Advanced Insight of Wellbore Strengthening Leads to Smart Selection of Preventive LCM

SHARP-ROCK TECHNOLOGIES, INC.

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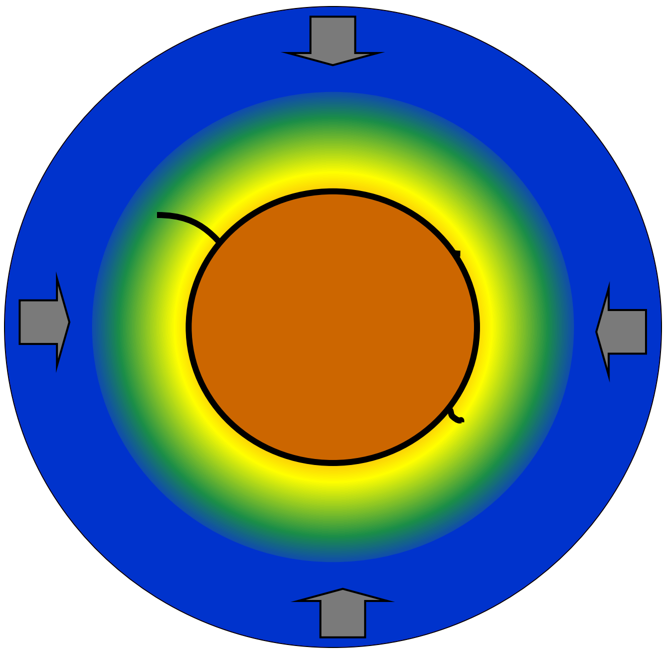
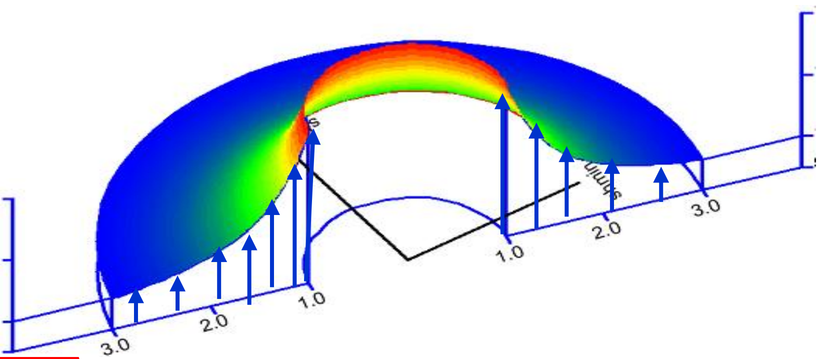
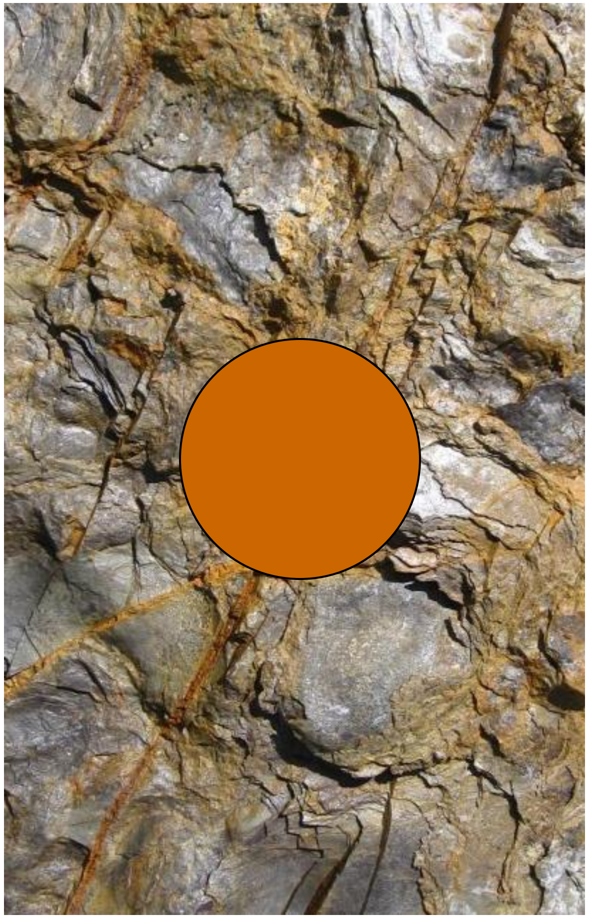
Oct. 14, 2025

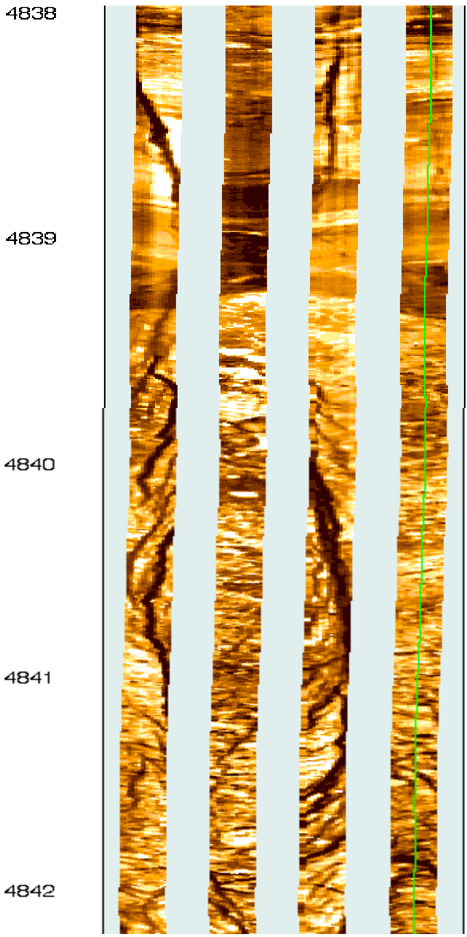
A Wellbore Weakened by Cracks

Lost Circulation and Preventive LCM



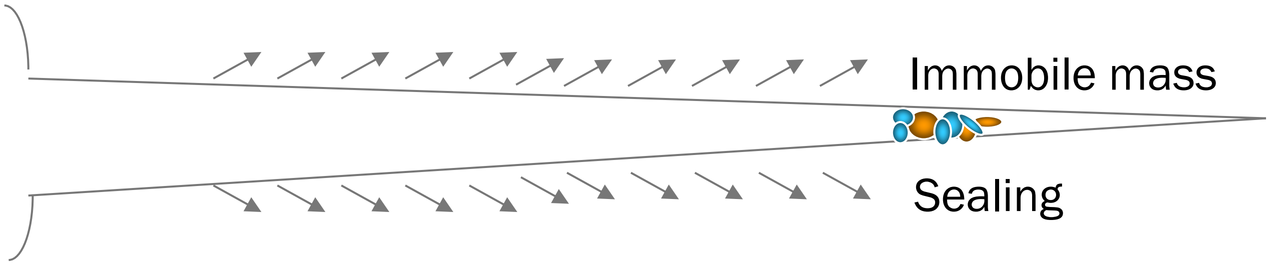




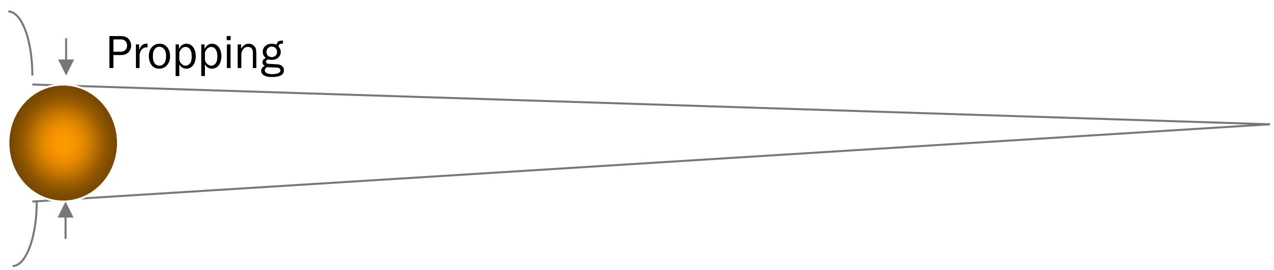


The History of What to Add and How Much to Add to Mud

1. Pretreat: Experience based. No rock mechanics theory to support and little lab proof, sometimes effective (all mud companies). What and how much to add based on someone's feeling.
2. Fracture tip screen-out: in line with rock mechanics theory, some lab proof with permeable rock only (COP). What and how much to add based on an empirical equation and some lab tests. (Since Fuh, et al., 1992)



