Formation Pressure Testers, Back to Basics.
A review of the acquisition, quality control and use of formation pressures.

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LPS Seminar - Everything Formation Testing
Thursday 14th December 2017

Outline;
• What's so great about Formation Pressure Testers (FPTs) ?
• What happens when we drill a well?
• Some thoughts on planning FPT acquisition.
• How do FPTs work and where do the pressures come from ?
• FPTs - how do we get the pressures ?
• How do we know the formation pressures are okay ?
• Summary
What's so Great About FPTs?

- Formation pressures at specific depths;
- Quartz and/or Strain gauges
- absolute or gauge pressure
- *pretest is short hand for pressure test*
- Temperature at specific depths;
- gauge (but close to formation temperature).
- Pressure gradients to establish;
- fluid density and fluid levels
- Permeability estimate (mobility – mD/cp);
- indication of reservoir quality
- Fluid Samples;
- identify fluid types
- PVT Laboratory quality samples possible
- formation fluid contaminants possible (Hg, H₂S, CO₂, etc)
- Can be run on wireline (EWL) and on LWD.
- Generally open-hole, but cased hole options available.

What happens when we drill a well?

- Drilling changes the pressure and temperature of the rocks and fluids at and near the borehole wall.
- All borehole measurements are affected to some extent by drilling mechanics and the drilling fluid.
- Drilling fluid (mud) has a number of roles in the drilling process, one of which is well control.
- To maintain well control, mud pressure (weight) is usually higher than the formation pressure.
- Mud filtrate invades the rock pores near the well, displacing the some or all of the native fluids.
- Filtrate invasion causes an initial increase of pressure in the formation near the borehole.
- Solids in the invading mud should form a mud cake on the borehole wall, this is designed to stop further invasion.
**What happens when we drill a well?**

- Filtrate invasion causes an initial increase of pressure in the formation near the borehole, but this pressure equilibrates to the formation pressure with time - if the formation has some permeability and a good mud cake has built-up to stop further invasion.
- We measure the weight (pressure) of the fluid columns in the formation and in the borehole (mud weight aka hydrostatic pressure).
- In the formation it is weight of the continuous fluid phase that we measure.

**Some Thoughts on Planning FPT acquisition**

- What are the well objectives, why are we running an FPT?:
  - Formation pressures - individual and/or gradients, and/or
  - Fluid samples - fluid identification and/or PVT Laboratory quality
- What is the borehole environment?
  - Temperatures and pressures - tools operating limits.
  - Hole size, shape and inclination can all impact probe/packer selection.
  - Mud issues; big overbalance can increase sticking risk, and solids may cause probe plugging, or may be abrasive and cause damage to the packer or seals etc.
- Are there any potential issues with the expected target formation(s)?
  - Unconsolidated / friable or low permeability and/or fractured
  - H₂S
- Plan optimum tool-string and running strategy - use service company expertise
  - Conveyancing - EWL, LWD?
  - Sticking and tension modelling required - involve well engineering in planning
  - Probe/packer choice

**Plan for safe operations and don't compromise on safety**
Formation Pressure Testers - how do they work?

- the tools usually consist of:
  - a probe and packer on a retractable pad
  - retractable backup arms
  - a pretest chamber (0.1 to 50cc)
  - gauges to measure pressure and temperature
  - pumps, flowlines and sample chambers
  - as well as conveyancing, power, communications and controls

Pressure gauges

- Pressure gauges operate by converting a pressure change into a mechanical displacement, or deformation.
- This deformation is then converted into an electrical signal that is processed by the measuring system.
- Temperature must be known accurately for the signal to be converted into pressure. So a temperature sensor is usually included within the gauge.
Formation Pressure Testers - how do they work?

Packers and Probes

- The packer is set against the borehole wall, sealing the probe from the borehole/drilling fluid.
- The probe connects the tool to the formation.
- Different packer and probe designs to address different reservoir conditions.

