PLT

STANDARD LENGTH
AND
SHORT COMPACT
PRODUCTION LOGGING TOOLSTRINGS

User Guide

For more information please refer to our manuals or contact sales@sondex.com.

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Sondex manufactures both standard length and short compact production logging strings. This user guide addresses the principles of measurement, logging operations and use of the data for both strings.

Functional Description

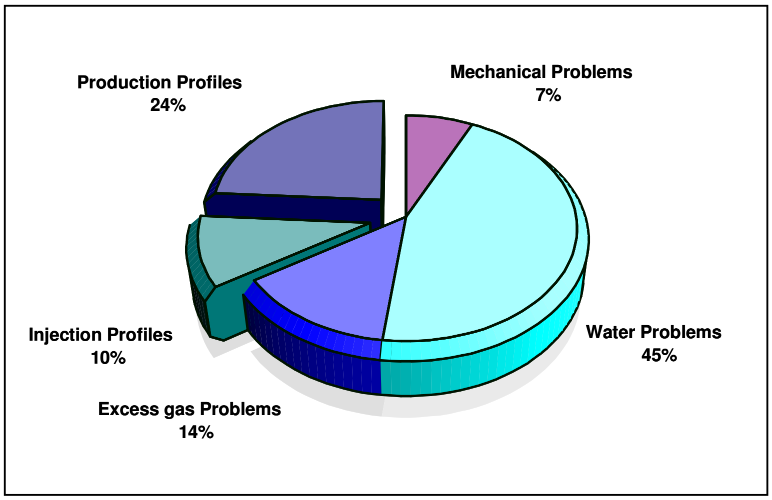
Production Logging Tools (PLT) are used to gather fluid data which is used by oil companies to maximize hydrocarbon recovery or manage fluid profiles for injection wells.

Log data is used to

- Identify producing zones and the fluids from them – oil, water, gas or mixtures.
- Detect leaks, low pressure zones or problem zones that require remedial work to repair the damage or block off zones
- Calculate qualitatively the flowrates of oil, gas and water from each producing zone
- Profile injection fluids - these are typically water or gas.

Production logging (PL) is an essential part of reservoir management. During the life of a field problems will occur that reduce oil or gas production, in many cases the wells are old and the reservoir is mature. PL information helps towards correcting these problems.

A typical breakdown of 100 logging operation analysed by the prime reasons for the job is illustrated below. Often there are secondary reasons.

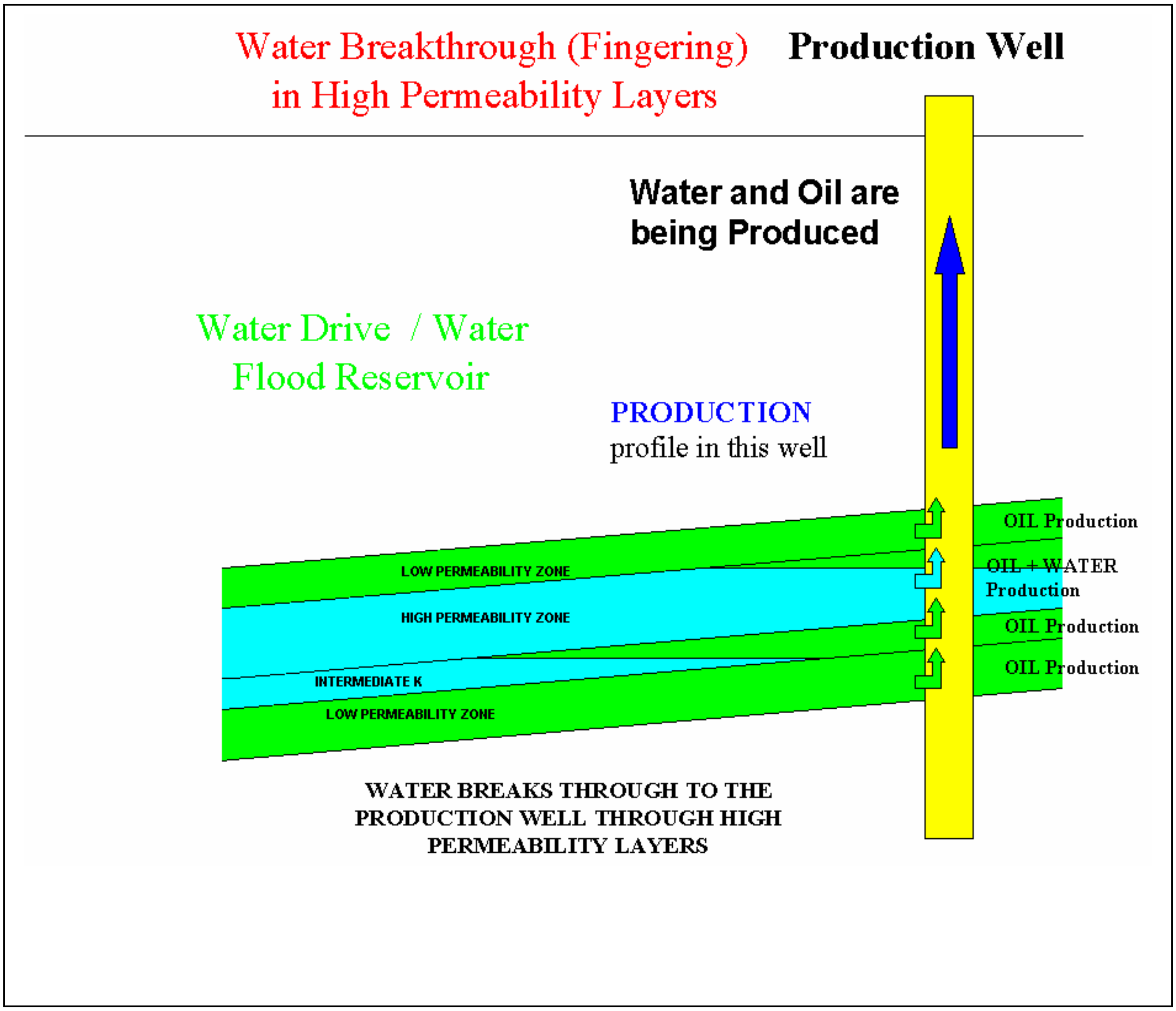


Production Profiling	To profile the well to check how it is performing against expectations. Includes the determination of layer pressure in multi zone wells.
Injection Profiling	To determine the injection profile of a water or gas injection well.
Water Problems	The majority of PL jobs are performed because large volumes of unwanted water are produced. Water production is very expensive because it limits hydrocarbon production and has to be treated and disposed of safely. Locating the source of the water production is vital towards planning remedial work in wells that produce water.
Excessive Gas Problems	This limits the flow of oil. In some cases this gas has to be flared which is a waste of energy and detrimental to the environment. Locating the source of the gas production is important when planning remedial work in these wells.
Mechanical Problems	Gross mechanical problems such as holes in tubing can be located using production logging tools. Leaks through damaged casing or tubing strings must be repaired. Blocked perforations can also be identified.

Example of water production due to fingering

In this example of a reservoir with strong water drive, the most permeable layers are depleting faster than the less permeable layers. As oil moves from the high permeability zone water replaces it and eventually flows into the wellbore resulting in reduced oil production. Water viscosity is lower than oil, as such it is produced preferentially which lowers the overall flowrate by loading up the well and causes disposal problems at surface. Production logging tools are used to identify from which perforated zones the water is coming from.

Subsequent remedial work to shut-off the water zone will increase the oil production from zones which remain open by allowing the bottom hole pressure to be lowered i.e. increase the drawdown.



Short Compact Production Logging Toolstring components.

The main elements of the Short Compact Toolstring (SCT) are the Quartz Pressure/CCL (QPC) tool and the Capacitance/Temperature/Flowmeter (CTF) tool. By combining multiple sensors the overall tool length is reduced compared to a standard length PLT string using similar sensors. Uing a shorter toolstring is particularly important in operations where rat-hole and rig-up height are critical such as tractor or coiled tubing logging and on very small platforms. The SCT is available in two sizes, $1^{11}/_{16}$in (43mm) OD and $1^{3}/_{8}$in (35mm) OD. The combination of sensors provide complementary information for wellbore fluid analysis.

Combined Pressure and CCL tool (QPC)

The **Quartz Gauge** measures changes in downhole flowing and shut-in pressures. This information indicates the efficiency of the well and performance of the reservoir. In the absence of a dedicated density tool it can also be used to estimate density.

The **CCL** sensor responds to changes in metal volume such as at casing joints, completion items or perforations. It is mainly used for depth correlation though can be used to detect holes and perforations.

Gamma Ray tool

Measures natural gamma ray radiation levels in the wellbore. Used for depth correlation, lithology and radioactive scale identification which is associated with water production.

Inline Spinner (ILS)

The ILS flowmeter is used as a back up flowmeter in conjunction with a CFS or CFB and when it is necessary to log in tubing and casing in one logging run. (combined with a fullbore flowmeter)

Density

Oil, water and gas have different densities. By measuring the overall density of the wellbore fluid the fraction or holdup of each phase can be calculated.

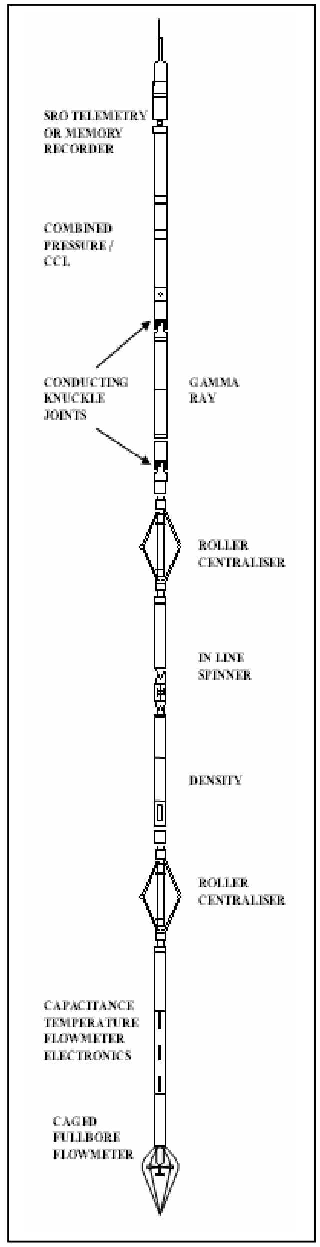
Combined Capacitance, Temperature and Flowmeter (CTF)

Oil, water and gas have different dielectric responses The **Capacitance** sensor responds to the dielectric properties of the fluids in the wellbore. The tool has different frequencies in gas, oil and water but it is principally used to measure the water fraction in the mixture.

The **Temperature** sensor responds to small temperature changes - indicating fluid movement inside and/or outside of the completion. Temperature changes can be used to qualitatively identify fluid type, volume and direction of flow.

