Webinars

Can Formation Testing Time be Cut in Half and Generate Ten Times the Data?

Mark Proett Consulting LLC
June 2, 2022

KAPPA

SPE International

1

Webinars

SPE Webinars are Sponsored by:

SPE
SPE Foundation

SPE International

2

Mark Proett - Profile

- Petroleum engineering consultant with over 40 years experience (Aramco, Halliburton & Schlumberger).
- Known for publications advocating automated testing methods, focused sampling and the viability of formation testing-while-drilling (FTWD).
- 80 US patents and more than 60 technical papers, most of which deal with sampling and testing methods.
- Numerous Industry Awards including:
  - SPWLA Distinguished Speaker (twice) and SPE Distinguished Lecturer (twice)
  - 2008 SPWLA Distinguished Technical Achievement Award
  - 2013 SPE Gulf Coast Regional Formation Evaluation Award
  - 2017 the SPE International Formation Evaluation Award
- BSME from the University of Maryland and a MS Johns Hopkins University

3

Can Formation Testing Time be Cut in Half and Generate Ten Times the Data?

Mark Proett Consulting LLC
June 2, 2022

KAPPA

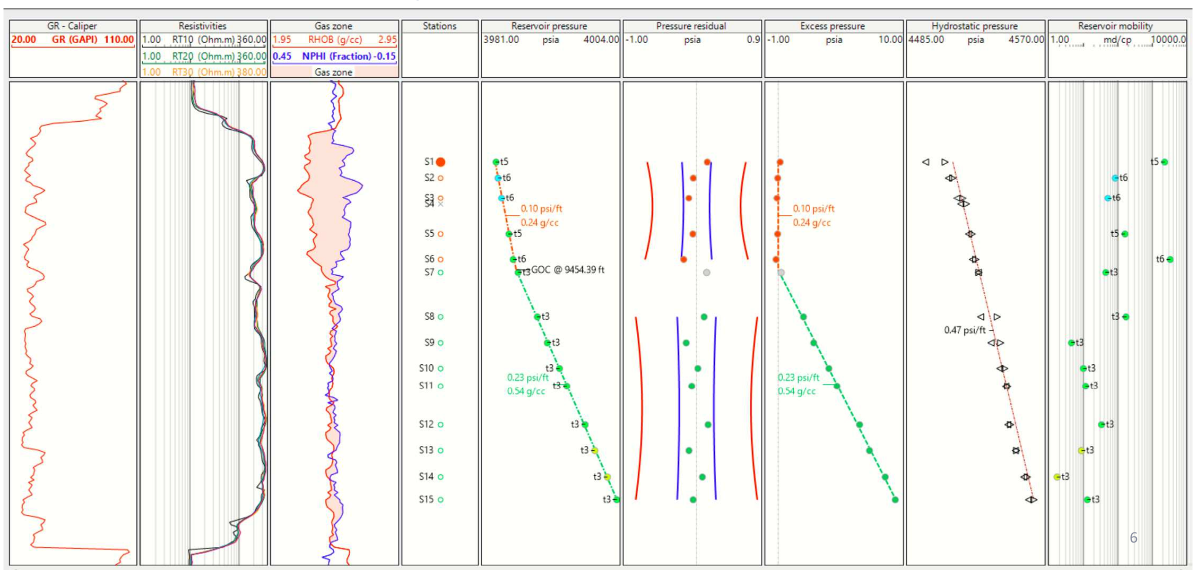
4

Overview

- The trouble with pretests
- Interval Pressure Transient Testing (IPTT - MiniDST)
- What is needed k_h, S, k_v/k_h, h for every pretest
- Probe geometry anisotropy dependency
- Probes and heterogeneities (dip & azimuth)
- New probe designs can resolve heterogeneities
- Concluding remarks

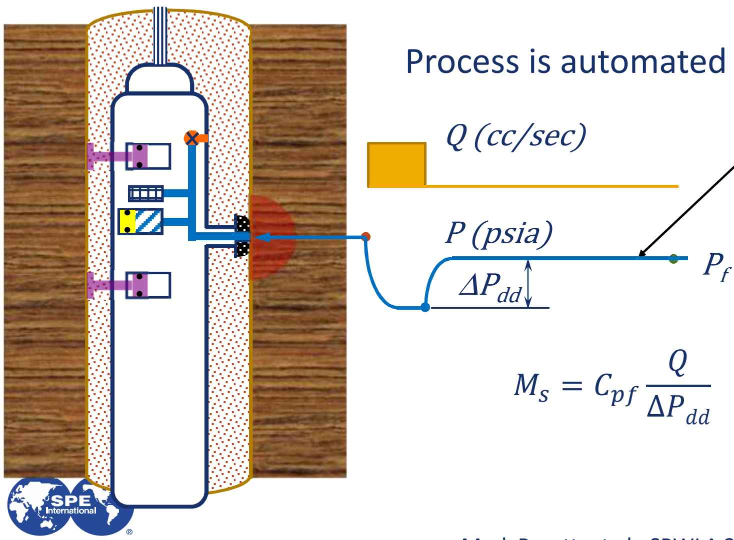
5

Typical Pretest Pressure Survey (Courtesy KAPPA-Azurite)



Formation Tester Pretest (5-15 min typ.)

Process is automated by software providers



Quality of Test Data

Final Buildup Pressure

$$M_s = C_{pf}\frac{Q}{\Delta P_{dd}}$$

Spherical Mobility (md/cp)

