Spectral Noise
Formation Pressure Determination
Multi-Layered Reservoirs
• **Problem:** Reservoir Pressure in Active Reservoir Zones

• **Common Solutions:** PTA, RFT, PLT,…

• **Alternative Solution:** TSNL

• **Advantages and Limitations**

• **Case Study:** Single and Dual String, Oil Producer.
Problem: Reservoir Pressure in Active Reservoir Zones

\[ P_e \] – Formation Pressure

Unit A

Unit B

\[ P_e^{(A)} \]

\[ P_e^{(B)} \]
Problem: Reservoir Pressure in Active Reservoir Zones
Formation Pressure in Single-Layer Reservoirs

Individual Layer Formation Pressure in Multi-Layer Reservoirs

Solution

PTA/Static Survey

Openhole pressure tester

Casedhole pressure tester

Multi-Rate PLT

Multi-Rate SNL

Production Loss

Expensive

Expensive Production Loss

Feasible

Feasible
## Limitations of common techniques

<table>
<thead>
<tr>
<th>Technique</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTA/Static Survey</td>
<td>- Well needs to be shut-in for a long time</td>
</tr>
<tr>
<td></td>
<td>- Possible channelings contaminate the data</td>
</tr>
<tr>
<td>Openhole pressure tester</td>
<td>- Can be recorded during open-hole survey only</td>
</tr>
<tr>
<td></td>
<td>- Can be affected by fractures/plugs/packers leaks</td>
</tr>
<tr>
<td>Casedhole pressure tester</td>
<td>- Data can be affected by possible channelings</td>
</tr>
<tr>
<td></td>
<td>- Perforated casing might be difficult to fix</td>
</tr>
<tr>
<td>Multi-Rate PLT</td>
<td>- Data are usually affected by channeling</td>
</tr>
<tr>
<td></td>
<td>- Threshold of spinner can miss small Q</td>
</tr>
<tr>
<td></td>
<td>- Reservoirs behind pipes are missed</td>
</tr>
</tbody>
</table>
Theory and Lab Tests

McKinley (1994):

Theory

\[ N \sim Q \cdot \Delta P \]

- \( N \) - Noise Power
- \( Q \) – Flow rate
- \( \Delta P \) - Pressure drop
Noise Power:

\[ N \sim Q \cdot \Delta P \]
Noise Power:

\[ N \sim Q \cdot \Delta P \]

Darcy’s law for a single-phase fluid:

\[ Q = k \cdot \Delta P \]
Noise Power:

\[ N = K \cdot \Delta P \cdot \Delta P \]
Noise Power:

\[ N = K \left( P_c - P_{wf1} \right)^2 \]
Noise Power:

\[ N = K(P_c - P_{wf1})^2 \]

Multi-rate SNL:

\[
\begin{align*}
N^{(1)} &= K(P_c - P_{wf1})^2 \\
N^{(2)} &= K(P_c - P_{wf2})^2
\end{align*}
\]
Spectral Noise Logging Tool (SNL) Physics
Spectral Noise Logging Tool (SNL) Physics

SNL

Acoustic noise
Spectral Noise Logging Tool (SNL) Specification

- Memory / Real Time*
- Length = 2.68 ft (0.816 m)
- Weight = 15.4 lbs (7 kg)
- Titanium body
- Maximum OD = 1.65” (42 mm)
- H₂S resistance < 25%
- Tmax = 302 °F (150 °C)
- Pmax = 9,000 psi (60 MPa)

<table>
<thead>
<tr>
<th>Frequency range, Hz</th>
<th>3 – 60,000</th>
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<tbody>
<tr>
<td>Frequency resolution, Hz</td>
<td>115</td>
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<tr>
<td>Dynamic range, dB</td>
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</table>
Logging Procedure and Data Processing

Stationary measurements

<table>
<thead>
<tr>
<th>DEPTH m</th>
<th>WELL SKETCH</th>
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<tbody>
<tr>
<td>X940</td>
<td></td>
</tr>
<tr>
<td>X950</td>
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<tr>
<td>X960</td>
<td></td>
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<tr>
<td>X970</td>
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</tbody>
</table>
Logging Procedure and Data Processing

High amplitude
Low amplitude
Fractures
Flow
Channels
Faults
Flow
Perforation
Flow
Completion
Flow
Borehole
Flow

Wellbore Flow
Fracture Flow
Flow Through Pores

Borehole Flow
Completion Flow
Perforation Flow
Channels Faults Flow
Fractures Flow
Large Pores Flow
Medium-Porous Flow
Small-Porous Flow

SNL Type Library

SNL Flowing

kHz

0.3
0.6
1
3
10
20
30

-60
-30 dB
Injection Rate:
- 250 m³/d
- 500 m³/d

Frequency Pattern - Rock Structure

Amplitude ~Q*ΔP
How to Calculate Noise Power
# How to Calculate Noise Power

<table>
<thead>
<tr>
<th>DEPTH (m)</th>
<th>WELL SKETCH</th>
<th>LITHOLOGY</th>
<th>PERMEABILITY (mD)</th>
<th>SNL FLOWING (kHz)</th>
<th>FULL NOISE POWER (SNL_NP 0-30 kHz)</th>
</tr>
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<td>X970</td>
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</tbody>
</table>

