*i*REPORT

Welltest 101: **Wireline**

Welltesting & Wireline

Responsibility Chain Management	Petroleum Reservoir and Production Engineering teams initiate hydrocarbon welltests. Well testing is about measuring and recording flow rate and pressure data. Wireline services run pressure instruments. Responsibility chain management of data requires an integrated team: from wellsite acquisition or collection; to field-office processing, data validation, and technical reporting; to engineering analysis (PTA, AOF, IPR) and legal submissions (AER, SEC). Corporate directors, managers, and stakeholders depend on reliable, traceable, advice from testing wells.
Welltesting Team	Talented and experienced wellsite equipment operators are always appreciated for safe running, installation, and recovery of scientific instruments. Knowledgeable and particular field-office technicians are valued for accurate, timely technical reporting. Engineers need to know what standards to expect, and to do whatever data processing might be required to achieve professional acceptance.
Wireline Team	Wireline can mean either Slickline or Braided line. Braided or twisted wire is used for heavy lifting and well logging. Slickline operators, equipment, tools, and instruments are intrinsic to petroleum welltesting.
Engineering Team	Engineering is quirky: words are different, acronyms are strange, expectations are high, accuracy and precision are standard protocols. All staff in the responsibility chain need an awareness of equipment, tools, and operations. Practical knowledge about quality control, data validation, and technical reporting ensures consistent, reliable deliverables. Literacy with oil patch nomenclature (words, acronyms, subscripts, superscripts) is requisite for effective communication and comprehension.
Bridging Technical Gaps	Welltest Specialists technical training material has been written to bridge technical gaps and help new staff get up to speed with welltest engineering workflow and workspace.
Pressure Data	This *i*REPORT will focus on topics related to wireline (slickline) deployment of subsurface pressure recorders (gauges or bombs) for welltesting purposes.

Instruments

Pressure Recorders

For welltesting purposes, subsurface pressure recorders (gauges or bombs) are the primary scientific instrument installed on single strand slickline. Data reporting and validation topics will herein be focused on pressure measurements.

Well Logging

Open and Cased Hole logs (Neutron, Sonic) are run on a heavier lifting multi-strand braided or twisted wireline. Production logs (flow spinners; pressure, temperature, and gradiometer gauges; even video cameras), are run on E-line, which has an Electrical coaxial cable up the middle of the braid for live data feed to surface display and control.

Wireline

Principals

Wireline is one method of running various scientific measuring instruments into petroleum wellbores. Basically, tools and devices are attached to one end of a long spool or drum of wire, which is attached to a winch. Gravity lowers everything down hole. The winch controls speed down, and lifts or jars equipment back up to surface.

BOP

A wellhead blow-out-preventor (BOP) must be installed to safely commence operations.

Lubricator

A lubricator (several sections of pipe) is attached to the top of the BOP. A grease valve and pulley are mounted on top of the lubricator to run the wire through. A crane or 'picker' lifts the lubricator up-and-down, on-and-off the BOP. Off the BOP, tool strings are hoisted up into the lubricator. Stabbed back on, opening the BOP pressures up the lubricator and allows the tool string to drop into the wellbore.

Winch

The winch is usually mounted on a truck but can be skid mounted for remote operations. A drop spool can also be employed if instruments need to be hung down hole (i.e. inside casing, with no tubing installed where collar-stops or darts could be landed, see tubing tools below).

Wire Types

Four types of wireline are available. **Slickline** is single-strand wire: operations are usually in tubing; carbon steel for sweet service; stainless steel for sour service (H_2S); common for welltesting. **Digital slickline** has a special coating for live communication with logging tools. **Braided** or twisted wire cable is employed in drill pipe or casing and is available either: plain for heavy duty use (fishing, perforating); or **E-line**, in which the wires are wrapped around an Electrical coaxial cable, for surface display and electronic control of downhole equipment, tools, and instruments (tractors, well logs, production logs, also sweet or sour service).

Wireline

Field Rig In

Illustrated below is a simplified terrestrial or land-based diagram of a wireline rig in. Subsea operations are quite similar, except the wellhead location has shifted down and a crane hoist is part of the rig.