3. Propping a fracture at the entrance or Stress Cage: (Since Alberty, et al., 2004)



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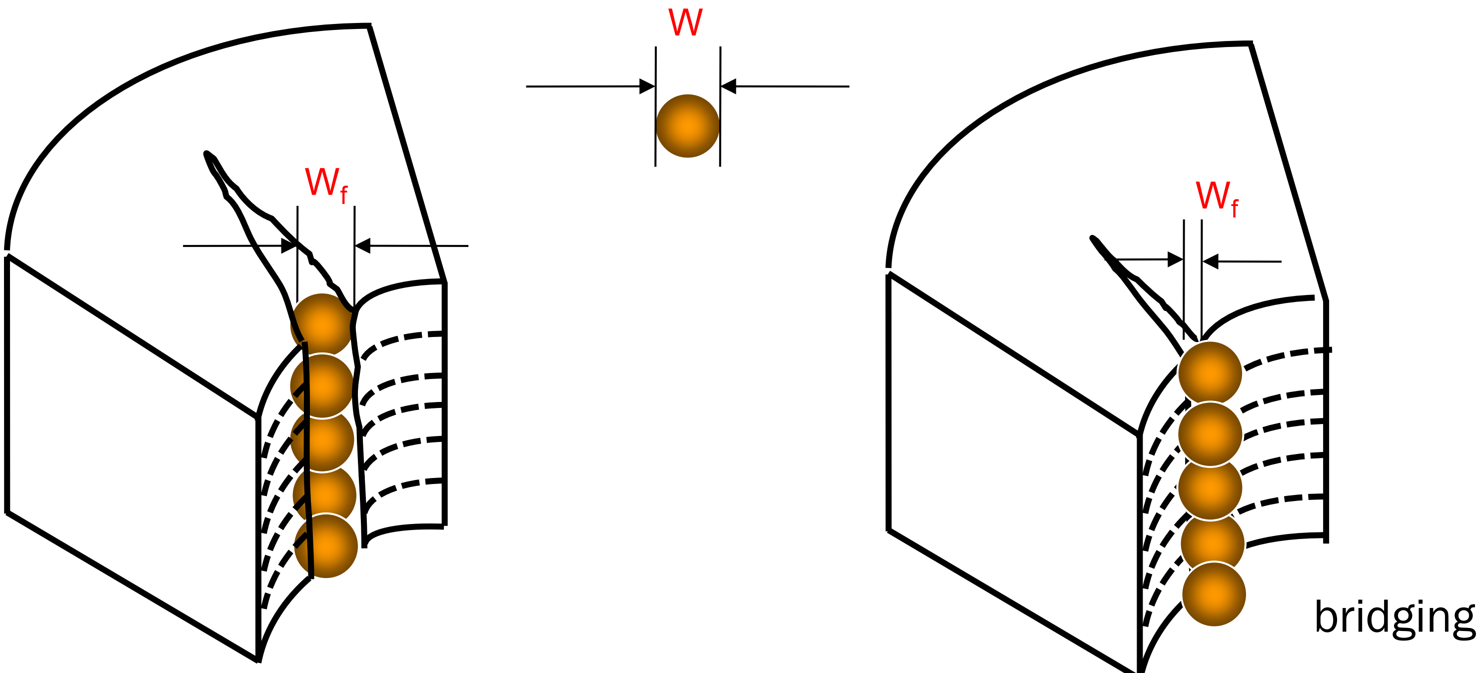
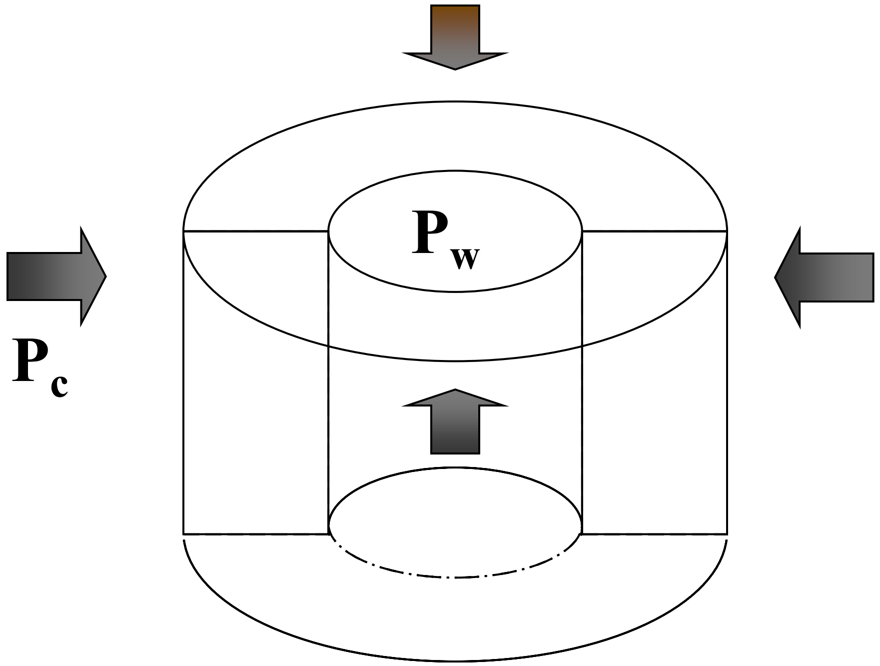
Prop or Seal a Fracture at the Entrance

Propping: W_f == W, exactly

Sealing: W_f << W



Theory: Sealing Cracks to Strengthen a Cracked Wellbore



P_c = 10,000 psi

P_w = ?

If no sealing, $P_w = P_c$ = 10,000 psi to push apart

If sealing, $P_w = 2P_c$ = 20,000 psi to push apart

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Reality: Seal or Prop a Fracture at the Entrance?

GPRI 2000

Numerous lab tests indicate sealing a

Theory: Prop or Seal a Fracture at the Entrance?

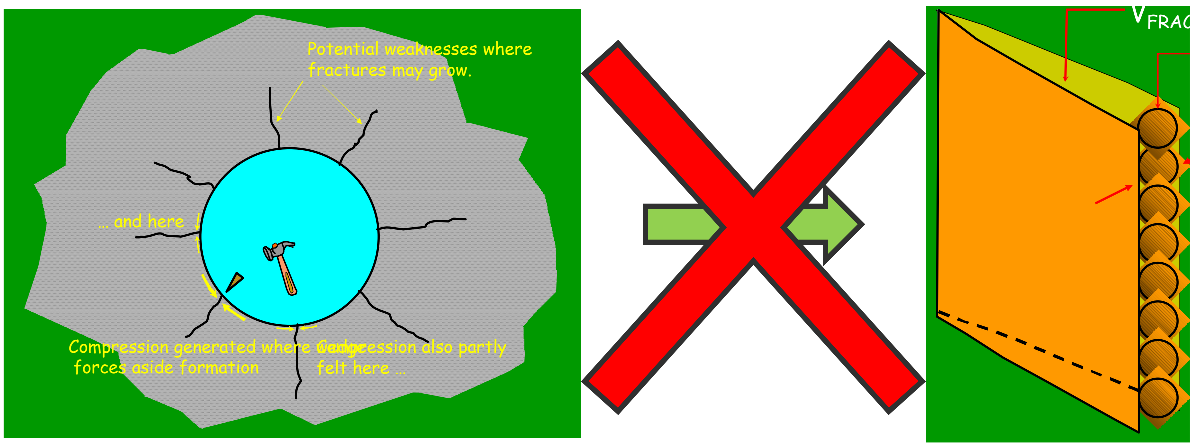
Theory: Studies have concluded the following for wellbore strengthening.
(1) Propping a fracture entrance is neither necessary nor sufficient.
(2) Sealing a fracture entrance is not only necessary but also sufficient.