Where do the pressures actually come from?
- some thoughts on depth measurements

- **Measured Depth - MD**
  - Measure point;
    - Drill-floor (DF), Rotary-table (RT) or Kelly-bushing (KB)
  - Datum - Elevation above:
    - Mean sea-level, Lowest astronomical tide, Ground level, Mud line

- **True vertical depth - TVD; (inclined boreholes)**
  - datum reference, DF, RT, KB, SS (Subsea, but MSL or LAT ?)
  - Inclination - from the vertical
  - Azimuth - well direction relative to North (but which North - True, Grid, or Magnetic?)
  - Survey accuracy
    - Inclination +/- 0.1 deg
    - Azimuth +/- 1.0 deg
Where do the pressures actually come from?
- some more thoughts on depth measurements

- Logger’s Depth
  - Wireline accuracy of +/- 0.5ft per 1000ft in ideal circumstances

- Driller’s depth
  - Generally accepted standard for accuracy of Driller's Depth is +/- 2 ft per 1000ft
  - it is the total length of all drill pipe and bottom-hole assembly lowered into the borehole
  - Drill-pipe tension, compression and buoyancy effects can cause errors in the depth

- LWD data is recorded in time, which is tied to Driller’s Depth
  - Memory data is linked to depth using synchronized clocks
  - Rapid changes in ROP and missed intervals can cause errors in the depth

- Key point - there is always some uncertainty in depth measurements.

FPTs - how do we get the pressures?

- Pressure tests (pretest) - operating basics
  - Plan where best to take pretests;
    - good borehole
    - potentially permeable formation
    - enough pretests to define fluid gradients or expected changes in pressures
  - RIH
  - Depth alignment;
    - FPT may be run on a different logging pass to other open-hole logs, so depth alignment is critical
    - Use GR Correlation pass (more than one if required), to make sure the FPT is on-depth with previous logs, so we know that the pretests are being taken where you want them to be taken.

  - and then prepare to set the tool to take your pretest...
FPTs - how do we get the pressures?

- Pressure tests - operating basics
  - Taking a pretest, at the predetermined depth;
  - The hydrostatic - before pressure is measured.
  - The packer is set against the borehole wall, sealing it from the borehole/drilling fluid.
  - The probe is pushed through the mudcake into the formation.
  - A small volume of fluid is withdrawn (0.1cc to 50cc) by the pretest chamber, causing a pressure drop (drawdown).
  - Pressure is then allowed to build-up and it will stabilise at the formation pressure if the formation is permeable.
  - The probe is withdrawn and the hydrostatic - after pressure is measured.
  - The tool measures these pressure changes as a function of time.
  - The draw-down can be used to estimate formation mobility, where drawdown is the difference between final flowing pressure and formation pressure.

FPT Quality Control - How do we know the formation pressures are okay?

- You should get properly tabulated data;
- Data - File number, depths (MD and TVD and their reference), Hydrostatic (mud) pressures (before and after), Formation pressure (if valid), Temperature, Mobility, Comments.
- record the ‘failures’ too, it is all useful information;
  - seal failures may indicate unconsolidated sand or tight formation (no mud cake)
  - tight tests may indicate low permeability formation
- You should get a Field Print
  - to investigation of any apparent issues.

<table>
<thead>
<tr>
<th>Field</th>
<th>Depth</th>
<th>Temperature</th>
<th>Mobility</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gusher Oil and Gas Co.</td>
<td>101/01/2000</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
FPT Quality Control

- Check the Before and After Hydrostatic pressures
  - are they the same within gauge accuracy (ie +/- 2psi for Quartz gauge)
  - shows that the gauges are working and temperature is stable
- Plot the Before and After Hydrostatic pressures against depth (TVDSS)
  - are the gradients consistent with the mud weight?
  - confirms that the gauges are reading accurately.

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FPT Quality Control

- Plot the formation pressures against depth (TVDSS) and check that they make sense when compared to:
  - all the other borehole data, such as apparently permeable formation
  - the formation fluid types and any observed fluid contacts
    - fluid gradients are functions of the fluids’ density
  - the formation pressure is within the expected range, and is consistent with off-set wells
FPT Quality Control

• Some Pretest Definitions;
  • **Normal Test** - Pressure builds to formation pressure and is stable. *Valid formation pressure*
  • **Dry Test** - Large drawdown and slow build up. *Does not give valid formation pressure.*
  • **Tight Test** - Big drawdown, little or no build up (extreme version of the Dry Test). *Does not give valid formation pressure.*
  • **Lost Seal or Seal Failure** - Packer seal fails – pressure builds back to hydrostatic. *Does not give valid formation pressure.*
  • **Supercharged** - When the overbalance of mud pressure into the formation has not dissipated from the region sampled by the FPT by the time that the FPT takes its pressure. *Does not give valid formation pressure*
  • **Probe or flow line plugging**, by fine grain material from the mud solids or from the formation being sampled. *Does not give valid formation pressure*

FPT Quality Control

Check the field print

• Good Test - stable formation pressure
  • Formation pressure is normally recorded until the measured pressure is changing by less than 1 psi/min for strain gauges or less than 0.1 psi/min for quartz gauges. Pressure stabilization is critical for accurately measuring formation pressure.

