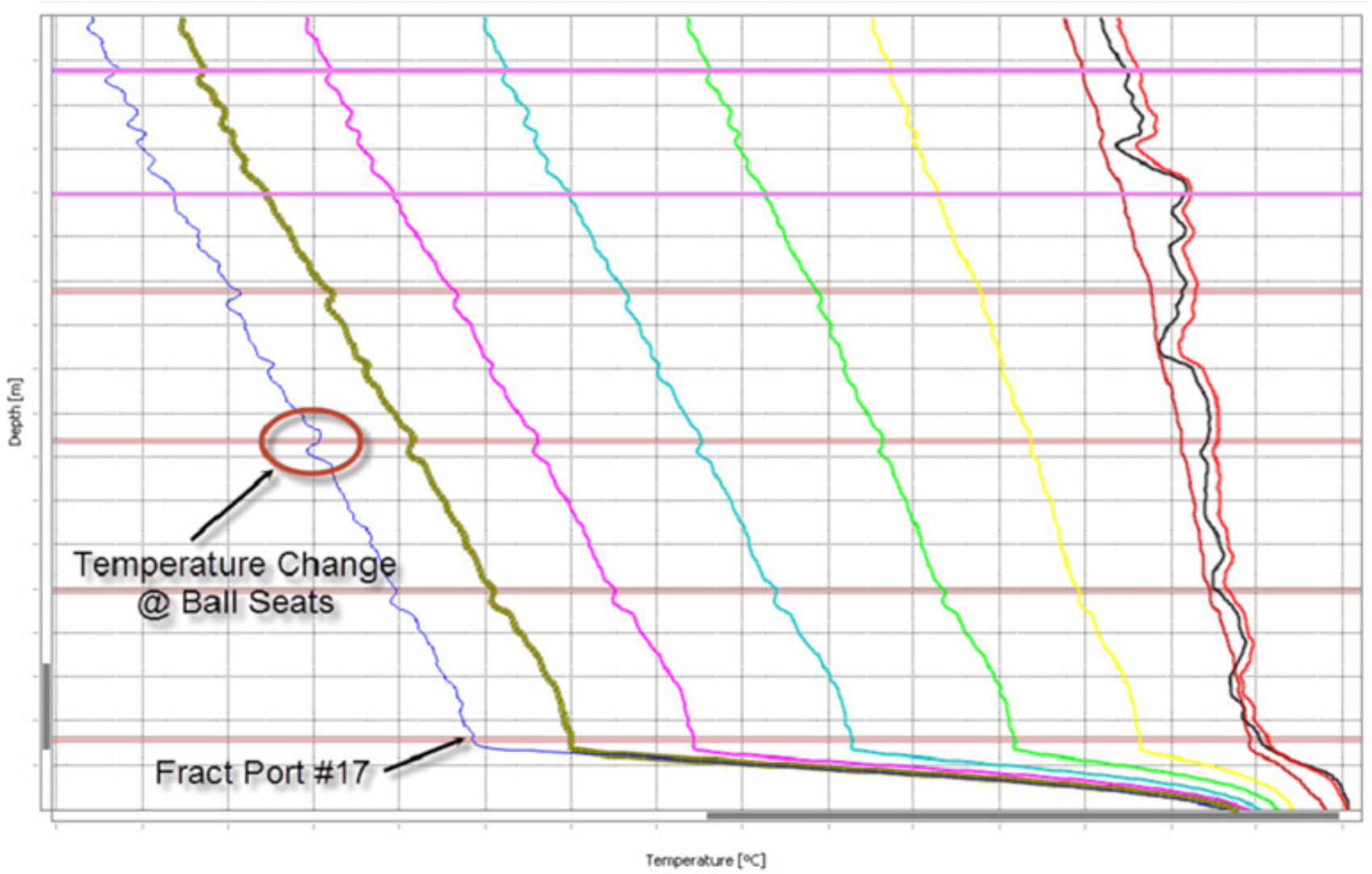
Case Study 1: Run #1 – Injection



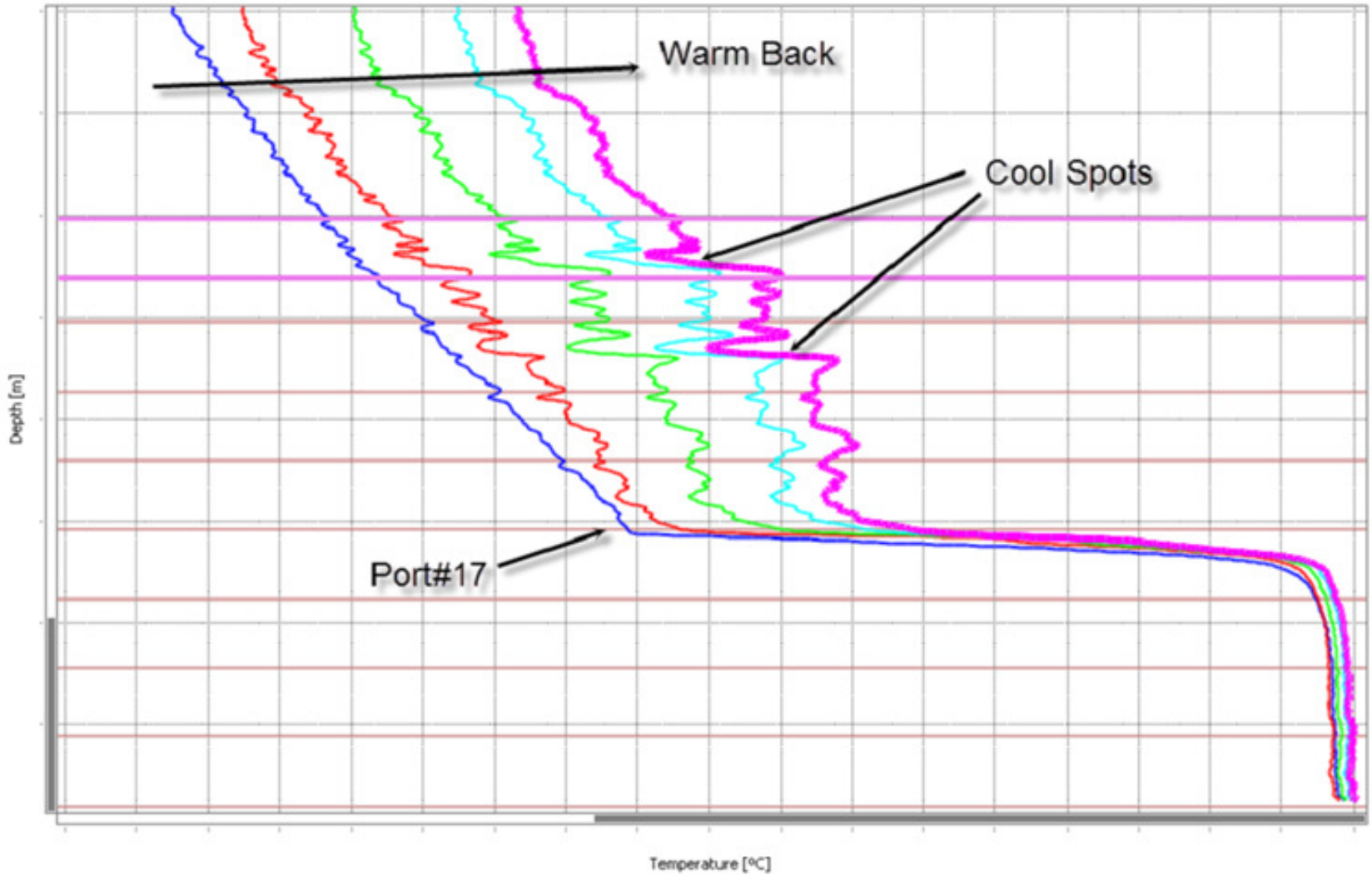
Case Study 1: Run #1 – Warm Back



Case Study 1: Run #3 - Injection



Case Study 1: Run #3 – Warm Back

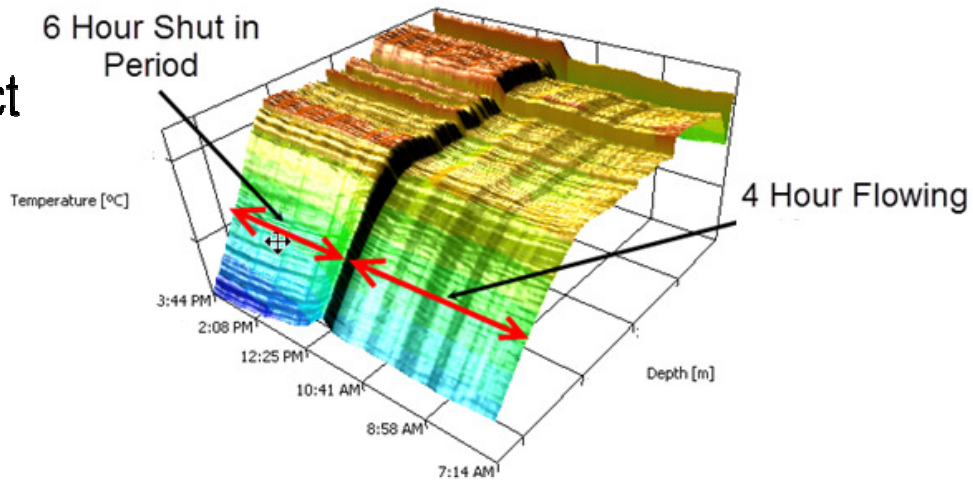


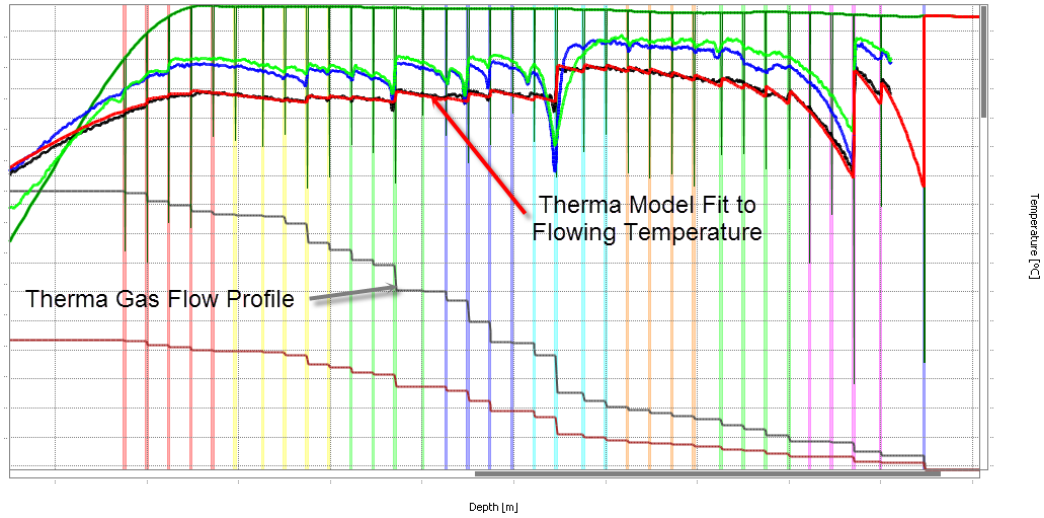
Case Study 1: Conclusions

- The first DTS measurement indicated cooling behind the completion (between stage tool and anchor packer)
  - Was not sufficient to indicate a leak
  - Less thermal conductivity between stage tool and formation
- The second DTS measurement indicated a large temperature change at frac port #17
  - Indicated the all of fluid was flowing through this leak instead of down the well
- Allows informed decision for the remaining well program

Flow Analysis - Production

- Horizontal Gas Well
- Relies on the Joule-Thomson effect
- $\Delta T = \mu_{JT} \Delta P$
- Thermal model matched to DTS data
- Qualitative Analysis
- Considerations
  - Fluid production – masks JT
  - Gas production – JT effect
  - Flow Path