The **Flowmeter** measures well fluid velocity using a turbine (spinner) impeller, the higher the fluid velocity, the faster the spinner rotates. Knowing the fluid velocity and tubing size, volumetric flowrate can be calculated. Spinner mechanical sections should be selected to suit completion size and fluid velocity. However in general, the largest spinner impeller that can be used will give the best results.

- ***Caged Fullbore Flowmeter:*** The spinner impeller is closed in tubing and opens up in casing to present a large diameter impeller, giving high sensitivity. It is protected by a springbow cage.
- ***Continuous Spinner Flowmeter:*** This spinner rotates continuously. It is typically used in tubing and in casing for high rate gas wells. It has roller bearings.
- ***Jewelled Spinner:*** This spinner rotates continuously. It has jeweled bearings which give superior performance at very high fluid velocity and in wells with sand or solids polluting the well fluids (which can jam up roller bearings).



The $1^{3}/_{8}$in (35mm) diameter SCT is recommended for small diameter tubing. There is a wide range of additional tools which can be run with the ultrawire SCT to enhance the results.

Standard Length Production Logging string components

Unlike the SCT, the standard length PL string consists of single sensor tools and is available with $1^{11}/_{16}$in (43mm) OD. Although the standard string is longer - 20.5ft (6.2m) compared to 16.2ft (4.9m) for the SCT - it offers greater flexibility of use.

Quartz Pressure gauge, QPS Measures changes in flowing and shut-in pressures, this information indicates the efficiency of the well and performance of the reservoir. In the absence of a dedicated density tool it can also be used to estimate density.

CCL The **CCL** sensor responds to changes in metal volume such as at casing joints, completion items or perforations. It is mainly used for depth correlation though can be used to detect holes and perforations.

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Temperature The **temperature** sensor responds to small temperature changes - indicating fluid movement inside and/or outside of the completion. Temperature changes can be used to qualitatively identify fluid type, volume and direction of flow.

Flowmeters The **flowmeter** measures well fluid velocity using a turbine (spinner) impeller, the higher the fluid velocity, the faster the spinner rotates. Knowing fluid velocity and tubing size, volumetric flowrate can be calculated. Spinner mechanical sections should be selected to suit completion size and fluid velocity. However in general, the largest spinner impeller that can be used will give the best results.

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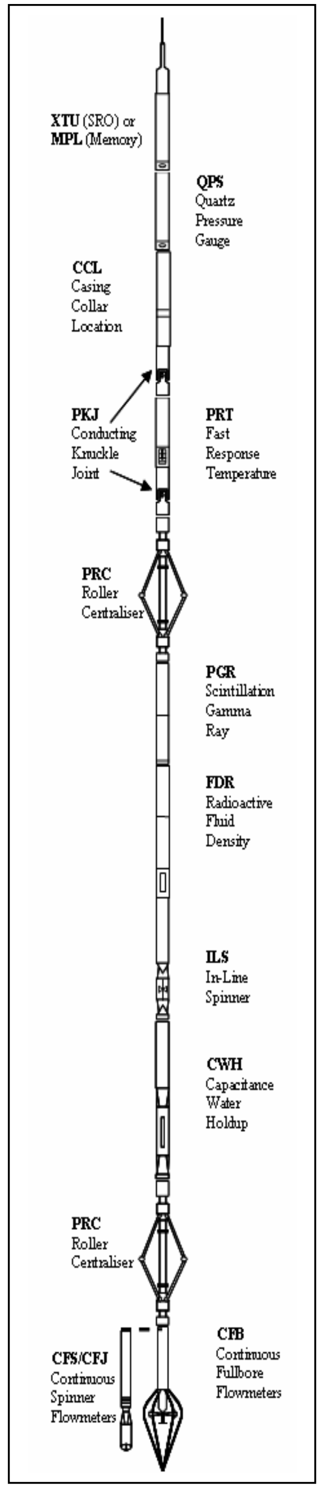


When running either the SCT or a standard PL toolstring some general points should be observed

- Deployment items such as centralisers, knuckle joints and swivel joints, are required as necessary.
- The spinner impellers and fluid ID tools should be run centralised.
- The flowmeter mechanical section should be selected to match the completion ID and make sure it will go through the minimum restriction in the well.
- The tools can be run in surface readout mode by adding a telemetry cartridge or, in memory mode by adding a memory recorder.

Key Points

Short Compact Toolstring:

- Uses combined sensor tools (QPC and CTF) to reduce overall toolstring length
- Available as 1 3/8" (35mm) and 1 11/16" (43mm) OD tools
- Are portable and have reduced rig up height
- The distance between sensors is reduced thus first readings are closer to the bottom of the logging interval
- Has fewer tool connections than a standard length PL toolstring
- Individual sensors on the QPC and CTF cannot be re-positioned or removed

Standard Length Toolstring:

- Uses separate tools
- $1^{11}/_{16}$in (43mm) tool diameter
- Separate tools offer more flexibility to configure toolstring but adds to the overall length.
- Overall length is approximately 4.5 ft (1.4 m) longer than the SCT.
- Has more tool connections than the SCT.
- Individual sensors can be re-positioned or removed.

Sensor Specifications

Sensor	Range	Accuracy	Resolution	Remarks
Quartz Crystal Pressure	16,000 psi	+/ - 3.2 psi	0.01 psi	Very accurate pressure measurements. Often perform better than specification.
CCL	Not applicable	Not applicable	Not applicable	
Gamma Ray	40,000 API	+ / - 5%	1 API	
Temperature	180 deg C	0.5 deg C	0.003 deg C	Response time better than 1 sec.
Density (Radioactive)	0-2 g/cc	0.02 g/cc	0.01 g/cc	Uses Am_{241} 150 mCi RA source
Density (Differential Pressure)	0-2 g/cc	0.03 g/cc	0.02 g/cc	Non radioactive. Pressure acts on two ports separated by a silicon fluid column inside the tool
Capacitance Water Holdup	0-100% water	Depends on holdup	1%	Optimum operating range 0-40% water holdup. Will work up to 100 % holdup but with reduced accuracy.
Flowmeter: Caged Full-bore	0-60 RPS	+/- 2 ft/min	0.1 RPS	Servicing is critical for optimum performance.
Flowmeter: Continuous Spinner	0-100 RPS	+/- 7-10 ft/min	0.1 RPS	Servicing is critical for optimum performance.
Flowmeter: Jewelled Spinner	0-115 RPS	+/- 7 ft/min	0.1 RPS	

Toolstring Dimensions (Typical toolstring):

Short Compact Toolstring:

Operating mode	Memory		Surface read-out	
Communication	Battery Housing/Memory Recorder		Cable Head/Telemetry crossover	
Combined sensors	Quartz Pressure / CCL		Quartz Pressure / CCL	
Ancillary	Knuckle Joint		Knuckle Joint	
Depth correlation	Gamma Ray		Gamma Ray	
Ancillary	Knuckle Joint		Knuckle Joint	
Ancillary	Centraliser		Centraliser	
Density	Radioactive Density		Radioactive Density	
Ancillary	Centraliser		Centraliser	
Combined sensors	Capacitance / Temperature / Flowmeter		Capacitance/Temperature/Flowmeter	
Length	17.0ft	5.2m	16.2ft	4.9m
Weight	81lbs	37kg	77lbs	35kg

Standard Length Toolstring

Operating mode	Memory		Surface read-out	
Communication	Battery Housing/Memory Recorder		Cable Head/Telemetry crossover	
Sensor 1	Pressure		Pressure	
Sensor 2	CCL		CCL	
Ancillary	Knuckle Joint		Knuckle Joint	
Sensor 3	Temperature		Temperature	
Ancillary	Knuckle Joint		Knuckle Joint	
Ancillary	Centraliser		Centraliser	
Sensor 4	Gamma Ray		Gamma Ray	
Sensor 5	Radioactive Density		Radioactive Density	
Sensor 6	Capacitance		Capacitance	
Ancillary	Centraliser		Centraliser	
Sensor 7	Caged Full-bore Flowmeter		Caged Full-bore Flowmeter	
Length	21.3ft	6.5m	20.5ft	6.2m
Weight	107lbs	49kg	103lbs	47kg

Example Production Logs

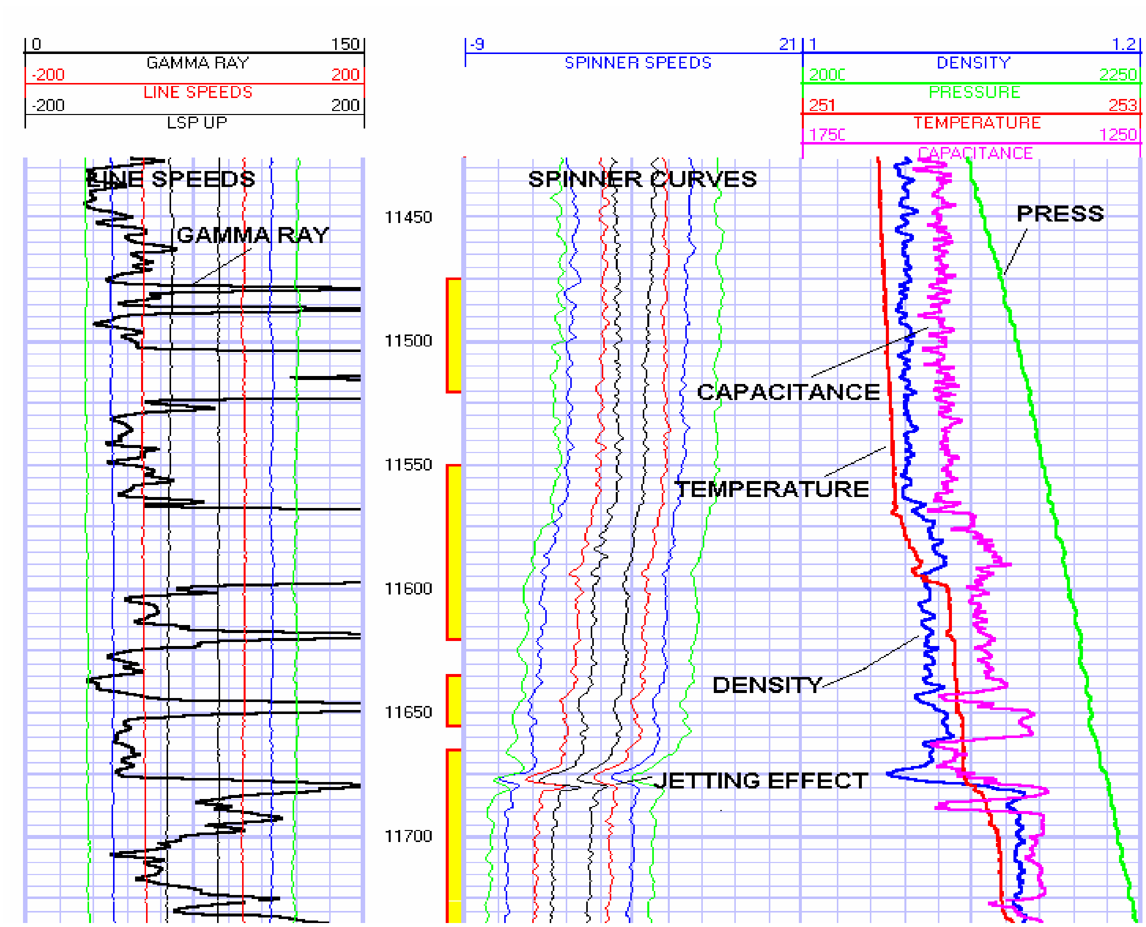
Example 1: Oil and water and production.

