Laboratory Simulation of Flow Through a Perforation

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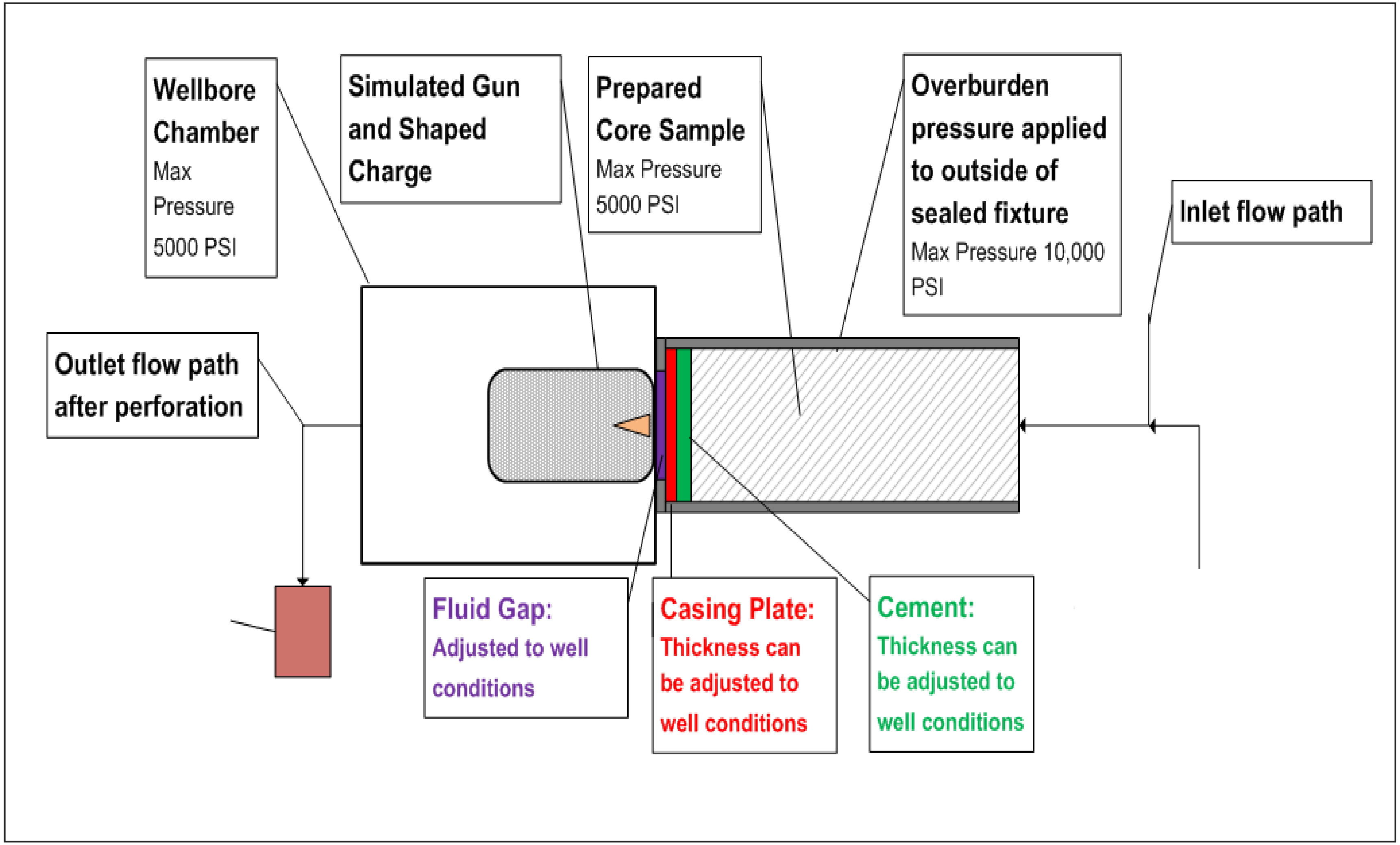
HALLIBURTON

