

Betaine:Anionic Surfactant Blend Ratio for Foam in Presence of Crude Oil

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Surfactants Used

Rhodia A- betaine (confidential)

Rhodia B- sultaine (confidential)

LB- Lauryl Betaine

AOS C₁₄₋₁₆ - Alpha olefin sulfonate (Stepan)

Note: All the surfactants under study in this presentation are done in

1. Sea water
2. Surfactant concentration -0.5 wt% based on active material

Outline

- **Part I**

*Foam studies absence/presence of crude oil in 100 Darcy US silica
20-40 sandpack*

A:AOS (9:1) blend

A:AOS(1:9) blend

Rhodia B (sultaine)

Summary

- **Part II**

Foam studies absence/presence of crude oil in Bentheimer core

Lauryl betaine (LB)

LB: AOS 7:3

LB:AOS 1:9

Summary

Part I

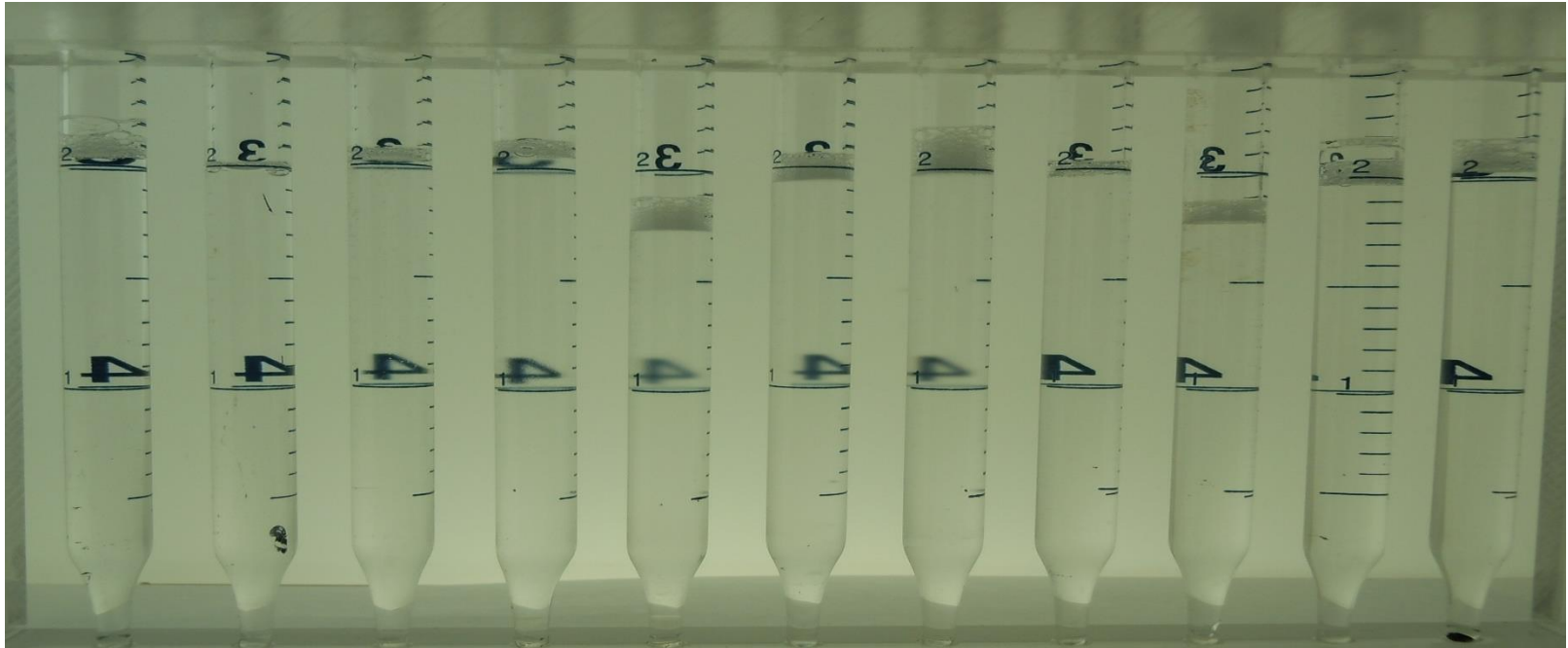
***Foam studies absence/presence of crude oil in
100 Darcy US silica 20-40 sandpack***