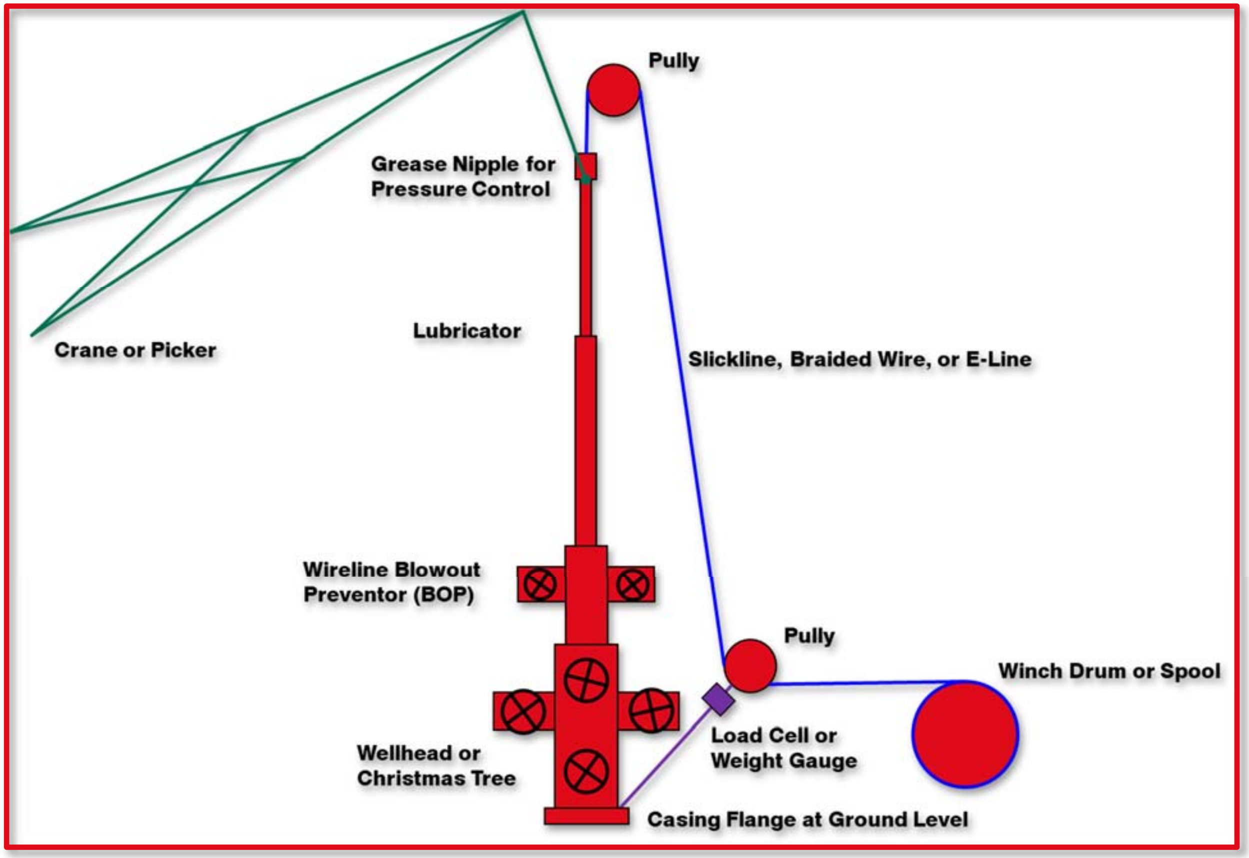
Wireline Basics Diagram

Lubricators are sectioned together depending on length of tool strings

Weight gauge load cell is cabled to the truck console

Depth gauge on the console is connected to the spool

Monitoring wellhead pressures is critical



Tools

Casing Tools

Braided wireline services operate inside drill pipe, the open hole, and casing to run bridge plugs, packers, well logs, perforating guns, and production logs (spinner surveys).

Casing Tests

There are several welltests that can be conducted up drill pipe or casing, without production tubing installed yet. Drill Stem Tests (DST) are conducted as implied, in drill pipe before rig release. Mini-Frac' or Diagnostic Fracture Injection Tests (DFIT), Step-Rate Tests (SRT), and Formation Leak-off Tests are conducted after casing has been cemented in. Perforation Inflow (underbalanced) or Injection (overbalanced) tests (PITA) are also common.

Tubing BHA

Tubing is run inside casing. Completion and workover strings employ heavy duty pipe for operations, and welltests are often conducted through the temporary installation. Production tubing is the final string for commercial production. Either way, a Bottomhole Assembly (BHA) will be configured for operations. For welltesting, it is critical to know where everything is: no-go nipple, packers, sliding sleeves, side ports, and especially profile nipples where we land tools.

Tubing Tools

In tubing, gauge rings are run to tag fill or fluid, and to be sure there are no obstructions before running other tools. Plugs (and their equalization prongs), collar stops and darts, hold-downs, and sliding sleeve shifting tools are used in welltesting. Overshots are run to retrieve tools. Jars are run to apply upward or downward striking forces to set or release tools, but also to shear safety pins and get out of the hole, leaving a stuck tool (fish) behind. Impression blocks have a facing of lead and are run to evaluate obstructions and fish but can also be good for locating a liquid level. There are many fishing tools, including wire catchers, over-shots, junk baskets, and magnets. Swabbing is also done with wireline, and wax cutters are run on wire. These are just a few of the basic tools, there are far too many to get specific.

Tubing Tests

Most common in oil and gas wells is the clean-up, single-point flow, and Pressure Build-up test (PBU). Absolute Open Flow (AOF) tests in gas wells or Inflow Performance Relationship (IPR) tests in oil wells are paramount for facility design and production operations. Laminar-Inertial or Isochronal Tests (LIT) may be ordered in high deliverability gas wells. Pressure Fall-Off tests (PFO) are conducted in water disposal and waterflood injection wells. Annual tests are also conducted on producing wells to monitor reservoir performance and depletion.

Subsurface Pressure Recorders

Gauge Types Pressure recorders are available in two basic types: strain gauges for general usage and quartz gauges, with higher resolution, where better accuracy is required. Strain or quartz elements provide a *primary amplitude signal*, from which *pressure is inferred*.

Calibration Recorders are calibrated in an oil bath, where temperature and pressure are applied by a certified source. Any gauge deviations are corrected employing a calibration equation.