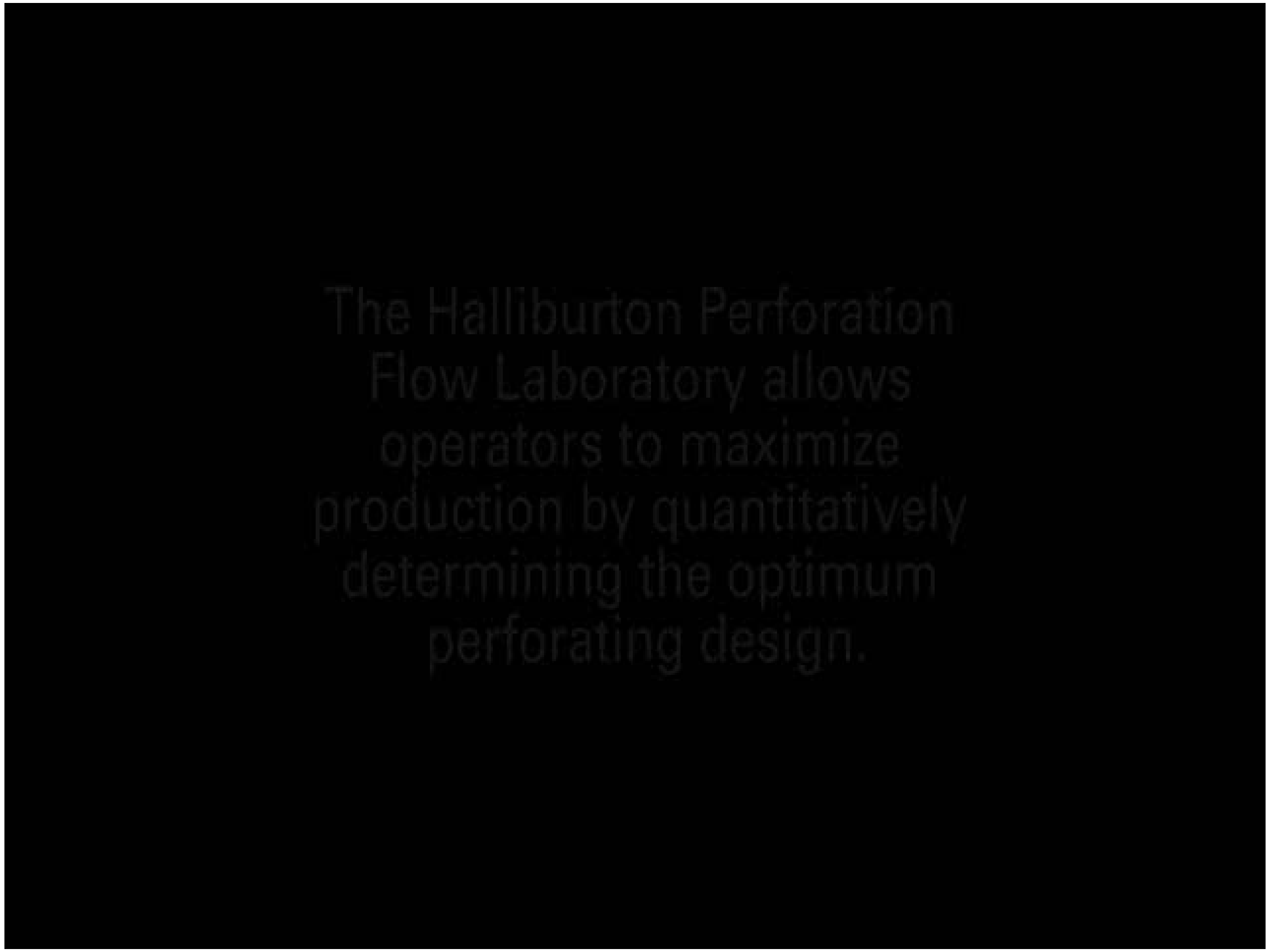
Background

- Section 4
- Flow performance methods
- Exploring differences between Downhole and Section 4 with an example
- Method of adjusting Section 4 to more closely match downhole
- Test results
- Summary

Section IV Configuration



Section IV Animation



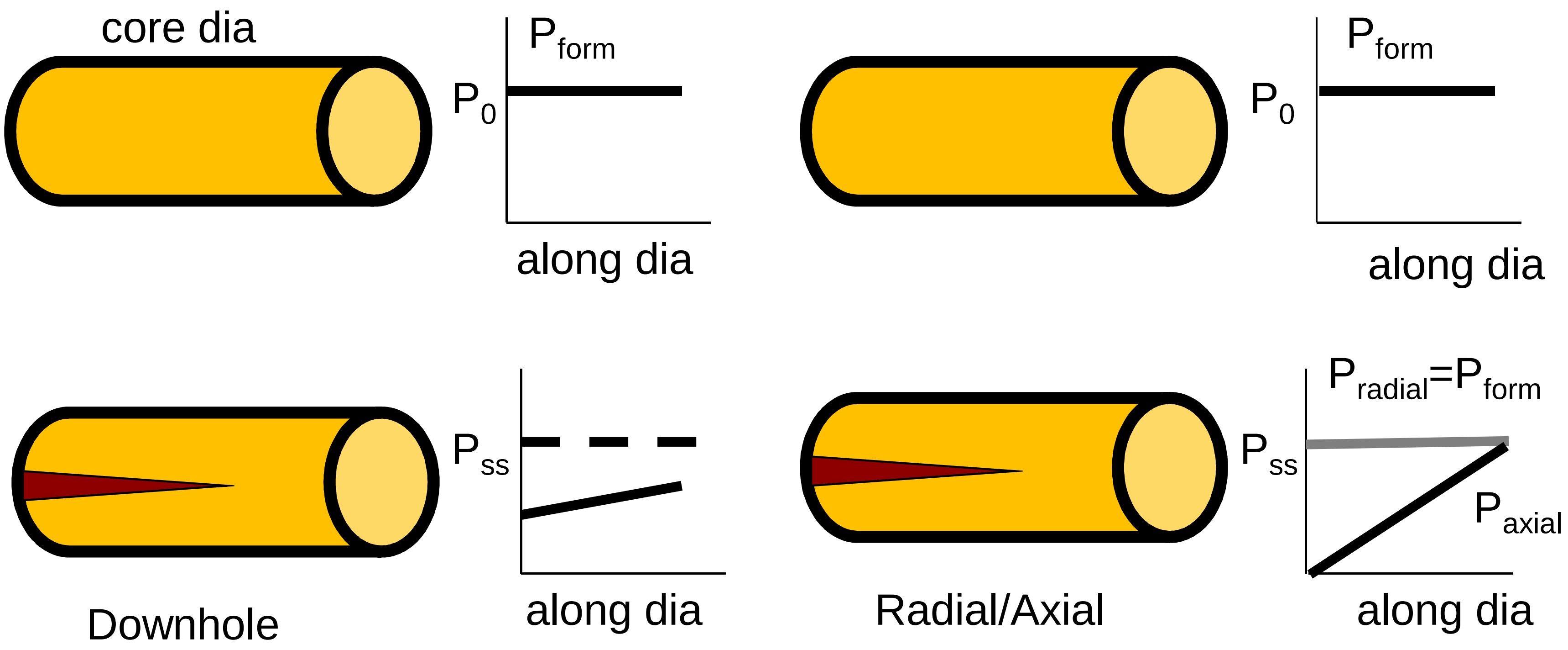
How API RP Sec 4 Compares with Downhole

Differences:

Section 4	**Downhole**
Single shot	**Several shots per foot**
Flow radially, axially, or both	**Flow from the formation follows path of least resistance**

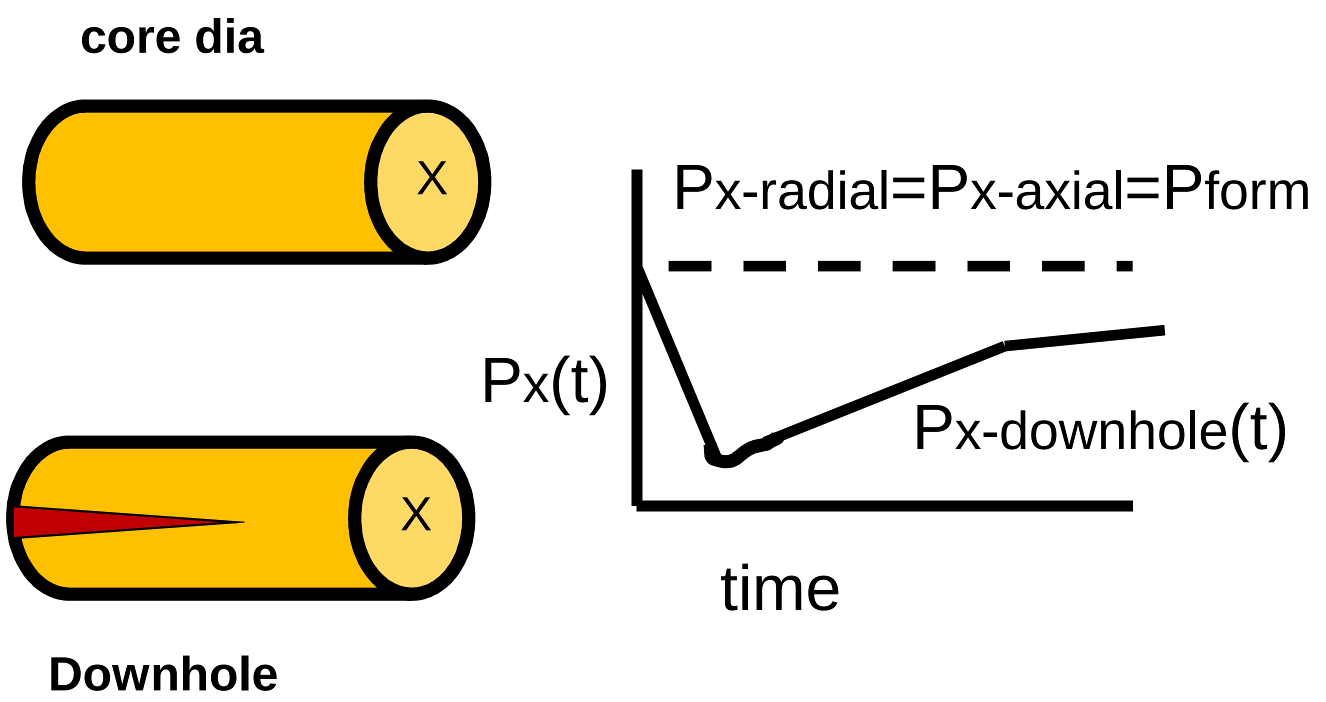
Some Issues With
Current Sec 4 Testing (cont.)