<u>Theory points to "sealing" as the correct direction.</u>

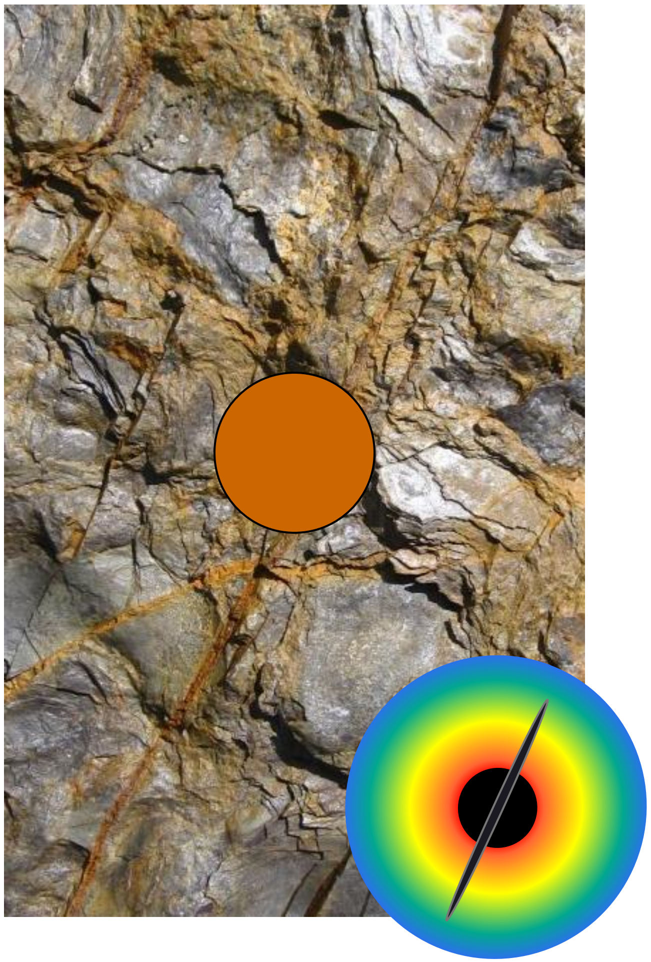
demo

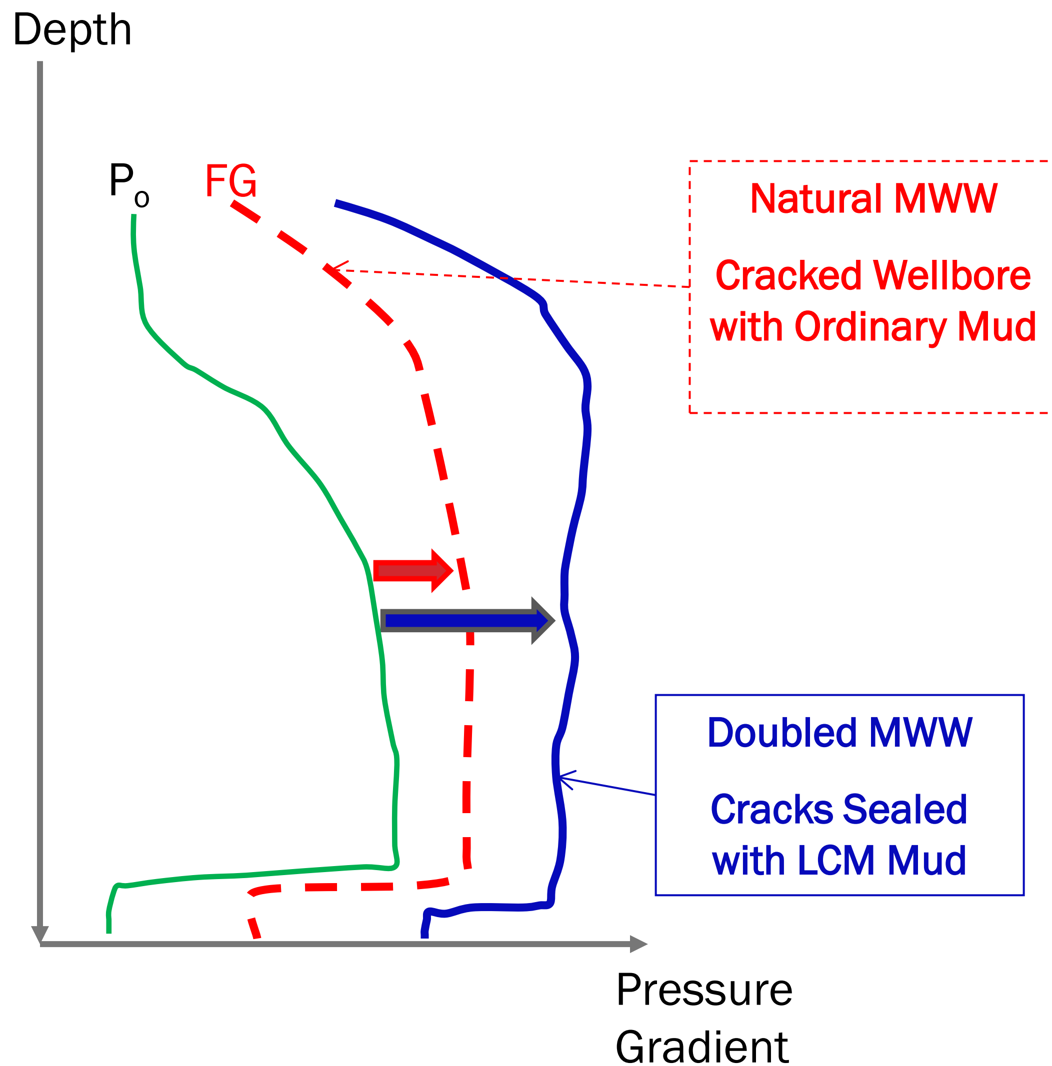
"Stress Cage" Concept

Assumption



Sealed = Strengthened: Doubled MW Window





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How to Securely Form a Seal to a Fracture?