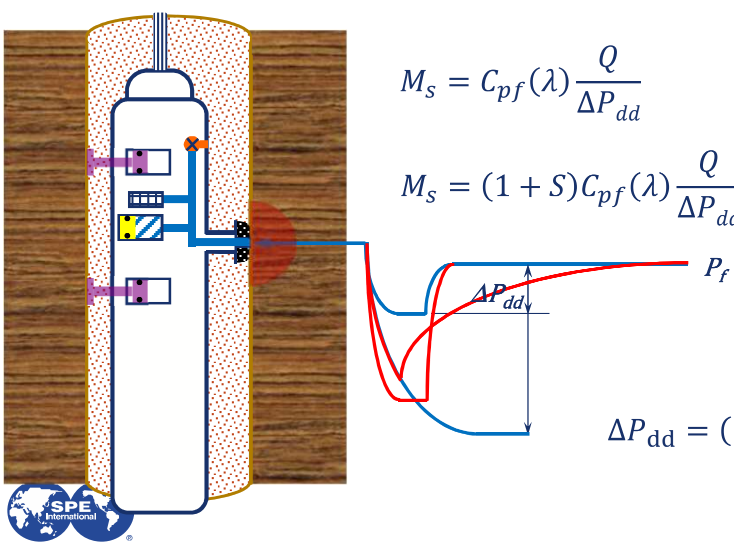
Mark Proett, et al., SPWLA 2014

7

The Trouble with Pretests

$$M_s = C_{pf}(\lambda)\frac{Q}{\Delta P_{dd}}$$

$$M_s = (1+S)C_{pf}(\lambda)\frac{Q}{\Delta P_{dd}}$$



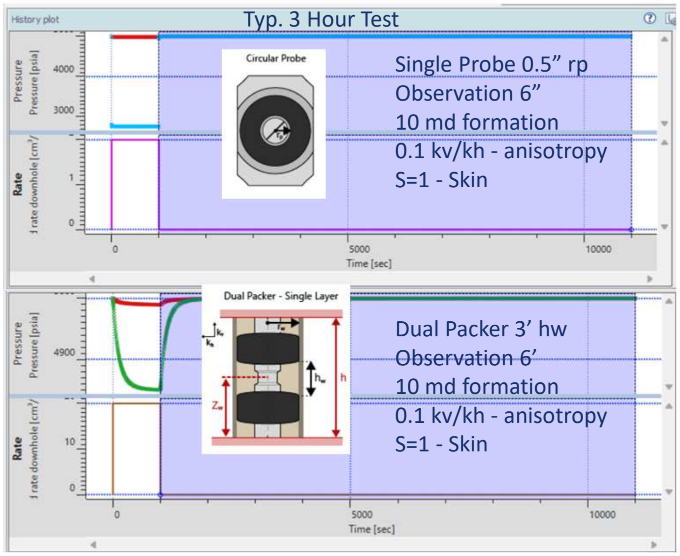
- Coefficient C_{pf}(λ, θ$_d$ & θ$_a$)
  - λ – anisotropy
  - θ$_d$ – bedding dip
  - θ$_a$ – azimuth
- Skin – Wellbore damage
- Low Perm (< 0.1 md)
- Small Scale (r_i)

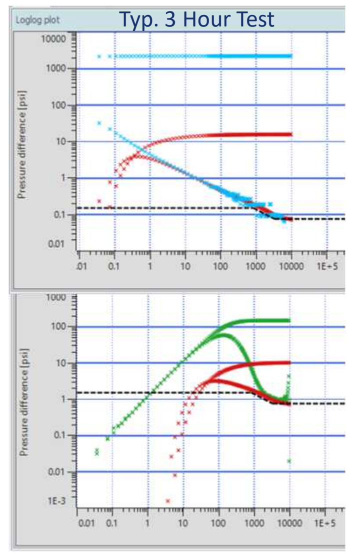
$$\Delta P_{\mathrm{dd}} = (1+S)C_{pf}(\lambda)\frac{Q_t}{M_s}\left(1-e^{-t/\alpha}\right)$$

8

IPTT 3-20+ Hour Tests (MiniDST)

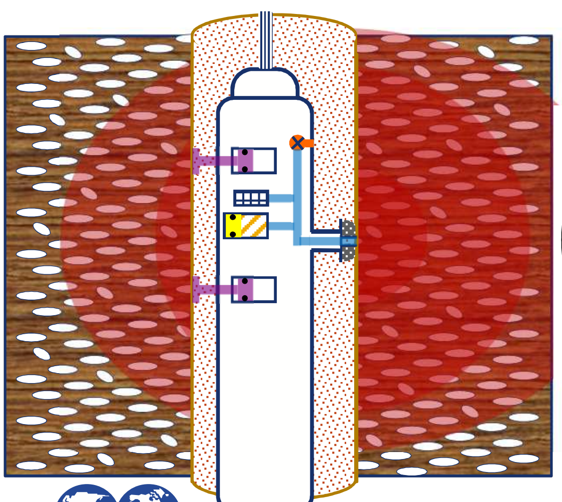
Objective k_h, S, k_v/k_h, h

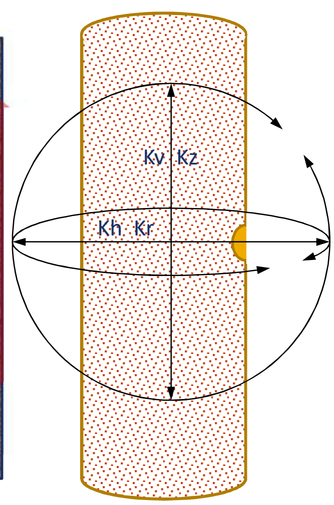




9

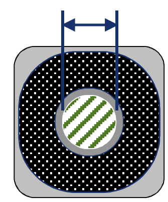
Typical Formation Tester – Circular Probe





Anisotropy Kv/Kh or Kz/Kr

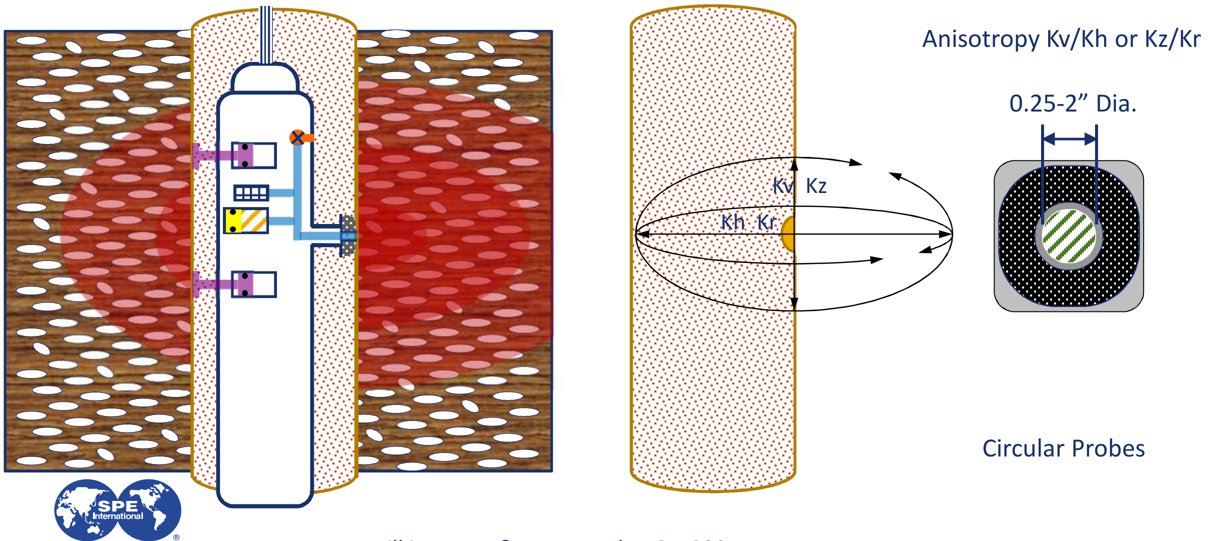
0.25-2" Dia.