- **Borehole flow**

**Legend:**
- SHALE
- SANDSTONE
- HYDROCARBON
- WATER
How to Calculate Noise Power

Fracture flow
# How to Calculate Noise Power

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Well Sketch</th>
<th>Lithology</th>
<th>Permeability (mD)</th>
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<th>Full Noise Power</th>
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**Reservoir flow**

[Diagram showing depth, well sketch, lithology, permeability, SNL flowing, and full noise power with color coding and labels for shale, sandstone, hydrocarbon, and water.]
How to Calculate Noise Power

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<tr>
<td></td>
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<td>0.1 mD 1000</td>
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</table>

SNL FLOWING
-60 kHz -30 dB

RESERVOIR NOISE POWER
SNL_NP 8-30 kHz

NP₁
NP₂

SHALE SANDSTONE HYDROCARBON WATER
Triple SNL vs Triple PLT

BOREHOLE FLOW PROFILE

DEPTH
m
0
QAPP_FL1 m³/d
200
0
QAPP_FL2 m³/d
200
0
QAPP_FL3 m³/d
200

Q1
Q2
Q3

H1_A1, Q1_A1
H2_A1, Q2_A1
H3_A1, Q3_A1

H1_A2, Q1_A2
H2_A2, Q2_A2
H3_A2, Q3_A2

H1_A4, Q1_A4
H2_A4, Q2_A4
H3_A4, Q3_A4

LIMESTONE
OIL
WATER

SKETCH
LITHOLOGY
PERM

0.1 mD
100
Calculated $P_i$ for A2 is affected by crossflow from A3

Calculated $P_i$ for A4 is wrong
Typical TSNL Program

Half reduced rate  Half increased rate  Regular rate
No change in total production/injection

Survey time

First rate  Second rate  Third rate

Time

Rate

Typical TSNL Program
Advantages and Limitations

**Limitations**
- No flow → No noise → No formation pressure
- Minimum of 3 flow rates
- Single phase inflow

**Advantages**
- No need to shut-in the well
- Individual layer pressure
- Pressure evaluation behind casing/tubing
- Pressure is not affected by cross-flow
Case Study References:

Case 1: SPE-177620 – Quantification of Reservoir Pressure in Multi-Zone Well under Flowing Conditions Using Spectral Noise Logging Technique, Zubair Reservoir, Raudhatain Field, North Kuwait

Case 2: SPE-177892-MS - Formation Pressure Evaluation for Producing Wells Without Shutting Down the Well, Using Multi Rate High Precision Temperature and Spectral Noise Logging (HPT-SNL)

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Case Study #1. Kuwait Oilfield – SNL Survey (Oil Producer)

- **Lithology**
- **Perm**
- **PRES**
- **SNL Flowing 1 (100%)**
- **SNL Flowing 2 (125%)**
- **SNL Flowing 3 (60%)**

<table>
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<th>DEPTH</th>
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<th>PERM</th>
<th>PRES</th>
<th>PRES_F1D1</th>
<th>SNL FLOWING1 (100%)</th>
<th>SNL NP1</th>
<th>SNL FLOWING2 (125%)</th>
<th>SNL NP2</th>
<th>SNL FLOWING3 (60%)</th>
<th>SNL NP3</th>
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<tbody>
<tr>
<td>ft</td>
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<td></td>
<td>-60 kHz</td>
<td>30</td>
<td>-30 dB</td>
<td>30</td>
<td>0.1 kHz</td>
<td>0.1</td>
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<tr>
<td>1 mD</td>
<td>10000</td>
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<td></td>
<td></td>
<td></td>
<td>3250 psi</td>
<td>3650 psi</td>
<td>0.1</td>
<td>5000</td>
<td>0.1</td>
<td>5000</td>
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- **P_wf1** - 3373 psi
- **P_wf2** - 3316 psi
- **P_wf3** - 3485 psi

- **Δt_1** - 7 h
- **Δt_2** - 10 h
- **Δt_3** - 9 h

SPE-177620 – Quantification of Reservoir Pressure from MR SNL
# Case Study #1. Kuwait Oilfield – SNL Survey (Oil Producer)

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- **P_{wf1}** = 3373 psi
- **P_{wf2}** = 3316 psi
- **P_{wf3}** = 3485 psi

Δt₁ = 7 h
Δt₂ = 10 h
Δt₃ = 9 h
Case Study #1. Kuwait Oilfield – Calculation Results (Oil Producer)

Pwf1-3389.7 psi
Pwf3-3504.8 psi
Pwf2-3332.3 psi

3611.0 psi RFT
3617.0 psi TSNL
3648.0 psi RFT

3598.0 psi TSNL

SPE-177620 – Quantification of Reservoir Pressure from MR SNL
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