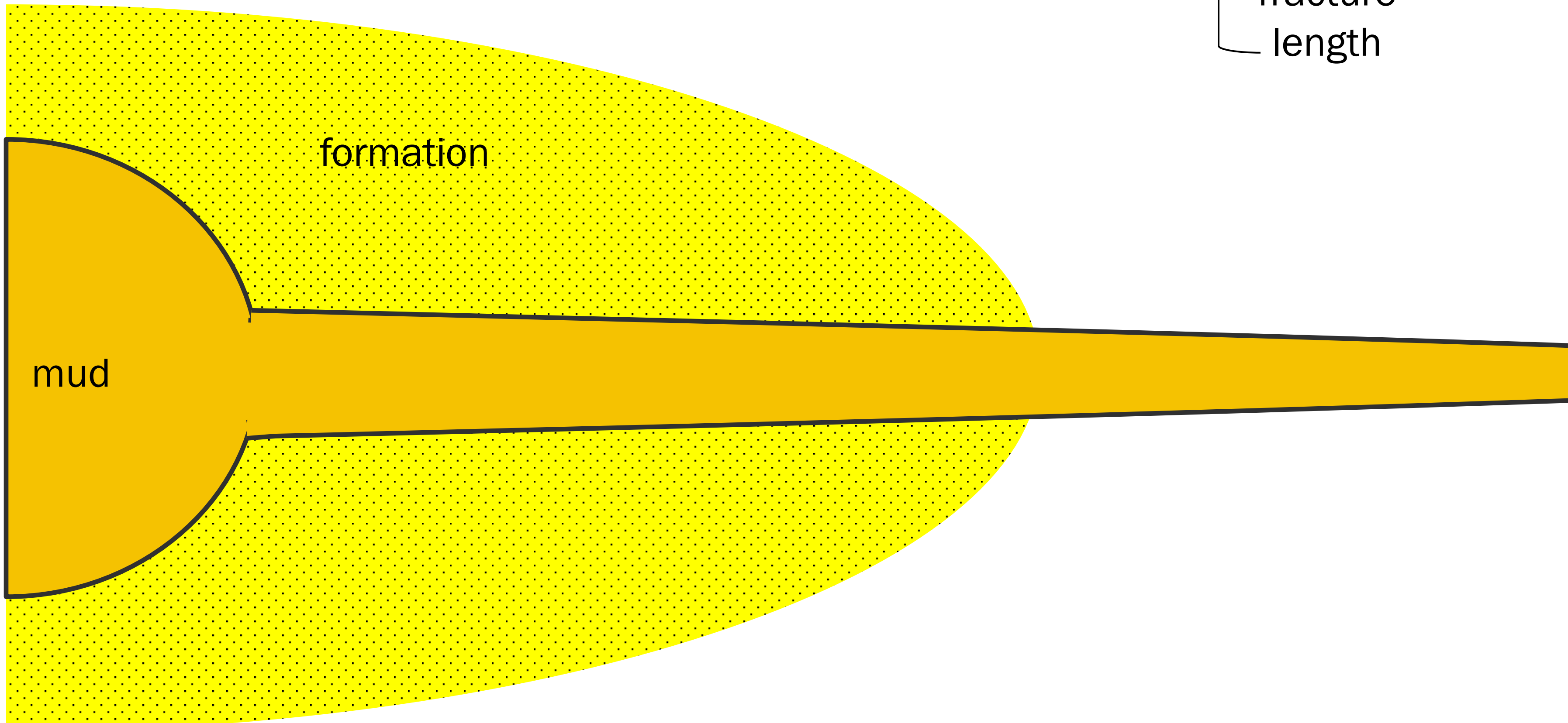
Wellbore Fracturing by Mud

Without Preventive LCM

fluid volume of a unit section of a wellbore
= fracture size

fracture width

fracture length



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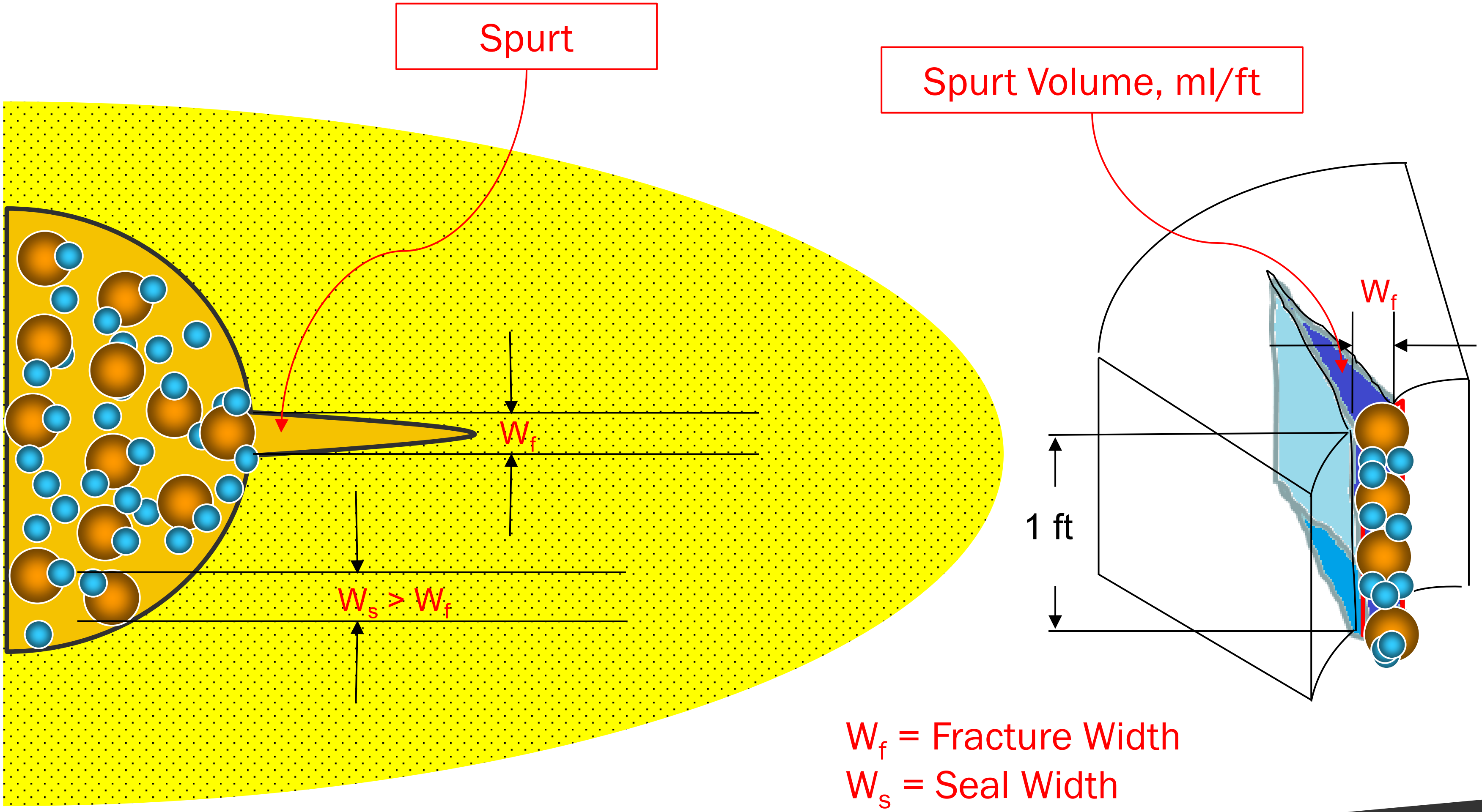
Fracture Sealing with LCM Particulates - Bridging

When spurt is small



W_f = Fracture Width
W_s = Seal Width

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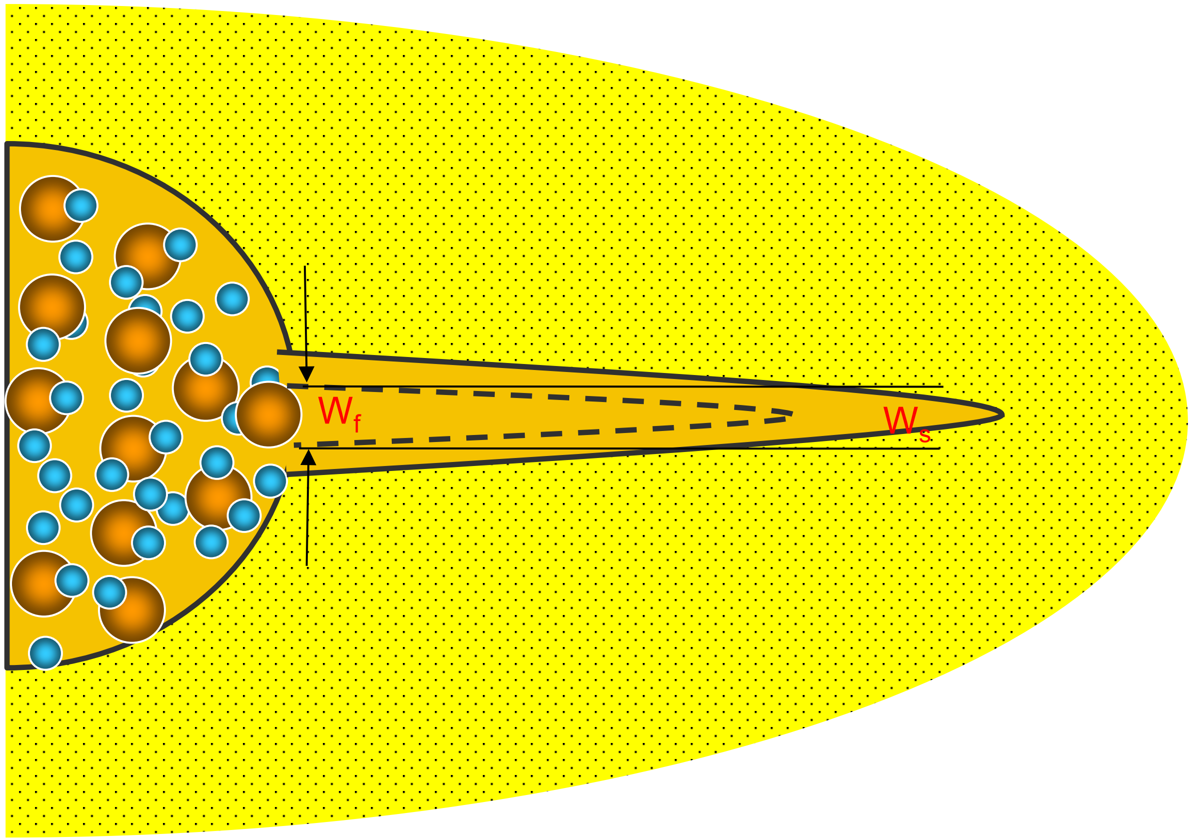
No Bridging, No Sealing, Continued Fracturing, Failure