Circular Probes

10

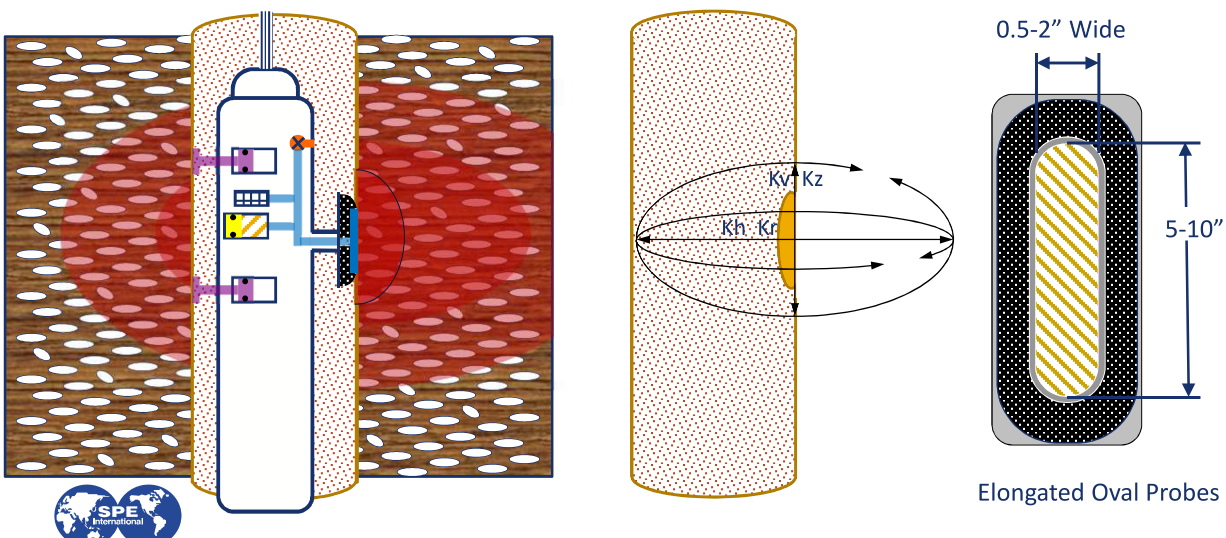
Typical Formation Tester – Circular Probe



Wilkinson, D. & Hammond, P. S. 1990

11

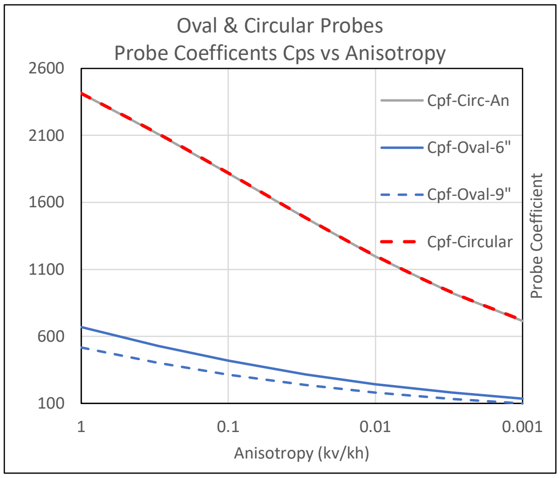
Typical Formation Tester – Elongated Probe

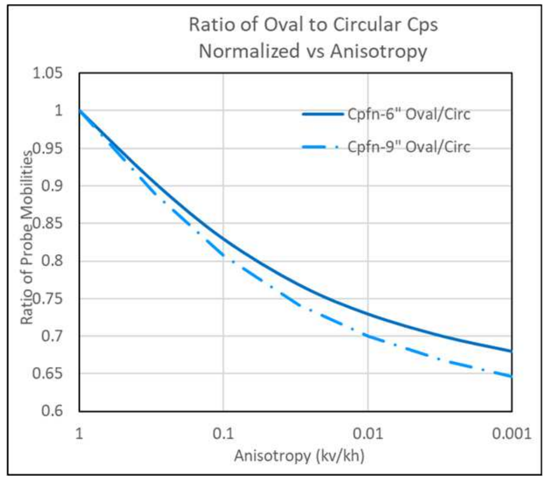


Larsen, L. & Allain O., KAPPA, SPE 2017

12

Probe Geometry & Anisotropy Dependency





Larsen, L. & Allain O., SPE 2017 & Wilkinson, D. & Hammond, P. S. 1990

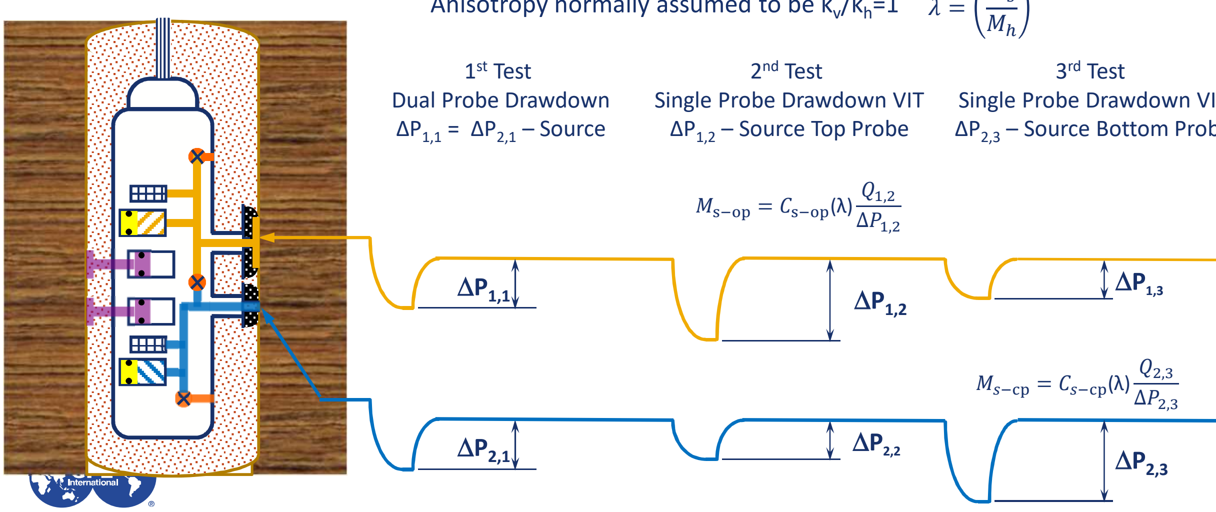
13

Pretest Sequence with Oval & Circular Probes

Anisotropy normally assumed to be $k_v/k_h=1$ $\lambda = \left(\frac{M_s}{M_h}\right)^3$

