APOGCE
Asia Pacific Oil & Gas Conference and Exhibition
25–27 October 2016 | Perth, Australia
Catching the Next Wave—
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Paper No. SPE 182329
Paper Title: The Effect of Wellbore Temperature Changes and Frictional Losses on Well Test Interpretation Results

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Society of Petroleum Engineers

Introduction

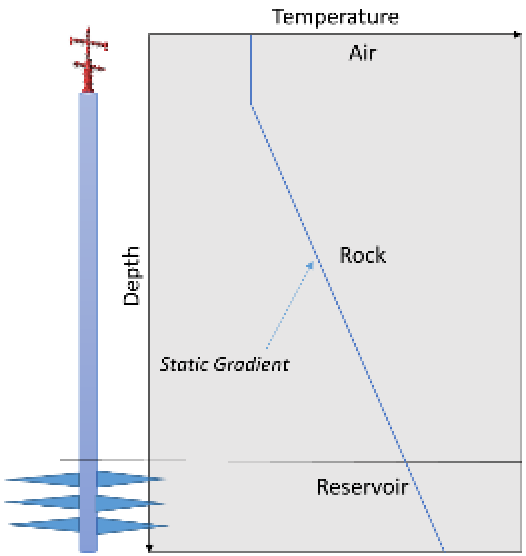
- DHPGs are now more cost-effective and widely available
- DHPGs reduce but do not eliminate wellbore effects
- In reality, not every well is equipped with a downhole gauge
- Fluids below the gauge are subject to
    - Frictional pressure drop
    - Changing fluid density/head due to heating/cooling
- The reservoir signal (delta pressure vs time) can be slightly masked or completely overwhelmed by the change in pressure head

Introduction

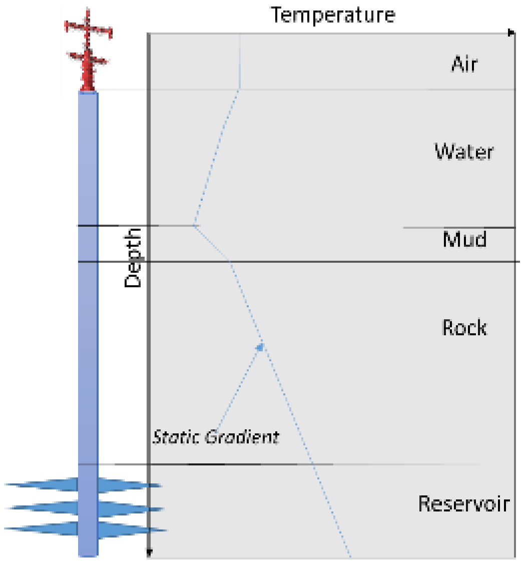
- Failure to account for friction below the gauge results in an artificially high skin
- Phase and thermal transient behavior has a significant impact on the permeability calculation
- Wells may be unnecessarily stimulated, or have errors in calculating the reservoir permeability and in-place volumes
- The wellbore modeling method presented in this paper significantly reduces/corrects these artificial errors in PTA calculations