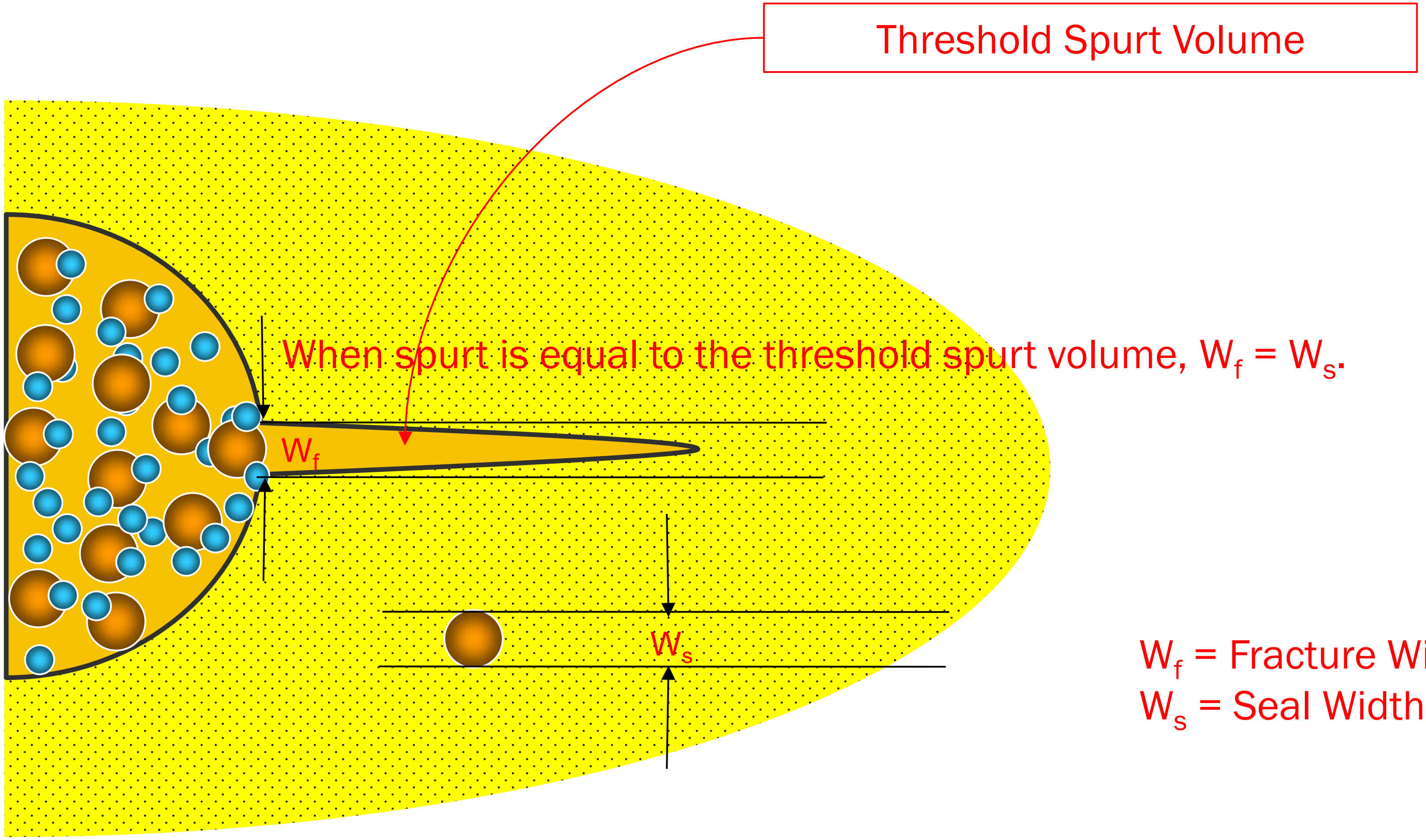
When spurt is large



$W_f > W_s$

W_f Fracture Width
W_s = Seal Width

A Very Unstable "Critical" State between Sealing and Fracing



W_f = Fracture Width
W_s = Seal Width

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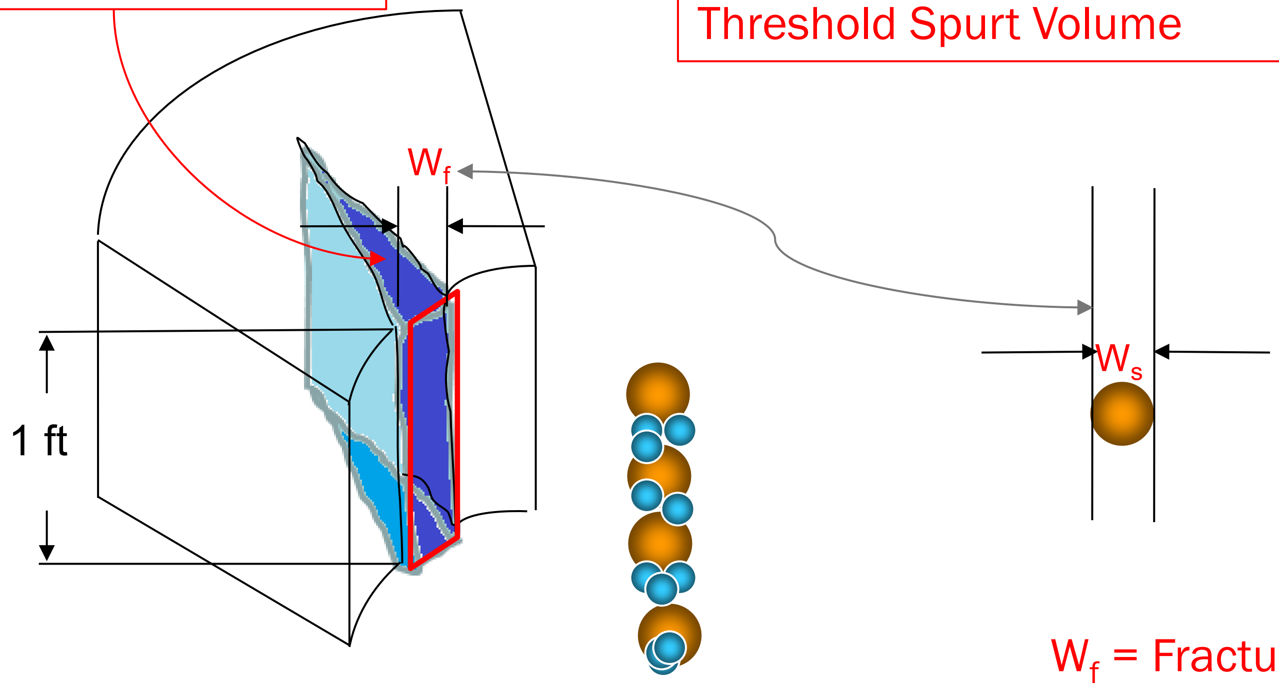
The One Condition to Seal a Fracture to Strengthen a Wellbore