- **Steady state flowing pressures do not match those downhole**



Some Issues With Current Sec 4 Testing (cont.)

- **Transient flowing pressures do not match those downhole**



Example

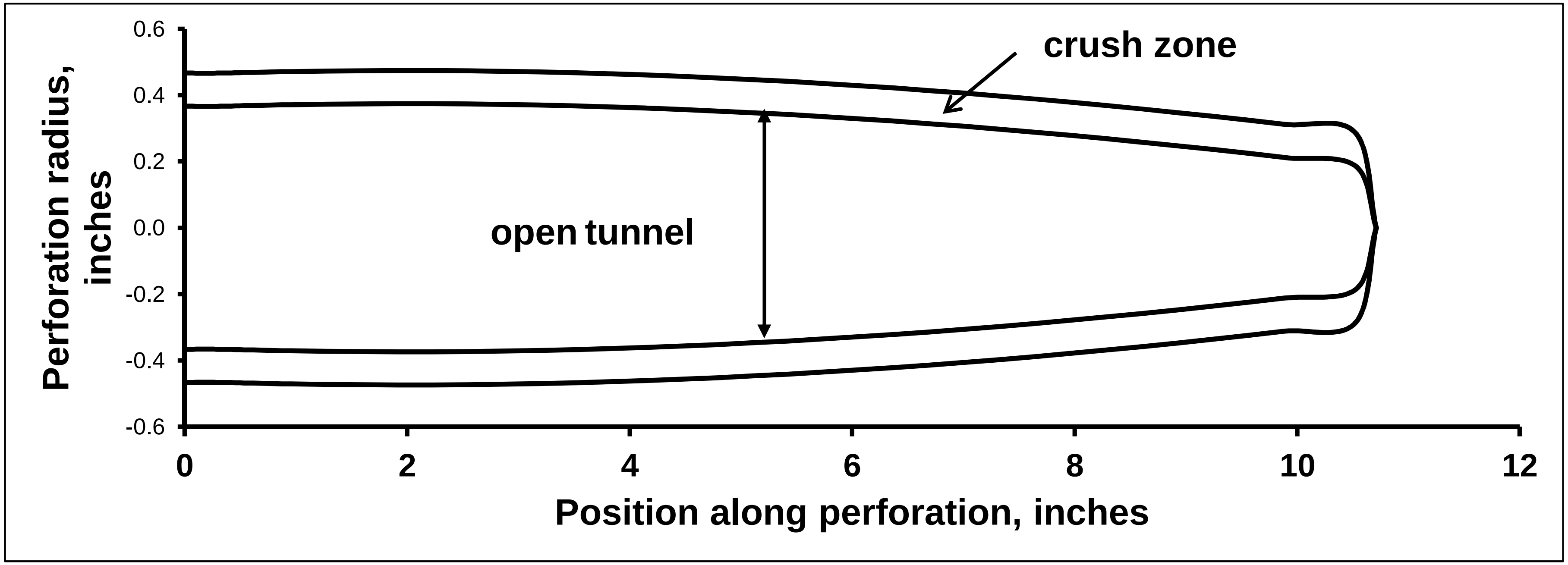
Downhole

– SPF	4
– Gun phasing	60 degrees
– Formation perm	k_h=500 md, k_v=100 md
– Crush zone perm	40% of formation perm
– Viscosity	2.35 cp
– Reservoir Radius	660 ft
– Wellbore Pressure	3,500 psi
– Formation Pressure	4,000 psi