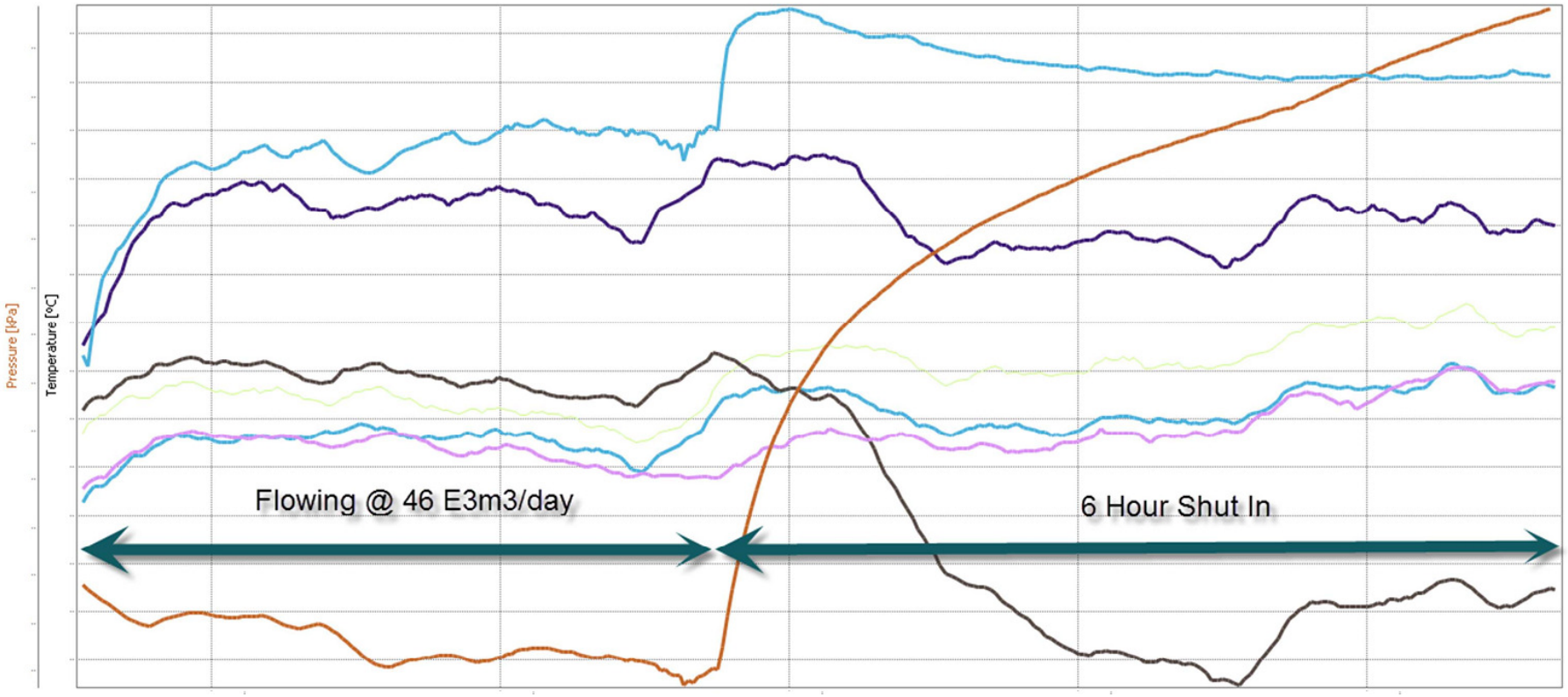




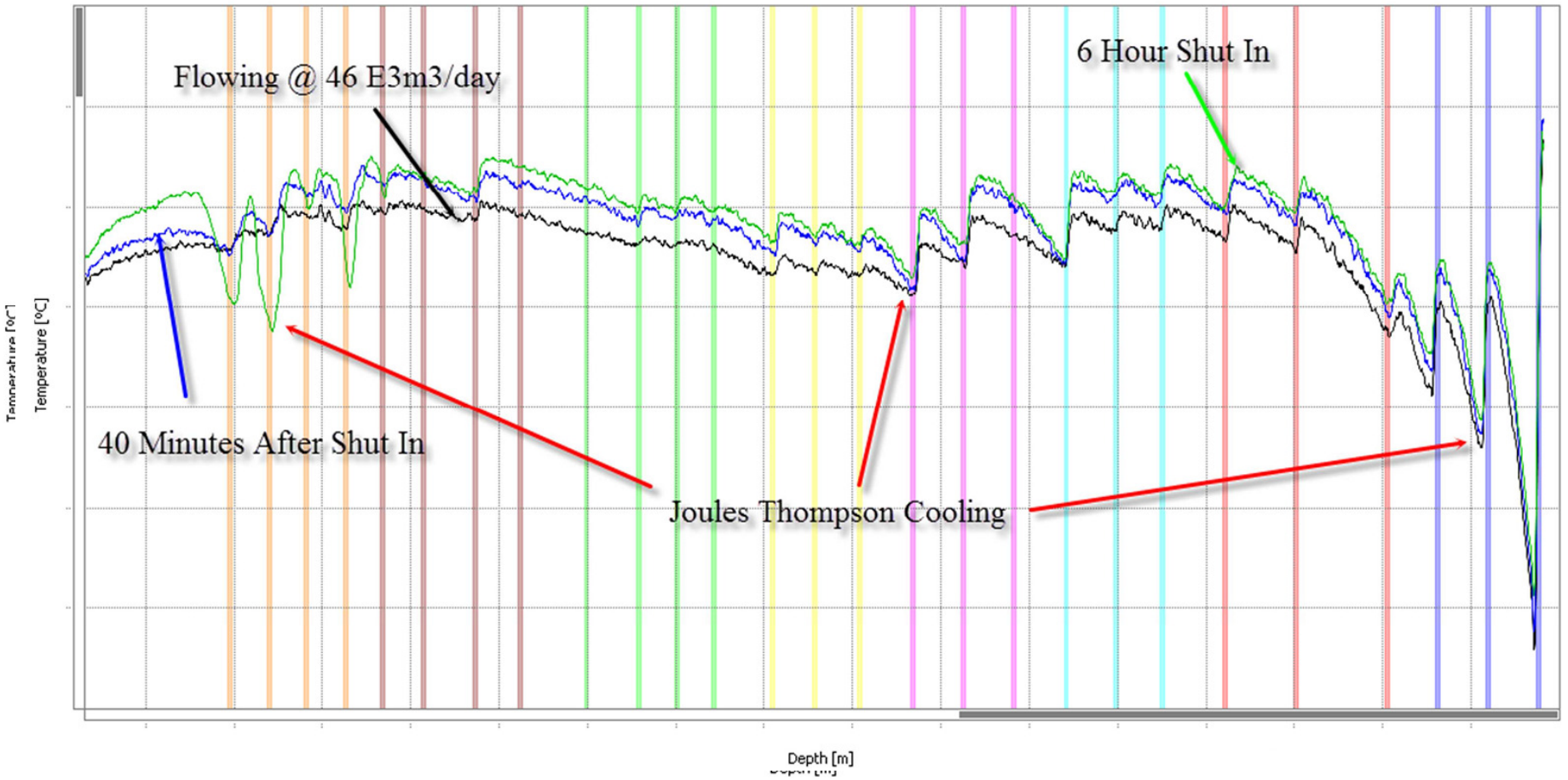
Case Study 2: Flow Analysis

- Horizontal shale gas well / +4000m PBTD
- Cemented plug and perf completion
- 8 stages and 25+ perforations
- Well flowing at an average of 46 E^3m^3/day (1.6 MMSCF/day)
- Objective: Production log to evaluate completion effectiveness (each stage's contribution)
