Laboratory Observations on Dynamic Effective Stress Associated with Dynamic Underbalance on Low and Moderate Strength Formations

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Agenda

- Define Dynamic Effective Stress (DES) and note its importance
- Brief description of two test cases
- Review CT scan images for each test case and discuss the results
- Review fast gauge response charts from second test case
- Conclusions / Comments

What is DES and its importance?

- It is the transient stress around the perforation tunnel at perforating
- It reaches a maximum immediately after charge detonation
- Duration is typically between 0.25 and 1.50 seconds
- It is a consequence of dynamic underbalance
- It is significant for optimizing gravel pack and injection operations

DES: mechanism that determines the condition of the perforation tunnel

1. **Debris filled tunnel but with competent walls** – more common with big hole (BH) vs. deep penetrating (DP) charges

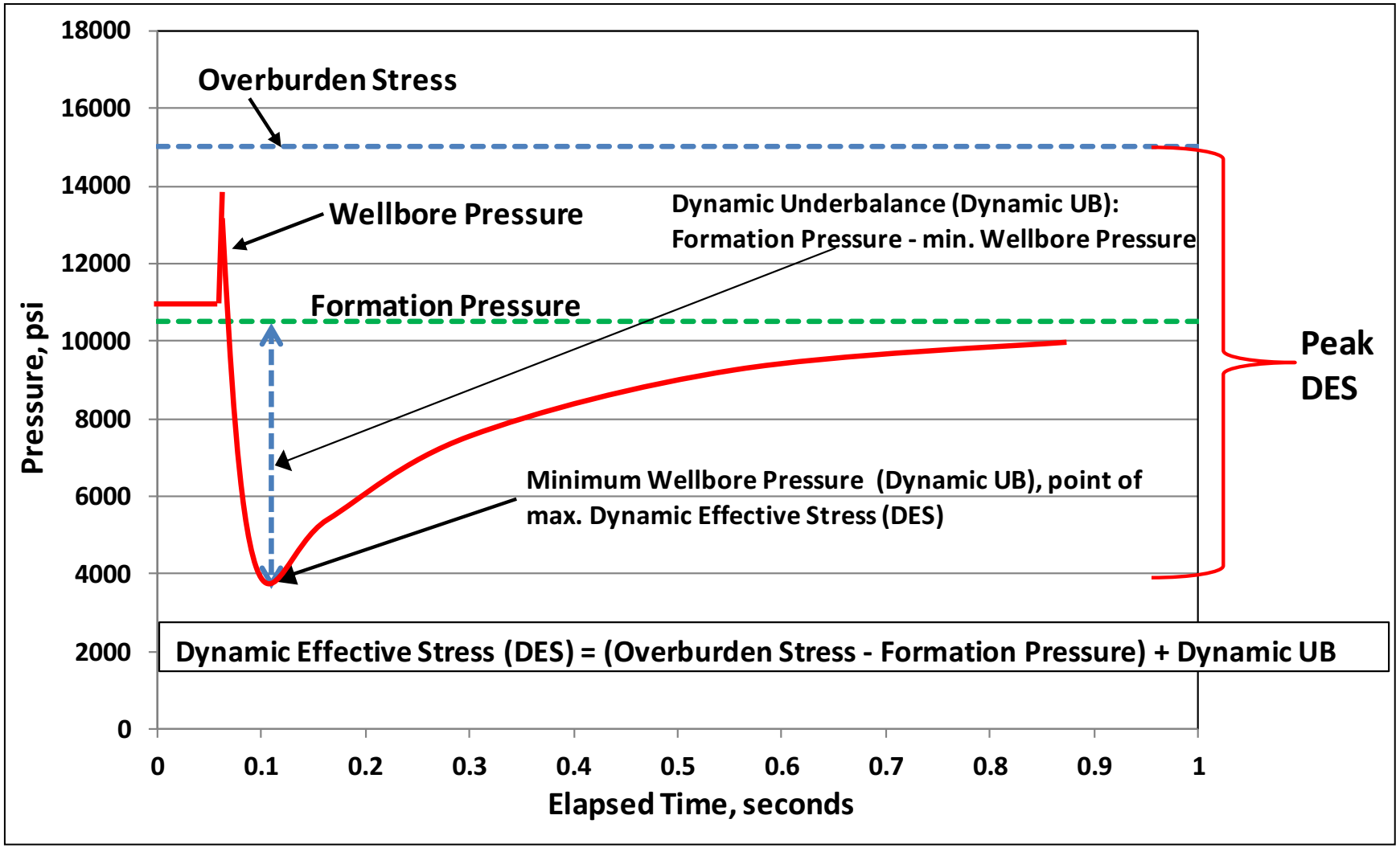
2. **Partial tunnel collapse –** usually when DP charges are used

3. **Failure with no tunnel walls** – occurs when a wellbore underbalance is combined with significant effective stress on a low UCS formation

