Cased Hole Reservoir Layer Pressure

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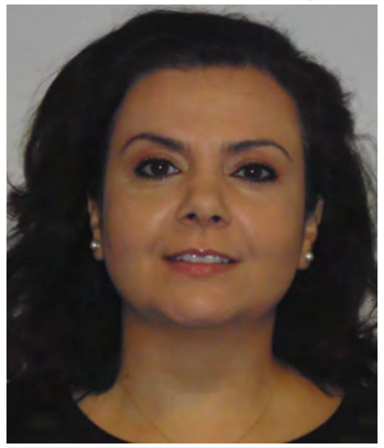

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One of the most critical measurements for reservoir management is that of formation layer pressure. Various methods are employed to determine reservoir pressure however many techniques only measure average reservoir pressure and should not be used for multi-zone reservoirs that are differentially depleted. Multi-rate PLT method is used to measure formation pressure across individual perforation intervals, but the assumptions that all fluid exiting / entering a perforation interval is confined to a particular unit (i.e. there is no fluid redistribution behind pipe) and uncertainties in unit thickness can result in significant errors. Triple Rate Spectral Noise Log method (TSNL), measures the pressure for each active layer independently, regardless of behind pipe fluid redistribution. TSNL, is based on the same hydraulic diffusivity equations as multi-rate PLT method but uses reservoir flow Noise Powers (NP) instead of trans-perforation flow rates (Q). This means that flowing reservoir units are evaluated independently even when fluid from multiple layers commingle to the same perforation intervals. Furthermore SNL directly measures effective formation (flowing) thicknesses behind pipe[1], which is an important input for the technique and also enables assessment of reservoir performance and helps refine estimation of reserves.

Triple Rate SNL (TSNL) Technology

SNL-HD is a passive tool, comprising of a battery, electronics and hydrophone with unrivalled sensitivity. The tool records the frequencies and amplitudes of acoustic energy associated with movement of fluid. Frequencies in range of 8 to 58,500 Hz are recorded in 115 Hz wide bands (512 channels). Each band has its own specific noise intensity. The tools dynamic range is 90 dB. This means that even when certain frequencies are very intense the less intense frequencies are not masked. The frequency bands and associated intensities / amplitudes for each station depth are then displayed on a SNL data panel (see figure 1).

Analysis of the data panel provides insight to the origin and character of fluid flow. The frequency of fluid movement is inversely proportional to the size, or aperture, of the flow path. For example, flow through large pores generates lower frequency noise than flow through small pores. Flow through open pipe will generate lower frequencies than that through a fracture. This principle enables High Definition Spectral Noise Tool (SNL-HD) to distinguish between the different sources and pathways of fluid movement, so commingled channelling and borehole noise can be separated from actual formation layer noise. The noise pattern geometry helps reveal the source of the noise; reservoir noise is characterized by wide frequency range streaks over discrete depth intervals, while borehole or cement channelling noise have much lower frequencies, narrower frequency range and are tracked over long depth intervals (parallel with wellbore).

The SNL-HD panel shows noise data in three dimensions: Depth, Frequency and Amplitude. Figure 1 illustrates noise acquired by SNL-HD for different fluid movement pathways. Displaying the SNL-HD data like this means that the noise associated with individual unit reservoir flow can be distinguished from that associated with the commingled borehole and cement channelling noise, allowing for each layer to be assessed independently[2]. The intensity (amplitude) of fluid flow noise is directly proportional to the product of flow rate and differential pressure. These relationships that determine frequency and intensity form the basis of TSNL technique.