1st Test	2nd Test	3rd Test
Dual Probe Drawdown	Single Probe Drawdown VIT	Single Probe Drawdown VIT
$\Delta P_{1,1} = \Delta P_{2,1}$ – Source	$\Delta P_{1,2}$ – Source Top Probe	$\Delta P_{2,3}$ – Source Bottom Probe

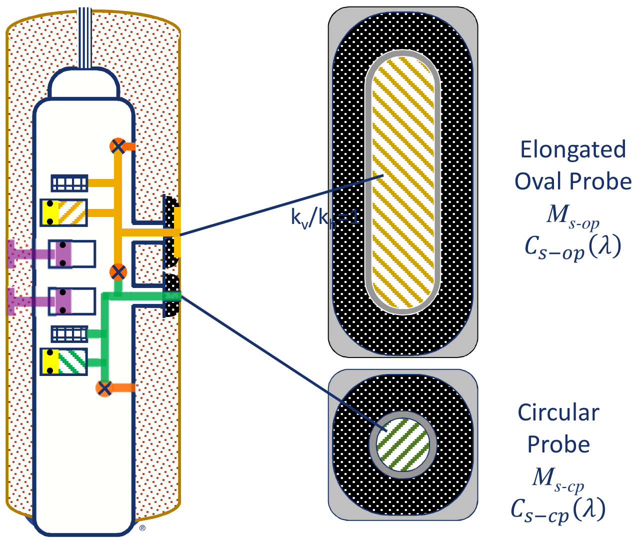
$$M_{s-\mathrm{op}} = C_{s-\mathrm{op}}(\lambda)\frac{Q_{1,2}}{\Delta P_{1,2}}$$

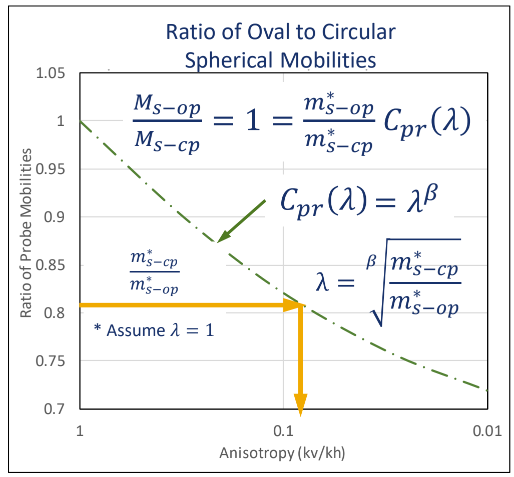


$$M_{s-\mathrm{cp}} = C_{s-\mathrm{cp}}(\lambda)\frac{Q_{2,3}}{\Delta P_{2,3}}$$

14

Formation Tester With Two Probe Shapes





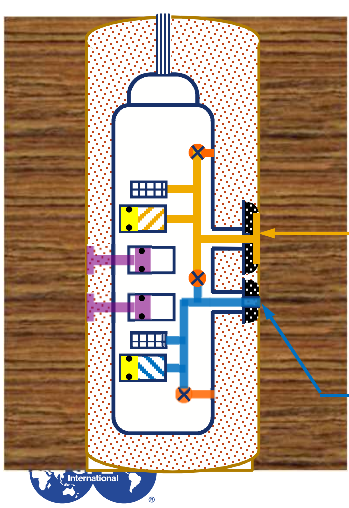
Pretest Sequence with Oval & Circular Probes

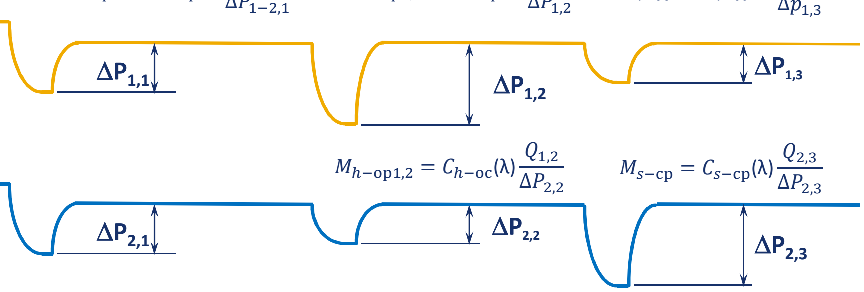
Anisotropy normally assumed to be k_v/k_h=1 $\lambda = \left(\frac{M_s}{M_h}\right)^3$

1st Test	2nd Test	3rd Test
Dual Probe Drawdown	Single Probe Drawdown VIT	Single Probe Drawdown VIT
$\Delta P_{1,1} = \Delta P_{2,1}$ – Source	$\Delta P_{1,2}$ – Source Top Probe	$\Delta P_{2,3}$ – Source Bottom Probe

$M_{s-ocp} = C_{s-ocp}(\lambda)\frac{Q_1}{\Delta P_{1-2,1}}$ $M_{s-op1,2} = C_{s-op}(\lambda)\frac{Q_{1,2}}{\Delta P_{1,2}}$ $M_{h-co} = C_{h-co}(\lambda)\frac{Q_{2,3}}{\Delta p_{1,3}}$

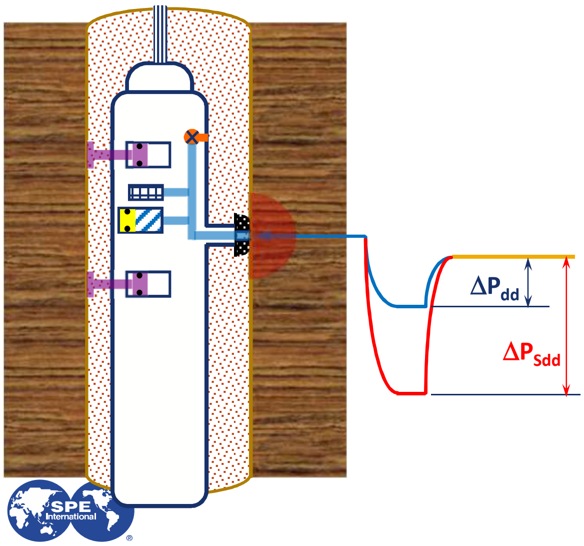
$M_{h-op1,2} = C_{h-oc}(\lambda)\frac{Q_{1,2}}{\Delta P_{2,2}}$ $M_{s-cp} = C_{s-cp}(\lambda)\frac{Q_{2,3}}{\Delta P_{2,3}}$