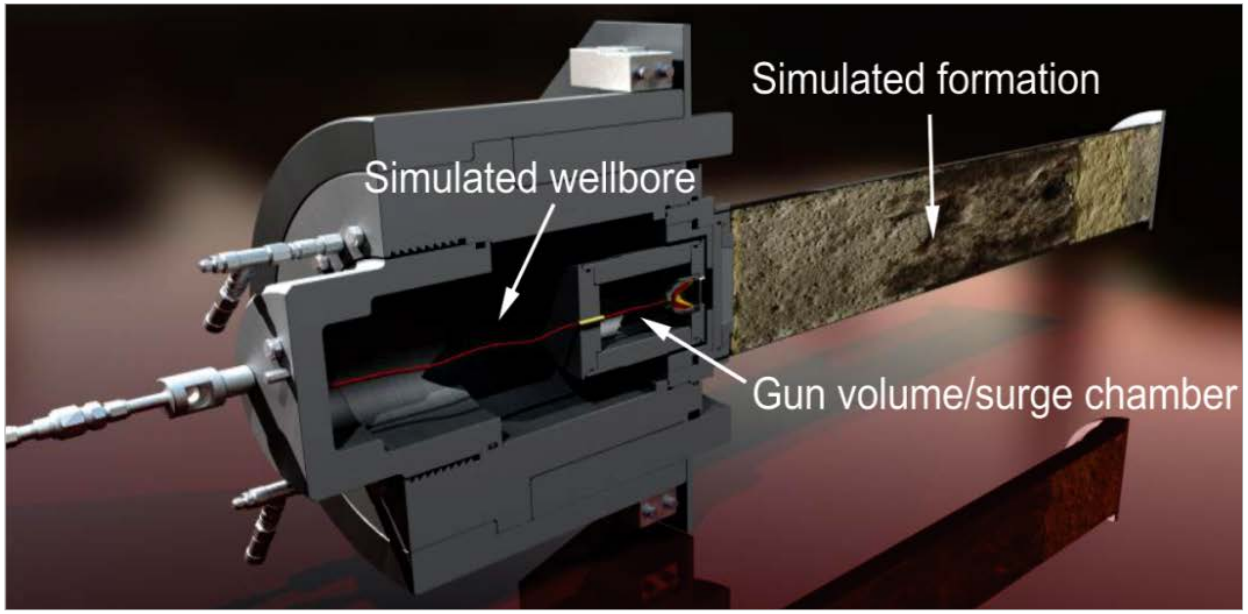
SPE distinguished lecturer Dr. Ian Walton: "Shear failure occurs when effective stress exceeds 3 to 5 times the UCS of the formation depending on tunnel diameter". SPE-90123-MS (2004) "A rock with strong cementation is more likely to support a competent cavity than a rock that is weakly consolidated. However, strength alone does not tell the whole story of how the rock will behave after being perforated. The capability of the virgin rock to support a perforation cavity is dependent on the compressive load, the UCS and on the diameter of the initial cavity. Based on Thick-wall cylinder tests, a model of tunnel stability was developed at SLB Cambridge Research Center. The model shows that shear failure occurs when the effective stress around the tunnel exceeds a certain multiple of the UCS. The multiple depends on the diameter of the tunnel and is most commonly in the range of 3 to 5 with narrow cavities being stronger than wider cavities."

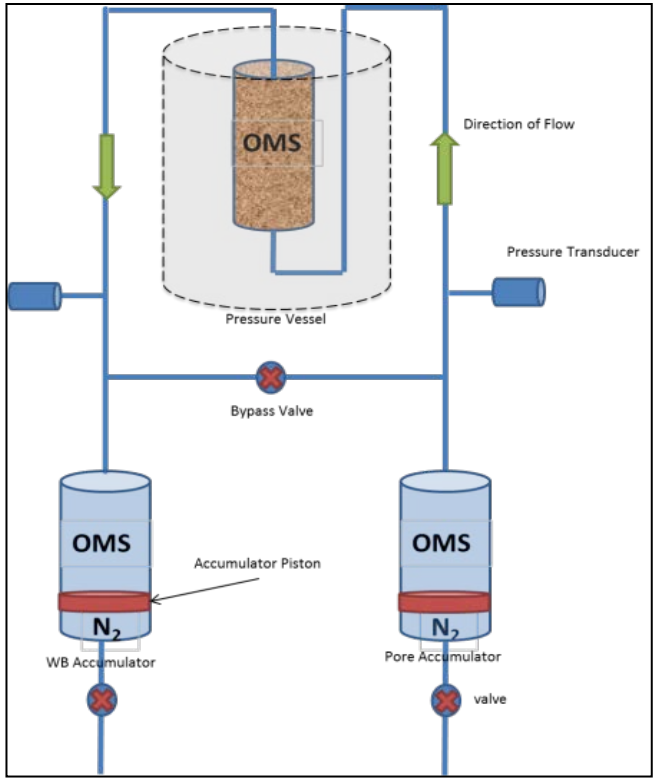
Determining DES

Fast Gauge Chart of Wellbore Pressure during Perforating



API RP 19B Section 4 Testing Apparatus Setup





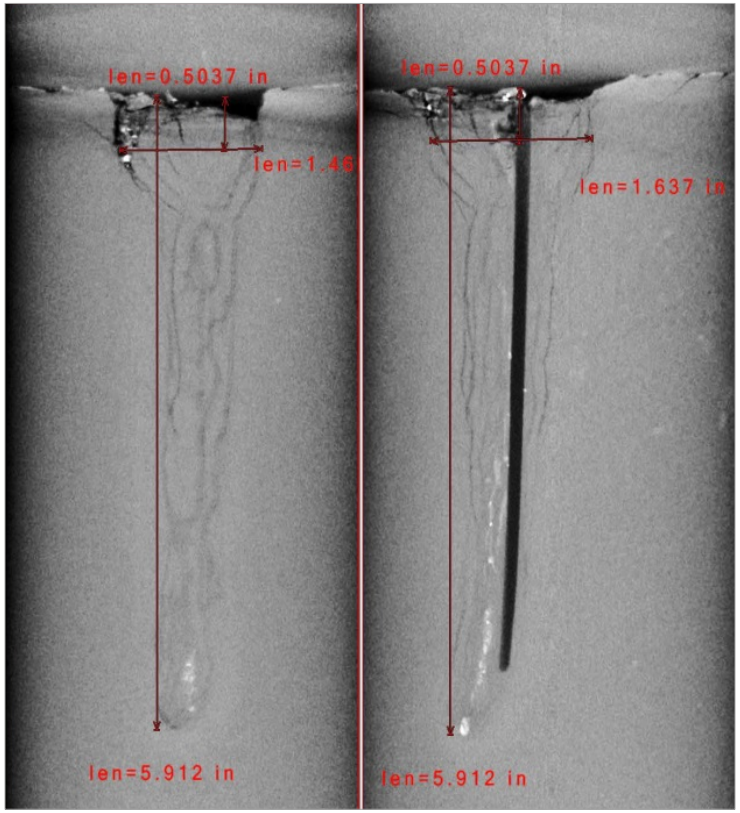
-Overburden Stress to 25,000 psi
-Formation Pressure to 20,000 psi
-Temperature to 400˚F