Background

<u>Temperature gradient inside well under static conditions (shut-in)</u>



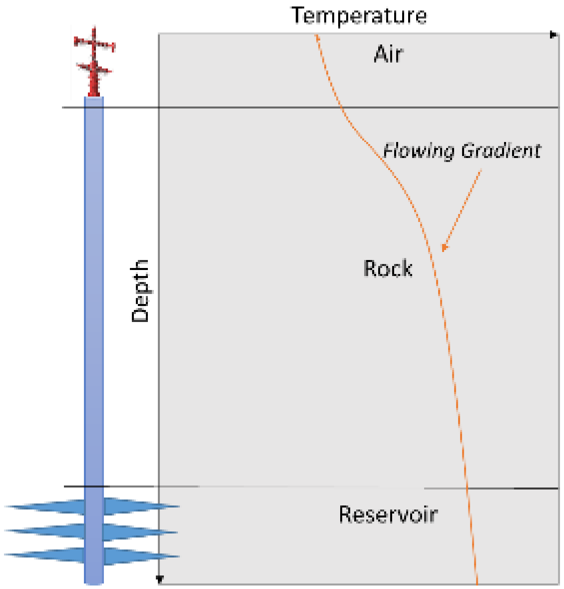
Static onshore well



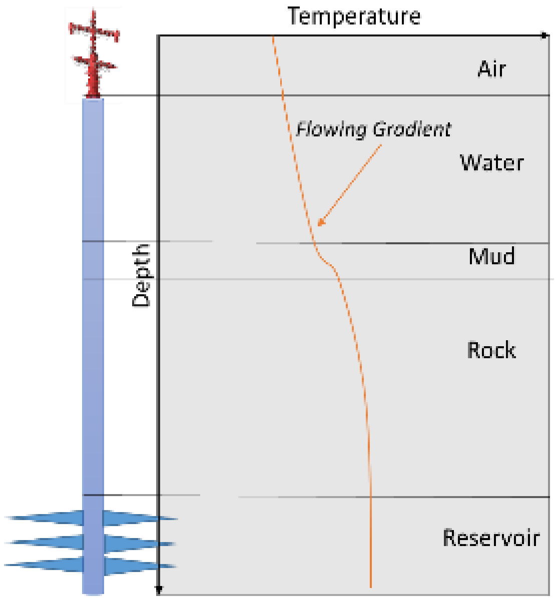
Static dry-tree offshore well

Background

Temperature gradient inside well under dynamic conditions (flowing)



Flowing onshore well

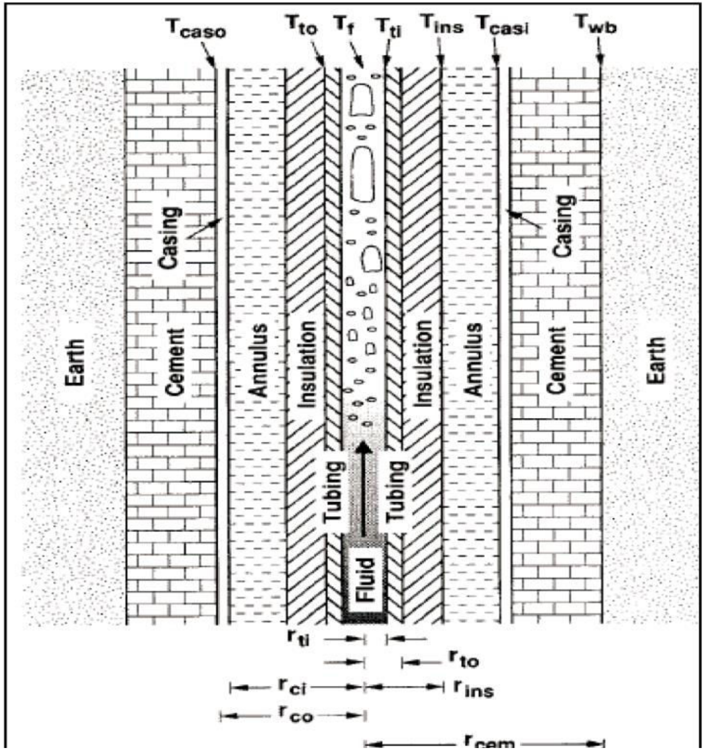


Flowing dry-tree offshore well

Background

- Modes of wellbore heat transfer
  - Conduction
  - Convection (natural)
  - Forced convection
  - Radiation (negligible)

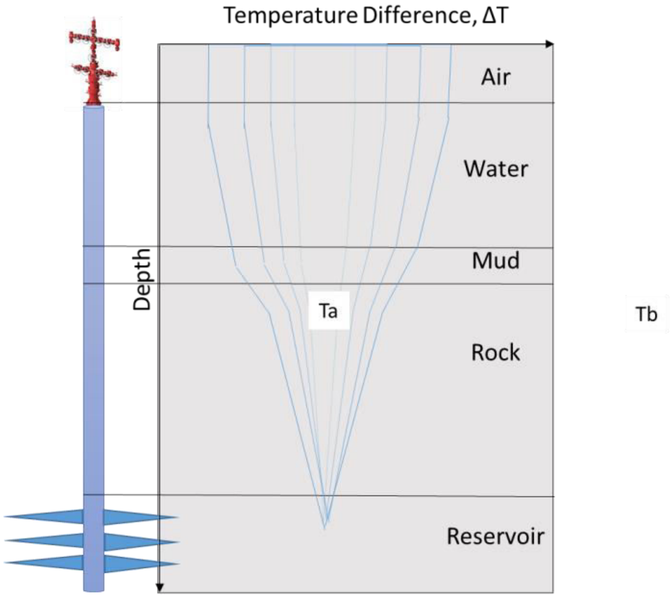
- Over-all heat transfer coefficient
  - Can sum up all of the resistances to wellbore heat to create a single over-all heat transfer coefficient



Background

Time dependence of heat transfer

- Temperature at any point along the well bore depends on
  - Fluid composition
  - Thermal gradient between the mid-stream fluids and the heat sink (formation, water, air, etc.)
- The temperature also depends on time