Pressure Range Electronic recorders measure absolute pressures and are available in a variety of ranges (i.e. 93–20 000 kPa_a). Try to choose gauges so pressures will fall between 20 % and 80 % of the range. Below 10 % of gauge range pressure data are much more prone to noise.

Clock A clock is required to obtain a data sequence. Clocks last as long as the batteries, but do malfunction once in a while, for various reasons (slow down, speed up, or stop).

Sample Frequency Clock sample frequency can be set on electronic recorders. Rapid sampling is fine for short tests or during times of rapid pressure change but can lead to excessive data file sizes in long tests. Slower sample rates can miss important data points, such as the final flowing pressure, but can allow for longer tests, as memory and battery power will last longer. Even for a long test engineers would never need more the 250 000 data points.

Temperature Sensor Temperature of the strain or quartz element must be known, so a thermometer is installed and provides another *primary input signal*. Note, then, that *calculated pressure is actually a secondary product.*

Quality Control

Cartesian Plots

Pressure data quality control and data validation require several Cartesian (time-based) plots for technical reporting. Overall or total test data are qualified using three basic plots relative to: #1) recorded pressures, atmosphere or barometric pressure to Y highest measured pressure; #2) test pressures, X lowest measured flowing pressure (p_{wf}) to Y highest measured pressure; and #3) relative to the recorder range, plotted in ≈10 % increments, as shown below.

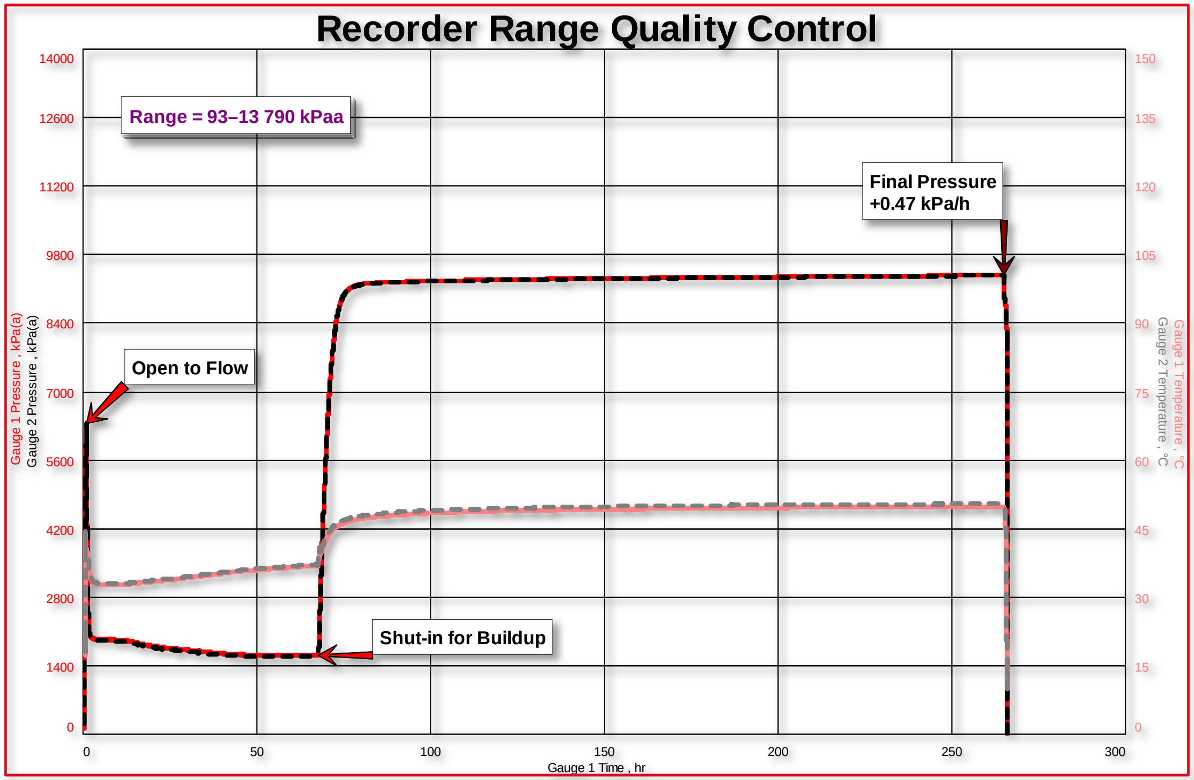
Ideal Flow & Build-up test

Pressure data appear normal

Temperature data suggest well cleaning up (JT cooling effects were lessening)

Passes AER 6 h, 2 kPa/h Rule

Recorder range was appropriate for well pressure magnitudes



This example is Cartesian plot type #3: scaled relative to the recorder range, 0 – 14 000 kPa in 1400 kPa steps (≈10 %). 93 kPa is the standardized atmospheric pressure for calculating and reporting in Alberta, Canada.