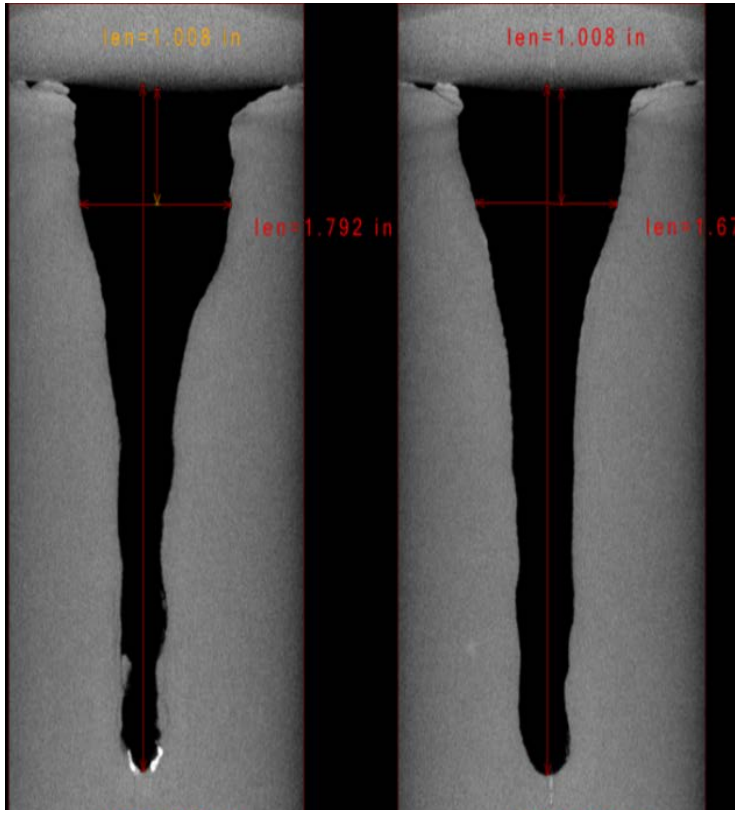
-Core Dia. to 12 in.
-Core Len. to 48 in.

Test Setup and Conditions for Set 1 at Low Pressure

Detail	Test 1	Test 2	Test 3	Test 4
Overburden pressure / Effective Stress (psi)	7,000 / (3,400 - 3,756)			
Formation - estimated UCS (psi)	Castlegate sandstone - 2,200 (OMS-saturated)		Saltwash Red sandstone - 890 (dry)	
Wellbore pressure (psi)	3,500	3,300	3,600	3,600
Formation (Pore) pressure (psi)	3,244	3,291	3,600	3,310
Per-charge free gun volume (cc)	240	180	180	180
Wellbore fluid	(OMS)	9-lbm/gal Brine	Odorless mineral spirits (OMS)	
Porosity (%)	26.0		20.0 to 23.5	
Permeability (md)	1000		2000	1850
Static wellbore Pre-perf. condition (psi)	+256	Balanced	Balanced	+290
Charge	4 5/8-in. Steel-cased big hole HMX			
Fluid gap (in.)	1.09			
Casing thickness (in.)	0.408 (4140 Steel)			
Cement thickness (in.)	0.75 (Class A Portland)			
Core diameter/length (in.)	7.0 (nominal) / 24.0 (nominal)			
Pore fluid	OMS			
Temperature (°F/°C)	77 / 25			