- A:AOS (9:1) blend
- A:AOS(1:9) blend
- Rhodia B (sultaine)

0.5 wt% A:AOS₁₄₋₁₆ sea water

A 9/1 8/2 7/3 6/4 5/5 4/6 3/7 2/8 1/9 AOS

VES VES



Clear

Not Clear

Clear

A:AOS -9:1, 1:9 was chosen for studying the foam behavior in sand pack.
VES-Viscoelastic (by visual observation)

Schematic of Set Up to Study Foam Behavior

Sand: US silica 20-40
Porosity = 0.36
Permeability ~100 Darcy

Inverted burette with
1:1_IPA:Water

Measuring
Gas/Liquid

BPR

Auxiliary Pump

Inlet

Outlet

2'L x 1"D Stainless steel sand holder

Co-Injection

Taps

Taps

Pressure
Transducer

Collecting
only Liquid

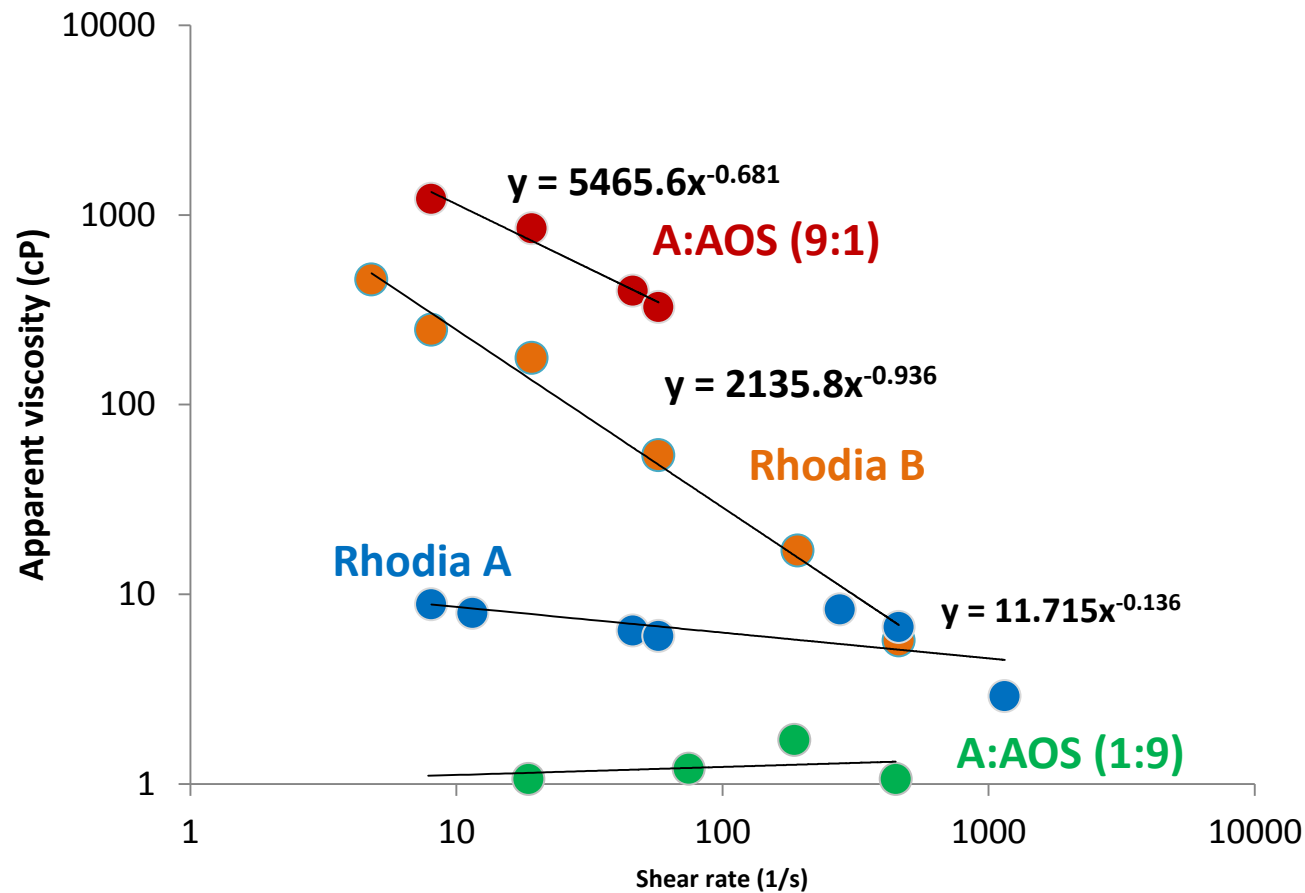
Surfactant
Pump

Mass-Flow
Controller

Check valve

N₂

Comparison of the single phase flow of Rhodia A, Rhodia B and A:AOS (9:1), A:AOS (1:9) in 100 Darcy sandpack