- Challenges:
  - Convey logging tools through 60.3mm tubing into 139.7 mm casing
  - Sand / debris downhole can negatively affect conventional spinners
  - Risk of leaving tool segments downhole
- Perform DTS log
  - Measure equilibrium temperatures during flow period
  - Shut in well to monitor warm back
  - Match thermal model to measured temperatures
  - Correlate flow rate according to induced JT temperature change

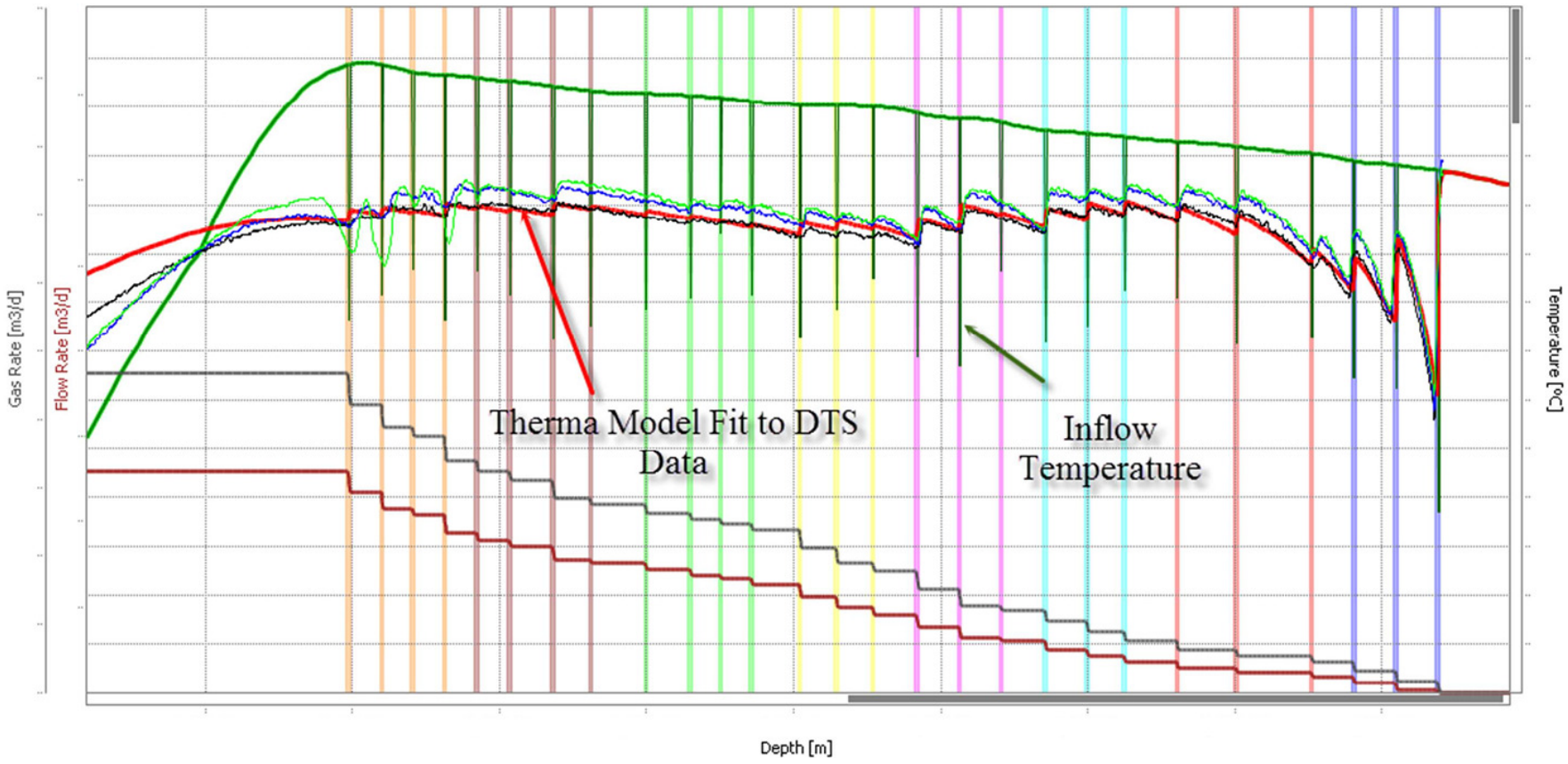
Select Depths – Temp and Press



Case Study 2: Temperature vs Depth



Case Study 2: Thermal Model



Case Study 2: Conclusion

- Joule Thomson cooling allows correlation of flowing gas rates at each perforation
- Contribution of each stage:

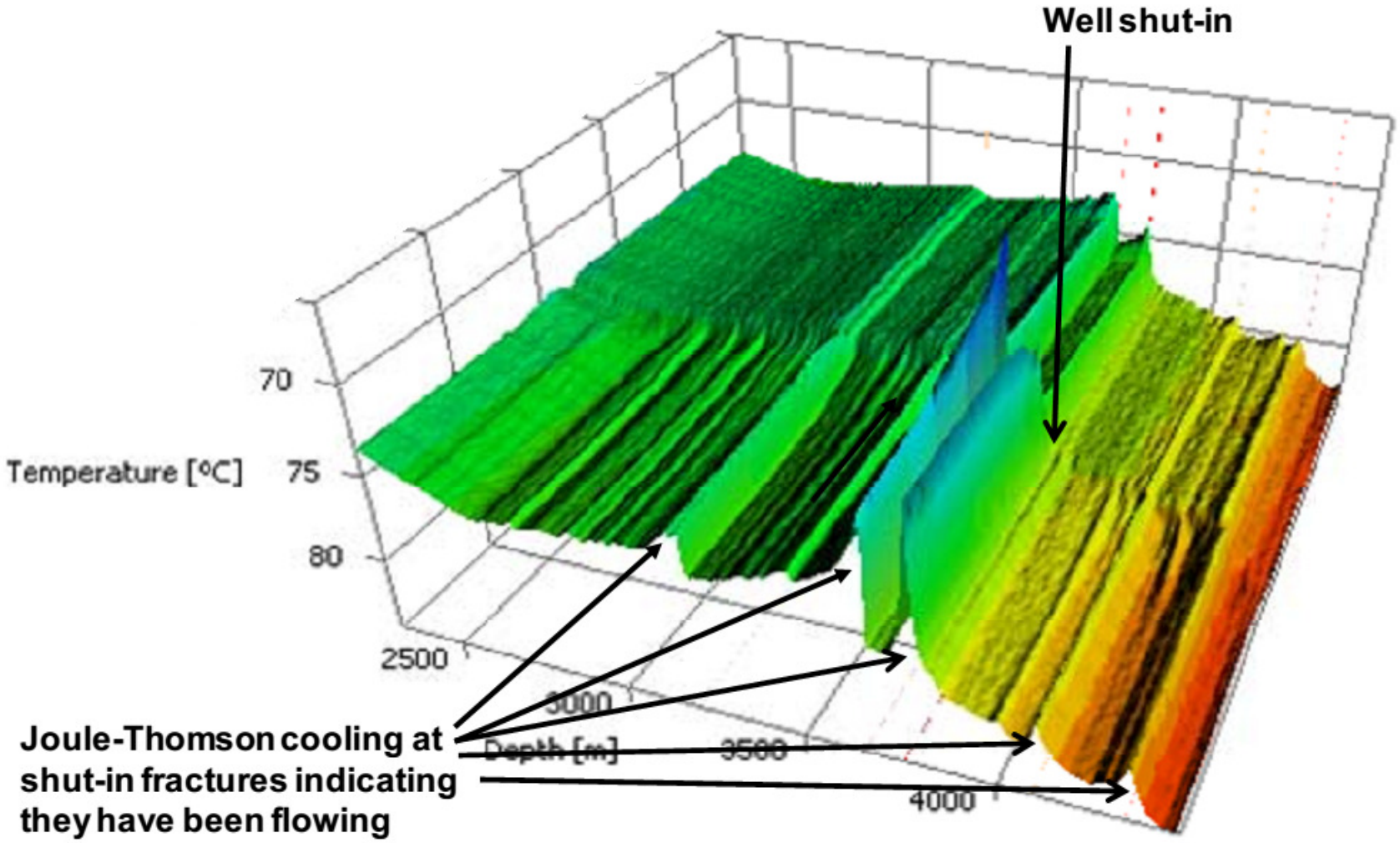
Stage	1	2	3	4	5	6	7	8	Total
Contribution	8%	10%	13%	13%	17%	5%	7%	27%	100

- Indicates each stage is producing
- Uppermost stage is contributing the largest portion of gas
- Completed without long BHA tool strings