Test 1





Safe DES/UCS ratio is 3-5

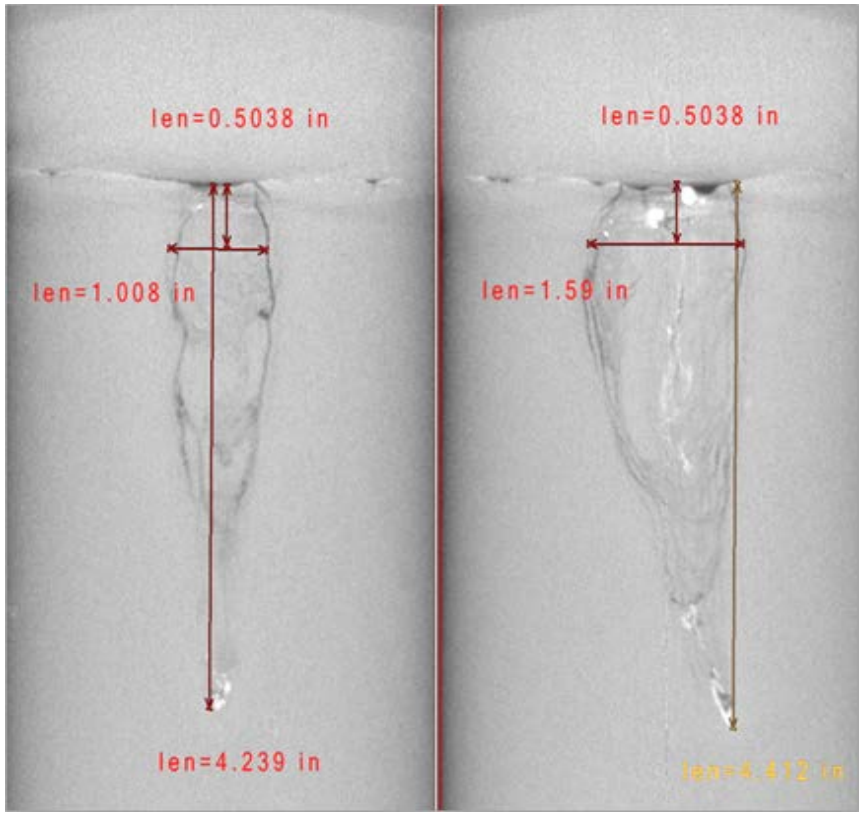
With UCS of 2,200 psi the DES/UCS ratio = 1.7

Post–Flow CT image shows debris is removed and perforation tunnel is competent

Wellbore: 3,500 psi, Pore Pressure: 3,244 psi, Static UB: 256 psi, Dynamic UB: 21psi,
DES = 7,000 (Overburden) - 3,244 psi + 21 psi =3,777 psi

Test 2

Safe DES/UCS ratio is 3-5

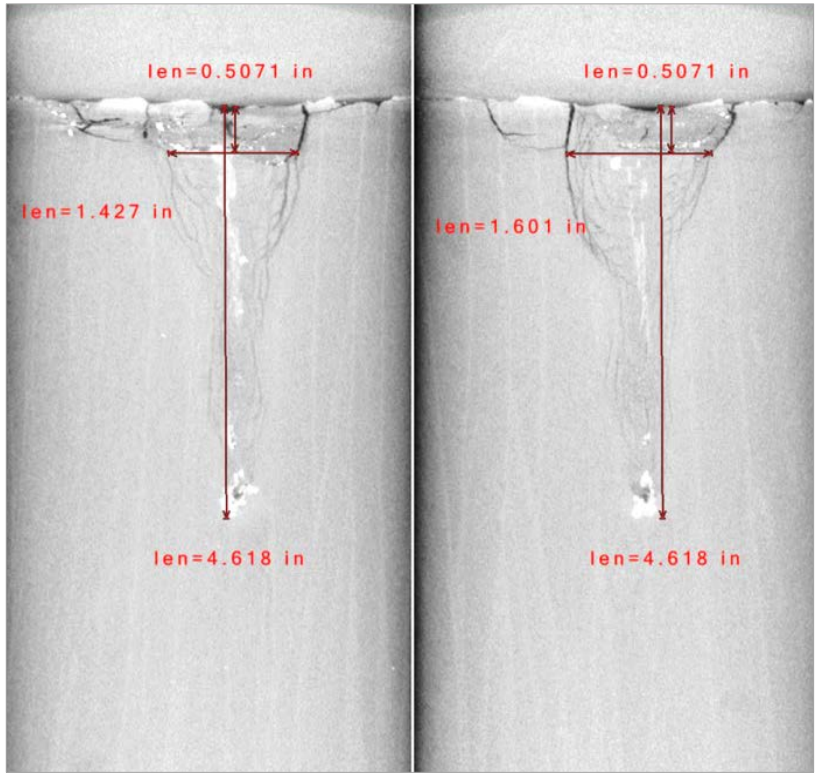


With UCS of 2,200 psi the DES/UCS ratio = 1.83

Wellbore: 3,300 psi, Pore Pressure: 3,291 psi, Static UB: 9 psi, Dynamic UB: 325 psi,
DES = 7,000 (Overburden) - 3,291 psi + 325 psi = 4,034 psi