Considering Near Wellbore Skin

Webinars



Without Skin

$$\Delta P_{\mathrm{dd}} = C_{pf}(\lambda)\frac{Q_t}{M_s} = \frac{1}{4\pi r_p}\frac{Q_t}{M_s}$$

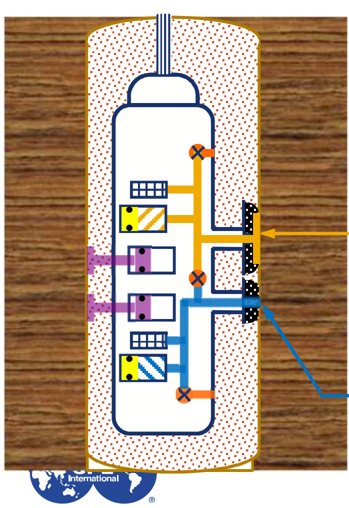
With Skin – Near Wellbore Damage

$$\Delta P_{S\mathrm{dd}} = (1+S_p)C_{pf}(\lambda)\frac{Q_t}{M_s}$$

Pretest Sequence with Oval & Circular Probes

Webinars

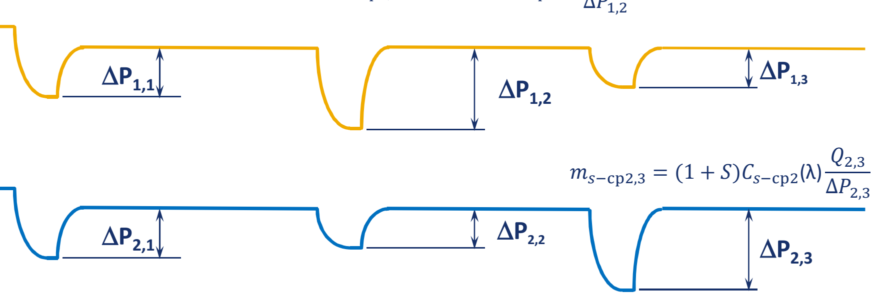
Anisotropy must be assumed due to $C_{pf}(\lambda)$ $\quad \lambda = \left(\frac{M_s}{M_h}\right)^3$



1st Test	2nd Test	3rd Test
Dual Probe Drawdown	Single Probe Drawdown VIT	Single Probe Drawdown VIT
$\Delta P_{1,1} = \Delta P_{2,1}$ – Source	$\Delta P_{1,2}$ – Source Top Probe	$\Delta P_{2,3}$ – Source Bottom Probe

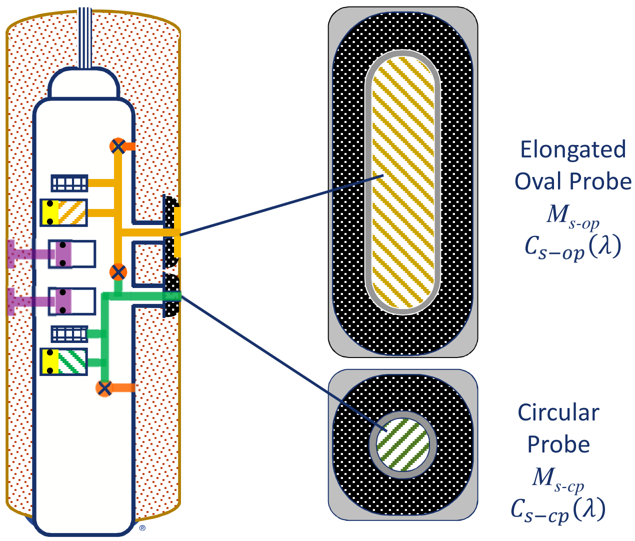
$$m_{s-\mathrm{op}1,2} = (1 = S)C_{s-\mathrm{op}1}(\lambda)\frac{Q_{1,2}}{\Delta P_{1,2}}$$

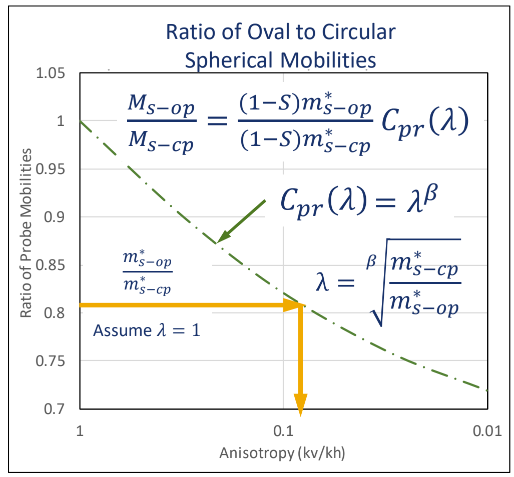
$$m_{s-\mathrm{cp}2,3} = (1+S)C_{s-\mathrm{cp}2}(\lambda)\frac{Q_{2,3}}{\Delta P_{2,3}}$$