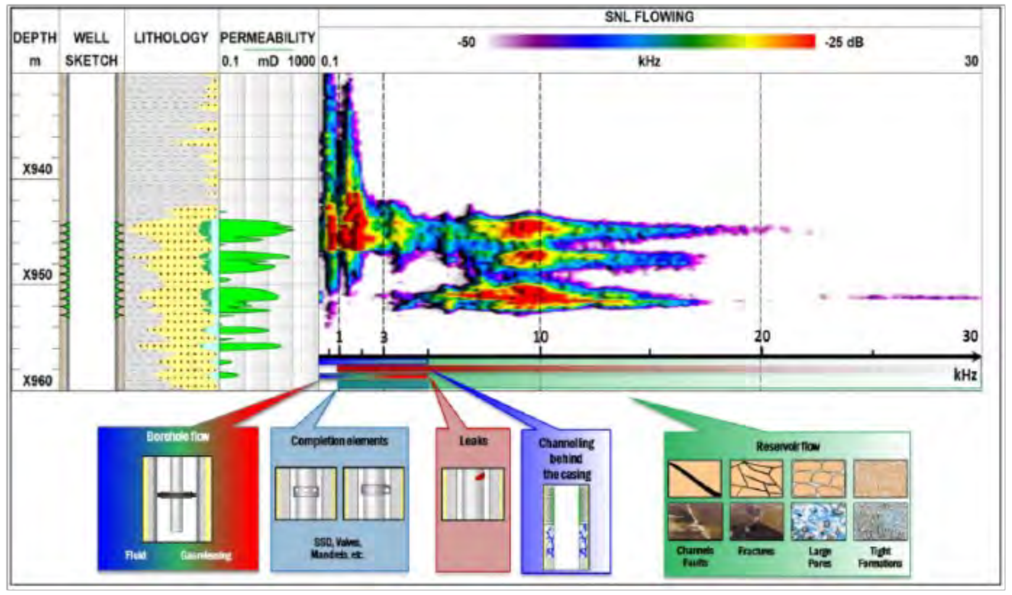

Figure 1 SNL-HD Interpretation Fundamentals

TSNL Concept of Measurement

This technique uses hydraulic diffusivity equations in conjunction with SNL noise power ratios in order to determine external boundary pressure of reservoir zones under flowing conditions. McKinley[1] pioneered the first

laboratory studies investigating the relationship between energy dissipated by fluid flow through a media (equivalent to the product of flow rate and pressure differential) and the strength of associated acoustic signal generated (noise power). Figure 2 presents McKinley's results, revealing a linear though scattered relationship. The scattered distribution of McKinley's data is linked to limitations of the equipment used at the time. Noise Power (NP) represents a fraction of kinetic energy that is lost from the system as noise, so it is not surprising that it varies linearly with system enthalpy. Little or no research work has been done since the McKinley experiments, until 2012 when the implications of what the study revealed were realised.

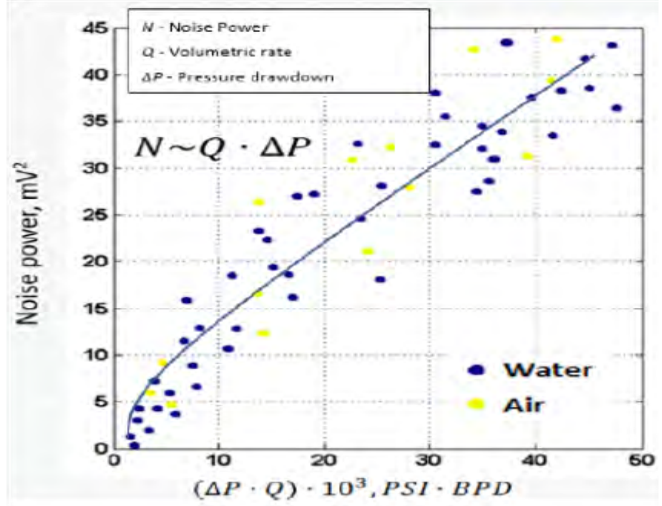

Fig 2: First realization of linear Q.dP vs NP relationship (McKinley[2])

Proportionality of NP with energy dissipation (Q.dP) allows for the substitution of Q with NP in hydraulic diffusivity equations (*see SPE 177892*). This means that a producing / injecting well can be kept on line, and simply by varying the flow rates one can determine pressure of flowing units. Unlike PTA with downhole gauges or multi-rate PLT method, TSNL records NP specific to discrete flow units, and can therefore determine individual layer pressures, even behind pipe.