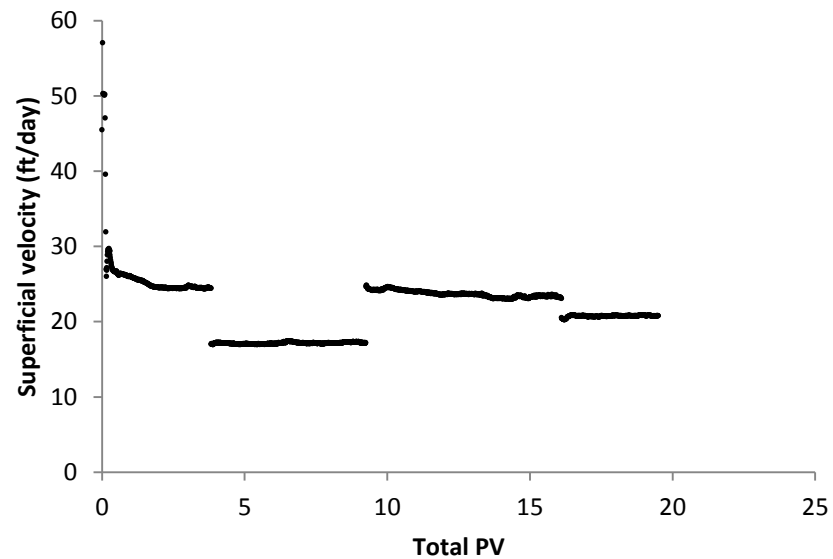
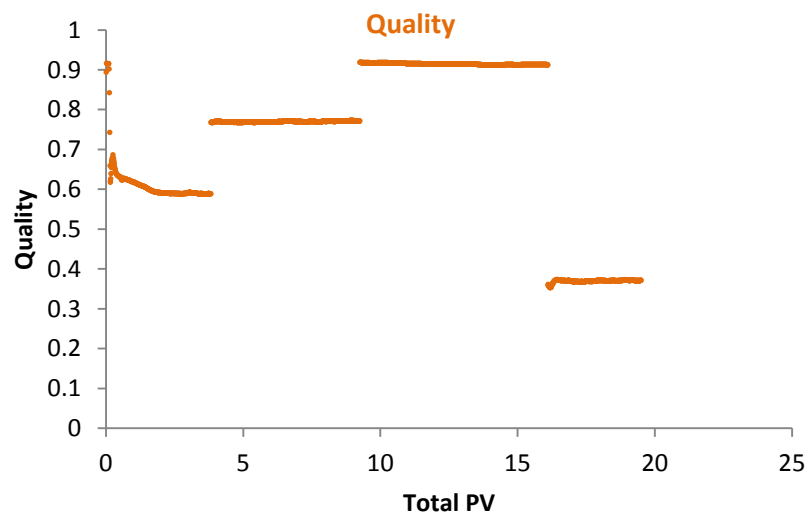
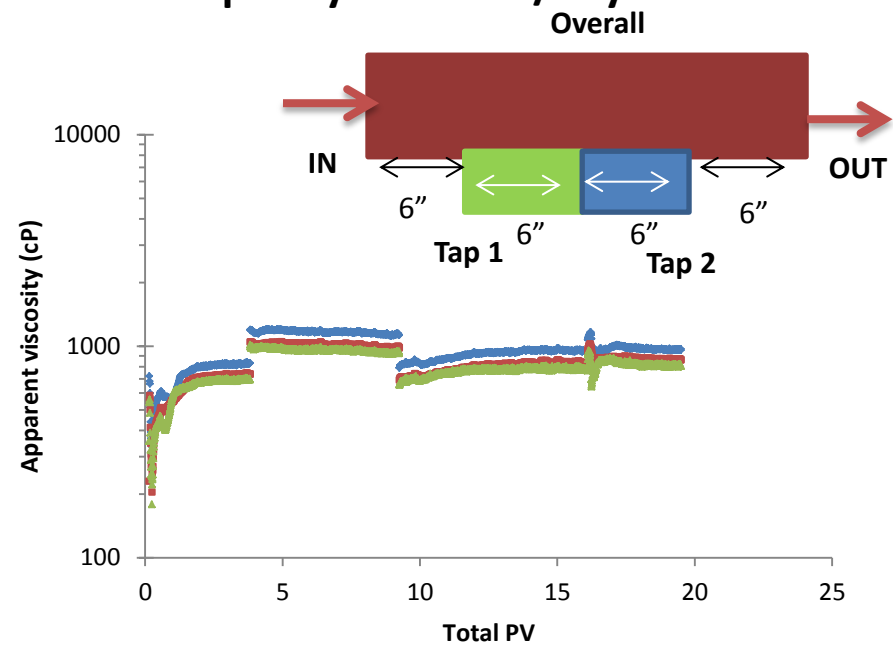
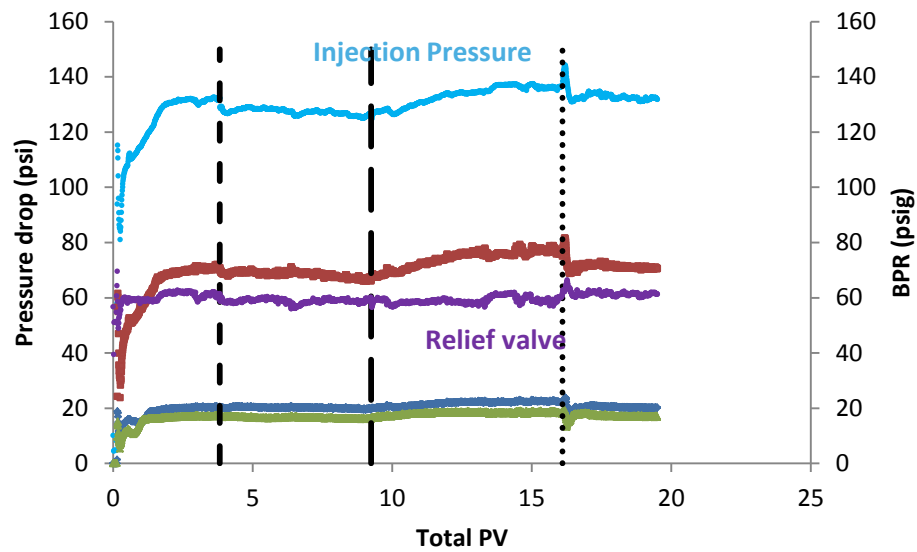


Shear thinning behavior is observed in Rhodia A, A:AOS (9:1) and Rhodia B. A:AOS (1:9) is Newtonian which is observed in the rheometer as well (rheometer data not shown)