18

Formation Tester With Two Probe Shapes



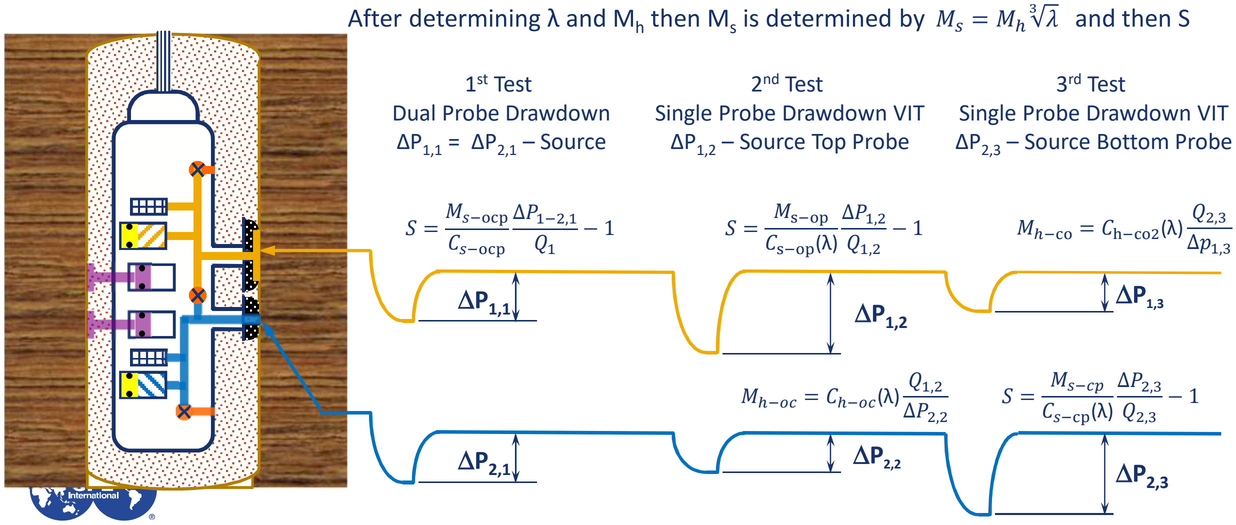


19

Pretest Sequence with Oval & Circular Probes

After determining λ and M_h then M_s is determined by $M_s = M_h \sqrt[3]{\lambda}$ and then S

1[st] Test	2[nd] Test	3[rd] Test
Dual Probe Drawdown	Single Probe Drawdown VIT	Single Probe Drawdown VIT
$\Delta P_{1,1} = \Delta P_{2,1}$ – Source	$\Delta P_{1,2}$ – Source Top Probe	$\Delta P_{2,3}$ – Source Bottom Probe



20

Solution is Overdetermined

6 – 7 Equations & 3 Unknowns (M_h, S & $\lambda=k_v/k_h$,)

$$\frac{M_{s-\mathrm{op}}}{M_{s-cp}} = 1 = \frac{m_{s-op}}{m_{s-cp}} C_{pr}(\lambda) = \frac{m_{s-op}}{m_{s-cp}} \lambda^{\beta}$$

Relationship between two probe geometries

$$\lambda = \sqrt[\beta]{\frac{m_{s-cp}}{m_{s-op}}} \qquad \lambda = \sqrt[\beta]{\frac{m_{s-cp}}{m_{s-ocp}}}$$

1 - Solve for anisotropy kv/kh

$$M_{s-ocp} = (1+S)C_{s-ocp}(\lambda)\,\frac{Q_{t,1}}{\Delta P_{1-2,1}}$$

2 - Pressure Test flowing from both circular & oval probes

$$M_{s-\mathrm{op}} = (1+S)C_{s-op}(\lambda)\,\frac{Q_{1,2}}{\Delta P_{1,2}}$$

3 - Pressure Test with oval probe

$$M_{h-oc} = C_{h-oc}(\lambda)\,\frac{Q_{1,2}}{\Delta P_{2,2}}$$

4 - Circular observation probe interference pressure

$$M_{s-cp} = (1+S)C_{s-cp}(\lambda)\,\frac{Q_{2,3}}{\Delta P_{2,3}}$$

5 - Pressure Test with circular probe

$$M_{h-\mathrm{co}} = C_{h-co}(\lambda)\,\frac{Q_{2,3}}{\Delta p_{1,3}}$$

6 - Oval observation probe interference pressure

Pretest Sequence with Oval & Circular Probes

After determining λ and M_h then M_s is determined by $M_s = M_h\sqrt[3]{\lambda}$ and then S

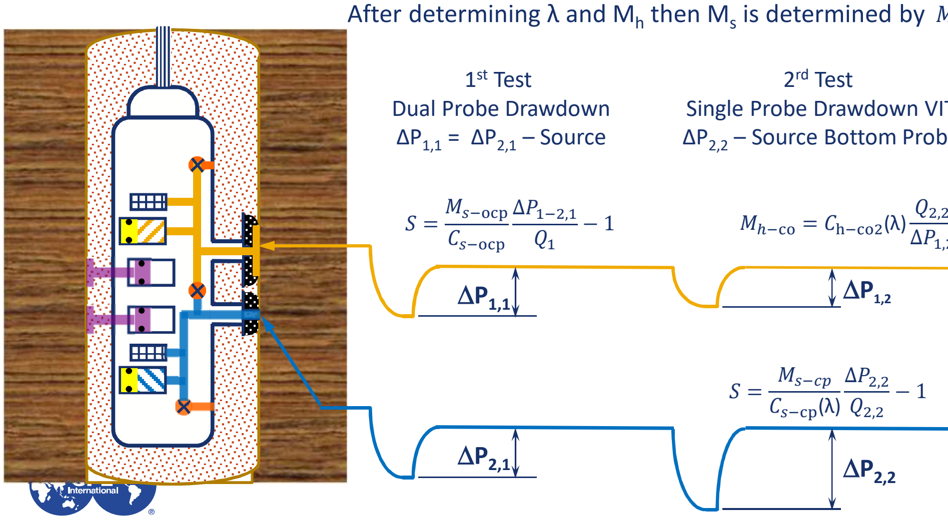
1st Test
Dual Probe Drawdown
$\Delta P_{1,1} = \Delta P_{2,1}$ – Source

2rd Test
Single Probe Drawdown VIT
$\Delta P_{2,2}$ – Source Bottom Probe

$$S = \frac{M_{s-\mathrm{ocp}}}{C_{s-\mathrm{ocp}}}\frac{\Delta P_{1-2,1}}{Q_1} - 1$$