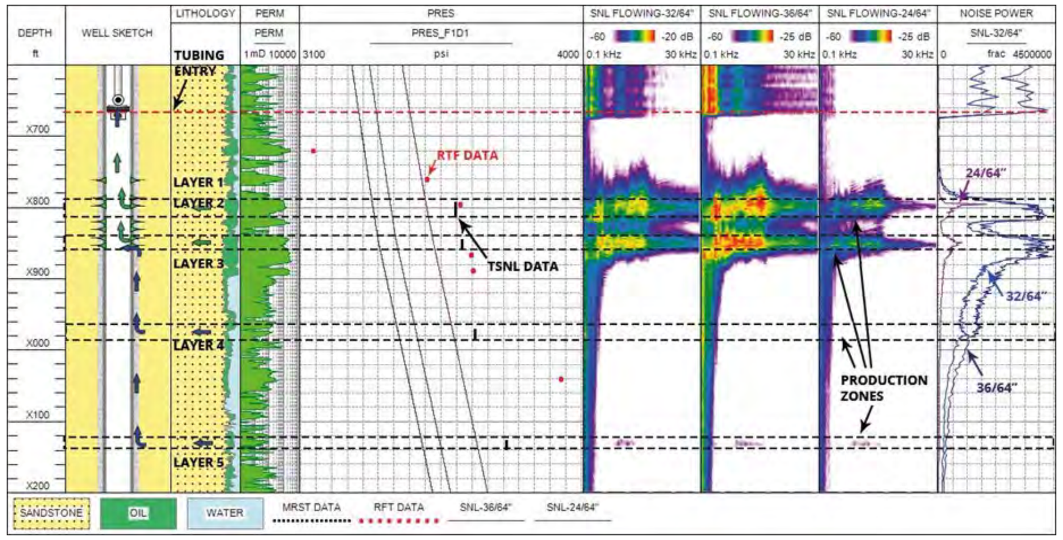

Fig 3: Tracks from left to right: depth, well schematic, lithology and saturation, permeability, pressure data (orange dot from RFT, black from TSNL, 3 pressure curves for each flow rate), SNL data for flow rate 1, 2 and 3, Noise Power curves derived from each SNL profile

Examples in Silicacious Deltaic Environment - SPE 177620 – MS

Spectral Noise Logging technique has been utilized to estimate the average reservoir pressure for each perforated layer in a multi-zone single completion oil producer. The noise logging survey has been carried out under flowing conditions with 3 different rates (see figure 3).

The main conclusions were as follows:

(1) The pressures estimated by the TSNL technique without shutting-in the well were in good agreement with the Open Hole Formation Tester pressures. Additionally SNL determined the effective flow thicknesses of all layers, identified the source of produced water and also tested intervals untested by RFT;

(2) The technology does not require shutting in the well, although it requires stable flow at conditions above fluid saturation point (single phase);

(3) This technology is particularly suited for when target zone is behind a tubing, such as in dual string well completions with a need for pressure measurement of the formation producing through the short tubing string, or for a non-perforated reservoir communicating with the wellbore through a cement channel.

The below table details some jobs where TSNL method has been used in various settings (sandstone, limestone, producers, injectors, etc) and calculated pressures has been verified.

Table 1: Verified TSNL Job Summary

Company	Formation Type	Fluid Type	Permeability mD	Prod Rate bpd	Inj Rate bpd	No. of Layers	Flowing Pressure psi	Determined Pressure psi	Offset Pressure psi
na[1]	heterogeneous sstn	Water	19		157 - 1270	1	3980 - 5147	2980	SIBHP 2926
KOC[2]	sstn	Oil	700	1200 - 1900		3	3316 - 3485	3598 , 3617, 3761	RFT 3611 , 3648, not tested
ADMA[3]	lmstn	Oil	90 - 100				3104 - 3326	3360	RFT 3403
na	semi-cemented sstn	Oil w/ high GOR	200	circa 2500		14	1810 - 1880	1837 - 1916	cross well verification
na	semi-cemented sstn	Oil	200	circa 1900		11	1860 - 1960	1882 - 1962	cross well verification
na	sstn	Oil	106 & 35	circa 300		2	3000 - 3060	3267 & 3092	3233 SIBHP

1 – SPE 182856, Formation Pressure Evaluation for Producing Wells Without Shutting Down the Well, Using Triple Spectral Noise Logging TSNL, 2016
2 – SPE 177620, Quantification of Reservoir Pressure in Multi-Zone Well under Flowing Conditions Using Spectral Noise Logging Technique, Zubair Reservoir, Raudhatain Field, North Kuwait, 2015
3 – SPE 177892, Formation Pressure Evaluation for Producing Wells Without Shutting Down the Well, Using Multi Rate High Precision Temperature and Spectral Noise Logging (HPT-SNL), 2015

[1] R.M. McKinley, F.M. Bower, R.C. Rumble. The Structure and Interpretation of Noise from Flow Behind Cemented Casing, Journal of Petroleum Technology, 3999-PA