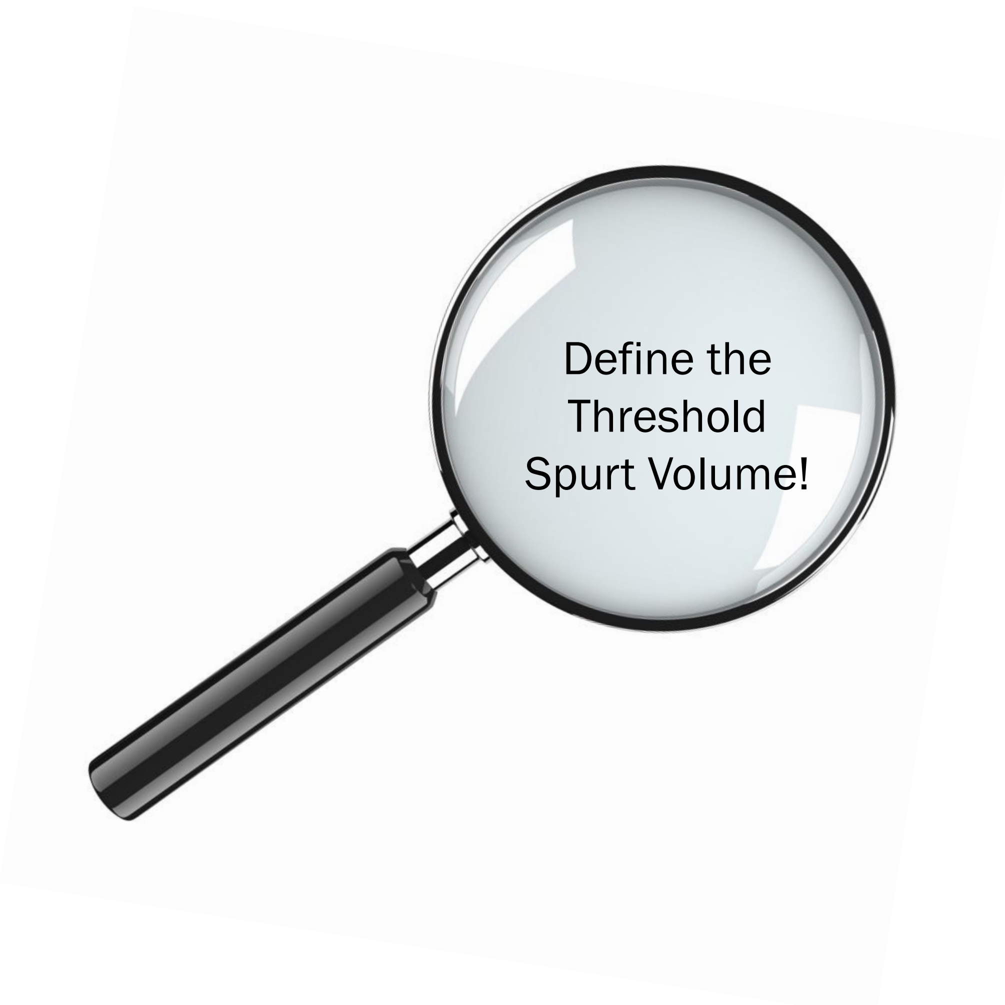
1. Define the Threshold Spurt Volume at $W_f = W_s$

2. Define a concentration of a selected LCM to have a spurt less than the Threshold Spurt Volume



W_f = Fracture Width
W_s = Seal Width

Quantify Fracture Behavior in a Wellbore

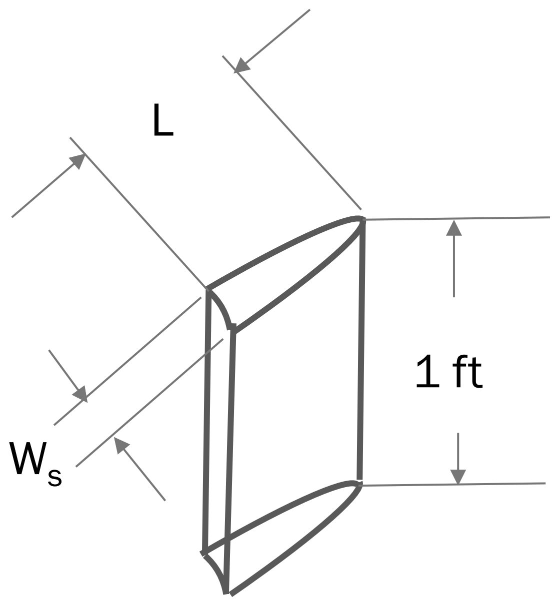


Different Wellbores May Have Different Threshold Spurt Volumes: Define the Threshold Spurt Volume with a Given Seal Width $W_s = W_f$

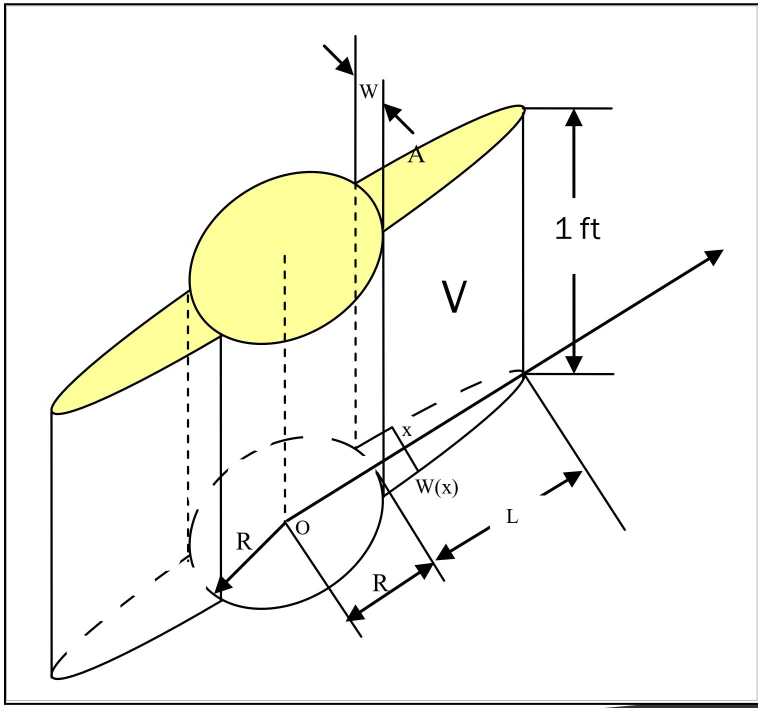
A stiffer wellbore tends to have a larger Threshold Spurt Volume.

$$Fracture\ Length\ L = \sqrt{\frac{W_s * E}{4(1-\gamma^2)(P_w - S_h)} + R^2} - R$$

(No more assuming a 6-inch fracture length)