In this example, water production in an oil-producing well has increased reducing oil content per barrel of liquids produced at surface. Before designing a programme of remedial work the oil company decided to run a production logging survey to identify which perforated zones were producing high levels of water and should be plugged off.

The log, in Fig 1, is a composite log of spinner curves (all passes) plus other sensors (slowest down pass). The spinner flowmeter gives the inflow profile and the density and fluid capacitance curves indicate the oil-water mixture at different depths. These curves show high turbulence as you would expect from a flowing mixture of oil and water. Scales for sensor curves have been expanded to show small changes, e.g. density is scaled from 1.0 to 1.2 g/cc. Without high resolution tools it would be hard to detect these small changes. The temperature curve also indicates the points of inflow and the gamma ray curve shows localized high levels of radioactivity which (in this case) are associated with water production. The spinner curves show fast fluid entry from the high permeability layer – known as jetting effect – at 11680. The next stage is to perform a numerical analysis of the data at a log interpretation centre to determine the oil and water in-flow and water cut of each zone.

The interpretation of this well is shown on page 21 of this guide.

Fig 1. Composite PL log

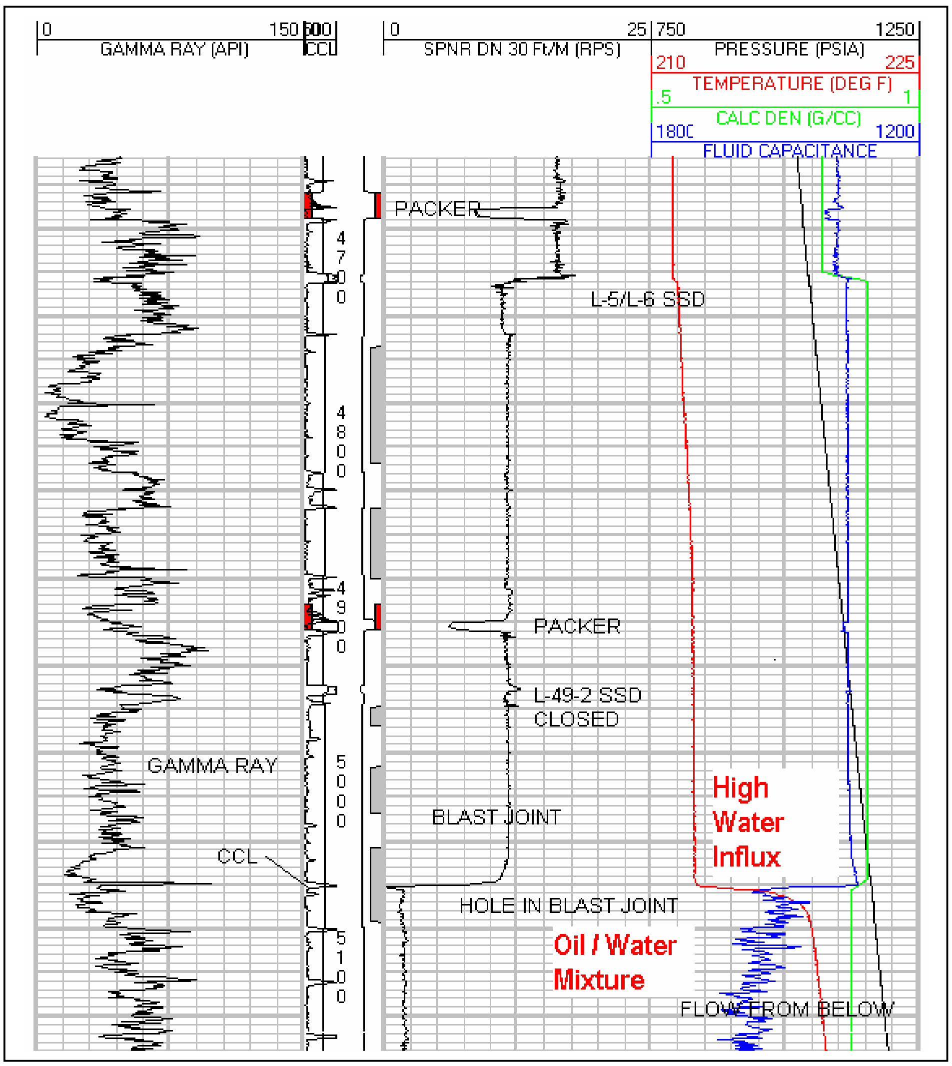


Example 2: High water production together with sand.

To shut off the water production in a well the sliding side door (SSD) at 4940ft was closed by slickline however the well continued to produced water. A production log was run confirm the status of the SSD. The log shows the SSD was closed but that there was a hole – caused by external sand erosion - in a blast joint at 5050ft adjacent to the perforations. The water cut of the flow through the hole was calculated to be 85%.

Although the total fluids produced from this zone had an oil cut of 15% this equated to 50% of the well's total oil production, therefore if the zone had been plugged to shut off the water this would have resulted in a significant reduction in oil produced at surface. The client decided not to carry out a remedial operation to patch the hole at this stage and to come back later when this zone has watered out fully (to be determined by production logging).

Example Log 2: Hole in blast joint



Sensor theory

Each of the sensors has a different principle of measurement.

Pressure: Wellbore fluid pressure acts directly on a quartz crystal which is oscillating at its natural frequency - changes in oscillation frequency are proportional to the changes in fluid pressure. Simultaneously well temperature also affects the frequency of the crystal, to compensate and correct temperature-associated changes a second temperature crystal is included within the gauge to measure the temperature of the pressure crystal but it is not exposed to well pressure.

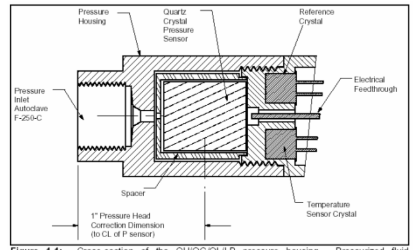
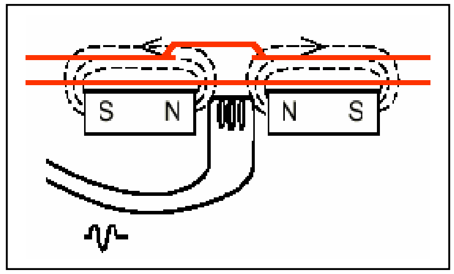


Figure 1-1: Cross-section of the QU/QG/QL/LP pressure housing. Pressurized fluid compresses the quartz pressure sensor, changing its frequency. The three quartz crystals are thermally coupled. The configuration of the 1XP and SXP is conceptually similar. In the TMC, the temperature sensor is co-located with the pressure sensor.

The reference crystal is used to reduce the output frequencies. In Sondex tools this crystal is also used to count the pressure and temperature frequencies enabling duplication of the original manufacturer's calibration accuracy.

An inconel bellows in the sensor arrangement acts to prevent well fluid contamination of the pressure crystal.

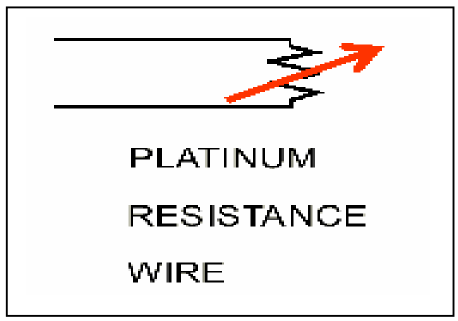
CCL: Two powerful magnets are positioned with opposite poles adjacent to each other, creating lines of magnetic flux which pass through the tool, tubing and a coil between the magnets.



When there is a change in metal volume the lines of magnetic flux are disturbed generating a small voltage in the coil which is converted to a frequency by a voltage-to-frequency converter.

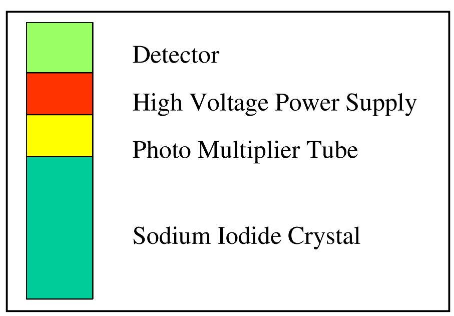
The CCL housing of the tool is non magnetic to prevent it effecting the measurement.

Temperature: A tiny platinum resistor sensor is enclosed in an Inconel probe needle exposed to the wellbore fluid. The resistance of the sensor is affected by temperature changes causing a voltage differential across the probe. This differential voltage is converted to a frequency and output as a temperature measurement. This measurement is then amplified electronically to give very high resolution.



The rapid response time of the sensor makes it able to detect tiny temperature changes. Therefore the tool has excellent resolution and is very accurate. The effects of changing line speed are minimised which allows for better temperature log overlays.

Scintillation Gamma Ray: When gamma rays from the formation or elsewhere strike the Sodium-Iodide crystal of the gamma ray detector photons of light are emitted (the crystal scintillates). The levels of light are very small so a photomultiplier tube (PMT) is used to amplify the signals to the level that they can be detected.

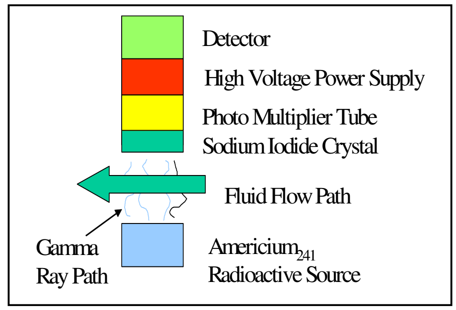


The detector circuit detects and filters the amplified signals which are then output from the tool as a gamma ray trace on the log.

The PMT requires a high voltage power supply to amplify the photons of light. The tool uses a large crystal.