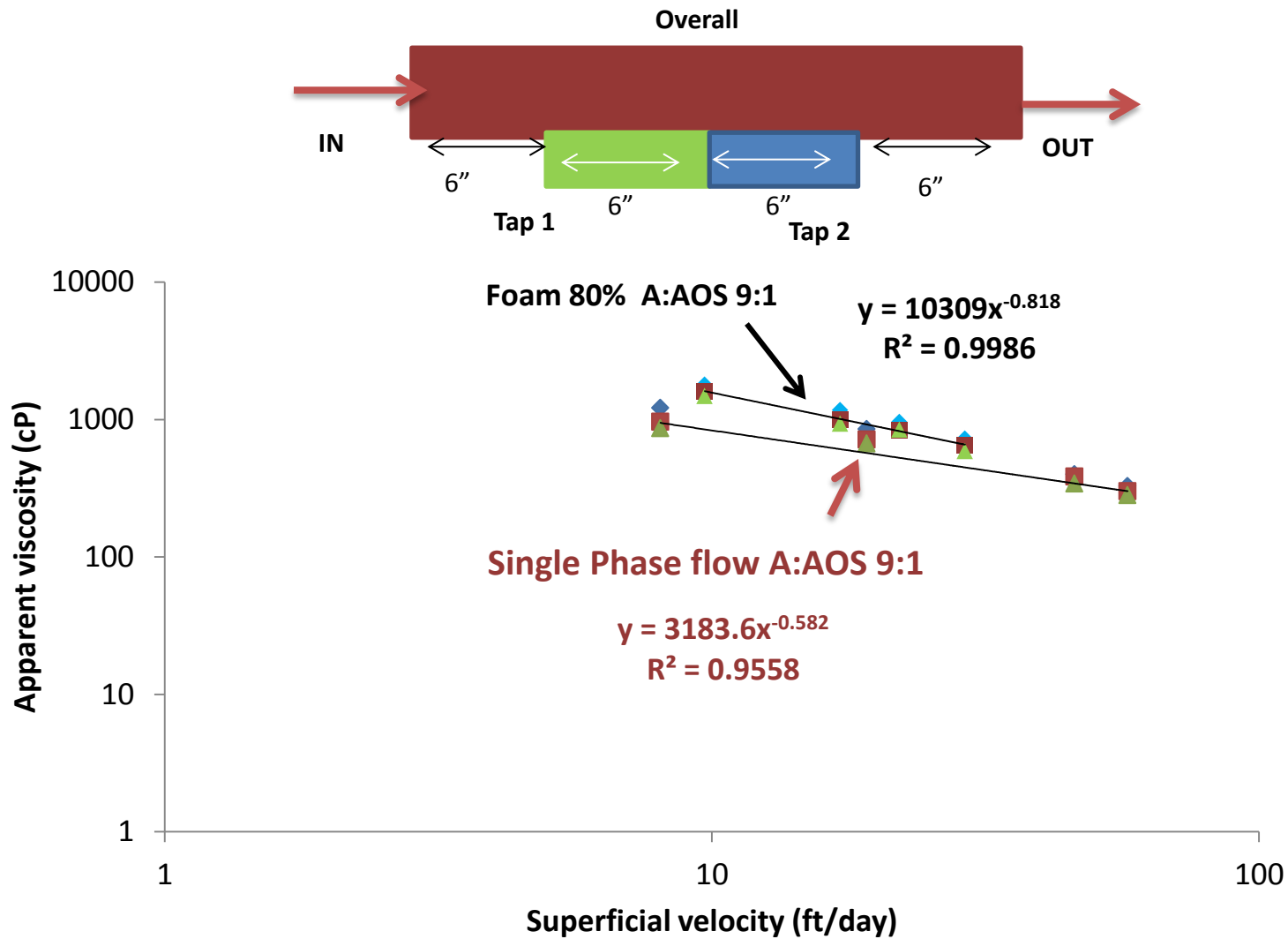
Surfactant blend A:AOS₁₄₋₁₆ foam behavior in absence of crude oil

- Typical Foam experiment conducted
- Comparison of A, A:AOS blends, B foam as function of quality
- Shear thinning behavior of foam for A ,A:AOS blends, B foam at transition foam quality