Background

Thermal Diffusivity and PVT

- The solution to the thermal diffusivity heat transfer problem (in the r direction in cylindrical coordinates) is the ratio of the time derivative of temperature to its curvature, quantifying the rate at which temperature curve becomes smooth
- $\frac{\partial^2 T_e}{\partial r^2} + \frac{1}{r}\frac{\partial T_e}{\partial r} = \frac{Cpe\rho_e}{k_e}\frac{\partial T_e}{\partial t}$
- Not always possible to solve

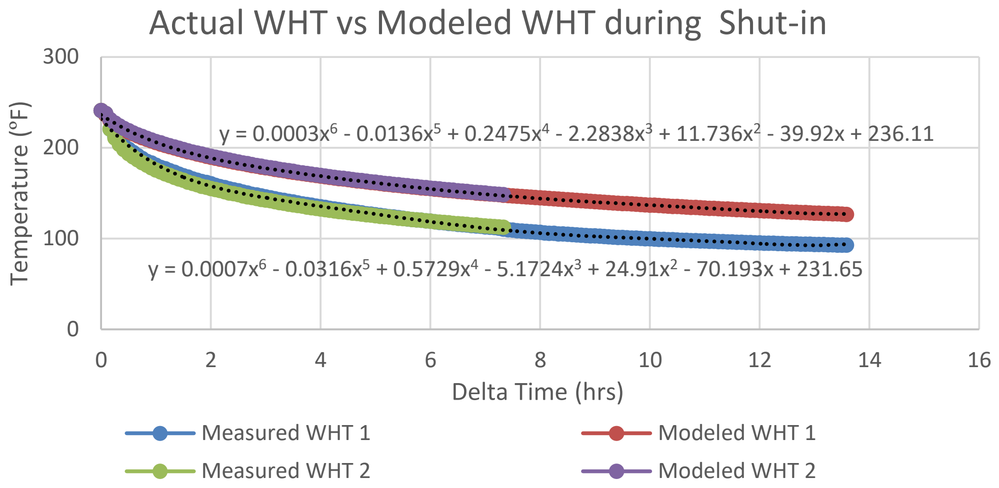
Background

Shape and Modeling of Temperature Response

- Wellhead gauge issues:
  - Indirect communication with the fluid
  - Temp. not measured below mudline
  - The measured temperature is influenced by external forces
- In such cases, it may not be possible to accurately convert the surface pressures to bottomhole conditions

Background

- Need to understand the shape of the temperature response to model the temp.



- Temp. curve follows 6-degree polynomial in both the shut-ins.
- The goal is to accurately convert the surface pressure to downhole conditions in a way that it matches the actual downhole gauge response

Background

- Thermal transients
- Impact of temperature on hydrostatic head
- Well bore friction and boundary layer disruption
- Impacts of wellbore effects on Pressure Transient Analysis Results

Methodology

- Phase behavior is important, all fluids are compressible to some degree
- Temp. & pressure dependence of the density & DPfriction in the mechanical energy balance
- Temp. at any point along the well bore needs to be predictable
- Set up a piece-wise continuous temperature profile for the geothermal gradient, setting pivot points at each of the major differences in heat transfer (i.e. water vs. mud)

Methodology

- Measure the temp. inside each of the major sections during dynamic conditions at a constant flow rate and fluid composition
- Determine the time-dependent shape of the temperature
- 1-, 2- or 3-rate testing may be required to obtain thermal-PVT-BHP match

Case Studies

- The wellbore model (dynamic thermal-PVT-friction model) was used to convert pressures

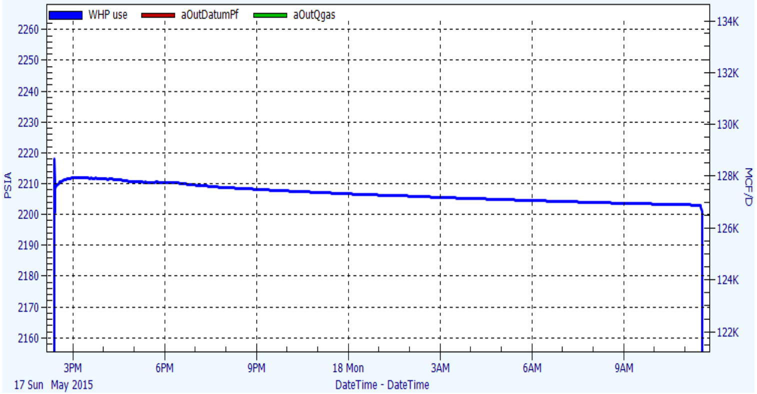
1. Dry Gas Well
2. Dry Gas Well (w/ WHPG & DHPG)
3. Gas-condensate Well (w/ WHPG &2 DHGPs)
4. Oil Well (with WHPG & DHPG)