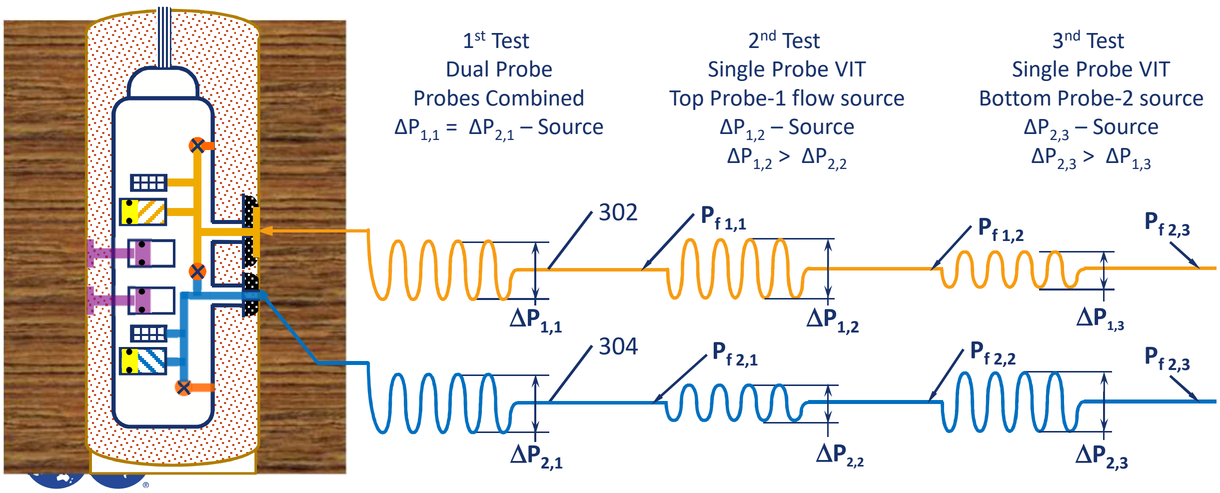
$$M_{h-\mathrm{co}} = C_{\mathrm{h-co2}}(\lambda)\frac{Q_{2,2}}{\Delta P_{1,2}}$$

$$S = \frac{M_{s-cp}}{C_{s-\mathrm{cp}}(\lambda)}\frac{\Delta P_{2,2}}{Q_{2,2}} - 1$$



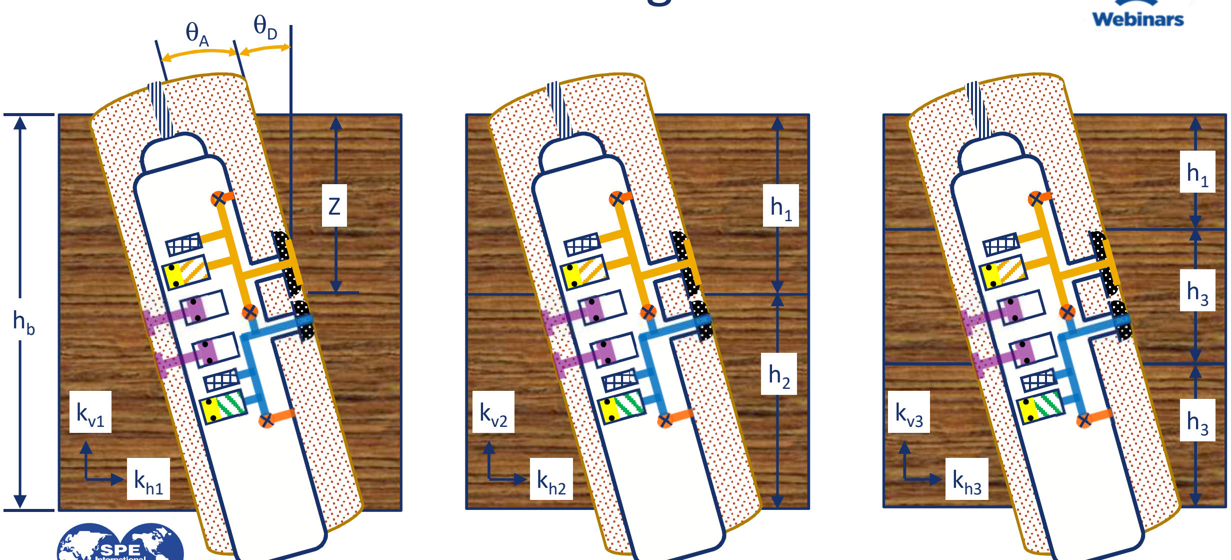
Pretest with Oscillating Pressure Waves

Alternative Testing Method- Low Perm



23

Formation Heterogeneities



24

Multi – Dimensional Solution

Input Formation Conditions
$r_D, f, \lambda(i), \theta_D, \theta_A, h_D(i), \beta(i), Z_D(1)$

Pressure and flow rate measurements.
$Q_{sp(n)}, \Delta p_{sp(n)}, \Delta P_{pp(m)}, P_{f(m)}$

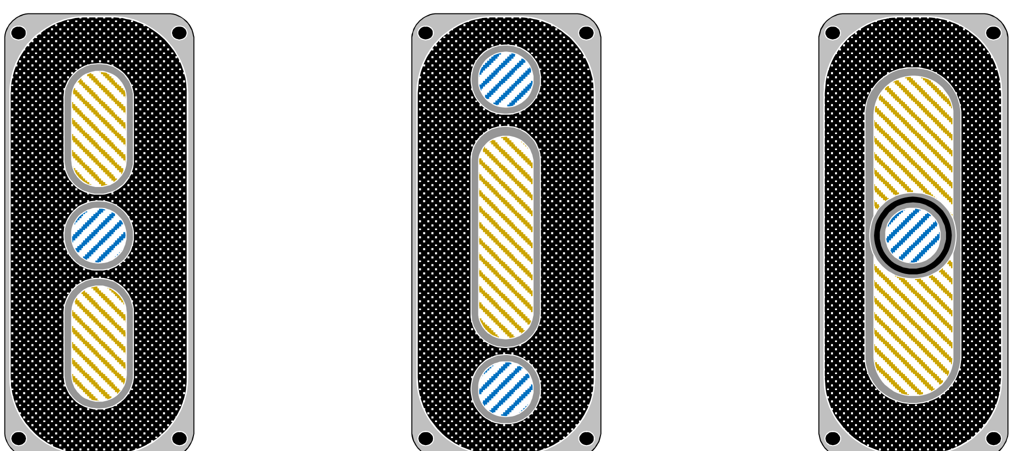
Regression using probe function library

Incrementing depth and azimuthal tool positions θ_A, $Z_D(j)$

Regression Results
$\lambda(i), \alpha(i), M_{\#}, M(i), S(i)$

25

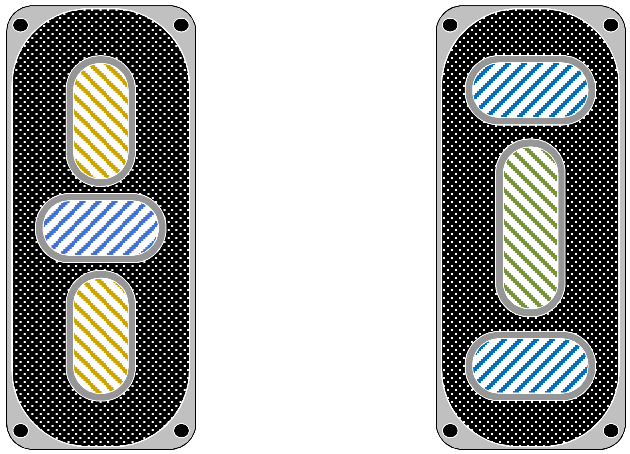
Enhanced Probe Designs
Circular & Oval Shapes