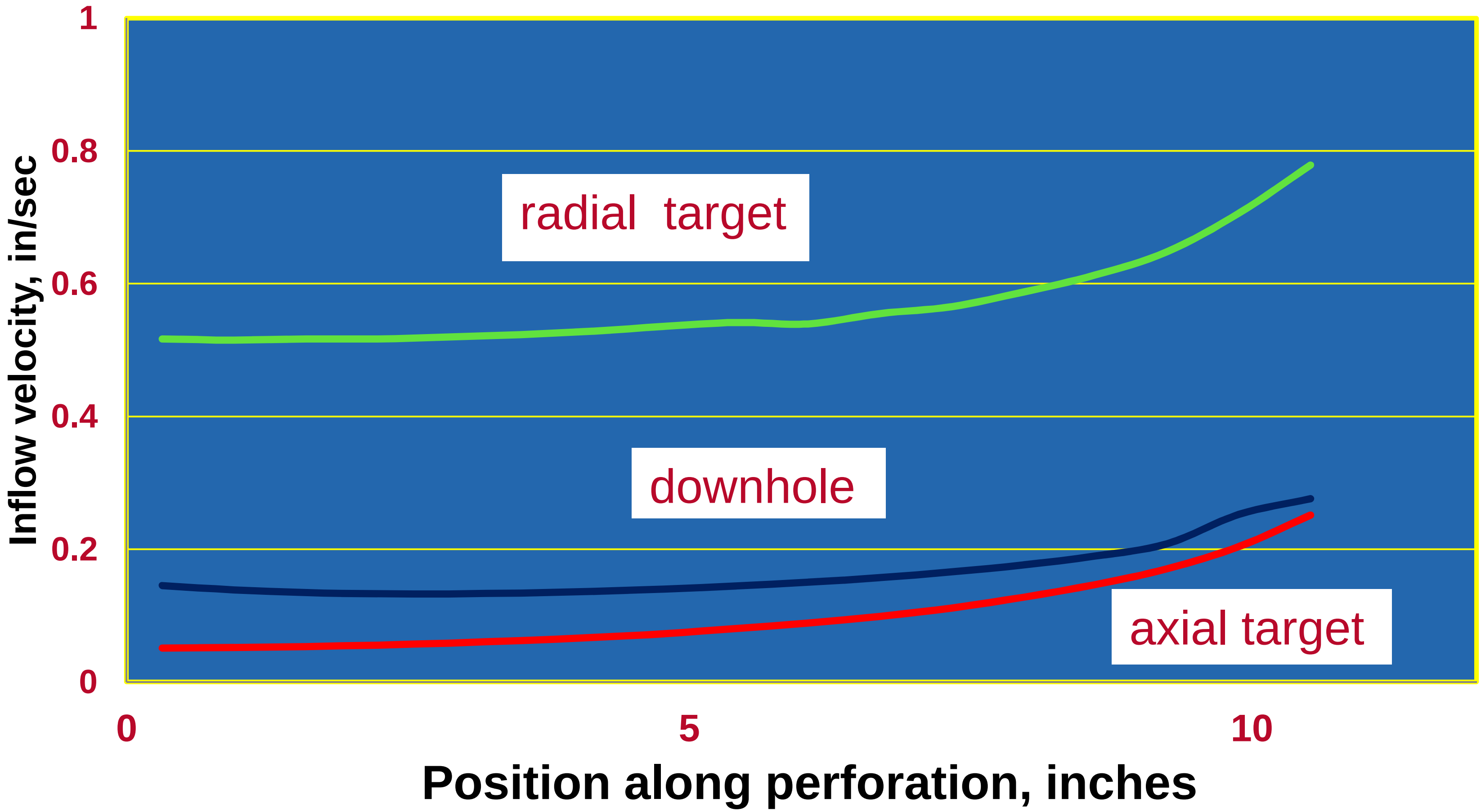
Target Core

– Diameter	7.0 in.
– Length	24 in.