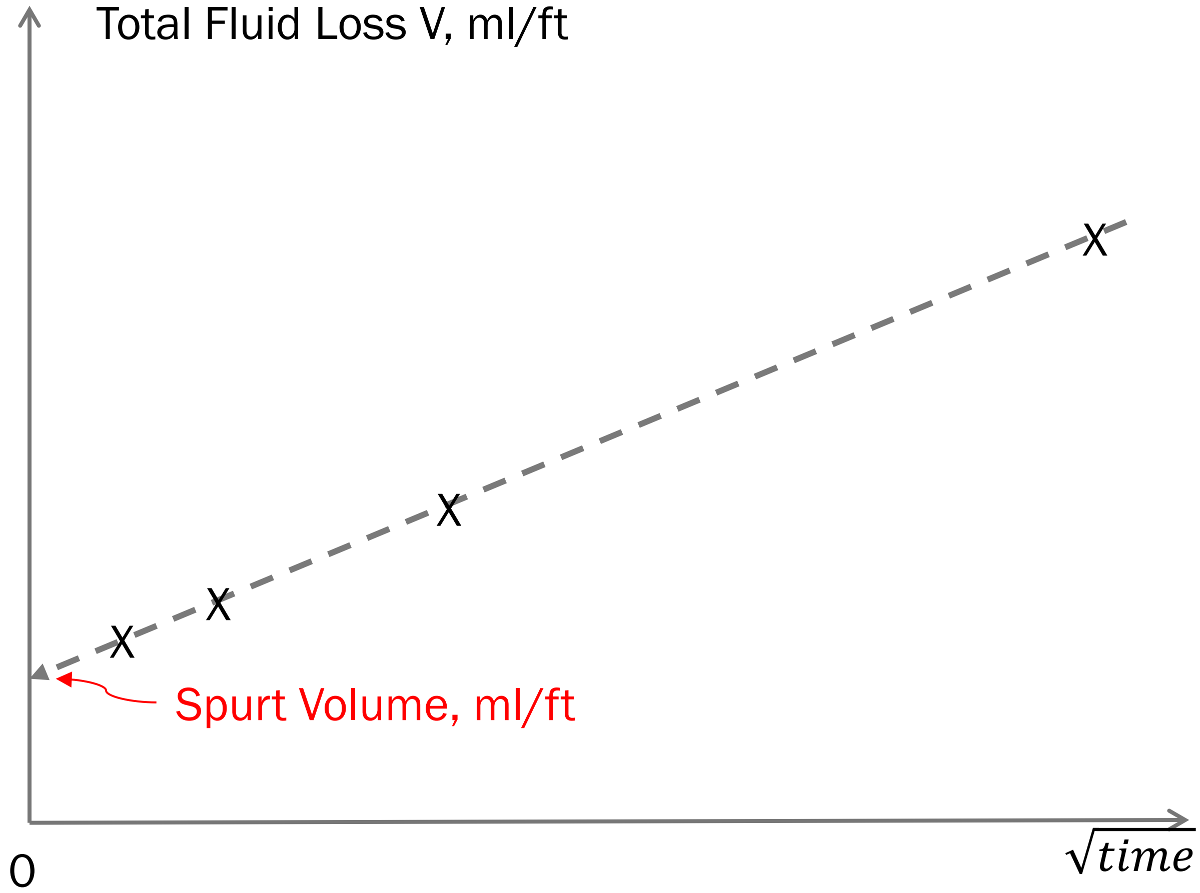


Threshold spurt volume



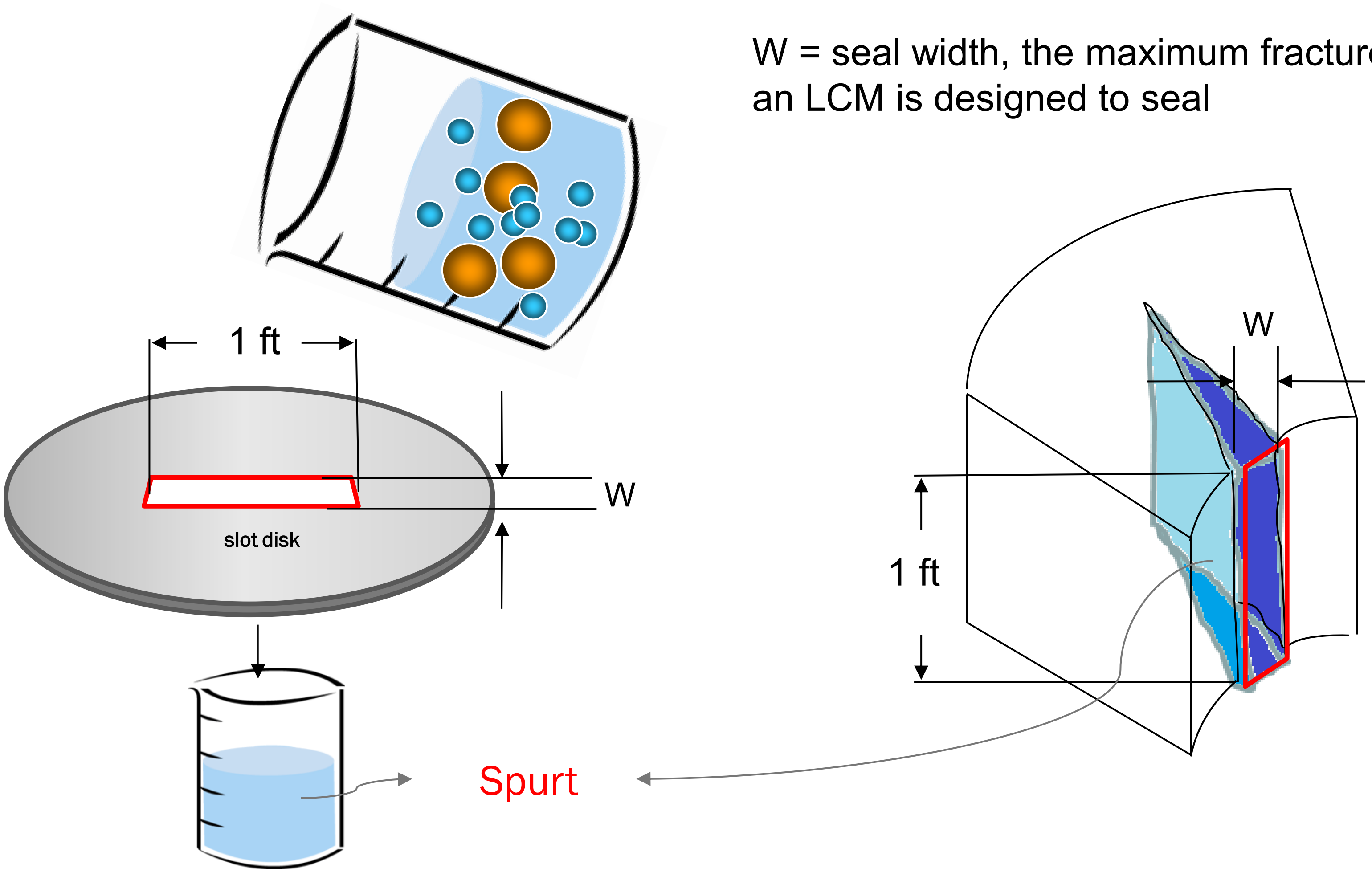
Quantify LCM Sealing Performance

A Lab Method to Define Spurt

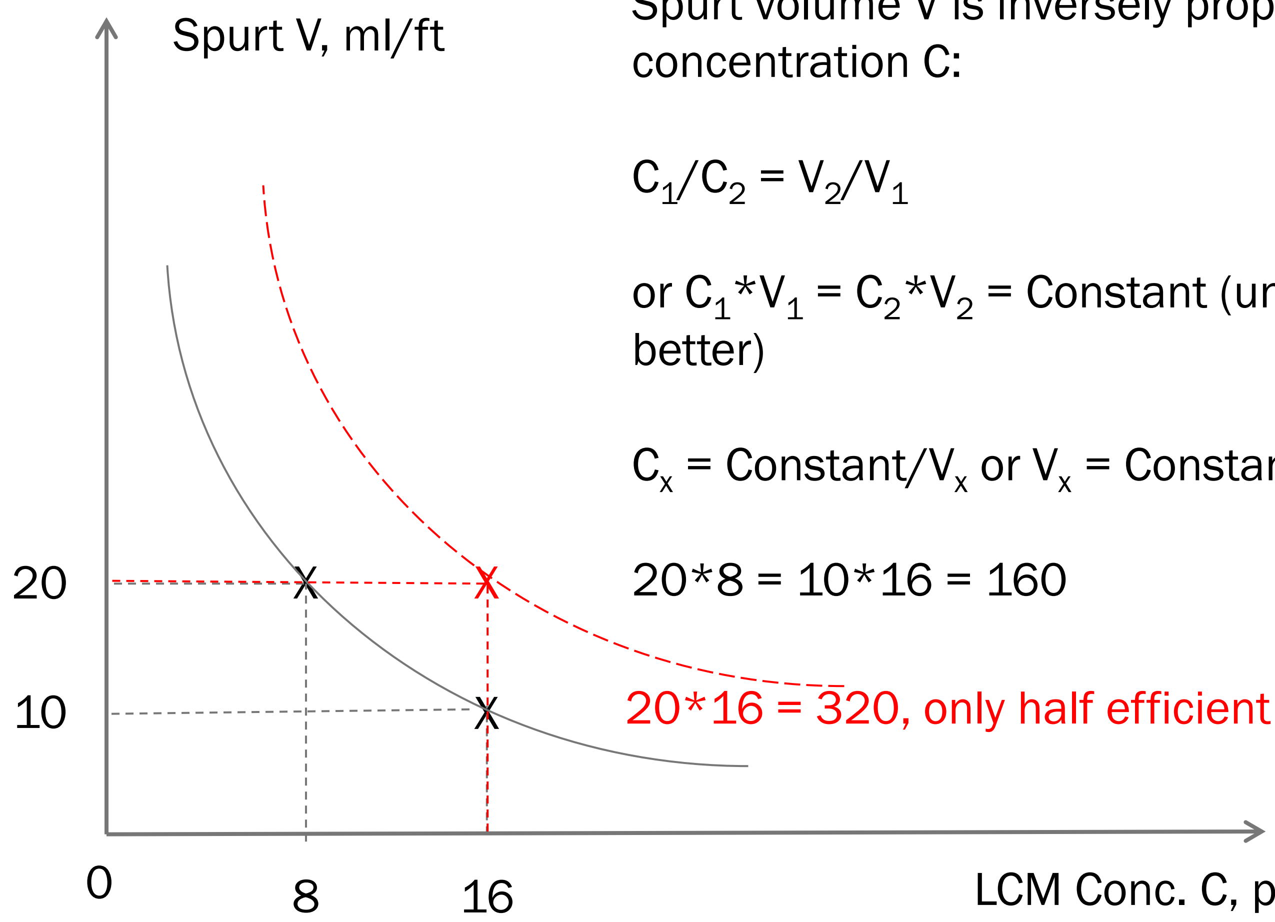


Measuring Spurt: Simulating the Flow into a Fracture

W = seal width, the maximum fracture width an LCM is designed to seal



Define Sealing LCM by Spurt



Spurt volume V is inversely proportional to LCM concentration C:

$C_1/C_2 = V_2/V_1$

or $C_1*V_1 = C_2*V_2$ = Constant (unique, smaller is better)

C_x = Constant/V_x or V_x = Constant/C_x

20*8 = 10*16 = 160

20*16 = 320, only half efficient

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LCM Comparison: 1000-micron Slot Width, 40 ppb (A Client's Lab Test Result)

Low Spurt LCM (Coarse) – A single sack LCM product

	Sharp-Rock (Coarse)			A Client's Coarse LCM		
Differential Pressure	500 PSI	1000 PSI	2000 PSI	500 PSI	1000 PSI	2000 PSI
Spurt, ml/ft	6.0	6.0	6.0	84.0	102.0	114.0

84/6 = 14 and 114/6 = 19 times

1 sack Sharp-Rock (Coarse) is equivalent to 14~19 sacks of a Client's Coarse LCM

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Apply Sealing LCM to Prevent Mud Losses

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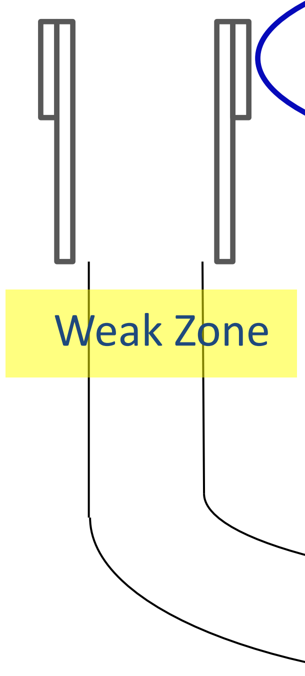
Application Example 1. When Data is Sufficient, Threshold Spurt can be Scientifically Defined

Weak Zone:

- Depth – 8000' TVD
- FG – 0.468/ft or 9.0 ppg equiv. (depletion)
- Max ECD (target strength) – 10.5 ppg equiv.
- YM – 2.5 M to 4 M psi
- PR – 0.13 to 0.18
- Hole Size – 8.5"

What to add and how much?

Formation Depth, ft	8000
Target Wellbore Pressure, ppg	10.5
FG, ppg	9.0
Young's Modulus, 10^6 psi	2.5
Poisson's Ratio	0.13
Hole Diameter, inch	8.5
Seal Width, micron	200
Fracture Length, inch	4.8
Fracture Volume, ml/ft	**5.3**
Safety Factor	1.1
Threshold Spurt Volume (Fracture Volume/1.1), ml	4.8
Final LCM Conc., ppb	**8.3**



Example Selected LCM	
Seal Width, micron	200
LCM Conc., ppb	10
Spurt volume, ml/ft	4.0

C_{min} = 10*4.0/4.8 = 8.3 ppb

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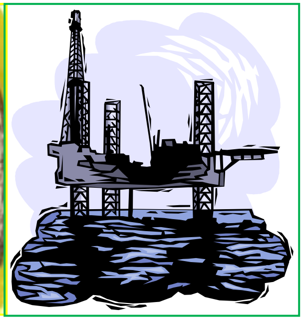
Rig-site Application and Maintenance

The Design:

Max. Spurt Volume, ml/ft	4.8
Mini. LCM Conc., ppb	8.3

Example Selected LCM	
Seal Width, micron	200
Spurt volume, ml/ft	4.0
Spurt Conc., ppb	10

1. To make the mud:
Add LCM to active mud to a concentration of 8.3 ppb.



What to add and how much?

2. Daily Maintenance:
Measure Spurt V, then calculate LCM Conc. C. Then compare with the designed final conc. to know the difference. Add more LCM as the difference indicates. Calculation is very simple!

Example:
If now Spurt V = 5.6 ml/ft,

C = 10*4.0/5.6 = 7.1 ppb
So 8.3 – 7.1 = 1.2 ppb more of the LCM is to be added.

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Application Example 2. YOU set a target spurt for a seal width when data is NOT sufficient (trial and error)

1. Based on experience, you set a target spurt control level

For instance: 10 ml/ft for sealing 500 micron width.

What to add and how much?

Define LCM concentration toward the target:

1. Select an LCM:

   500 micron seal width

   spurt = 3 ml/ft

   @15 ppb

2. Find the concentration for the target spurt of 10 ml/ft:

   3*15/10 = 4.5 ppb

3. Add 4.5 ppb of the LCM to make the mud to drill the well

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Application Example 3. Matching the Spurt of an Existing LCM (trial and error)

Existing LCM application:

1. Test the mud of an existing client's coarse LCM:

For a 1000 micron seal width, the spurt is 114 ml/ft at a concentration of 40 ppb.

2. If total mud is 1000 bbls, the total LCM needed is 40,000 lbs or 800 sacks at 50 lbs a sack.

What to add and how much?

The new well:

1. Select the Sharp-Rock LCM (Coarse) designed to seal 1000 micron width:

Spurt is only 6 ml/ft at 40 ppb.

2. Define concentration to match:

For the same 114 ml/ft spurt, the concentration of Sharp-Rock LCM to replace the client's LCM is 6 ml/ft * 40 ppb /114 ml/ft = 2.1 ppb.

3. Total LCM needed is only 2.1*1000 = 2100 lbs or 42 sacks for the same performance!

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Summary – Sealing by Controlling Spurt

Wellbore strengthening technology evolution has led us now to focus on

fracture sealing, not fracture propping.

Sealing fractures can double the mud weight window.

What to add and how much?

Condition: The spurt must be lower than a threshold volume.

Wellbore: Each wellbore may have a unique threshold spurt volume, defined by trial and error or rock mechanics calculations.

Preventive LCM:
- Quantify LCM performance by spurt
- Compare LCM performance by spurt
- Apply LCM by spurt for performance

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Special thanks to those pioneers in the wellbore strengthening area! Without their early hard work, the technology would not have come to even close to this point by now!

SHARP-ROCK
Performance LCM Provider

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