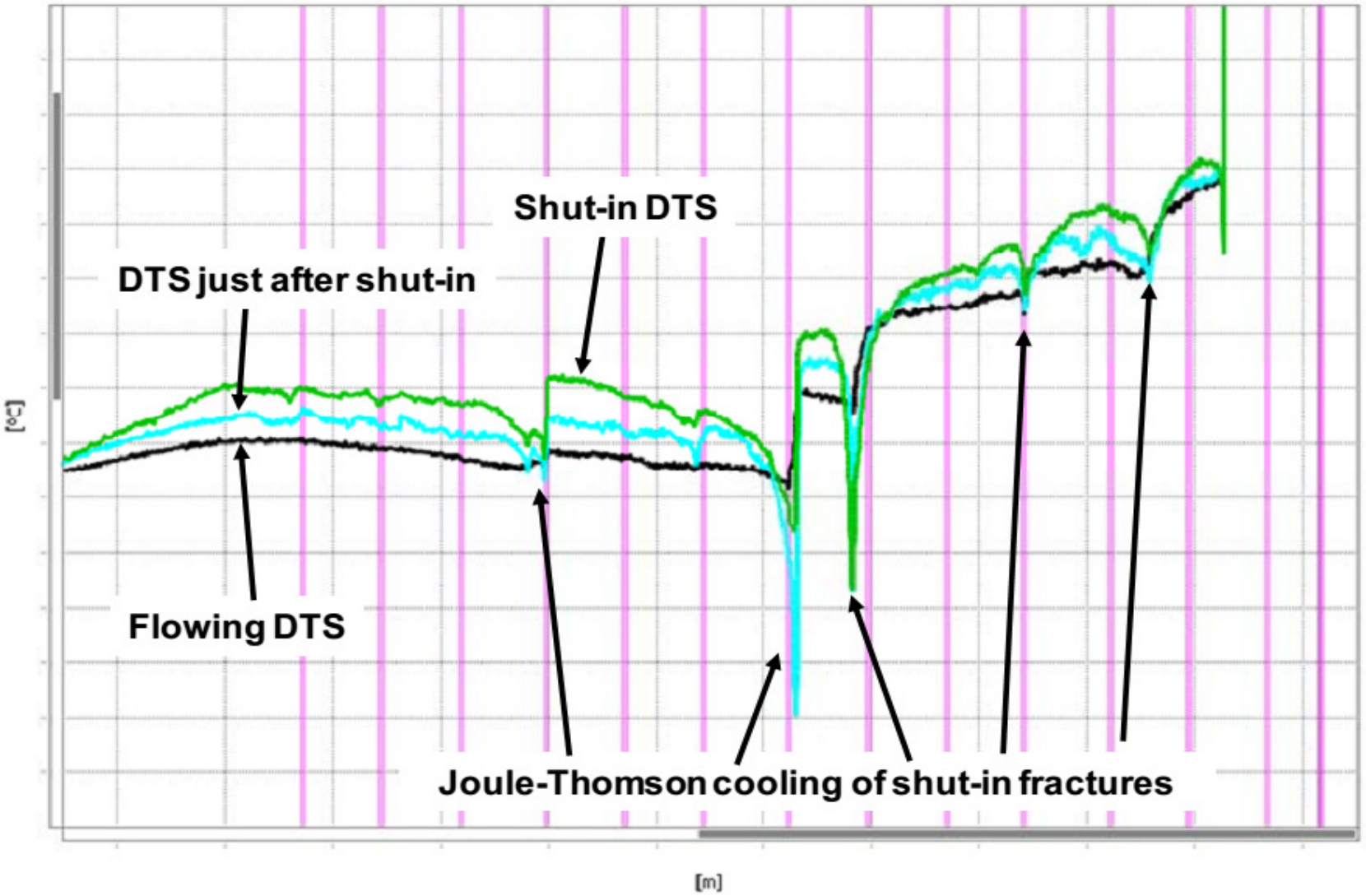
Case Study 3: Flow Analysis

- Horizontal shale gas well / +4500m PBTD
- Multi-stage open hole completion
- 14 ball activated sleeves
- Well flowing at an average of 85 E^3m^3/day (3.0 MMSCF/day)
- Objective: Production log to evaluate completion effectiveness (each stage's contribution)
- Challenges:
  - Sand / debris downhole can negatively affect conventional spinners
  - Risk of leaving tool segments downhole
- Perform DTS log
  - Measure equilibrium temperatures during flow period
  - Shut in well to monitor warm back
  - Match thermal model to measured temperatures
  - Correlate flow rate according to induced JT temperature change