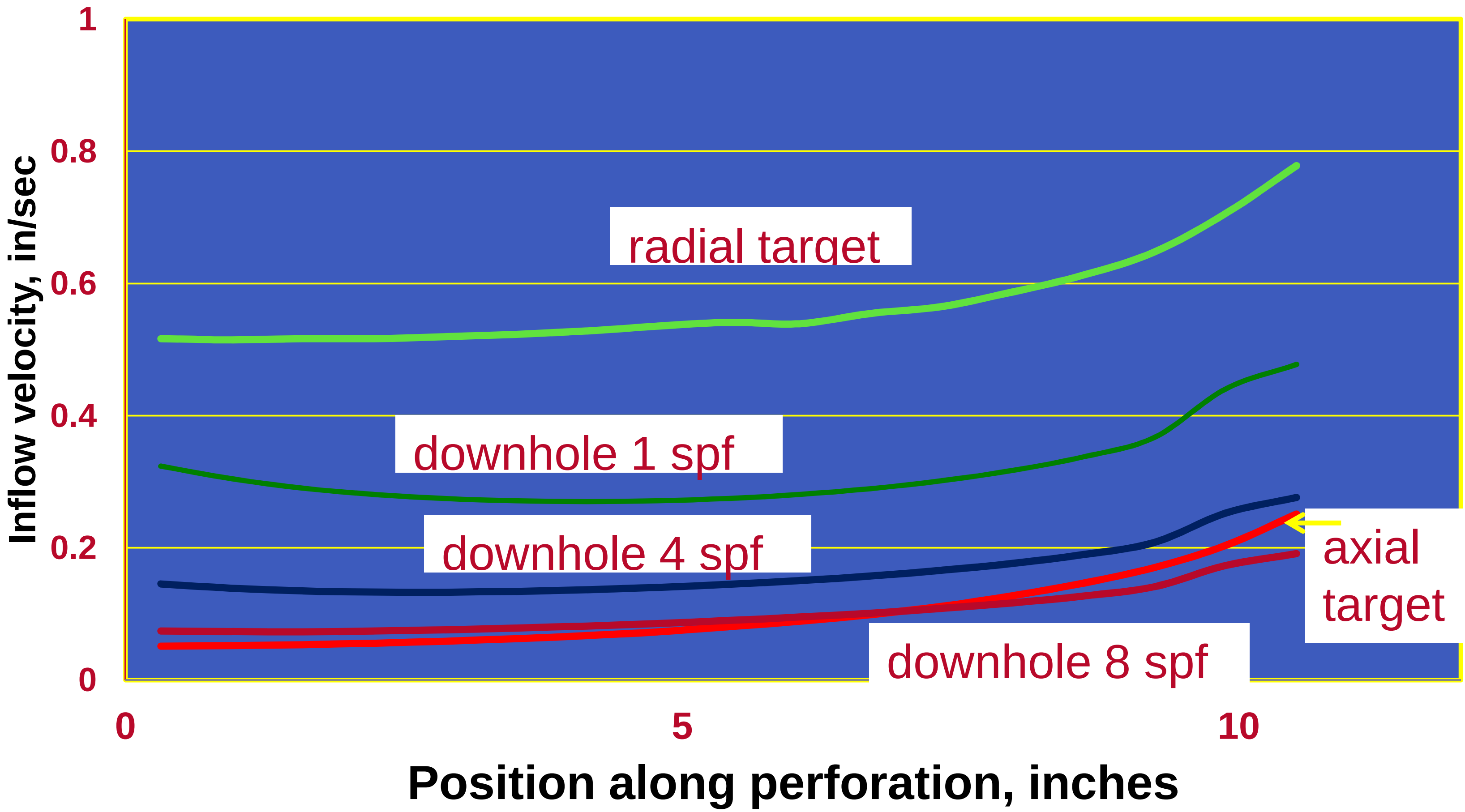
Perforation Geometry



Comparison of calculated downhole inflow velocities with Sec 4 targets



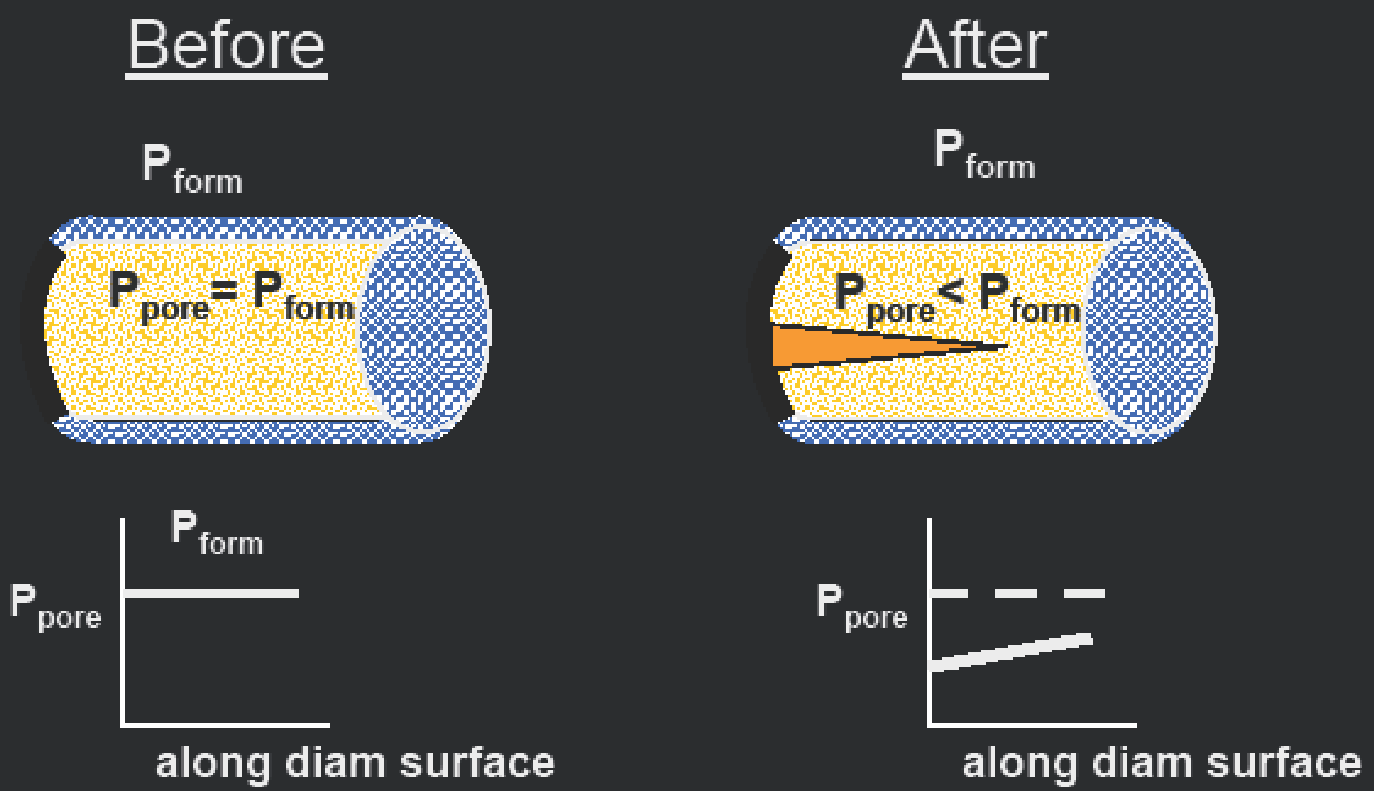
Comparison of calculated downhole inflow velocities with different shot densities



Conclusion: Neither radial nor axial targets duplicate the flow downhole.

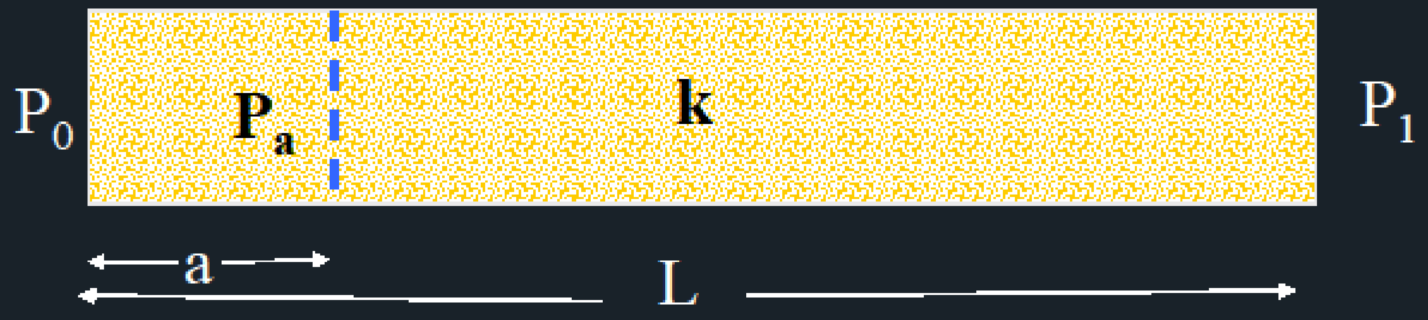
One Solution: Match flow impedance at the core boundaries with a specially constructed flow-impedance sleeve.