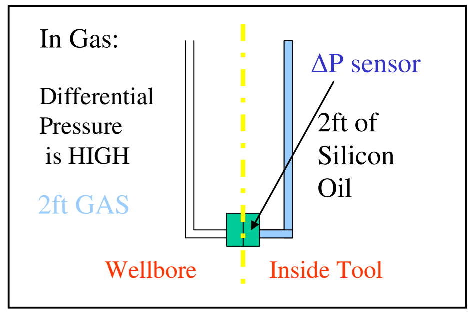
Sondex manufactures two types of density tool - Radioactive Density and Differential Pressure Density – both are described here.

Radioactive Density: Low energy gamma rays are emitted by a 150 mCi Americium$_{241}$ radioactive source in the bottom of the tool. The gamma rays are focused to cross a window through which the well fluids pass. Adjacent to the radioactive source is a scintillation gamma ray detector with the crystal designed to detect gamma rays from the source only.



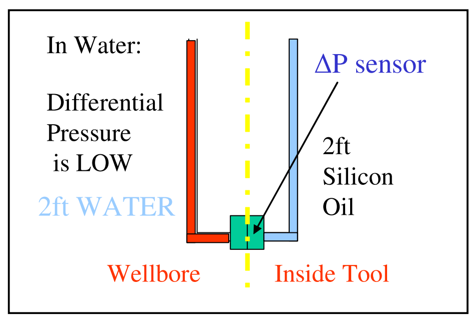
The number of gamma ray arrivals at the detector is in relation to the average density (photoelectric absorption) of the fluid. Thus low density fluids have a high number of arrivals and high density fluids a low number of arrivals. Fluid density can be calculated from the count rate using density/count rate calibration values.

Differential Pressure Density: The tool has two pressure ports that are 2ft apart and connected by a column of silicone oil, in effect it acts like a U-tube with silicon oil on one side and the wellbore fluids on the other. In the middle is a differential pressure transducer which is subject to the hydrostatic pressures of both fluid columns (silicone oil and wellbore).



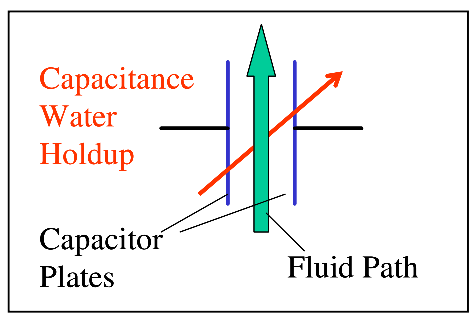
When the tool is in gas the transducer is exposed to gas pressure on one side and silicon oil pressure on the other. The difference between the two creates a high pressure differential across the sensor. However when the tool is in water the U tube is nearly balanced and the pressure differential is much lower than in gas. Thus by measuring the differential pressure calibrations can be applied to calculate the average density of wellbore fluids between the pressure ports of the tool.

As well inclination changes, the vertical spacing and hence hydrostatic pressure along 2ft of wellbore changes. In addition the silicon oil properties change with temperature and pressure. Therefore the tool has an on-board inclinometer and temperature sensor for data correction. Pressure for correction is from the quartz gauge.

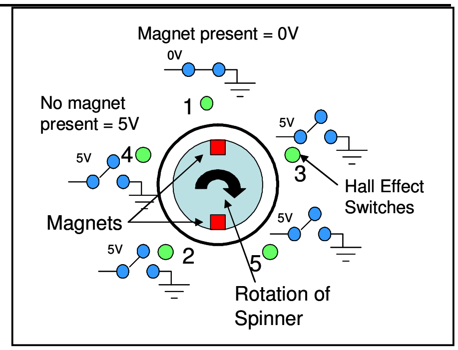


To prevent contamination of the silicon oil within the tool the tool employs water traps. A spring loaded pressure bypass is also fitted inside the tool to protect the transducer against differential pressure overload.

Capacitance: The capacitance tool is in effect an annular capacitor with the fluid passing through being the dielectric. The capacitor is charged up and when voltage reaches a certain level the voltage is switched back to zero to start charging up again. This causes an oscillation. The rate at which the capacitor charges up is in relation to the dielectric constant of the fluids passing through the tool. With hydrocarbons the capacitor charges up 'quickly' and so the frequency is high; with water the capacitor charges up 'slowly' and so the frequency is low.



Consequently the downhole hydrocarbon/water ratio can be determined from the output frequency together with a calibration chart. The tool is non linear in response to which phase (conducting or non conducting) is the dominant.



Flowmeter Sensor: Fluid movement passing the impeller in the spinner tool causes it to turn – this movement can be due to dynamic flow or the tool moving up and down the well.

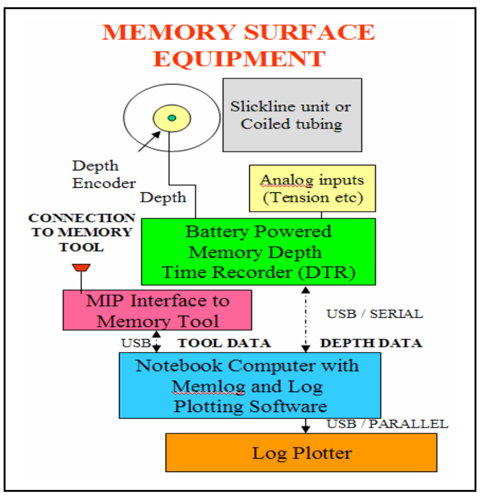
The flowmeter tool has 2 magnets on the spinner shaft and 5 Hall effect switches at 72 degree spacing. As the impeller rotates the magnets pass the Hall effect switches opening and closing the circuitry – when a magnet is adjacent to a switch the circuit is closed at 0V and when no magnet is present open at 5V. Therefore as the impeller rotates the switches are closed and opened at the rate of 10 pulses per rev. By counting the switching rate and the logic order of closing the switches the spinner rotation rate and direction can be measured.

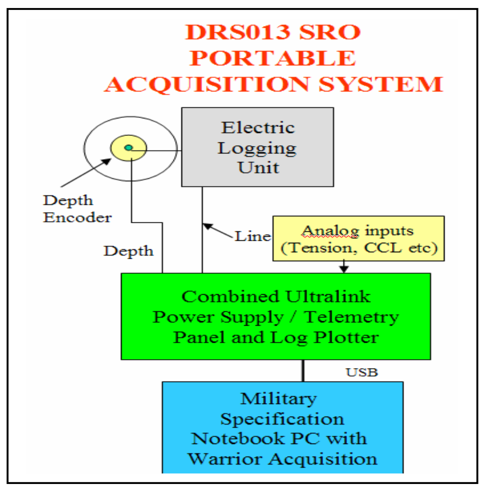
Telemetry

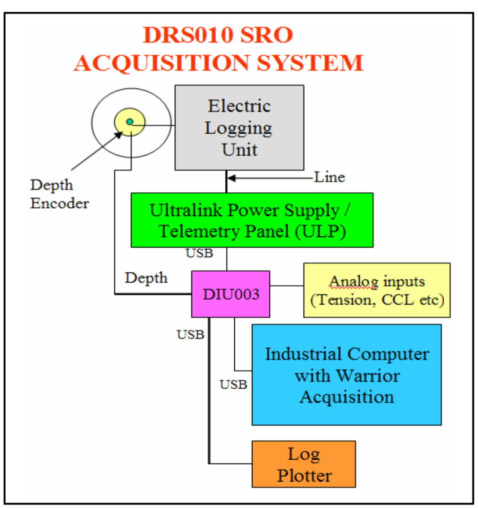
The tools operate on the Sondex UltraWire™ tool bus and are combinable with other tools using this telemetry system. UltraWire™ is an 18V fully digital telemetry consisting of 32 bit words at a rate of 500 kbps. For surface read-out (SRO) operations, an XTU telemetry controller is attached to the top of the string which crosses over to the UltraLink™ surface readout telemetry which is 190V and operates at a telemetry rate of 50-150 kbps.

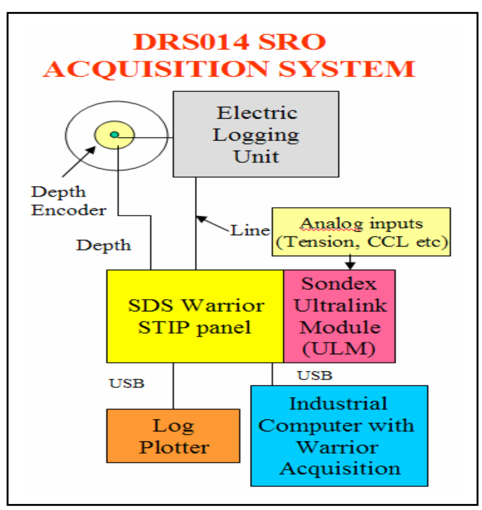
Acquisition systems

Sondex supplies a range of acquisition systems for surface communication with downhole tools and data processing. The 'hardware' is illustrated below:









Memory Surface Equipment: The memory tool is programmed and downloaded via a Memory Interface Panel (MIP). Depth, time and line speed are recorded by the battery powered Depth-Time Recorder (DTR). After the job the MIP and the DTR are downloaded and each data set merged to produce the logs.

DRS013 Portable SRO System: Depth pulses and tool data are fed into a portable combined depth, telemetry and log plotter panel. A Sondex modified version of SDS Warrior software is used to record, process the data and to plot logs. The logging computer is typically a high specification (ruggedized) Notebook PC.

DRS010 Rack Mount SRO System: Tool data is fed into a separate UltraLink™ telemetry panel. Depth pulses are fed into a separate Depth-Interface Unit (DIU) which also acts as a USB hub. A Sondex modified version of SDS Warrior software is used to record, process the data and to plot logs, the log plotter is separate. The logging computer is typically an industrial specification rack mount PC.

DRS014 SDS Warrior STIP Rack Mount SRO System: The SDS Warrior STIP panel can run a variety of different manufacturers tools. To run Sondex UltraWire™ tools a Sondex UltraLink™ Telemetry Module (ULM) is fitted within the STIP, when an UltraWire™ service is called up internal relays switch the line to the ULM. Depth pulses are fed into the STIP panel which also acts as a USB hub. The Sondex modified SDS Warrior software records and processes tool data which is plotted as logs. The log plotter is separate. The logging computer is typically an industrial specification rack mount PC.

Operations

The choice of Real-time or Memory data acquisition.

The client usually decides whether to perform surface read-out (SRO) or memory (MRO) operations. With surface read-out PL, sensor and depth data are acquired real-time and displayed on the surface logging acquisition system instantaneously. However, with memory operations the tool data and depth data are recorded and stored downhole in the memory module and once the logging survey is complete and the tools are returned to surface the data is downloaded, merged and processed.

Advantages of SRO PL operations: The major advantage is ability to see real time what is happening downhole and respond quickly, e.g. repeat logs can be carried out in zones of interest, tool status can be checked or on-the-spot decisions can be made to change the logging programme if the log curves give unexpected information. SRO is also preferred if rig time is expensive and if wells are very hot.