Typical foam study - A:AOS 9:1 foam as function of quality at ~ 21 ft/day

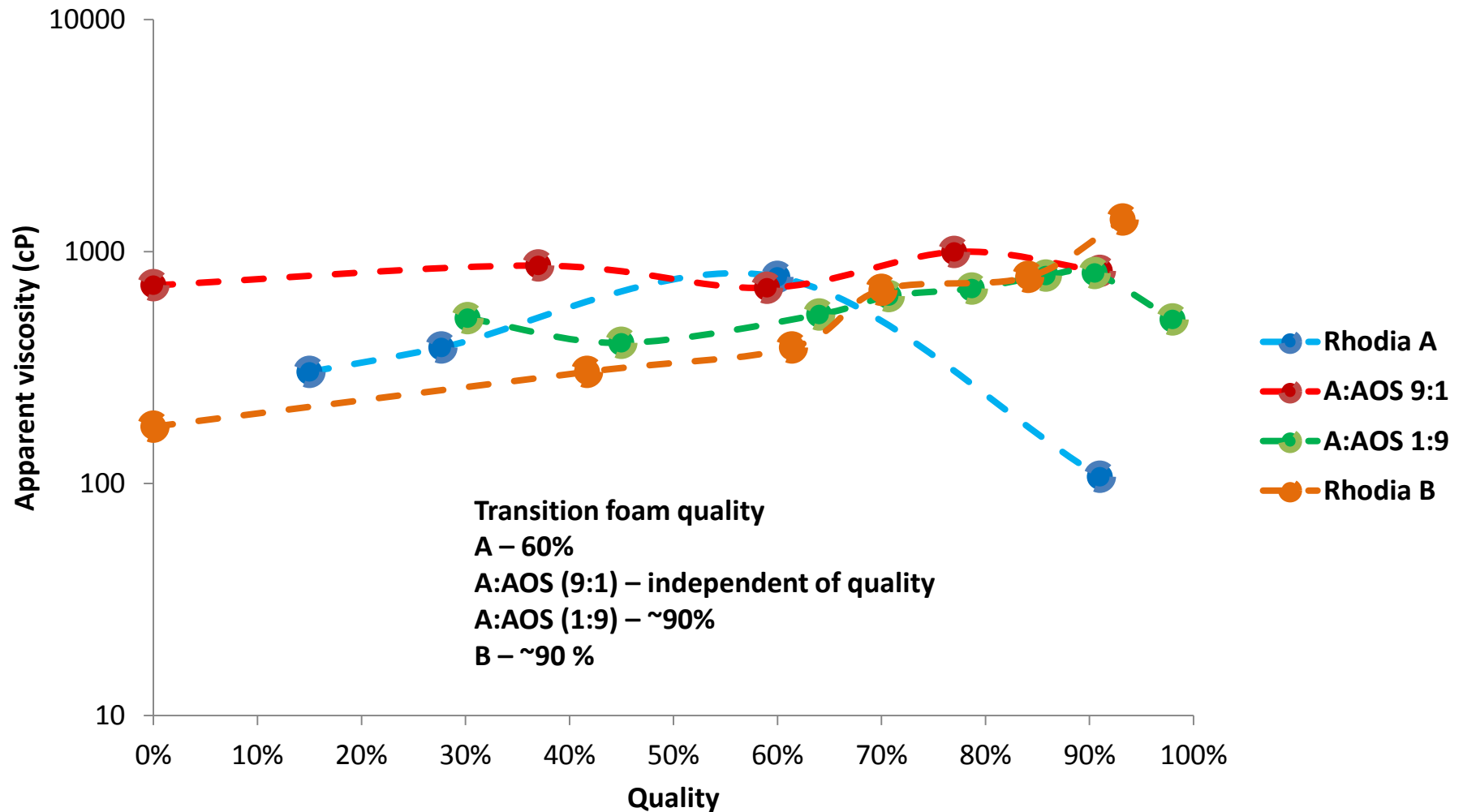


Comparison of foam strength with single phase flow A:AOS (9:1)