Pressure Response with Impedance Sleeve

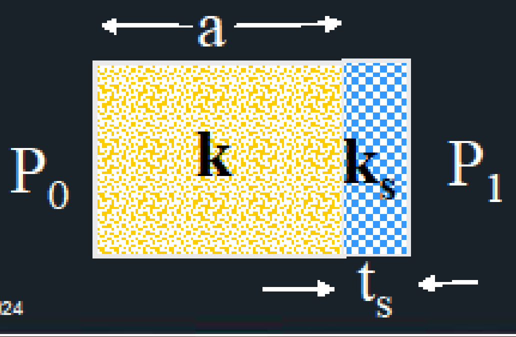


Flow Impedance Principle

One-dimension (axial flow) illustration



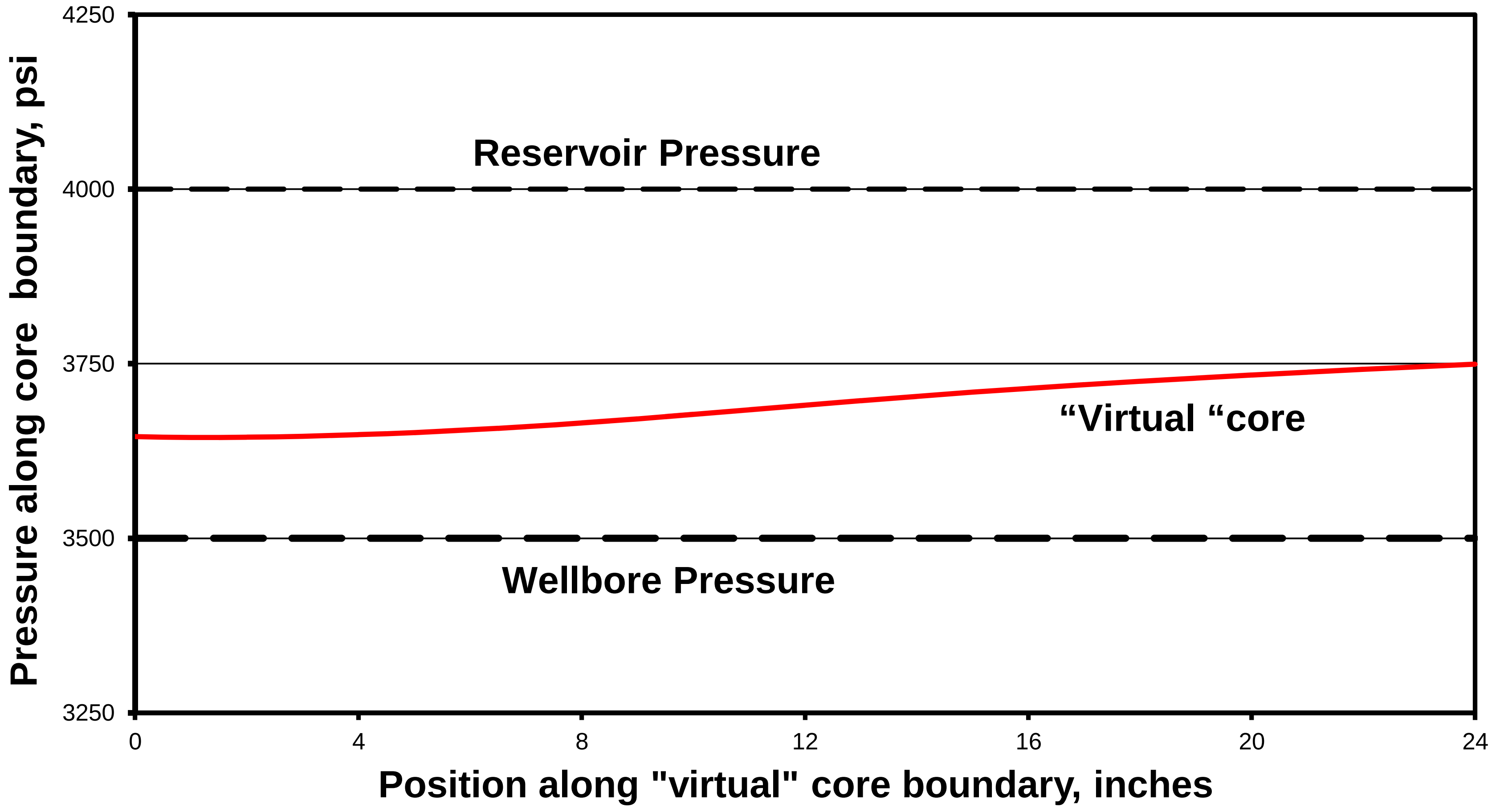
Equivalent to



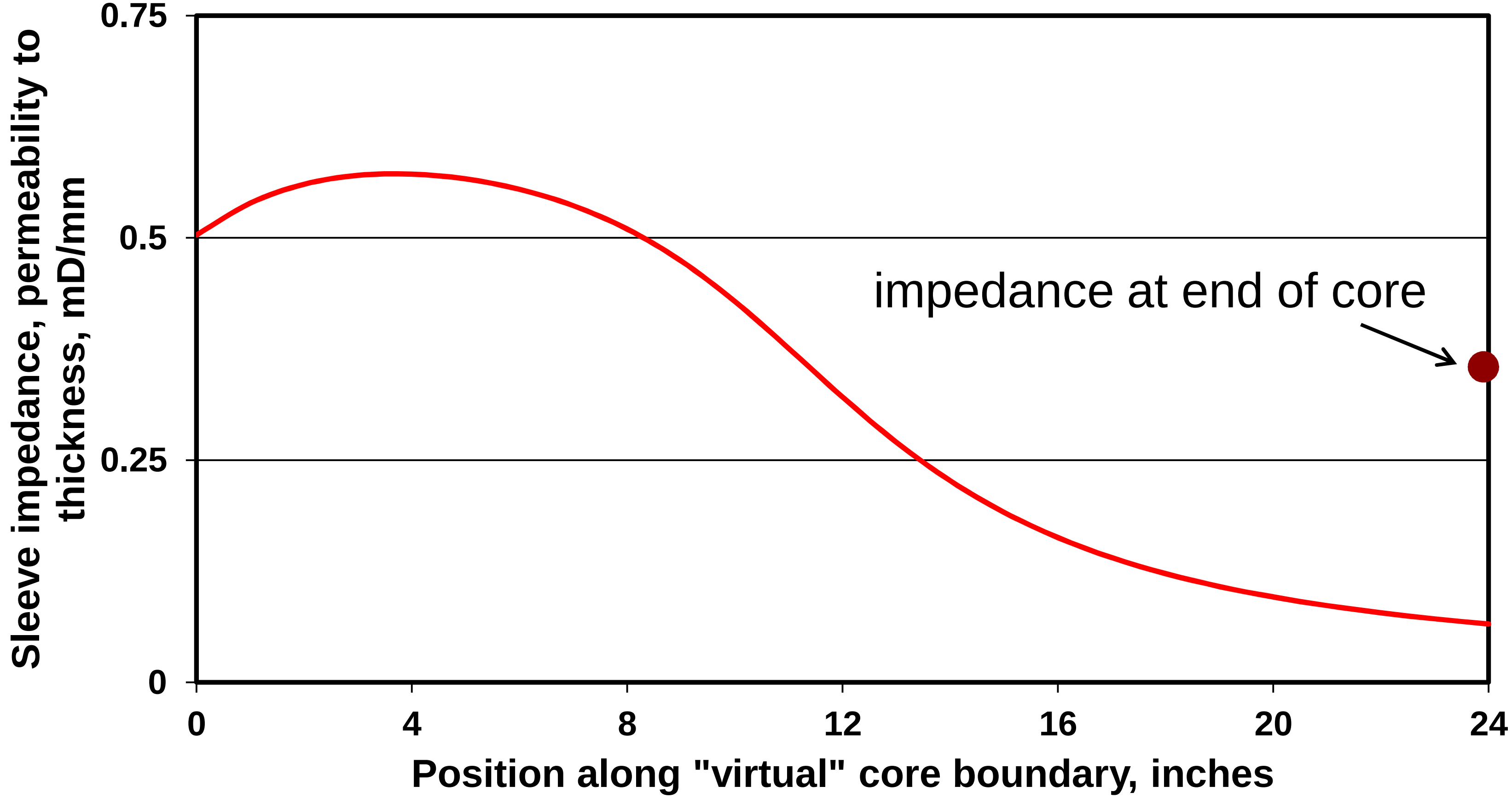
$$\frac{t_s}{k_s} = \frac{L}{k}\,\frac{P_1 - P_a}{P_1 - P_0}$$