Advantages of Memory PL operations: The major advantage is that minimal equipment and logistics are needed which offers a significant cost saving. The tools may be deployed on non-conducting slickline or coiled tubing. Memory logging is easily facilitated because less equipment is required to be sent to the rig. Telemetry concerns in sour wells and where rig power is poor are mitigated because data is not sent uphole on the logging cable.

Memory logging offers easy start up for new service companies and fits in well with contracted coiled tubing and slickline services already in place. For high profile jobs two memory PLT strings may be run in tandem.

The logging program:

The oil company usually defines the logging program. However, before the job, well information (deviation, bottom hole pressure and temperature, tubing sizes etc) is required for planning purposes. The program will usually consist of a set of flowing logging passes and one or more shut in logging passes, if pressure build-up data is required the logging operation will contain extended time with the well shut in for a pressure build up.

It is safer to shut the well in for running the tools into the well and for pulling out of hole. However in some cases, particularly if there is a chance of “killing” the well or excessive flow re-stabilisation time, the oil company may elect to run in the hole with the well flowing. In this event great care should be taken. Usually multiple passes are made so as to calibrate the flow meter in-situ and to provide additional logging passes to help with the interpretation. The logging program will vary between a memory PLT job and a SRO job. With memory PLT the tools are in effect being run blind and it is not possible to confirm the correct operation of the tools. Therefore extra planning and precautions are needed.

An example logging program for a **Memory PLT operation** may be: (BTH = ‘Below Tubing Hanger’)

1) Conduct a toolbox safety meeting.
2) Shut in the well if required.

3) If required, remove the sub surface safety valve and lock out any other safety valves.
4) Rig up wireline pressure control with a drift string. Zero the tools at the tubing hanger.
5) Perform a drift run to PBTD using a gauge ring (gauge max OD must pass though completion min ID).
6) Tag the bottom of the well and write down wireline depth of PBTD. Bottom logging depth is __m above wireline PBTD. If necessary adjust the bottom depth of the subsequent logging interval. POOH.
7) Rig up the memory PLT string consisting of
   Battery-Memory section-Pressure-CCL-Knuckle Joint-Temperature-Knuckle Joint-Centraliser-Gamma Ray-Density-Fluid Capacitance-Centraliser-Flowmeter.
   Zero the tools at tubing hanger.
8) Open the swab valve and run in hole at a maximum 50m/min, slowing down to 10 m/min to pass through the gas lift valves and other completion items.
9) Stop at _____ m BTH and log down at 10m/min from _____m BTH to _____m BTH to record a Gamma Ray-CCL correlation log across the tail pipe (Optional).
10) Pick up slowly until the top centraliser tags end of tubing. This should be at _____ m BTH. If wireline depth is significantly different from completion depth, adjust the logging interval and logging station depths.
11) RIH to ______m BTH (the top of logging interval).
12) Open up the well to flow on the normal choke size watching tool weight carefully. Flow the well _____hrs monitoring production rates and wellhead pressure until they are stable.
13) Perform the flowing logging passes:
   Log down at 10m/min from _____ m BTH to _____ m BTH.
   Log up at 10m/min from _____ m BTH to _____ m BTH.
   Log down at 20m/min from _____ m BTH to _____ m BTH.
   Log up at 20m/min from _____ m BTH to _____ m BTH.
   Log down at 30m/min from _____ m BTH to _____ m BTH.
   Log up at 30m/min from _____ m BTH to _____ m BTH.
   Log down at 40m/min from _____ m BTH to _____ m BTH.
   Log up at 40m/min from _____ m BTH to _____ m BTH.
14) Perform the flowing logging stations above and below each perforation:
   Stop 5 minutes at ______m BTH
   Stop 5 minutes at ______m BTH
   Stop 5 minutes at ______m BTH
   Stop 5 minutes at ______m BTH
   Stop 5 minutes at ______m BTH
   POOH to m BTH
15) Shut In the well for ______hrs to record pressure build-up data. Note: If the well is free of sand production the client may elect to drop the tools to mid perforations or 10m below the bottom perfs before shutting in the well. This will minimize the effects of segregation in the wellbore and give better quality pressure data.
16) Perform the shut in logging passes:
   Log down at 10m/min from _____ m BTH to _____ m BTH.
   Log up at 10m/min from _____ m BTH to _____ m BTH.
   Log down at 20m/min from _____ m BTH to _____ m BTH.
   Log up at 20m/min from _____ m BTH to _____ m BTH.
   Log down at 30m/min from _____ m BTH to _____ m BTH.
   Log up at 30m/min from _____ m BTH to _____ m BTH.
   Log down at 40m/min from _____ m BTH to _____ m BTH.
   Log up at 40m/min from _____ m BTH to _____ m BTH.
17) Perform shut in logging stations above and below each perforation:
   Stop 5 minutes at ______m BTH
   Stop 5 minutes at ______m BTH
   Stop 5 minutes at ______m BTH
   Stop 5 minutes at ______m BTH
   Stop 5 minutes at ______m BTH
   POOH to _____m BTH
18) POOH at maximum 50 m/min slowing down to 10 m/min to re-enter the tubing (with the top of string at ______ m BTH) and to pass through the completion items. Watch the weight carefully for any signs of over-pull. Slow down just below safety valve depth and 50m below surface slow down to pass through the wellhead and to re-enter the lubricator. Check the tools are in the lubricator before closing the swab valve.
19) Rig down tools and check the PLT data before completing the rig down of pressure control equipment.

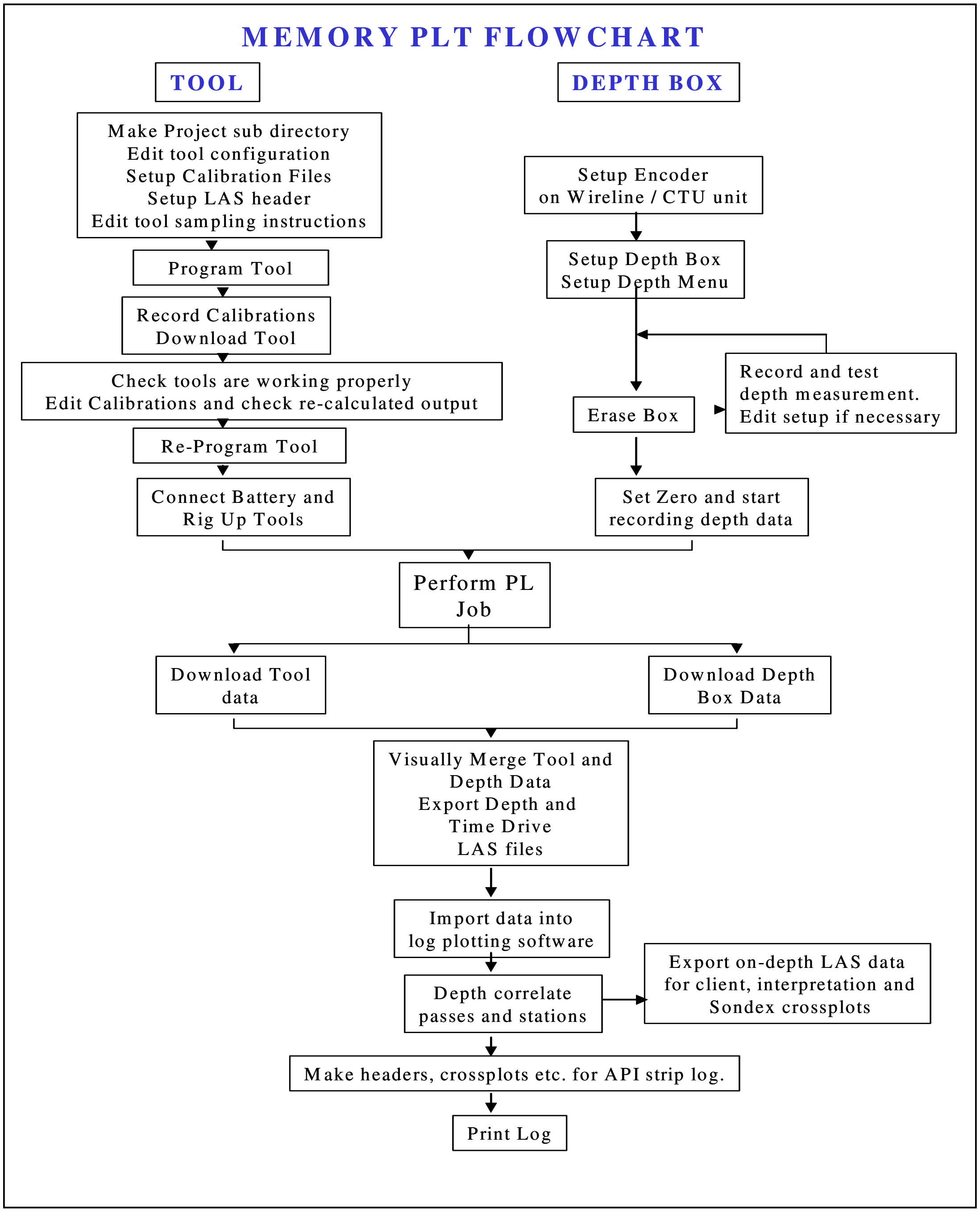
For **Surface Readout operations** the equivalent logging program would be**:**