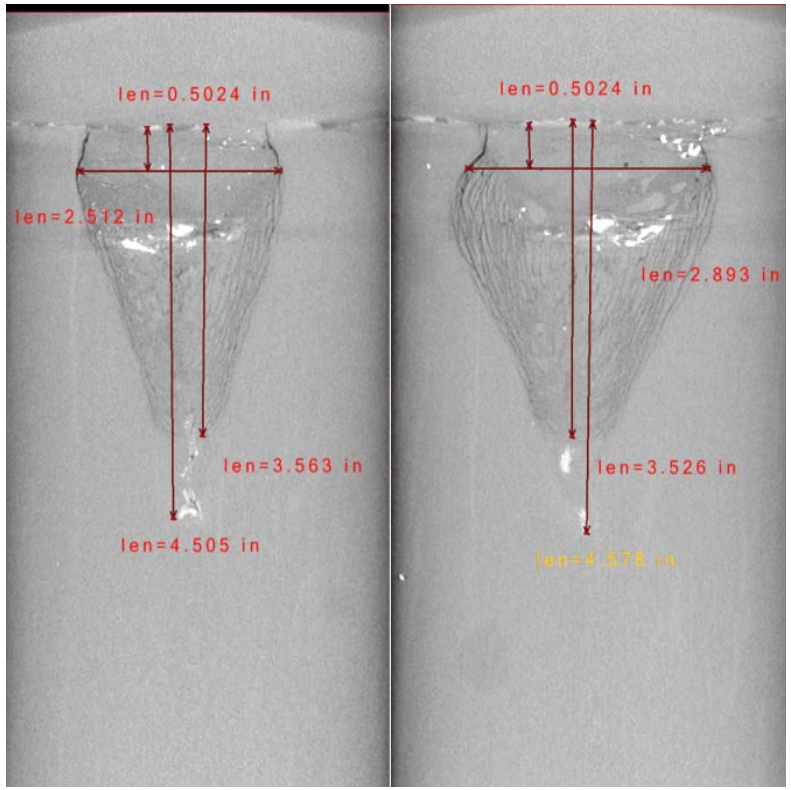
Test 3 and Test 4

Safe DES/UCS ratio is 3-5



With UCS of 890 psi the DES/UCS ratio = 4.2

Wellbore: 3,557 psi, Pore Pressure: 3,267 psi Dynamic UB: 10 psi
DES = 7,000 (Overburden) - 3,267 psi + 10 psi = 3,743 psi



With UCS of 890 psi the DES/UCS ratio = 4.4

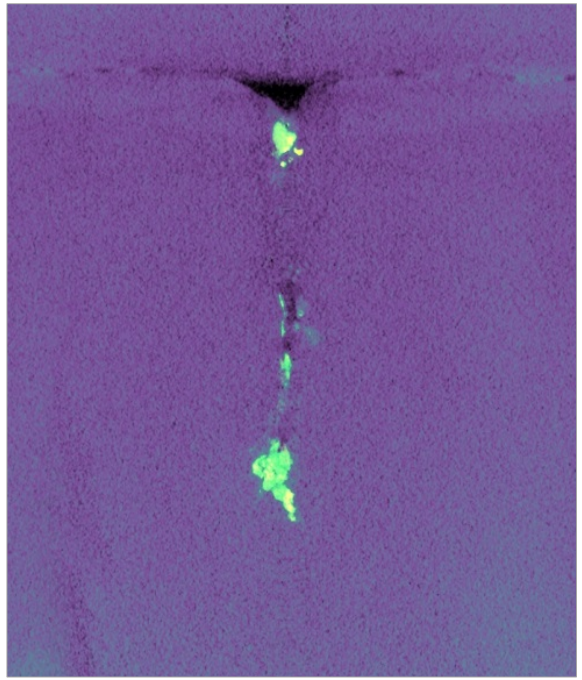
Wellbore: 3,293 psi, Pore Pressure: 3,326 psi Dynamic UB: 284 psi
DES = 7,000 (Overburden) - 3,326 psi + 284 psi = 3,958 psi

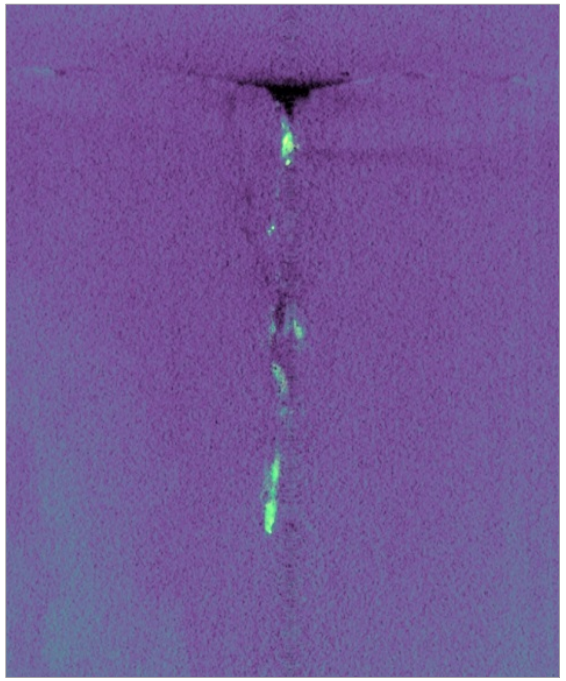
Test Setup and Conditions for Set 2 at High Pressure

Detail	Test 1	Test 2	Test 3
Target DUB / DES (psi)	6,000 / 16,000	10,500 /20,400	8,000 / 18,000
Overburden pressure / Effective stress (psi)	26,000 / 10,000		
Formation - estimated UCS (psi)	Kansas sandstone - 3,600 (TerraTek 2014) (OMS-saturated)		
Formation (Pore) pressure (psi)	16,000	16,000	16,000
Wellbore pressure (psi)	16,200	16,200	16,200
Wellbore fluid	OMS	OMS	OMS
Porosity (%)	20.1	24.6	19.9
Permeability (md)	30	30	30
Static condition (psi)	+200	+200	+200
Charge (in.)	6 3/4 Steel-cased big hole HMX		
Fluid gap (in.)	1.480		
Casing thickness (in.)	0.650 (17-4 Stainless Steel)		
Cement thickness (in.)	1.19 (Class A Portland)		
Core diameter/length (in.)	9.00 /18.00 (nominal)		
Pore fluid	OMS		
Temperature (°F/°C)	77 / 25		