$$\sim \frac{pressure}{velocity}$$

Downhole pressure along boundary of “virtual” core



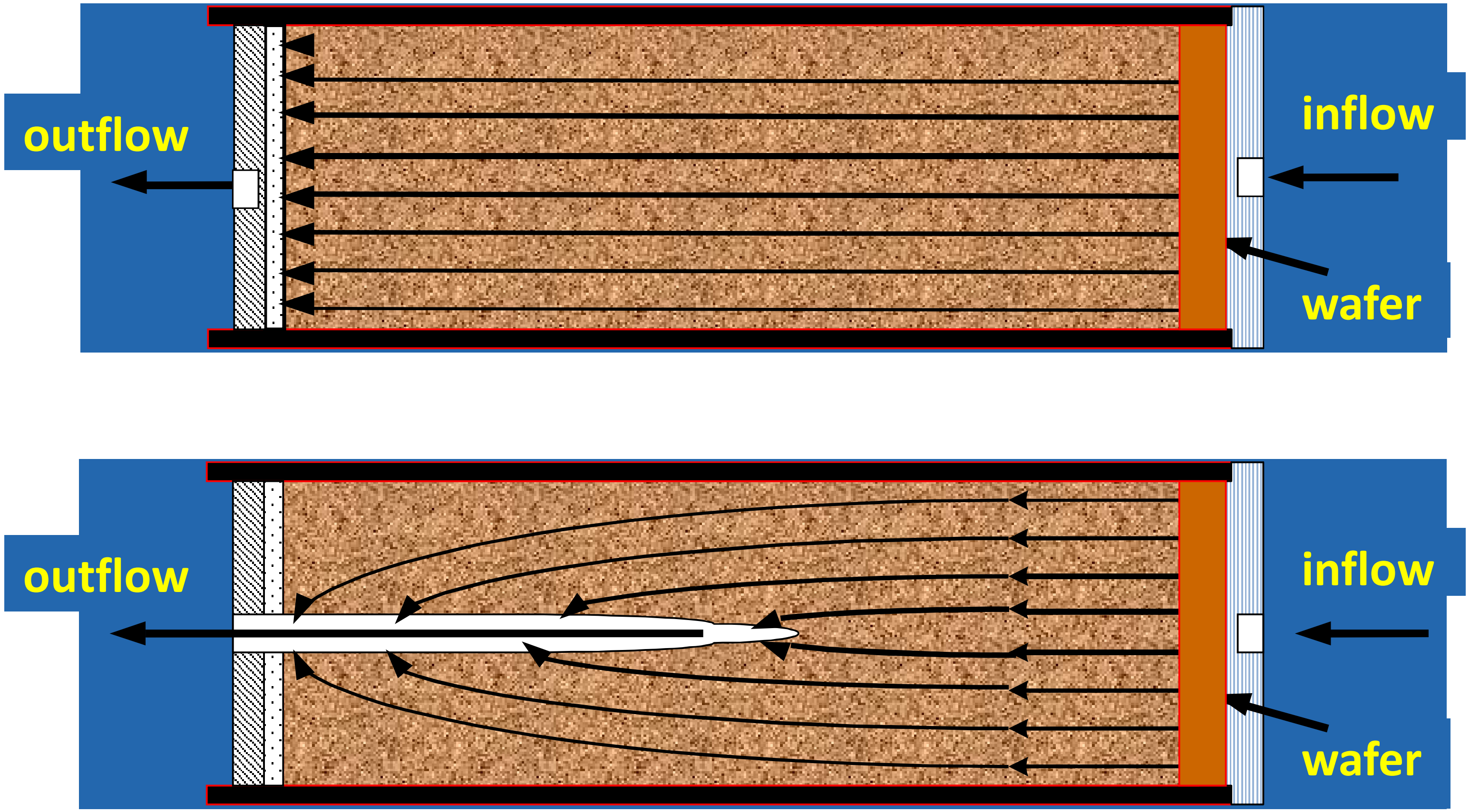
Sleeve Impedance along boundary of “virtual” core



Procedure

- Define downhole parameters (perforation shape, formation pressure, etc.)
- Specify target core dimensions
- Calculate downhole flowing pressure and velocity at "virtual" core diameter
- Calculate impedance sleeve.
- Manufacture and assemble sleeve on target core
- Follow normal Section 4 test procedures, substituting modified target

Schematic of Modified Axial Flow Target



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Flow Results

SUMMARY OF FLOW RESULTS WITH NO WAFER					
Baseline (No Wafer)	Permeability (mD)	Impeded Permeability (mD)	Post-Perforation Permeability Index (mD)	Production Ratio 1.19 average	Perforation Flow Efficiency (%)
Test 1	418	418	485	1.16	77
Test 2	472	472	576	1.22	81

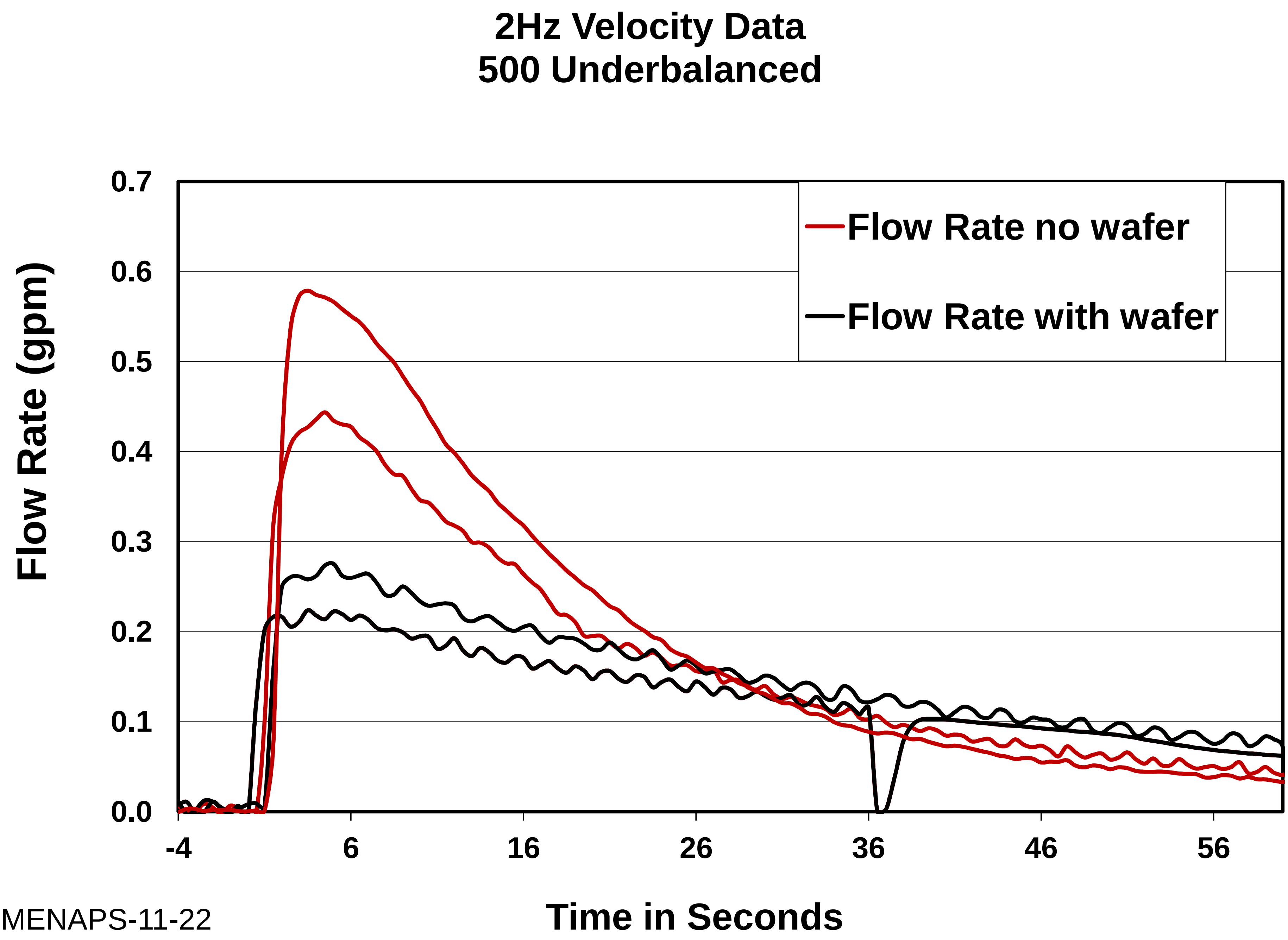
SUMMARY OF FLOW RESULTS WITH WAFER					
With Wafer	Permeability (mD)	Impeded Permeability (mD)	Post-Perforation Permeability Index (mD)	Production Ratio 0.88 average	Perforation Flow Efficiency (%)
Test 3	537	256	238	0.93	62
Test 4	563	237	213	0.90	60
Test 5	584	321	263	0.82	55