1. Dry Gas Well

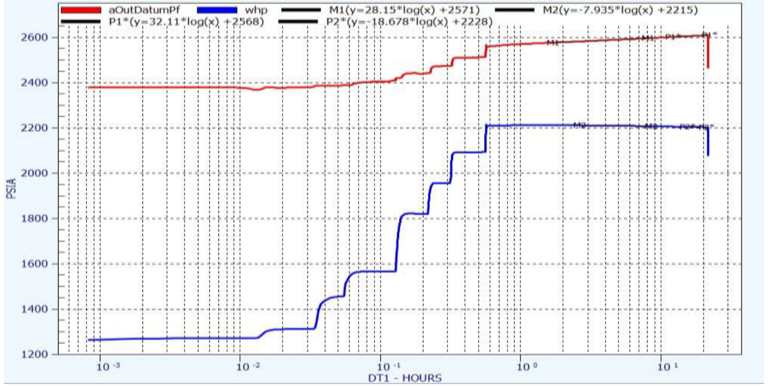
- Well type: offshore dry-tree
- Mid-completion depth: 8352' MD/7719' TVD
- Gas Gravity: 0.69
- Condensate Yield: 12 BBL/MMscf
- Gas rate prior to shut-in: 169,079 Mscf/d

- WHP was decreasing during the shut-in
- WHP was increasing during the drawdown prior to the shut-in
- The change in hydrostatic head was more rapid than the pressure response from the reservoir

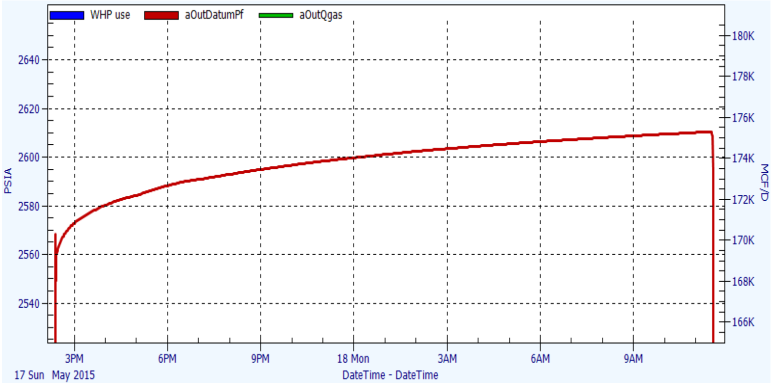
Plots



WHP downward trend close-up



Semi-log plot

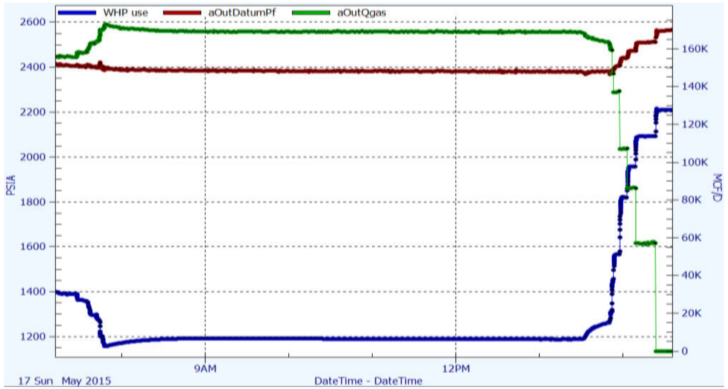


Cartesian BHP plot

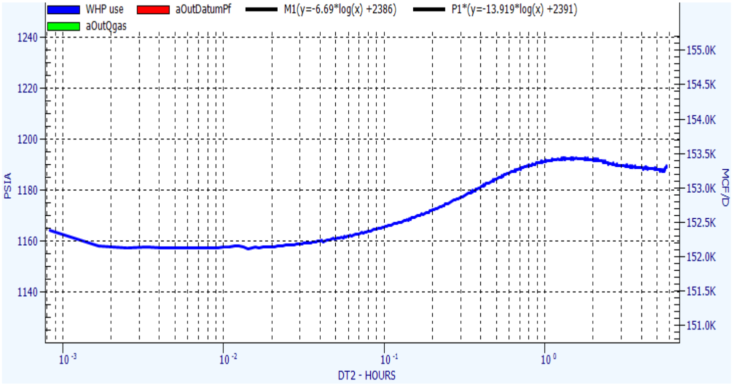
Well Test Results

Pressure	Slope	Skin	DP Skin	DP Skin/Q	Permeability-thickness	Permeability	Comments
	(psi/cycle)		psi	psi/MMcf/D	mD-ft	mD	
WHP							Unanalyzable
BHP	28.15	2.2	54	0.319	24516	21	