Test 1

Safe DES/UCS ratio is 3-5





With UCS of 3,600 psi the DES/UCS ratio = 4.6

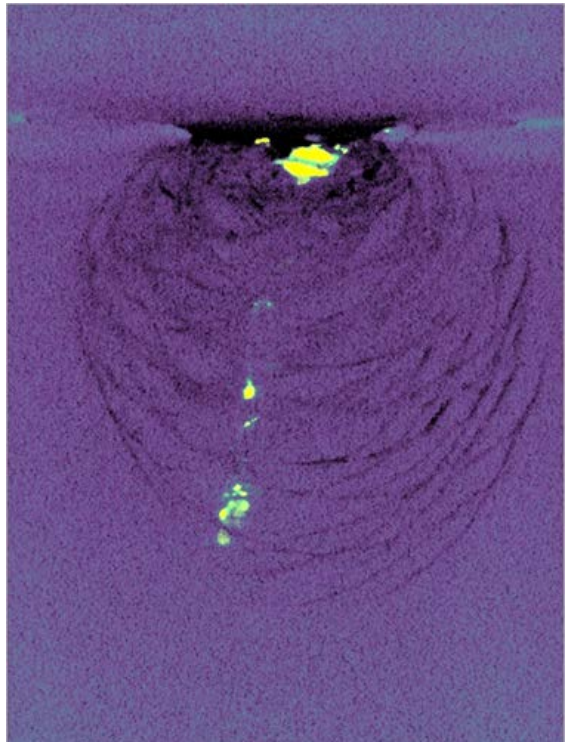
Wellbore: 16,200 psi, Pore Pressure: 16,000 psi Dynamic UB: 6,506 psi

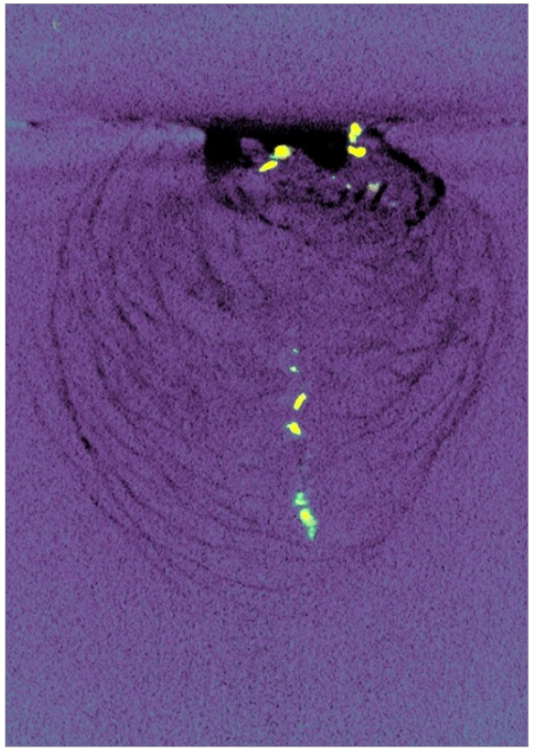
DES = 26,000 (Overburden) - 16,000 psi + 6,506 psi = 16,506 psi

Test 2

Safe DES/UCS ratio is 3-5

DES effect seen by hemispherical fracture banding contained within the BH impact zone.



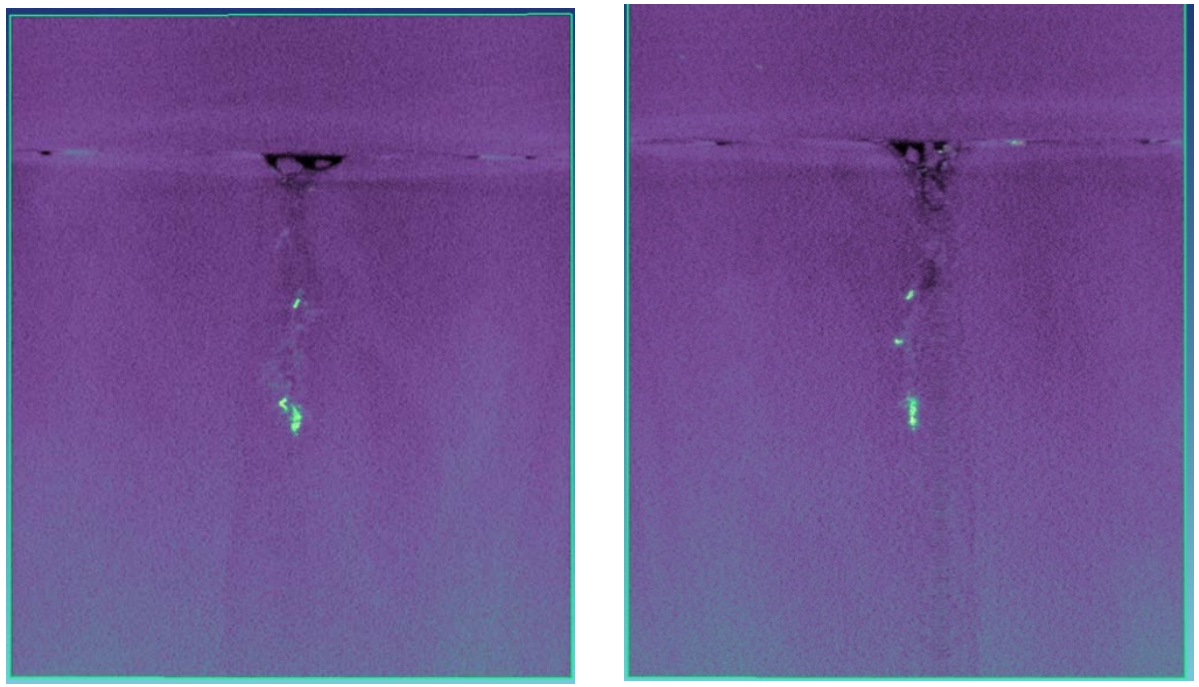


With UCS of 3,600 psi the DES/UCS ratio = 6.7

Wellbore: 16,200 psi, Pore Pressure: 16,000 psi Dynamic UB: 14,100 psi
DES = 26,000 (Overburden) - 16,000 psi + 14,100 psi = 24,100 psi