26

Probe Designs with Orthogonal Oval Shapes

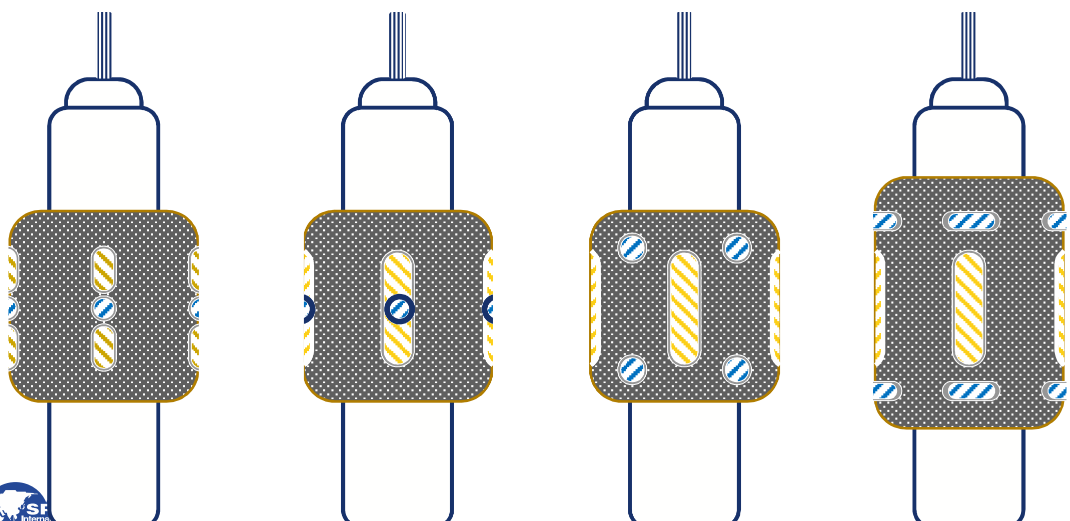
Webinars



27

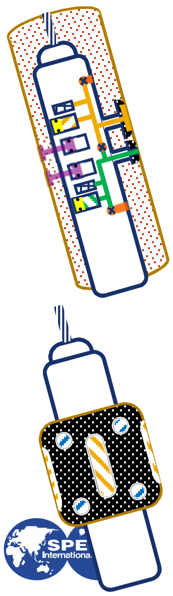
3D Expandable Probe Designs

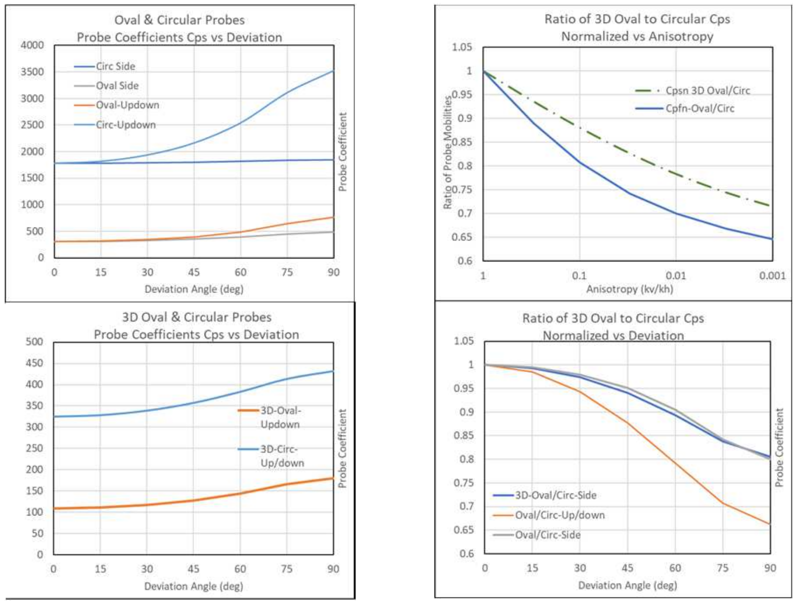
Webinars



28

3D Probes vs Single Probes





29

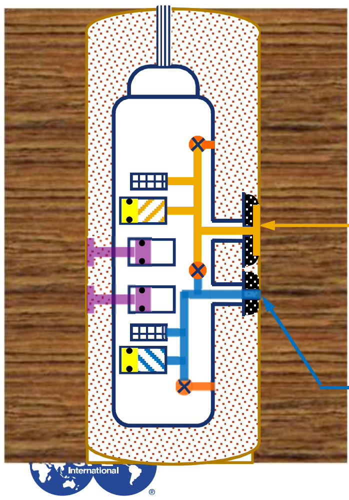
Concluding Remarks

- Using probes of different shapes can enhance pretesting capabilities
  - Skin and Anisotropy can be determined.
  - Greater accuracy for true mobility/perm & anisotropy results
  - Can include the effects of dip angle, azimuthal orientation & heterogeneities
  - 3D Probes can provide a more upscaled measurement
  - New probe designs could improve the sensitivity to anisotropy
- Pretesting methods are unchanged, but generating 10x more data
  - IPTT: Typically, 3-20hrs & not always successful
  - Pretest: Typically, 10-15mins & 10x more tests & data

30

Simulation with Oval & Circular Probes

Simulation	Cs-cp	kvkh	Mh	Ms	S
Inputs		**0.1**	**10**	**4.64**	**3**
	0.84	0.30	9.51	6.37	3.82
		0.10	9.51	4.42	3.10



$$S = \frac{M_{s-\mathrm{ocp}}}{C_{s-\mathrm{ocp}}} \frac{\Delta P_{1-2,1}}{Q_1} - 1$$

$$S = \frac{M_{\mathrm{s-op}}}{C_{\mathrm{s-op}}(\lambda)} \frac{\Delta P_{1,2}}{Q_{1,2}} - 1$$

$$M_{h-\mathrm{co}} = C_{\mathrm{h-co2}}(\lambda) \frac{Q_{2,3}}{\Delta p_{1,3}}$$

$$M_{h-oc} = C_{h-oc}(\lambda) \frac{Q_{1,2}}{\Delta P_{2,2}}$$

$$S = \frac{M_{s-cp}}{C_{s-\mathrm{cp}}(\lambda)} \frac{\Delta P_{2,3}}{Q_{2,3}} - 1$$