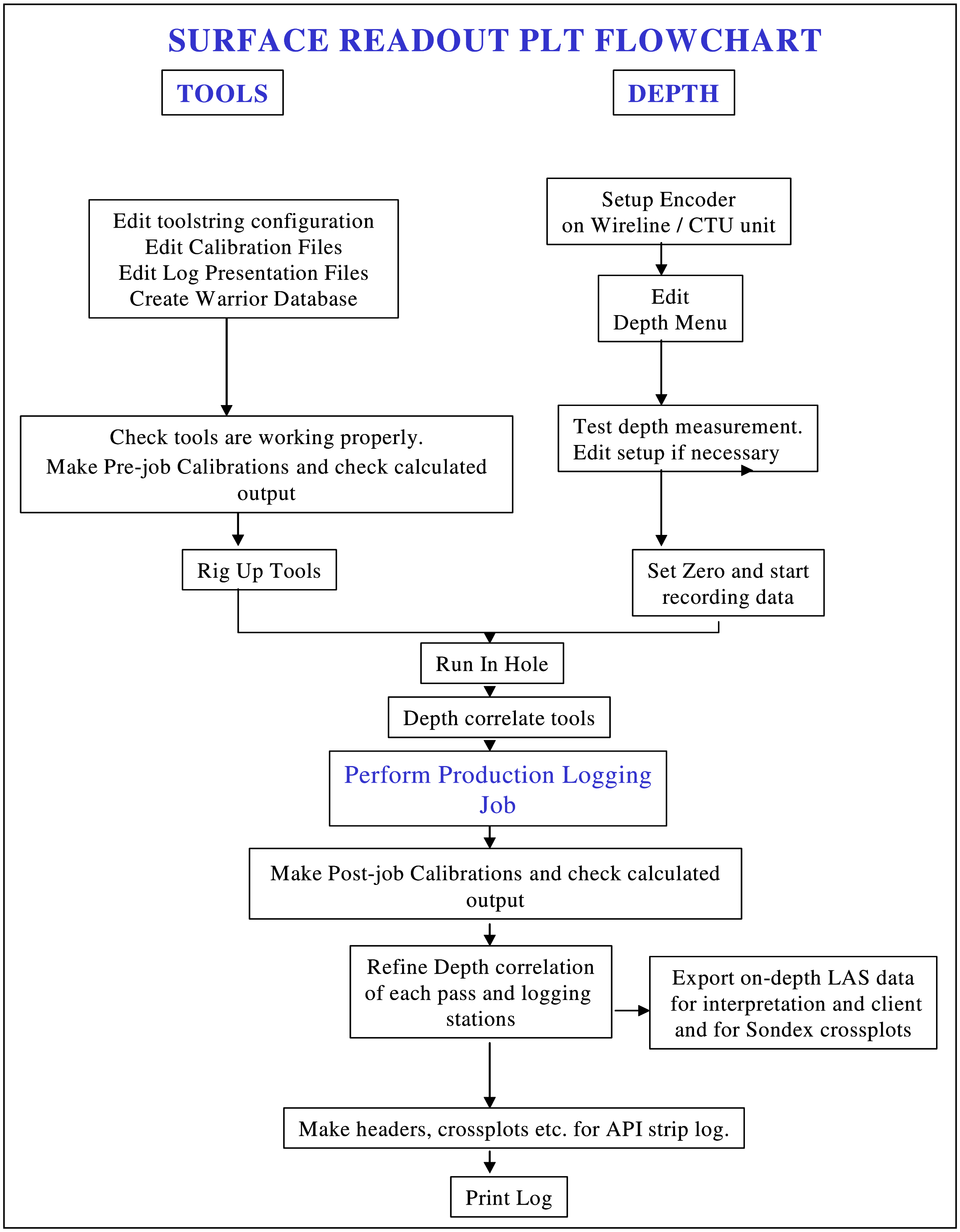
1) Conduct a toolbox safety meeting.
2) Shut in the well if required.
3) If required, remove the sub surface safety valve. Also lock out any other safety valves.
4) Rig up wireline pressure control with drift string. Zero the tools at the tubing hanger.
5) Perform a drift run to PBTD using a gauge ring (gauge max OD must pass through completion min ID).
6) Tag the bottom of the well and write down wireline depth of PBTD. Bottom logging depth is __m above wireline PBTD. If necessary adjust the bottom depth of the subsequent logging interval. POOH.
7) Rig up the PLT string consisting of
   Rope Socket, Telemetry Controller-Pressure-CCL-Knuckle Joint-Temperature-Knuckle Joint-Centraliser-Gamma Ray-Density-Fluid Capacitance-Centraliser-Flowmeter.
   Zero the tools at tubing hanger.
8) Open the swab valve and run in hole at a maximum 50m/min, slowing down to 10 m/min to pass through the gas lift valves and other completion items.
9) Exit the tubing and stop at a point in the well with good gamma ray character. Log up at 10m/min to record a log for depth correction.
10) By reference to the PLT GR/CCL log and original open hole log, correct the logging depth to match the original (master) log depth.
11) Pick up into the tubing. Stop at _____ m BTH and log down at 10m/min from _____m BTH to _____m BTH to record a gamma ray / CCL correlation log across the tail pipe (Optional).
12) RIH to ______m BTH (top of logging interval).
13) Open up the well to flow on the normal choke size watching tool weight carefully. Flow the well _____hrs monitoring production rates and wellhead pressure until they are stable.
14) Perform the flowing logging passes:
    Log down at 10m/min from _____m BTH to _____m BTH.
    Log up at 10m/min from _____m BTH to _____m BTH.
    Log down at 20m/min from _____m BTH to _____m BTH.
    Log up at 20m/min from _____m BTH to _____m BTH.
    Log down at 30m/min from _____m BTH to _____m BTH.
    Log up at 30m/min from _____m BTH to _____m BTH.
    Log down at 40m/min from _____m BTH to _____m BTH.
    Log up at 40m/min from _____m BTH to _____m BTH.
15) Perform the flowing logging stations above and below each perforation:
    Stop 5 minutes at ______m BTH
    Stop 5 minutes at ______m BTH
    Stop 5 minutes at ______m BTH
    Stop 5 minutes at ______m BTH
    Stop 5 minutes at ______m BTH
    POOH to m BTH
16) Shut In the well for ______hrs to record pressure build up data. Note: If the well is free of sand production the client may elect to drop the tools to mid perforations or 10m below the bottom perfs before shutting in the well. This will minimize the effects of segregation in the wellbore and give better quality pressure data.
17) Perform the shut in logging passes:
    Log down at 10m/min from ______m BTH to _____m BTH.
    Log up at 10m/min from _____m BTH to _____m BTH.
    Log down at 20m/min from _____m BTH to _____m BTH.
    Log up at 20m/min from _____m BTH to _____m BTH.
    Log down at 30m/min from _____m BTH to _____m BTH.
    Log up at 30m/min from _____m BTH to _____m BTH.
    Log down at 40m/min from _____m BTH to _____m BTH.
    Log up at 40m/min from _____m BTH to _____m BTH.
18) Perform shut in logging stations above and below each perforation:
    Stop 5 minutes at ______m BTH
    Stop 5 minutes at ______m BTH
    Stop 5 minutes at ______m BTH
    Stop 5 minutes at ______m BTH
    Stop 5 minutes at ______m BTH
    POOH to _____m BTH
19) POOH at maximum 50 m/min slowing down to 10 m/min to re-enter the tubing (with the top of string at ______ m BTH) and to pass through the completion items. Watch the weight carefully for any signs of

over-pull. Slow down just below safety valve depth and 50m below surface slow down to pass through the wellhead and to re-enter the lubricator. Check the tools are in the lubricator before closing the swab valve.

20) Rig down the tools and pressure control equipment.

Operations Flowcharts

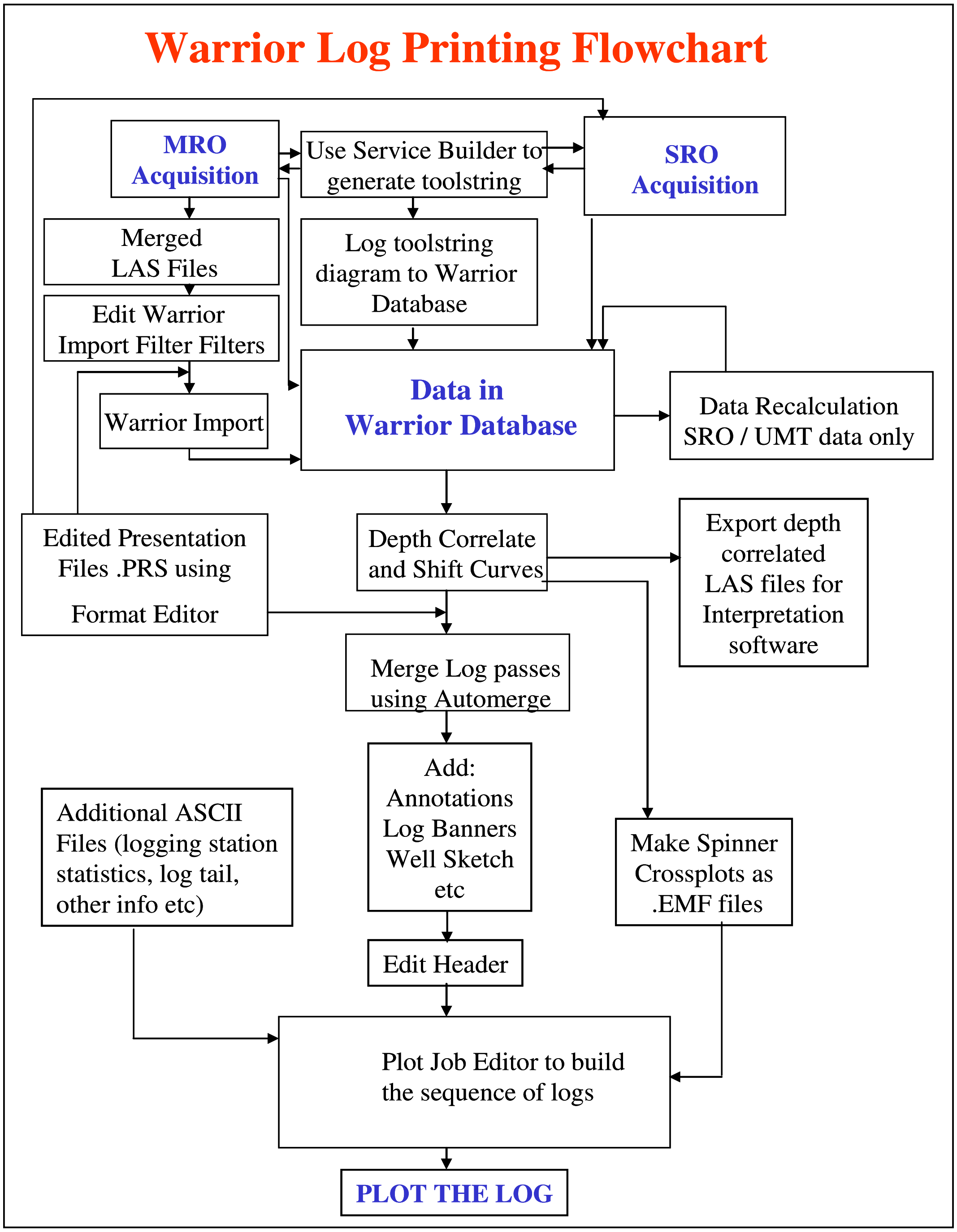




Software and Acquisition

- SRO PLT is performed using a Sondex modified version of the Windows® based Warrior software.
- Memory PLT is performed using Sondex Windows Memlog which programs the tools, merges the data and outputs the logging passes in LAS (Log ASCII Standard) format or directly into a Warrior database.
- LAS data read directly into the interpretation software.
- API strip logs can be plotted as using Warrior software or other strip log plotting software.

The generic software flowchart for producing logs with Warrior is illustrated below.