Test 3

Safe DES/UCS ratio is 3-5

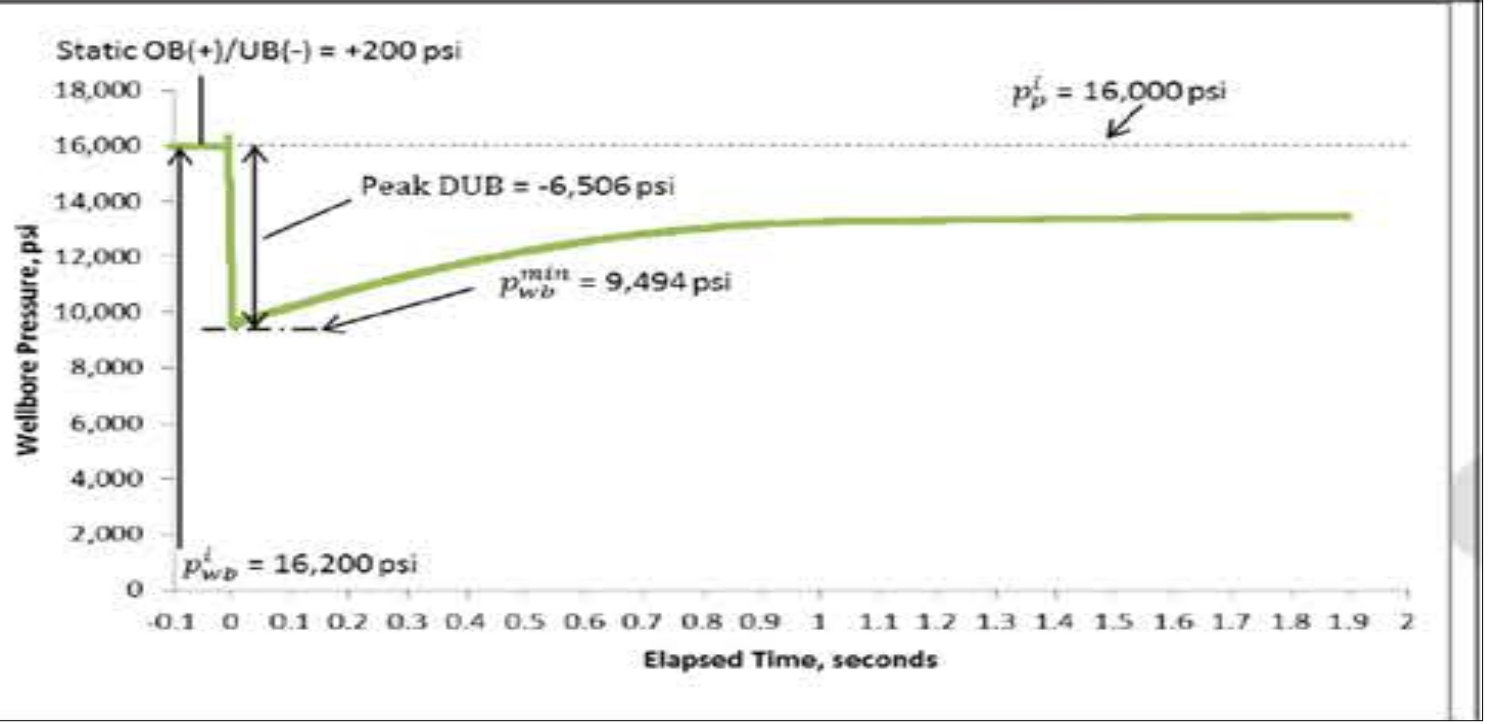


With UCS of 3,600 psi the DES/UCS ratio = 4.9

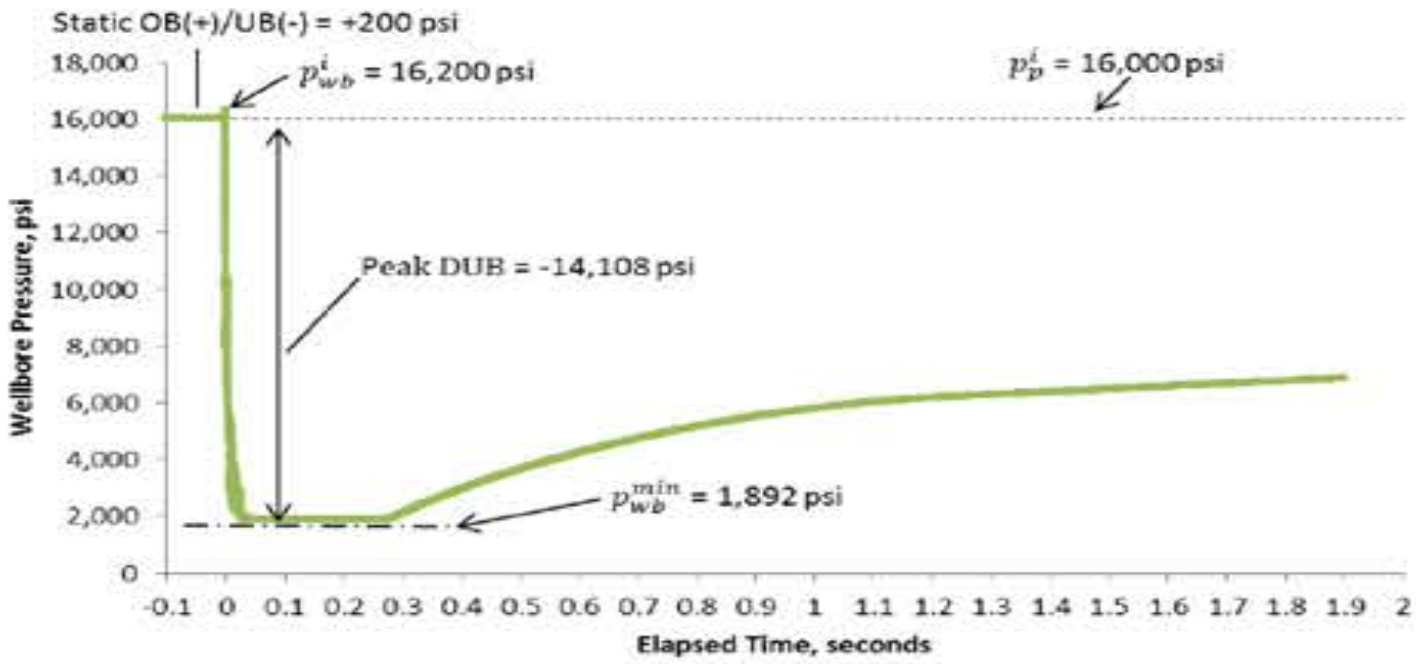
Wellbore: 16,200 psi, Pore Pressure: 16,000 psi Dynamic UB: 7,553 psi