Recorder Run-In

Liquid Level

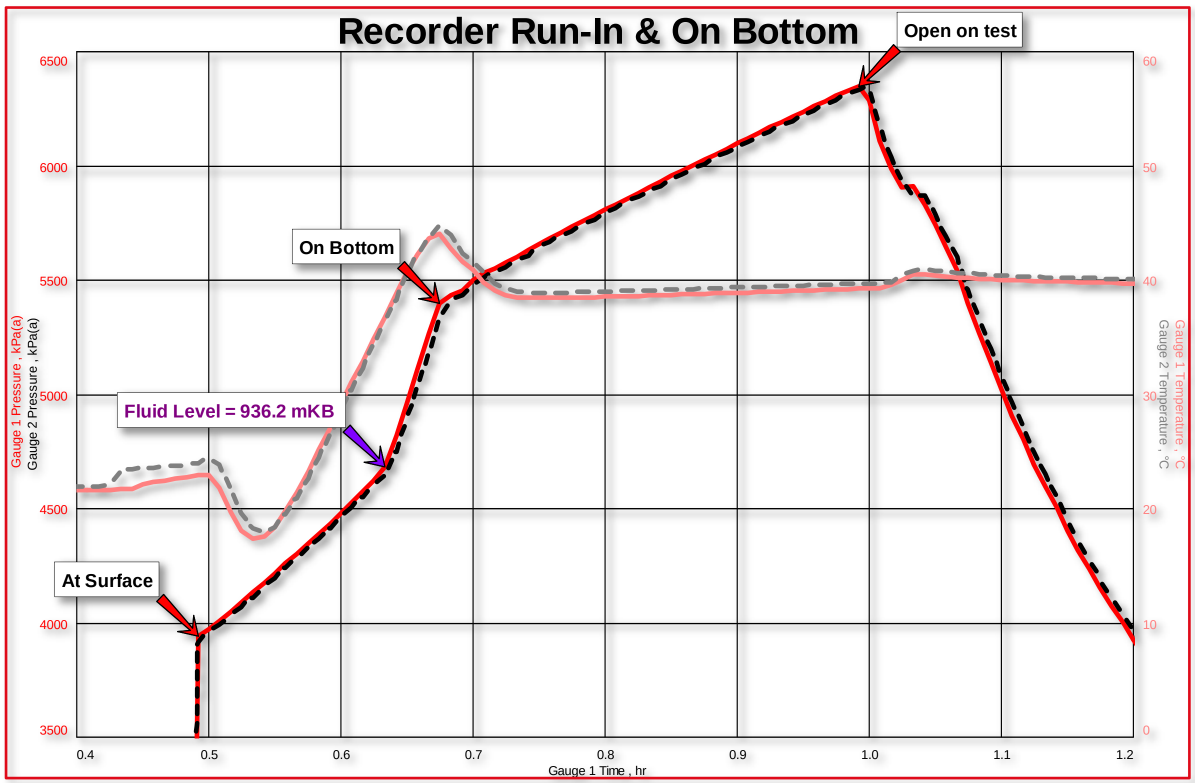
When recorders are run into a well they are measuring pressure vs. time (Δp/Δt). Liquid levels can be observed based on changes in the Δp/Δt slope. Approximate liquid levels can also be calculated assuming a constant running speed (Δd/Δt). This is close enough to qualify possible pressure gradients and magnitude of the initial measured pressure (i.e. the measured pressure may be low due to a liquid column between gauge RRD and MPP).

Obvious change in run-in slope defines liquid or fluid or emulsion level (m)

Approximate gas/emulsion interface can be calculated (m)

Approximate gas & emulsion gradients can be calculated (kPa/m)

Note that recorders were landed immersed in the liquid column so RRD to MPP increment was liquid



Running speed (m/s) can be estimated by the time difference between surface and on bottom. Interface depths (m) can be estimated, and fluid/gas gradients (kPa/m) can be calculated.

Recorders On Bottom

Initial Pressure

With recorders on bottom it is important to note the trend. If pressures are still building (as per plot, above), stabilized conditions have yet to be achieved. Pressures may drop if the zone is still over charged from kill fluids, over-balanced perforating, a fracture treatment, or if there is interference or communication. The best condition, for analytical purposes, is a flat, stabilized pressure trend yielding a valid estimate of initial reservoir pressure.

Purging Production Facilities

Wellbore Fluids

Most often the initial pressure is just *before purging* portable production test facilities. This operation usually causes one of two patterns. If the wellbore is gas filled, a characteristic drawdown spike occurs (∨). If there is liquid in the hole, the pressure may spike upwards (∧) due to increasing the liquid head between gauges and MPP (i.e. sucking liquid into the wellbore). Pattern is a good indicator of wellbore fluid composition.

Flow Testing

Important Events

Production testing, flow drawdown, is what sends pressure transients out into the reservoir. The flow test may be designed as a *single point* or *multi-point isochronal*. The final flowing pressure, immediately before shut-in for the extended pressure buildup, is a critical event. Multi-point tests may be done as a *modified isochronal*, with equal flow and shut-in sequences, or *flow-after-flow*, with equal flow sequences but no shut-in periods (i.e. for high permeability systems). The flowing (and shut-in) pressures, at each step, are also important events for multi-point tests.

Flowing Trends

Flowing pressures *increasing* might be due to the near wellbore region cleaning up or liquid loading. Flowing pressures *decreasing* usually indicates that stabilized conditions have yet to be achieved. Be cognizant of counteracting effects by comparing surface flowing data.

Pressure Buildup

Quality Control — Pressure buildup data should always be examined for quality control and anomalies.