Calibration

The required calibration varies according to the tool type:

Tool Name	Required Calibration
Quartz Crystal Pressure	Drift is less than 3 psi/year. Not necessary to re-calibrate (see transducer manufacturers website www.quartzdyne.com) but can be checked against another quartz gauge for verification. If a tool is out of calibration it will be obvious to the operator. If the transducer needs re-calibration it is best to send it back to the manufacturer.

Gamma Ray	Calibrated with a 400 API calibration sleeve. The calibration should be checked every month. Some clients do not require a calibrated log.
Density	Calibrated before the job in air and fresh water. For the radioactive density tool additional calibration values for oil and salt water are measured or calculated.
Temperature	Sondex provide a multi point calibration. This is valid for the life of the tool.
Fluid Capacitance	Function checked before the job in air and water. Calibrated using downhole data to account for changes in fluid dielectric properties with pressure and temperature.
In-line Flowmeter	Calibrated in the downhole environment against line speed.
Fullbore Flowmeter	Calibrated in the downhole environment against line speed.
Jewelled Flowmeter	Calibrated in the downhole environment against line speed.
CCL	This does not need calibration. The log is scaled to match the response.

Using the tool data and interpretation

The principal **tools** used for production log interpretation are:

- The flowmeter to measure the total flowrate of the mixture in the well;
- The fluid identification tools (typically density and capacitance) to split up this flow into each of the phases (oil, gas and water). The fraction of each phase is known as its 'holdup'.

In addition:

- Temperature is used for a qualitative interpretation and to highlight inflow points.
- Pressure and temperature are used for PVT corrections to determine fluid properties and to correct from downhole volumes to surface volumes. An abnormally low or high flowing pressure may also indicate a problem.
- Gamma Ray and CCL are to position the logs on depth.
- When radioactive scale is present gamma ray indicates water production zones.
- Data from additional tools may be needed to improve the accuracy of the results. Especially in horizontal wells.
- Accurate wellhead flow rates are very useful as the calculated rates in 100% flow should match them.

In two phase flow only one fluid ID tool (typically density) is needed however it is recommend that a minimum of two fluid identification tools are run to compare responses. In 3 phase flow two fluid identification tools are needed (typically density and capacitance, however gas holdup can also be used).

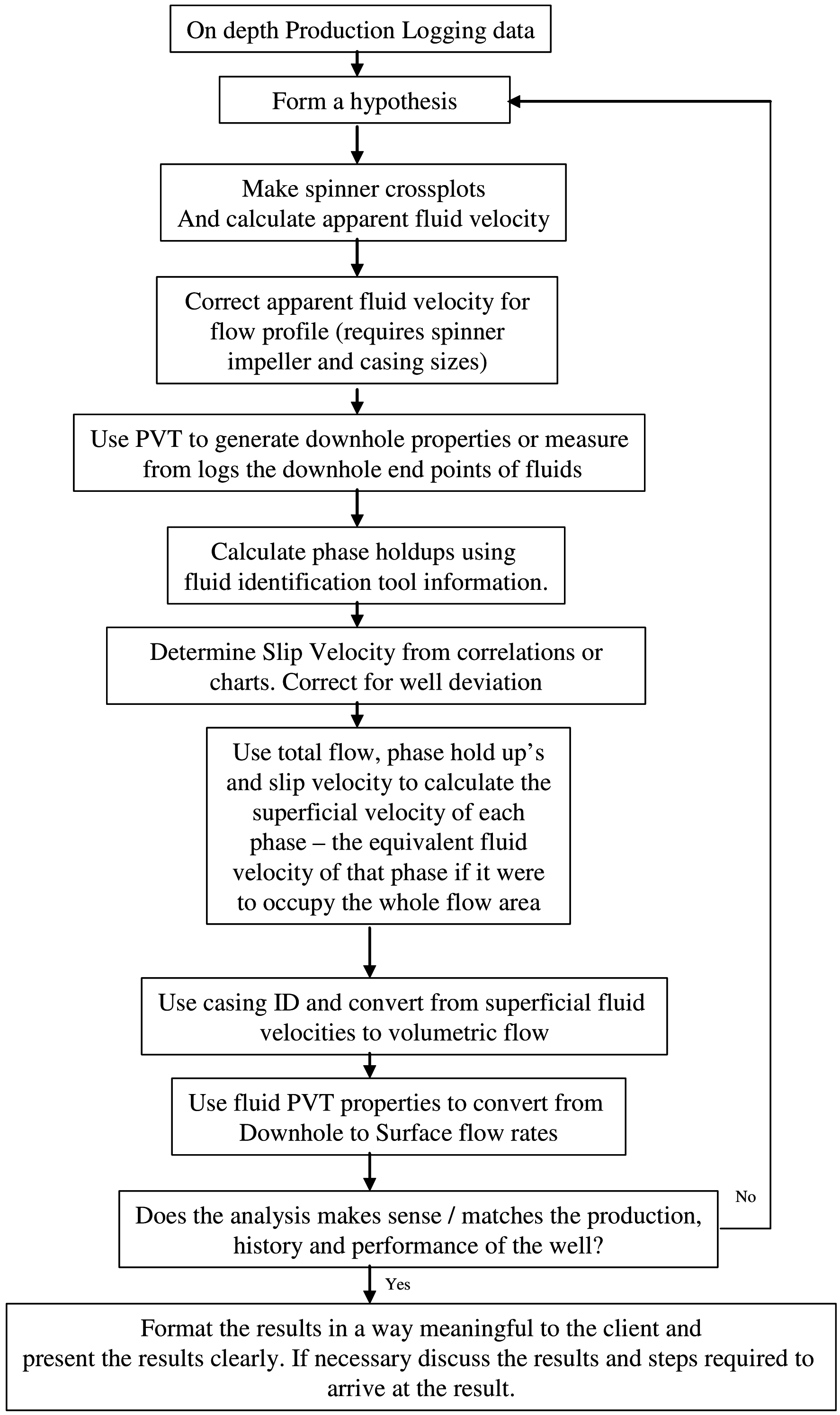
As a result of density differences the fluid phases will travel up the well at different speeds (e.g. oil will travel upwards faster than water) this needs to be corrected for in the final calculation. The relative speed of one phase to another is known as the slip velocity. Slip velocity values are generated from correlations applicable to different models and can be a potential source of error. Production wells are dynamic (the mixture and conditions are changing continuously) and the skill of the log interpreter is vital when analyzing the data and log curves – remember the interpreter performs the analysis and not the software.

Interpretation Flowchart

There are several PL analysis software packages on the market. They each have different strengths but the overall methods of the analyses are similar from one package to another.

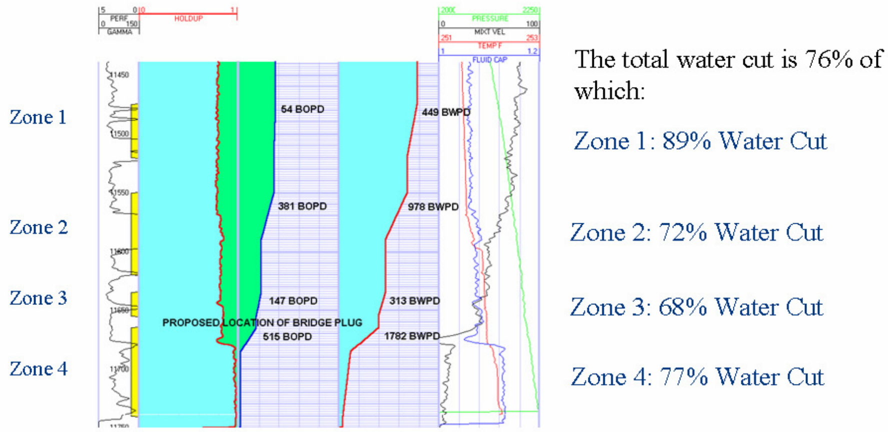
It is also possible to perform the analysis by hand as the mathematics are not complicated, but this is of course more time consuming and produces a non standardised report. However it does allow for adjusting the analysis to match a theory (which though not ideal, may be required due to limitations in how representative the measurements are).

Production Logging Interpretation Flowchart



Example interpretations:

PLT Example Results

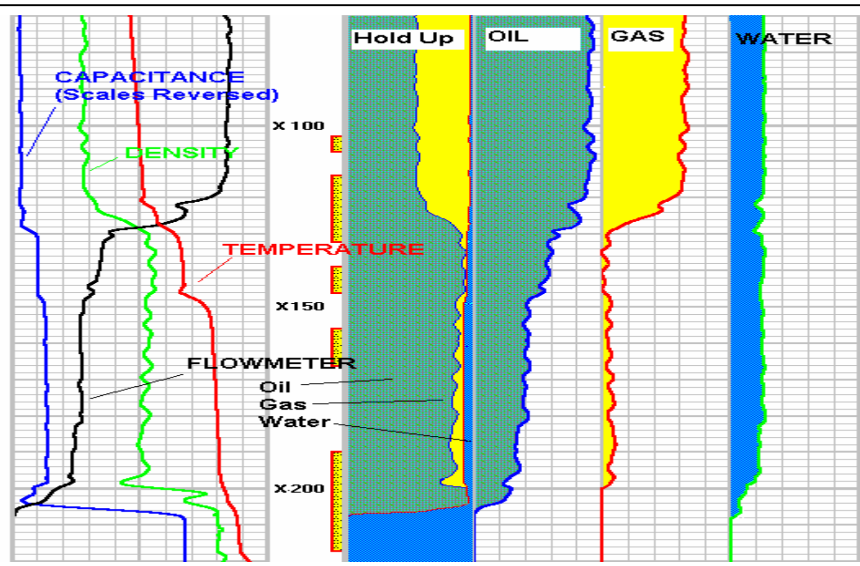


The PL job shows that if a bridge plug is set in the planned position at 11665ft then 515 BOPD from zone 4 will be lost and the well will continue to produce at 76% water cut – we recommend that the water shut off job is deferred and PL jobs are performed in the future to ascertain when the zone is watered out.

Example 3

Example 3: This is the interpretation of the data of **Example 1**. The client was planning to set a bridge plug to isolate the lowest zone which he believed had watered out. Before performing the remedial work a PL job was run as a check. The PL interpretation shows that the lowest zone is producing water but is still producing significant oil (46% of the well's total oil production) and that the other zones are producing both oil and water. It was decided to defer the remedial work until the lowest zone is fully watered out.

For this analysis of 2 phase flow (oil and water) the total flow is from the flowmeter and the individual phases have been split up using density data. The holdup track on the left is an illustration of the fraction of the wellbore occupied by each phase as derived from density.



Example 4

Example 4: This is an interpretation of a well flowing gas, oil and water. Although the well has several zones, the interpretation shows there to be a single reservoir with gas at the top, oil in the middle and water at the bottom. To interpret the well, first the flowmeter is used to determine total flowrate, then the capacitance tool is used to determine the water holdup (fraction) in the well, and finally knowing the water holdup we can use density data to determine the oil and gas holdups. At the top of the well it is easy to see the reduction in density when the gas enters the wellbore.