DES = 26,000 (Overburden) - 16,000 psi + 7,553 psi = 17,553 psi

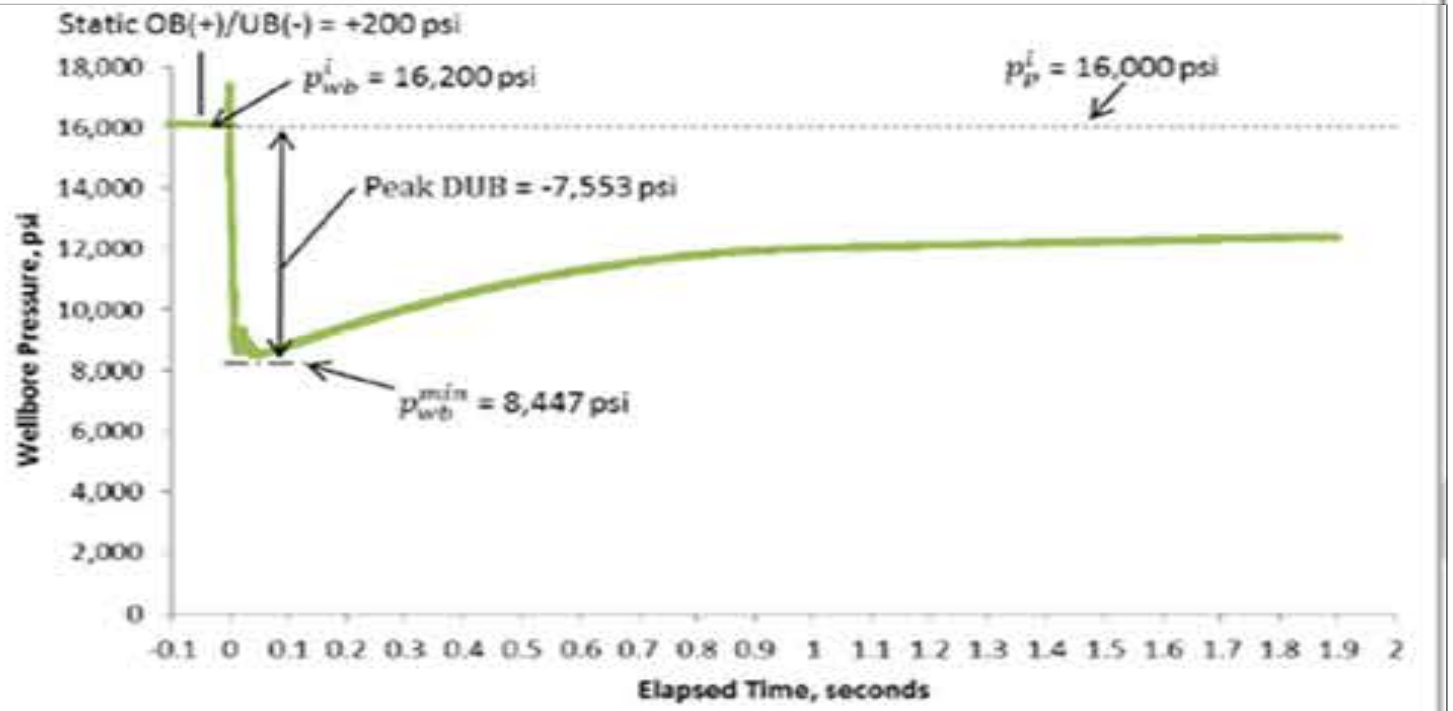
Fast Gauge Data For Test 1

Test No.	Fast Gauge Wellbore Pressure Response
1	

Fast Gauge Data For Test 2

Test No.	Fast Gauge Wellbore Pressure Response
2	

Fast Gauge Data For Test 3

Test No.	Fast Gauge Wellbore Pressure Response
3	

Conclusions/Comments

- Dynamic effective stress is the by-product of the dynamic underbalance and should be considered in dynamic underbalance design.
- It is the determinant for perforation tunnel collapse because that is the stress that can lead to failure, tensile and shear.
- Lower viscosity is favorable for avoiding collapse in terms of reducing the peak of DES and time exposure to high DES.
- Based on CT images from a similar HP testing project, DES effects on limestones should be considered separately, mainly due to narrower tunnels.
- DES can be modeled in shock hydro simulations with a modified rate-dependent strength model, a future plan.

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QUESTIONS? THANK YOU