Penetration Results

SUMMARY OF PENETRATION RESULTS			
Test Number	Wafer	Open Tunnel Length, inches	Total Core Penetration, inches
1	No	10.80	13.55
2	No	10.71	13.90
3	Yes	10.62	12.80
4	Yes	10.65	13.60
5	Yes	10.52	13.70

Photo of Split Cores

Test 1 **Test 2** **Test 3** **Test 4** **Test 5**



2Hz Velocity Data
500 Underbalanced
Flow Rate no wafer
Flow Rate with wafer
Flow Rate (gpm)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-4
6
16
26
36
46
56
Time in Seconds

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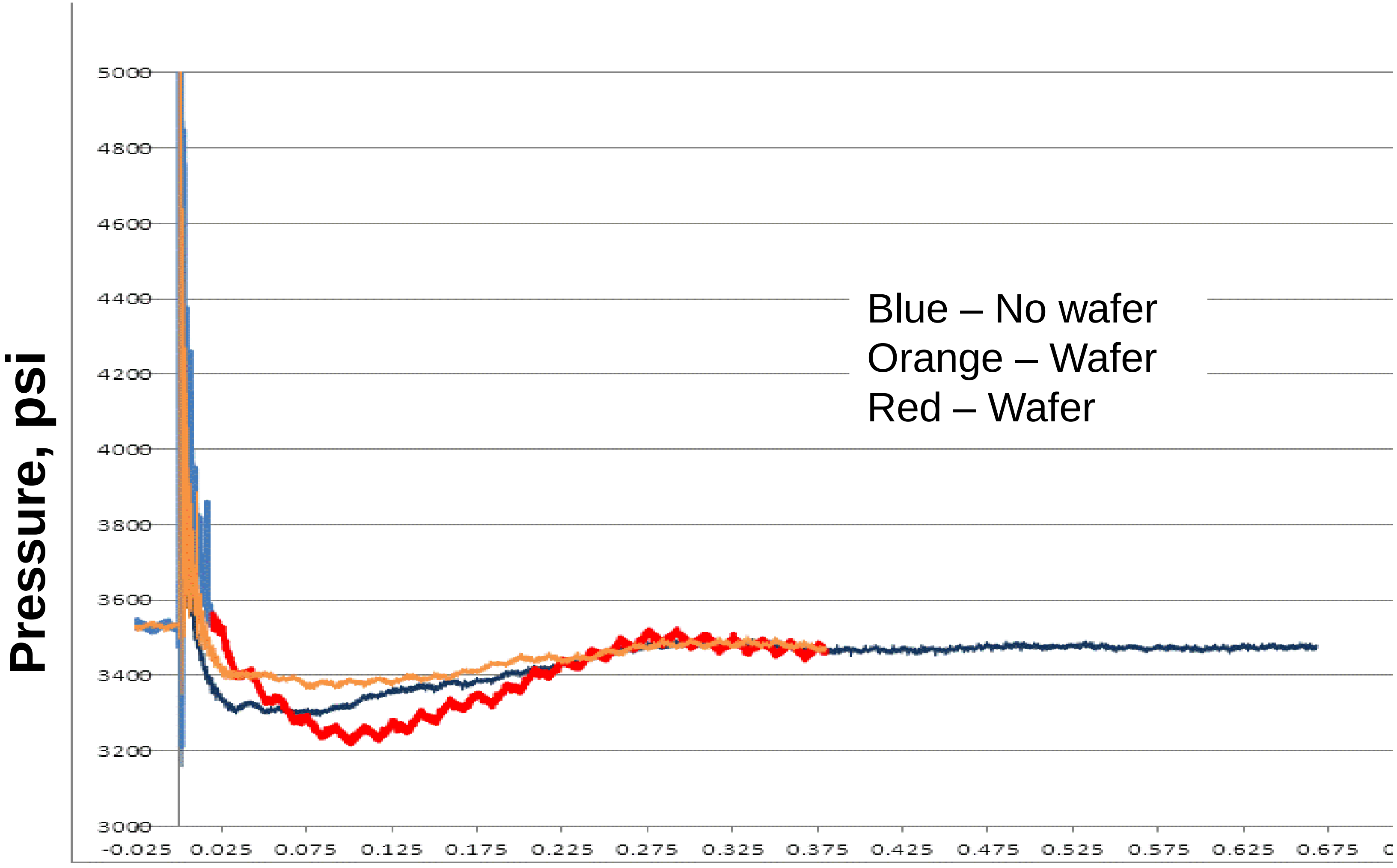
Transient Wellbore Pressure



Time, seconds

Summary

- We point out opportunities to improve simulating downhole conditions with a small-scale Section 4-type test:
  - We describe a more realistic simulation of pore pressure during the perforating process by modifying a conventional Section 4 target

Summary

- We point out opportunities to improve simulating downhole conditions with a small-scale Section 4-type test:
  - We describe a more realistic simulation of pore pressure during the perforating process by modifying a conventional Section 4 target

- Initial testing indicates that there could be significant differences between conventional Section 4 results and more realistic simulations of downhole flow

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Thank You!
Questions/Comments?