Early-Time — Several phenomena might cause data anomalies shortly after shut-in. Phase redistribution (gas going back into solution) can cause a *hump* in the early-time data. Liquid fill-up can cause a *drop* in pressures (changing from gas above MPP to a liquid head). A falling liquid level may cause a sudden *increase* in pressures, as the column between recorders and MPP changes from liquid to gas.

Middle-Time — One might also observe liquid shifts well into the build-up. Other completion operations (i.e. on an up-hole zone) may affect the build-up, which could suggest communication behind pipe, across a packer, or through a leaking plug (not good).

Late-Time — Longer term one might see shut-in pressures start to *decline*, suggesting communication or interference from offset producing wells or isobaric pressure gradients due to drainage.

Temperature Data

Quality Control — Temperature data should also be examined for quality control and anomalies. Temperature data are a good indicator of wellbore and reservoir characteristics.

J-T Cooling — Joule-Thompson cooling usually dominates flowing temperatures in gas wells as a function of gas expansion through the perforations. If the magnitude of this cooling *decreases* (less cool, as illustrated above) then the near wellbore region might be cleaning up.

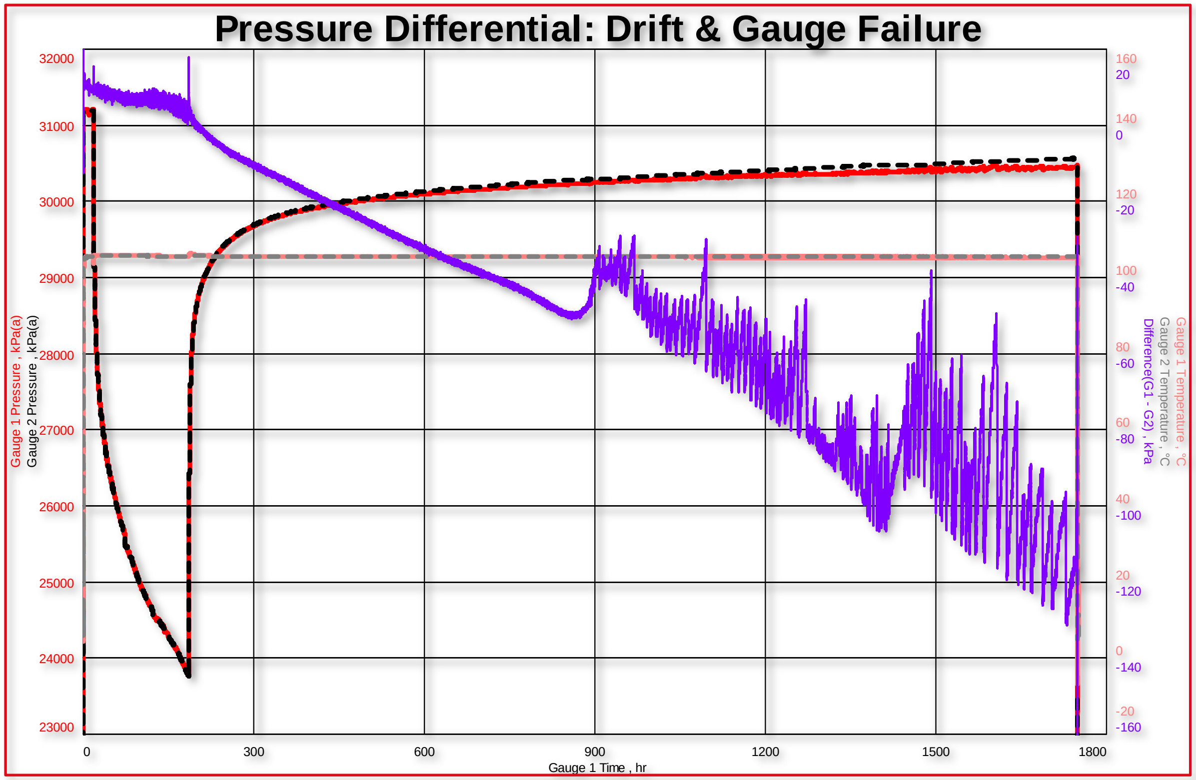
Warming — With recorders usually installed above the perforations, temperatures *warming* above landing temperature usually indicates liquid loading (i.e. liquid from the formation warms the gauges up). One anomaly to watch for immediately after shut-in is a spike in temperature indicating adiabatic heating (a gas compression phenomenon).

⇅ Differentials

Diagnostic

Differentials should be created for both pressure and temperature traces, for quality control and data validation. Liquid shifts are most clearly exhibited by differential diagnostics. Drift is evident from the differential. Every effort should be undertaken to identify an erroneous or malfunctioning recorder (pressure gauge).

Pressure differential data illustrate that recorded data were drifting apart before total failure of both gauges



This example is Cartesian plot type #2: relative to test pressures, X lowest measured flowing pressure (p_{wf}) to Y highest measured pressure, Y axis = 23,000 – 32,000 kPa.