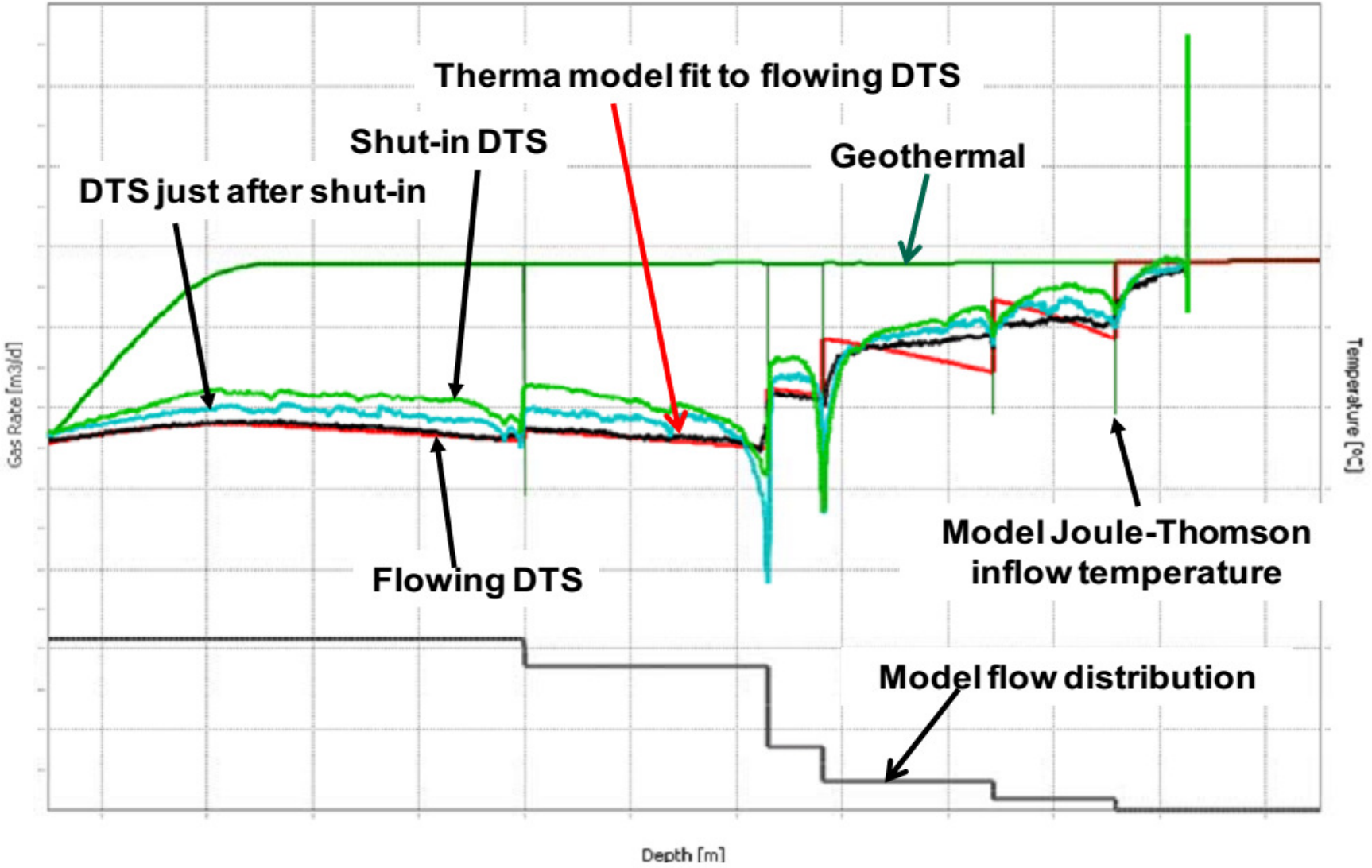
Case Study 3: Inverted Temp Profile



Case Study 3: Temperature vs Depth



Case Study 3: Thermal Model



Case Study 3: Conclusion

- DTS measurements showed temperature responses at the sleeves
- Only 5 of the 14 fractures displayed temperature responses.
- Joule Thomson cooling allowed correlation of flow rates
- Distribution of flow:

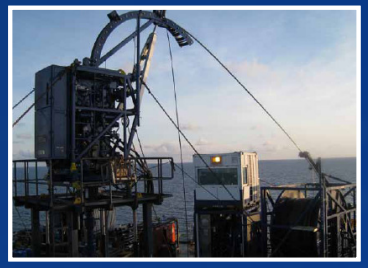
Sleeve	4	5	7	8	11	Total
Contribution	6%	11%	20%	48%	15%	100

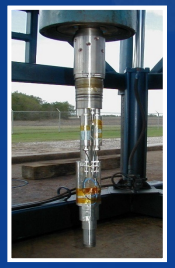
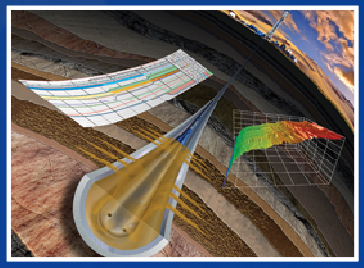
- Completed without long BHA tool string

Summary

- DTS can be a very effective method of detecting leaks
  - Temperature response must be induced
  - The larger the anomaly the higher the certainty
  - Provides real time measurements
- Joule Thomson effect can be used to correlate flow rates based on the thermal response of flowing gas or liquids
- DTS logging can help address challenges of conventional production logging
  - Debris / sand within the wellbore
  - Change in completion or restricted profiles
  - Reduces chances of lost tools
- Candidate wells are evaluated on an individual basis
  - Production rates (Gas / Water / Oil)
  - Drawdown pressures

Thank You!



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