Note that the pressure appears in more than one track, and that each of these tracks has a different scale, showing more sensitivity as we move towards the right.
**FPT Quality Control**

**Dry Test**
- Big draw-down, slow build-up, not stable
- can be caused by low permeability formation or
- can be caused by big and/or sudden drawdown causing fluid phase separation and relative permeability barriers to flow,
- or thick mud cake, or bad formation damage
- Does not give valid formation pressure

**FPT Quality Control**

**Seal failure**
- damaged packer
- little or no mud cake
- rugose or riffled borehole
- Does not give valid formation pressure
FPT Quality Control - Supercharging

- Supercharging is the build up of high pressure around the borehole due to the hydrostatic head of the mud filtrate that has not dissipated after drilling.
- Usually associated with low permeability formations;
  - where the mud filtrate pressure has not had time to equilibrated to formation pressure,
  - and/or where the thin mud cake does not adequately isolate the formation from the borehole.
- Supercharging can be a bigger problem with LWD as there is active mud circulation.

Low permeability formation can have thin or no mud cake

FPT Quality Control

Supercharging

- Really big draw-down, buildups back towards hydrostatic
- not stable
- low formation permeability
- Does not give valid formation pressure

papers on trying to correct for supercharging;
- Mark A. Proett and Wilson C. Chin, 1996; *Supercharge Pressure Compensation Using a New Wireline Testing Method and Newly Developed Early Time Spherical Flow Model* SPE-36524

NB: this is an older field print with time increasing from top to bottom
Formation Pressure Testers - Back to Basics.

Summary:

- Formation Pressure Testers are GREAT tools.
- What happens when we drill a well?
  - We change the formation and the fluids.
- Some thoughts on planning FPT acquisition.
  - Involve the service company and the well engineers
  - Plan for safe operations and don't compromise on safety
- How do FPTs work and where do the pressures come from?
  - QC the depths.
- FPTs - how do we run the tool?
- How do we know the formation pressures are okay?
  - QC the pressures.
- What else should we worry about?
  - Oil field units and those conversion factors.

Bonus Slide 1 - Formation Pressure Testers - What's in a name?

- **FPT** - formation pressure tester, not a company trade name, and not specific to conveyancing.
- **WFT** - wireline formation tester, not a company trade name, but specific to wireline.

Some of the many Company specific trade names (in alphabetically order):

- **DFT** - drilling formation tester
- **FMT** - formation multi-tester
- **GeoTap**
- **MDT** - modular dynamic tester
- **MFT** - compact formation pressure tester
- **PressureWave**
- **RCI** - reservoir characterization instrument
- **RDT** - repeat dynamic tester
- **RFS** - repeat formation sampler
- **RFT** - repeat formation tester
- **SFT** - sequential formation tester
- **SFTT** - sequential formation test tool
- **SRFT** - slim-hole repeat formation tester
- **StethoScope**
- **TesTrak**
- **XPT** - pressure-xpress

Some examples of EWL and LWD FPT logging tools
Bonus slide 2 - What else is there to worry about? Units

- Oil field units include:
  - depth - feet or metres
  - volumes - barrels, cubic feet, cubic centimetres, gallons, (US or Imperial ?)
  - fluid density - g/cc, lb/cubic-foot, ppg, SG
  - pressure - psi or Bar; - gauge or absolute ?
  - pressure gradients - psi/ft or psi/m or bar/m
  - time - seconds
  - permeability – milli-Darcies
  - viscosity - centipoise
  - temperature – degrees Fahrenheit or Celsius

- Often need conversion factors which increases the chance of error

- SI units
  - depth/length/diameter - metres, millimetres
  - volumes - cubic metres
  - pressure - Pascal
  - fluid density - kg/cubic-metre
  - permeability – square metres, square millimetres
  - time – seconds (but not minutes and hours)
  - temperature - Kelvin
  - viscosity - pascal-second

Bonus Slide 3 - Formation Pressure Data - Some notes on fluid levels

Some capillary pressure theory;

- due to buoyancy and gravity, hydrocarbons displace water from the reservoir, with the bigger pores (capillaries) displaced first and smaller pores later.
- Free water level (FWL), is where capillary pressure is zero.
- Oil or Gas water contact (OWC/GWC) is the first occurrence of hydrocarbons.
- FWL is not the same as GWC or OWC.
- FWL - OWC = Entry Pressure Height
- Transition zone, between OWC and Irreducible Sw
- The intercept between water gradient and oil or gas gradient on gives FWL (not OWC or GWC)