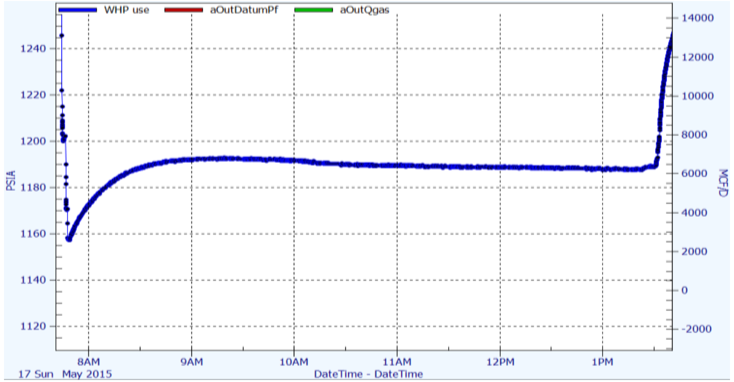
Plots



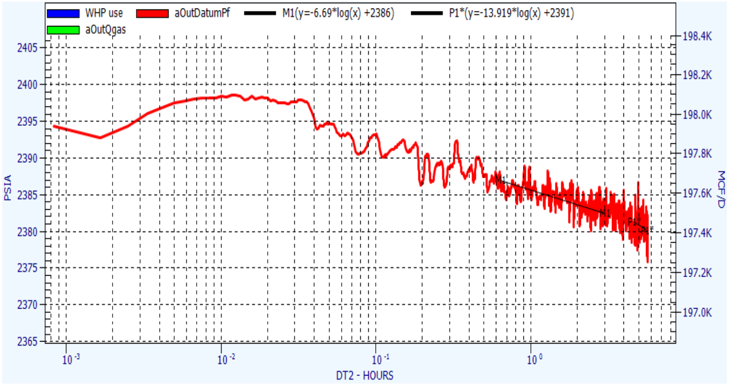
Drawdown cartesian Plot



WHP semi-log plot



Drawdown WHP Plot



BHP semi-log plot

Well Test Results

Pressure	Slope	Skin	DP Skin	DP Skin/Q	Permeability-thickness	Permeability	Comments
	(psi/cycle)		psi	psi/MMcf/D	mD-ft	mD	
WHP							Unanalyzable
BHP	-6.69	4.9	28	0.166	107436	90	

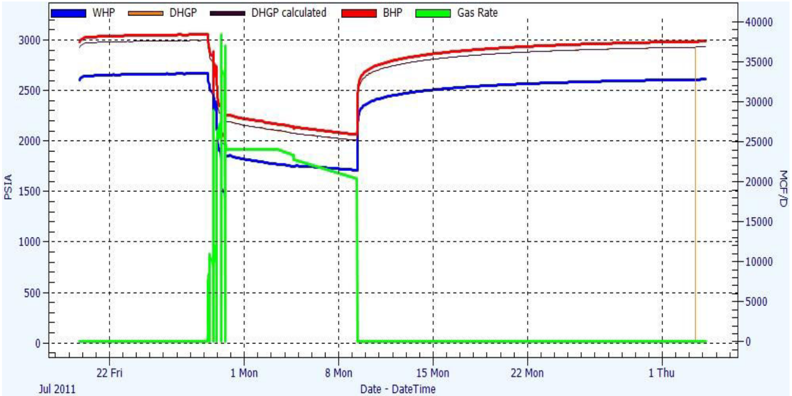
2. Dry Gas Well (w/ WHGP & DHGP)

- Well type: onshore
- Mid-completion depth: 6,490’ TVD
- Gauge depth: 5,426’ TVD
- Gas rate prior to shut-in: 20,405 Mscf/d

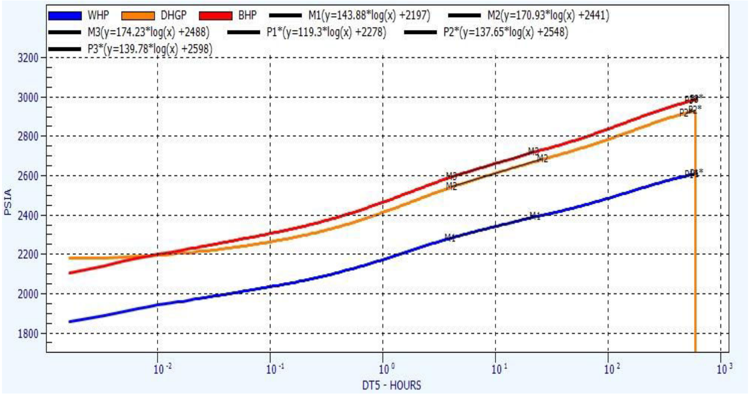
Observations:

- WHP mid-time slope was “flatter” than DHGP mid-time slope due to slope suppression
- Skin, Dpskin, k, kh, ROI values erroneously high as point of measurement moves up the well bore
- Effects of thermal transients can play a significant role even in low perm wells