Additional tools

In some cases the interpretation of the data is not straightforward more ‘clues’ (input data) are needed to improve the chance of finding an accurate solution. Hence additional Sondex ultrawire tools can be run in addition to the tools already mentioned.

Diverter Basket Flowmeter for low rate wells.

Flowrate in wells is measured by fluid velocity. When the flow rate is low or the casing size large then the fluid velocity may drop to the level that it cannot reliably be measured by conventional spinners. One solution is increase the fluid velocity by reducing the available flow area. This is achieved by using a diverter flowmeter where a basket is opened downhole to divert the flow through a small ID spinner section; in this way flowrates as low as 25 BPD (4 m3/d) can be measured. After taking the measurement the basket is closed and re-opened at the next station.

Though this operation can be performed in memory mode it is best done in surface readout mode so as to check correct operation of the tool.

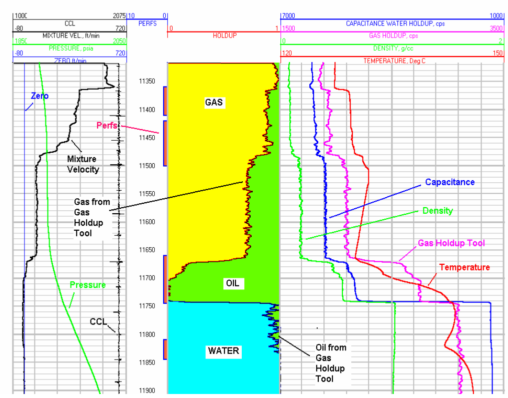
This tool can also be used to measure the true flowrate when spinner tools show anomalous downward flow in deviated wells due to phase segregation and fluid re-circulation.

DBT tool

Gas Hold-up Tool (GHT)

Traditional hold-up tools have a localized measurement. The Sondex Gas Hold-up Tool (GHT) is used to give an across wellbore gas hold-up measurement which is particularly useful in high gas to oil ratio wells where density tools do not have sufficient resolution or are affected by the high fluid velocities.

The principle of the tool is that a low energy Co_{57} source emits gamma rays that interact with well fluids, some are back scattered to the gamma ray detector in the tool. In this way fluid with high molecular density (such as oil and water) gives a high count rate and gas - which has low molecular density - gives a low count rate. A tungsten disk is used to prevent gamma rays traveling straight across to the detector. The energy level of the gamma rays is such that the properties of the fluids in the formation are not measured.



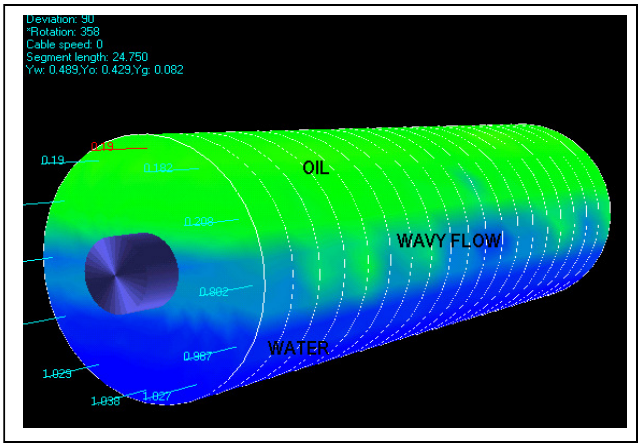
Holdup calculation from GHT data

Capacitance Array Tool (CAT)

Data interpretation in horizontal wells and high angle wells is very difficult because fluid phases may segregate, slug or re-circulate along the high angle section which can result in stratified flow. Conventional tools which measure the centre of the wellbore only measure flow properties in the middle of the wellbore and not what is at the top or bottom of the wellbore. Measurements across the wellbore are needed. The Capacitance Array Tool (CAT) has 12 micro-capacitance sensors deployed on bow-spring arms that open circumferentially around the wellbore. Each sensor measures localized fluid capacitance and hence individual phase hold-up. This can then be used to give a more accurate PL interpretation. The data may also be converted in to a 3D flow profile which visualizes how the fluids are moving along the well and helps to get the interpretation correct.

The software also generates the average holdups of oil, gas and water. Additional across wellbore PLT tools are under development please contact Sondex for more information.

This image below is from CAT data showing stratified wavy flow of oil and water in a horizontal well. Wavy flow is because one phase (in this case oil) is traveling significantly faster then the other.



Tool Maintenance

Basic levels of cleaning and general maintenance should be carried out on all Sondex production logging tools as described in the relevant tool manuals. If they are properly serviced and run carefully it is expected that tools will last a long time. Depending on the number and type of jobs the typical lifetime is between 5-8 years. Consumable spares are available as stock from Sondex.

The table below indicates some of the routine maintenance. Always consult the appropriate tool manual for servicing and maintenance requirements. Tools exposed to H_2S should be prepared in accordance with manual guidelines. Advice from Sondex may also be sought.

Tool	Routine Maintenance
Roller Centraliser	Change rollers as required. Inject grease through grease ports. Change ‘O’ rings.
Knuckle Joints	Inject grease through grease ports.
Swivel Joint	Change ‘O’ rings. Refill with silicon oil as required.
Quartz Crystal Pressure	Refill the chamber around the bellows with silicon oil. Change ‘O’ rings.
CCL	Change ‘O’ rings.
Gamma Ray	Change ‘O’ rings.
Temperature	Change ‘O’ rings. Keep the probe clean.
Density (Radioactive)	Change ‘O’ rings.
Density (Differential Pressure)	Drain and refill the tool with silicon oil between jobs. Use a vacuum pump for the servicing.
Capacitance	Change ‘O’ rings. Clean inner probe.
Flowmeter: Caged Fullbore	Change bearings as required. Blow on impeller to check it turns freely. Refill oil.
Flowmeter: Continuous Spinner	Change bearings as required. Blow on impeller to check it turns freely. Refill oil.
In Line Spinner	Change bearings as required. Blow on impeller to check it turns freely. Refill oil.
Flowmeter: Jeweled Spinner	Adjust and change bearings as required. Blow on impeller to check it turns freely.

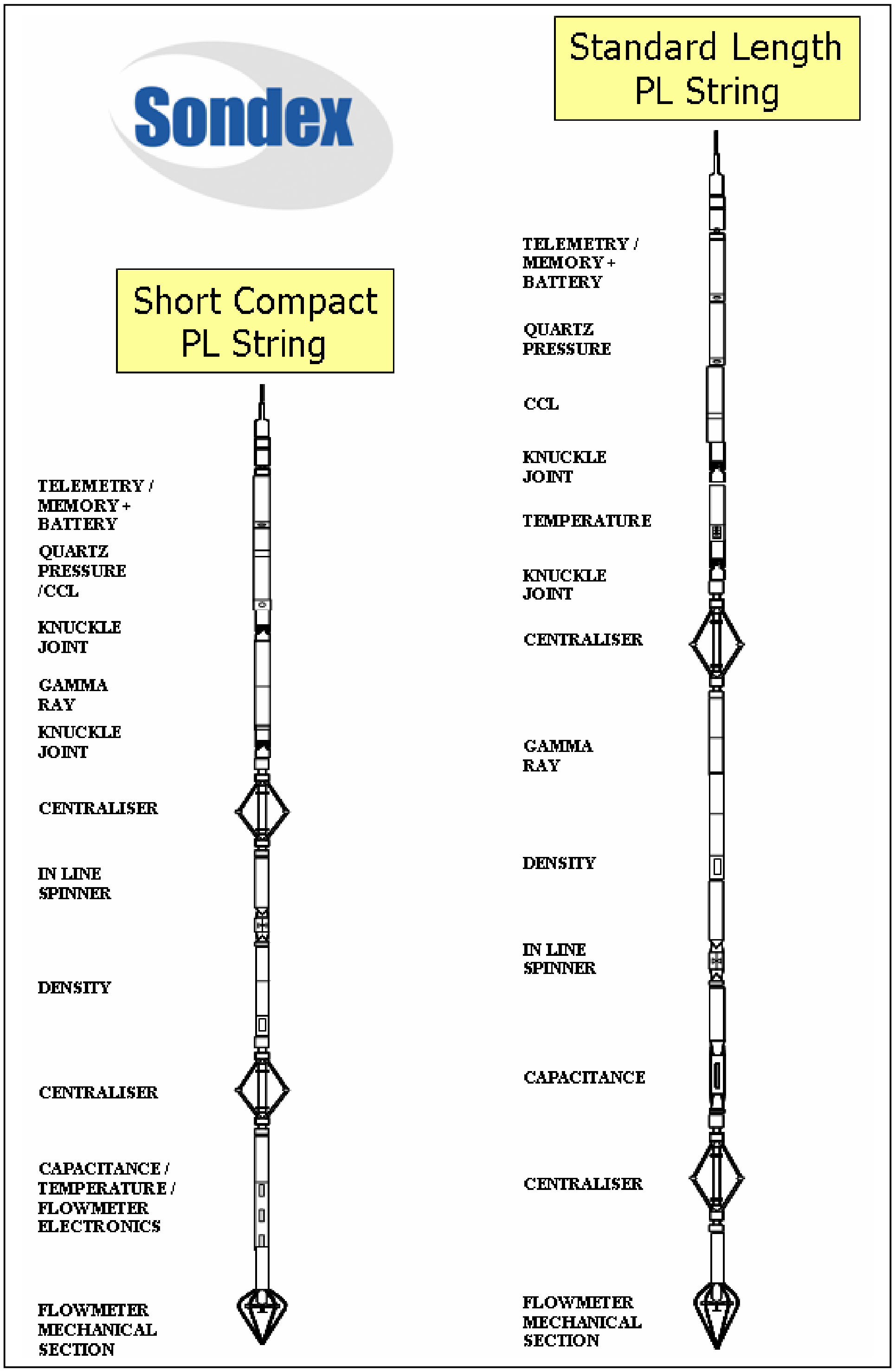
Storage and transport

The tools should be stored and transported in foam lined protective casing with the Sondex watertight end caps fitted. Protect the tools from shock as much as possible. For long periods of storage, lightly oil the tools with WD40 to prevent possible corrosion. Tools exposed to H_2S should be cleaned with fresh water and allowed to ‘breathe’ for several hours.

For individual tools:

Tool	Storage / Transport
Quartz Crystal Pressure/CCL	After filling with silicon oil fit a blanking screw to the pressure port.
Gamma Ray	Do not store near the CCL.
Density (Radioactive)	Do not store near the CCL. Follow radioactive source safety procedures.
Density (Differential Pressure)	Open transport/bypass screw, close pressure port screws. Store in carry tube.

Illustration of the make up of Sondex
Short Compact and Standard Length PL Strings



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