Run-in & Reverse Gradients

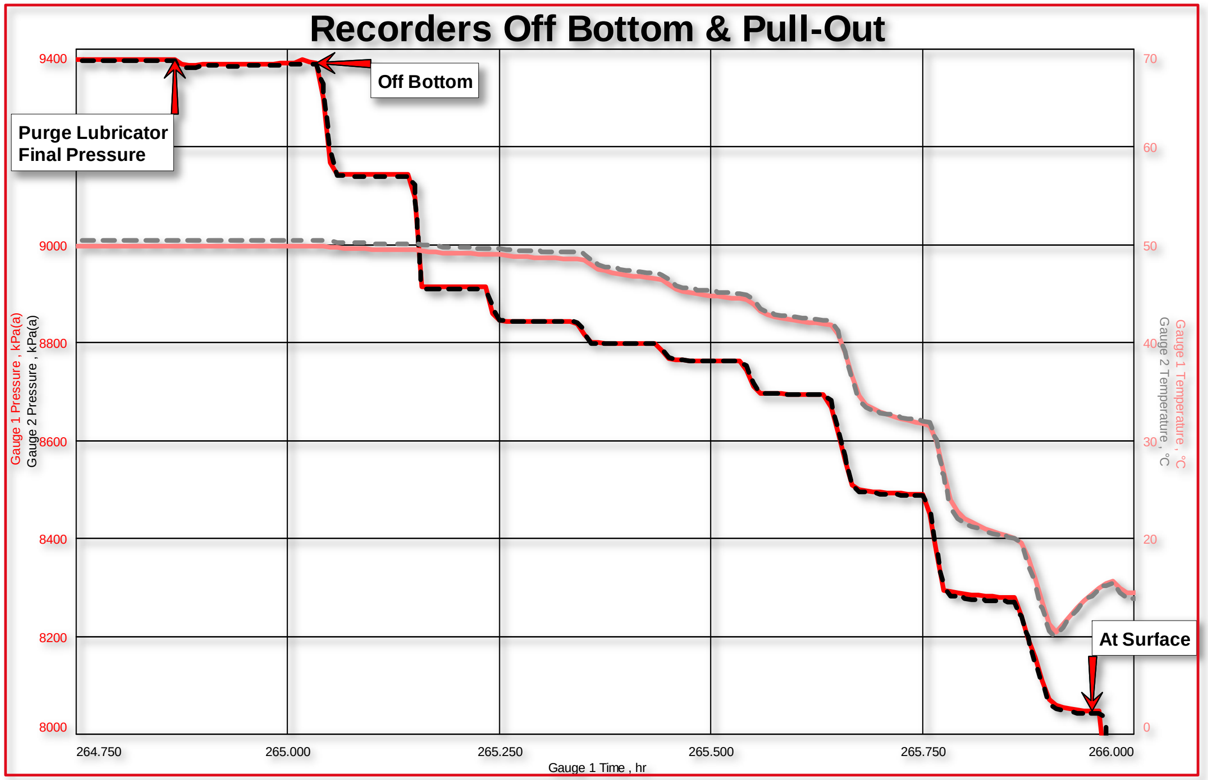
Incomplete Data

Sometimes a static gradient survey is conducted while running gauges into the well before they are left on bottom. Pulling a static gradient survey, at the end of the buildup, while recovering the recorders, is known as a reverse gradient. While these practices save a bit of money and time, they often miss critical information on wellbore fluid composition. Fluid gradient between Recorder Run Depth (RRD) and Mid-Point of Perforations (MPP) remains unknown. This can result in only a *partial liquid gradient being measured*.

Modern practice is to pull a reverse static gradient survey off bottom, while recovering pressure gauges

Reverse surveys do not measure gradients between RRD and MPP

Unknown increments can lead to some uncertainty and inaccuracy in analysis and engineering (PTA)



Purging the Lubricator

Final Pressure

The final test pressure should be taken immediately *prior to purging the lubricator,* since this operation causes a slight flow, effectively ending the buildup. Purging the lubricator at the end of the test is very much like purging production facilities: in a gas filled wellbore a downward spike (∨) occurs but if liquids are present an upward spike may occur (∧).