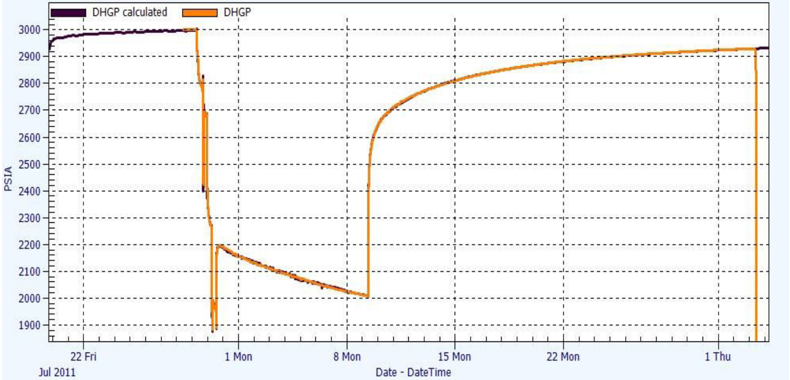
Plots



Cartesian plot



PBU semi-log plot



Measured vs. DHGP

Well Test Results

Pressure	Slope	Skin	DP Skin	DP Skin/Q	Permeability-thickness	Permeability	ROI
	(psi/cycle)		psi	psi/MMcf/D	mD-ft	mD	ft
WHP	143.88	-1.26	-157.12	-7.7	595	5.95	2843
DHGP	170.93	-2.1	-376	-18.5	465	4.65	2632
BHP	174.23	-2.3	-342	-16.8	451	4.51	2613

- The WHP was converted to the DHG depth to fine-tune the model and obtain a match
- The DHGP was then converted to mid-completion bottomhole conditions

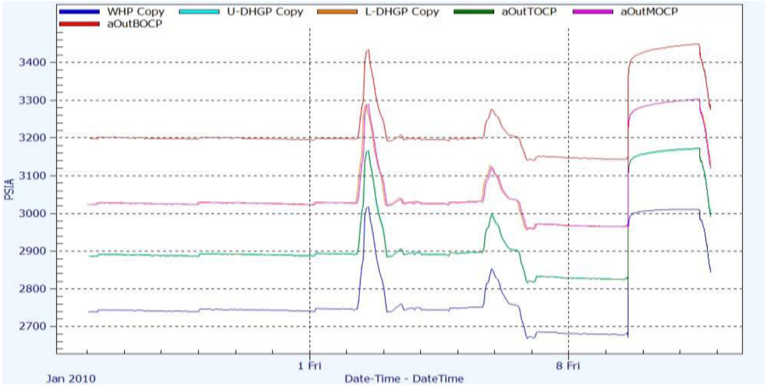
3. Gas-condensate Well (with multiple gauges along the well bore)

- Well type: Offshore Subsea
- Mid-completion depth: 8,743' TVD
- DHGauge depths: Surface gauge, DHG @ 5,020', DHG @ 6,851' TVD
- Gas rate measurements via Venturi meter @ surface
- Gas rate prior to shut-in: 20,405 Mscf/d

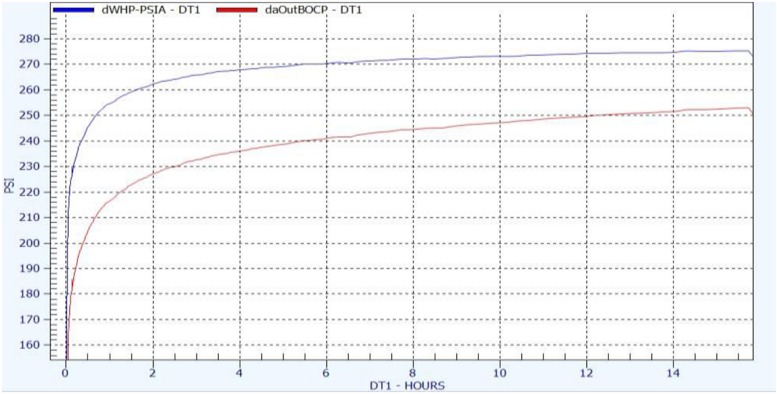
Observations:

- WHP was converted to respective gauge depths to obtain a match
- PTA analysis performed on WHP results in many folds increase in skin, perm, kh etc.
- DHGPs also suffer from wellbore effects (cooling) and PTA suggests that the well is a stimulation candidate

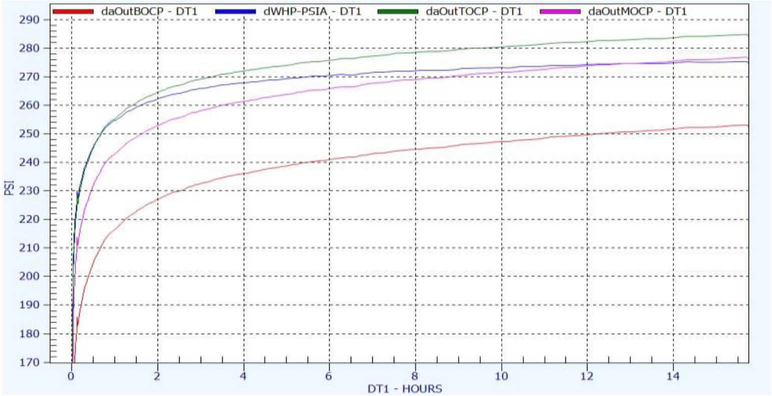
Plots



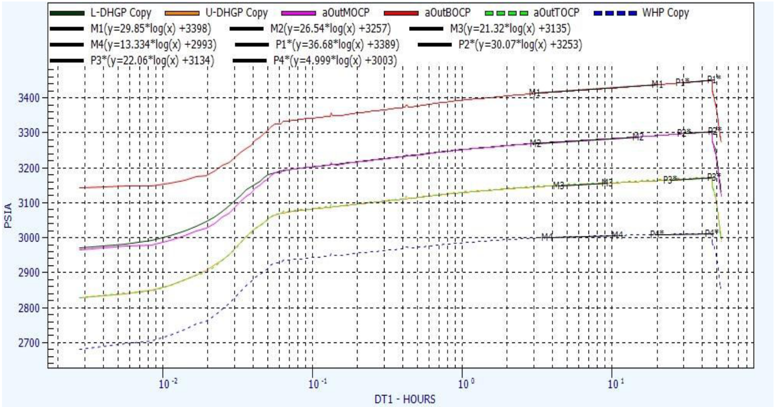
Cartesian Plot



WHP & BHP DP plot



DP plot



PBU Semi-log plot

Well Test Results

Pressure	Slope	Skin	DP Skin	DP Skin/Q	Permeability-thickness	Permeability	ROI	P*
	(psi/cycle)		Psi	psi/MMcf/D	mD-ft	mD	ft	psia
WHP	13.33	20.8	242	2.14	27318	361	4007	3018
U-DHGP	21.32	10.5	194	1.72	16758	222	3195	3200
L-DHGP	26.54	6.4	149	1.32	13264	175	2886	3343
BHP	29.85	3.6	93	0.82	11616	154	2746	3499

PTA Results from converted BHP suggest that the well has low skin, moderate permeability and is not a stimulation candidate

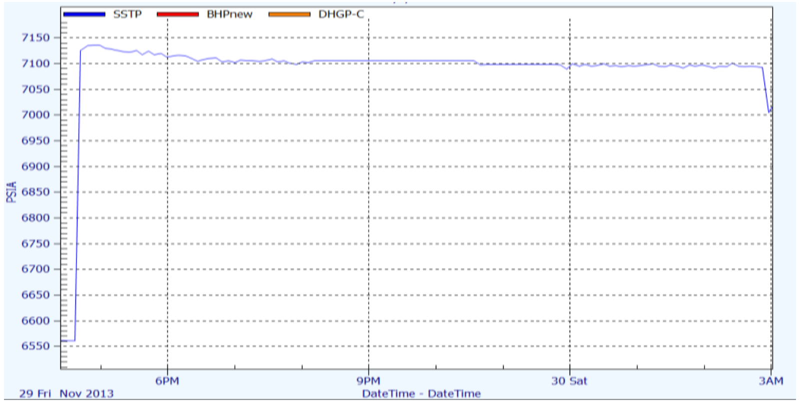
4. Oil Well (with WHP & DHG)

- Well type: Offshore Subsea
- Mid-completion depth: 15,567' TVD
- DHGauge depth: 14,631' TVD
- Oil rate prior to shut-in: 4,200 STB/d, single phase
- Flowing and shut-in pressures were above Pb

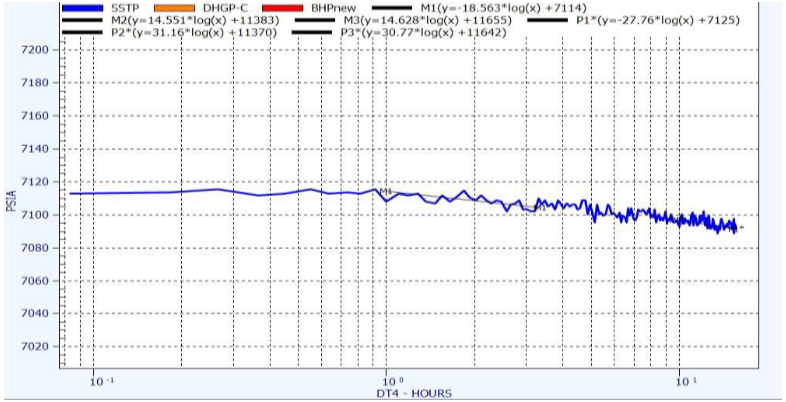
Observations:

- WHP decreases during shut-in, data non-analyzable
- DHG data looks similar to BHP since gauge is set close to perforations

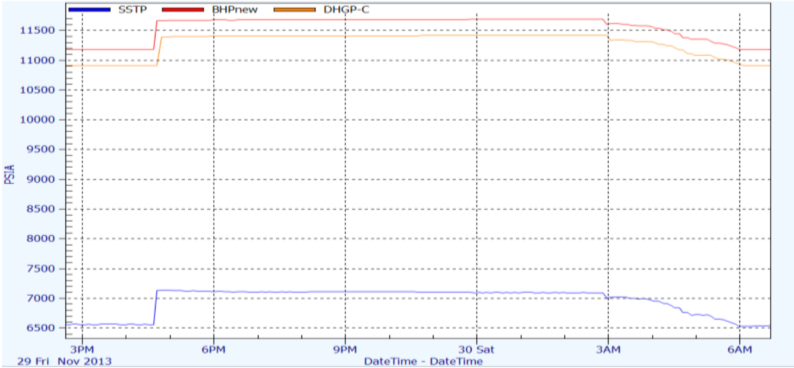
Plots



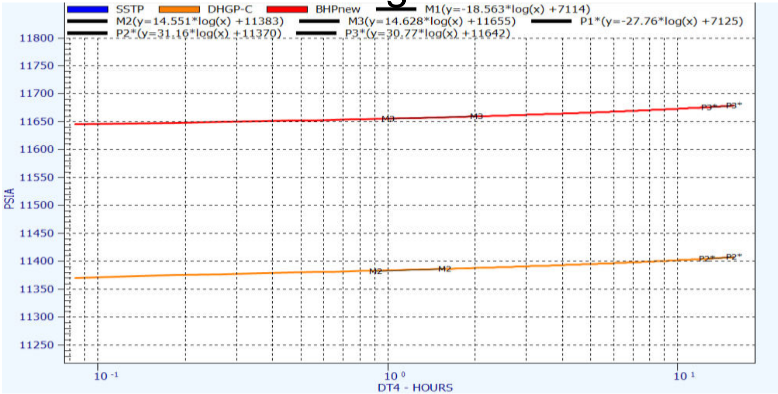
Cartesian WHP Plot



Semi-log WHP Plot



Cartesian WHP, DHG & BHP Plot



DHGP & BHP Semi-log plot

Well Test Results

Pressure	Slope	Skin	DP Skin	DP Skin/Q	Permeability-thickness	Permeability	
	(psi/cycle)		psi	psi/STB/D	mD-ft	mD	
WHP							not analyzable
DHGP	14.551	34	429	0.102	32476	260	
BHP	14.628	33.6	428	0.102	32605	261	

Since DHG is close to the mid-completion point, the PTA results based on DHG and BHP are similar

Conclusions

- The fluid flow in pipe is understood for a variety of flowing conditions
- The heat transfer mechanisms are often not included in most of the conventional methods for calculating the BHP
- Correlations were developed and simplified
- It was forgotten that the often bad assumptions (including “average temperature”) that were made to make the math simple were still there

Conclusions

- PTA on data measured above the completion can lead to inaccurate results and interpretations
  - Need a coupled, dynamic thermal-PVT wellbore model with tuned friction parameters
  - A semi-empirical method has been developed
  - Can convert downhole gauge data, or even surface gauge data, to mid-completion bottomhole conditions
  - Calculated response is representative of the true reservoir response.
- Proposed method honors the physics, acknowledges the lack of required inputs to solve the theoretical equations

Conclusions

- The well bore is broken into sections based on the primary means of heat transfer and is then segmented
- The shape of the vertical flowing and static temperature profiles is honored
- It requires:
  - A static temperature profile (static survey)
  - One or more flowing surveys (3-rate test)
  - This data is then used to predict the wellbore temperature profile as a function of heat capacity of the well fluids with time

Conclusions

- Just because a gauge's pressure response increases during a build-up does not mean that the response is representative of the reservoir response.
- It is no longer acceptable to analyze wellhead or downhole gauge data without correcting for heat transfer and the effect it has on the rate of change of density/head of the fluid below the gauge.

Thank You / Questions

The authors would like to thank all those who are present! The floor is now open to questions.