Conventional Static Gradients

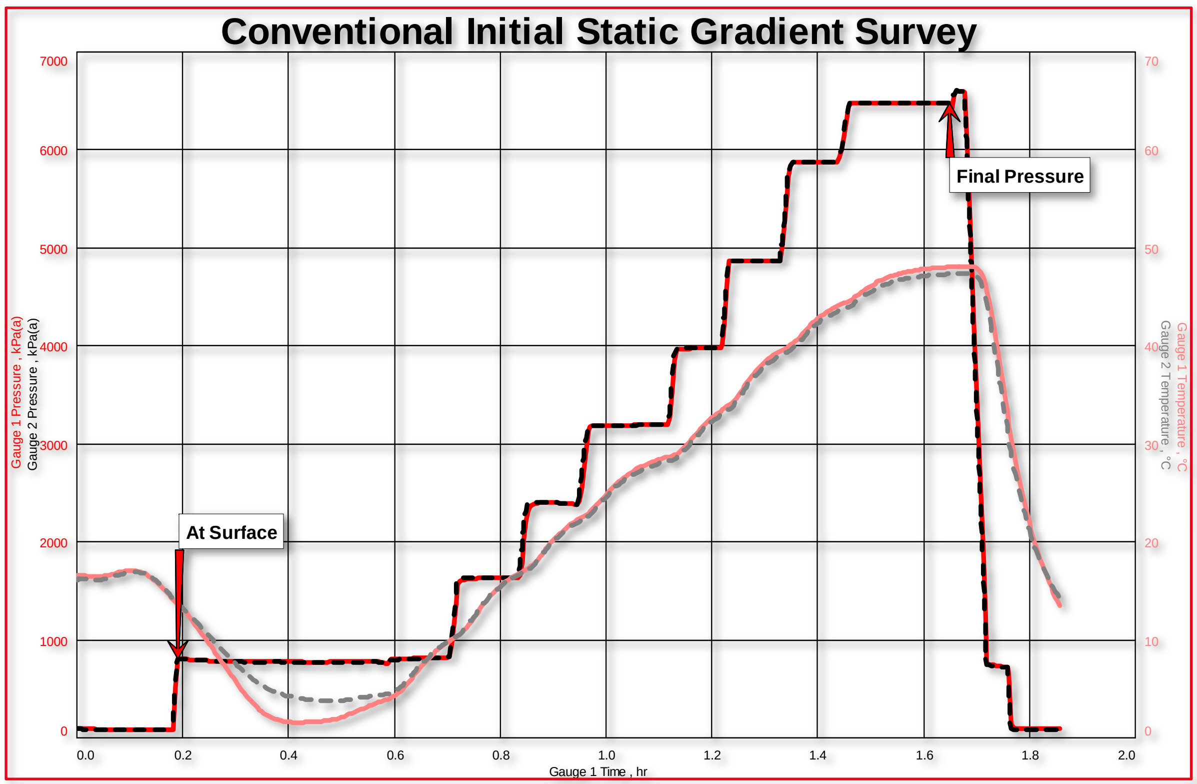
Definitive Data

Conventional static gradient surveys are run to MPP, often to PBTD, and definitively measure wellbore fluid interfaces and gradients. Conventional gradients are the preferred method.

Stand-alone conventional static gradient survey

Gradients from surface to MPP are measured

Gas, oil, and water were identified in this example test



Conventional Static Gradients

Definitive Data

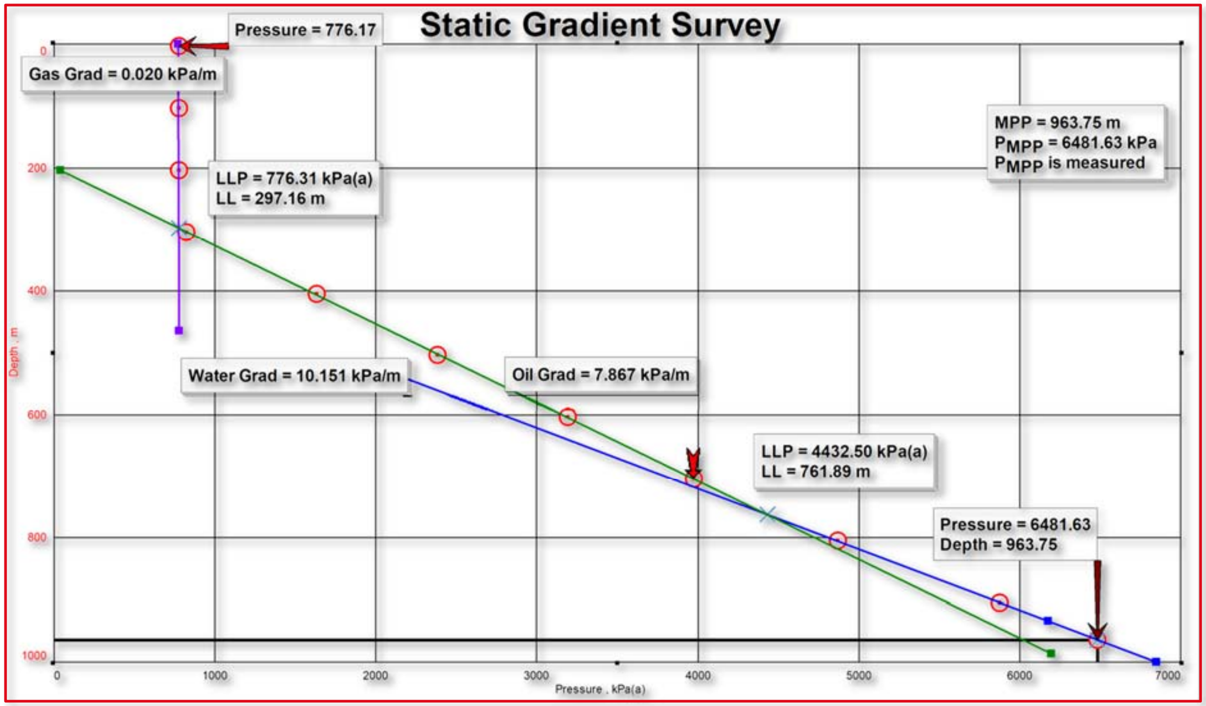
Continuing the example from above, this conventional static gradient survey clearly detected all three effluent columns, interfaces, and gradients: gas over oil over water.

Stand-alone conventional static gradient survey

Gas head to 300 m depth

Oil column to 760 m depth

Water to MPP at 964 m depth



Tubing & Casing Pressures

Hand-Held Gauge

Initial and final tubing and casing pressures are important for welltest engineering. Measurements help with quality control and can suggest annular liquid levels or possible gas composition differences between tubing and annulus (i.e. air in the casing— a volatile situation which must be rectified before tie-in).

Government Regulations

Regulatory Boards

In Canada, petroleum well testing is controlled by provincial boards, each with a variety of rules, regulations, and submission requirements:

1. Alberta Energy Regulator (AER, has also been known as ERCB & AEUB)
2. British Columbia Oil and Gas Commission (BC-OGC)
3. Saskatchewan Industry and Resources (SIR)

1 Alberta Requirements

Act & Regulations

Alberta has the most stringent requirements and one should be thoroughly familiar with Oil and Gas Conservation Act 151/71, AER published guides G3, G5, G40 and G60 as well as General Bulletins 2003-01, 2003-05, and especially 2003-15 (the PAS file mnemonic guide).

ERCB.pas Files

All wireline data, reports and pressure transient analyses (PTA) are required to be submitted to the AER, in electronic format, via their web site, as PAS files (pressure ASCII standard). The GRD.pas file supports gradient surveys while the TRG.pas file supports extended or flow and buildup tests (with or without PTA).

2 kPa/h Rule

There are numerous checks to validate the data. In particular, there is a check to verify if data can be submitted with or without PTA, known as the “2 kPa/h Rule”.

- Note that, to be submitted without PTA, G40 requires pressures building less than 2 kPa/h — but the Board’s computer has built-in leniency and checks for pressures building less than 2.5 kPa/h, to pass submission requirements.

- Stand-alone static gradient surveys are checked over the last 2 h on-bottom time for compliance with the 2 kPa/h rule.

- Extended tests and buildup tests are checked over the last 6 h on-bottom time for compliance with the 2 kPa/h rule.

Data Quality

Despite the Board’s attempts to ensure data quality, through computer validation checks, there are loopholes allowing false representation. All purchased AER.pas files should thus be reviewed by a qualified welltest interpretation and pressure transient analysis expert.

2 British Columbia Requirements

Regulations

All test data and applicable analyses must be submitted, as per requirements of Section 95 of the *Drilling and Production Regulation*. Well testing requirements are further detailed in Section 6.7 of the *British Columbia Oil and Gas Handbook*.

Submissions

Welltest submissions to the BC-OGC are via Zipped e-mail of PAS file data. Reports should be prepared by qualified welltest interpretation experts. Wireline data are documented on the Reservoir Pressure Survey Test Report (OGC-061-PST form).

3 Saskatchewan Requirements

Submissions

Welltest submissions to the SIR are still via paper copy. Absolute Open Flow (AOF) reports should be prepared by qualified welltest interpretation experts, with the accompanying ERCB-EG-32 form (predating AER.pas electronic files).

ⓘ Contact

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Wireline Nomenclature

Tubing	**Tools run on the tubing string by the service rig**
BHA	Bottom Hole Assembly, the collection of tools run at the end of the tubing string (packer, nipples, etc.).
Collar	Short, threaded, link, connecting two sections or lengths of drill pipe, casing, or tubing together.
Packer	Isolates upper/lower zones in dual completions. Includes a nipple profile in the on/off mechanism.
Sliding Sleeve	Can be opened or closed, allowing fluids to flow from the annulus up the tubing. Includes a profile.
Nipple	A short tool with an internal profile that specific tools can latch or lock in to (plugs, darts, etc.).
Profile	Designated such as D, S, W, R, X, XN, etc. For matching wireline tools (plugs, darts, etc.)
No-Go	The last item on the tubing string, with a narrow internal diameter, to prevent tools falling through.
Testing	**Wireline tools run into tubing for well testing purposes**
Gauge Ring	Hollow, open ring tool with specific diameter, run before any other tools, to be sure tubing is clear.
Collar Stop	Will lock into the space between tubing sections to hold or retain pressure recorders at run depth.
Dart	Will lock into a matching profile, to hold or retain pressure recorders at run depth.
Plug	Used to isolate lower and upper zones. Will lock into profiles or collars. See prong.
Prong	Part of the plug, run last, pulled first to open smaller holes to equalize, before pulling full-bore plug.
Recorders	**Tools run with the pressure recorder string**
Fishing Neck	At the top of the tool string, for separating from and leaving tools, or attaching to and recovering tools.
Bomb Wells	Secondary encasements, to hold recorders and protect them from sour gas, filled with inhibited fluid.
Hold-down	Attached above the tool string, to prevent high gas flow rates from blowing recorders up-hole.
Miscellaneous	**Other wireline tools used for running and recovering**
Sinker Bars	Heavy metal sections used simply for weight, to help gravity lower tools into wellbores through fluids.
Jars	Hydraulic or mechanical tools that can exert upward or downward "hammer-like" striking forces.
Overshot	Latches on to the top of the fishing neck to retrieve tools.
Wellhead	**Equipment attached to the wellhead**
BOP	Blow Out Preventer, to shut-in and control well flow, shearing the wire, if problems occur.
Lubricator	Several sections of pipe, above the BOP. For loading tool strings into, before running down-hole.
Stuffing Box	At the top of the lubricator, the wire runs through a pully, and a packing nut which holds pressure.
Weight Gauge	With pulley to direct wire to the stuffing box, measures weight on the tool string.
Truck	**Equipment on board the truck**
Counter	Measures wire length, to determine depth. Zeroed with tool string touching casing flange (CF).