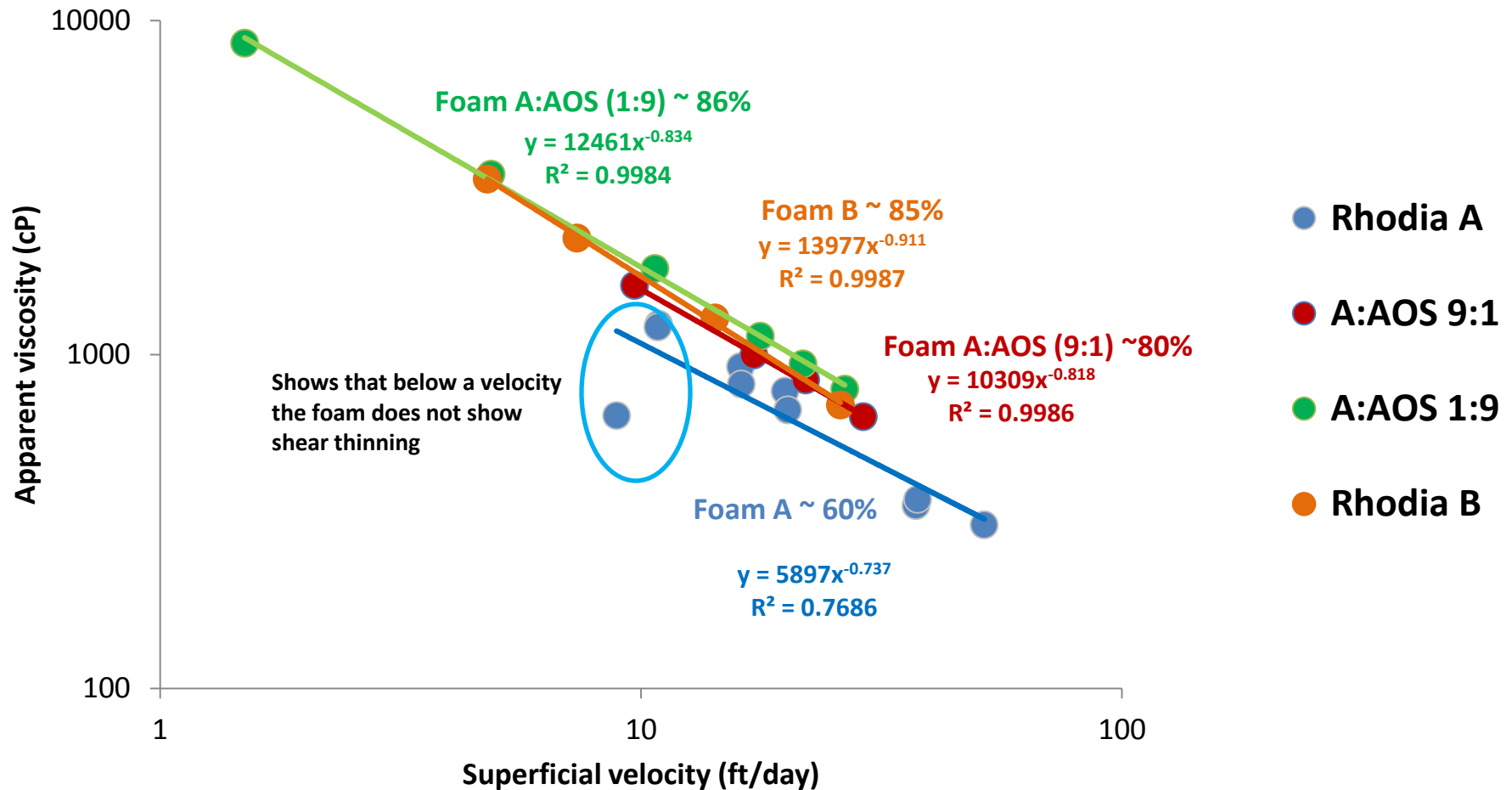
There is very modest increase in foam strength compared to single phase flow.

Comparison of the surfactants foam strength at ~20-25 ft/day



Foam strength of Rhodia A is weakened after 60% foam quality. When A is blended with AOS in 1:9 ratio, strong foam with high gas fraction (~90%) can be observed. The viscoelastic seems A:AOS (9:1) is independent of quality.

Shear thinning behavior of foam of A, A:AOS(9:1), B at the quality with highest apparent viscosity

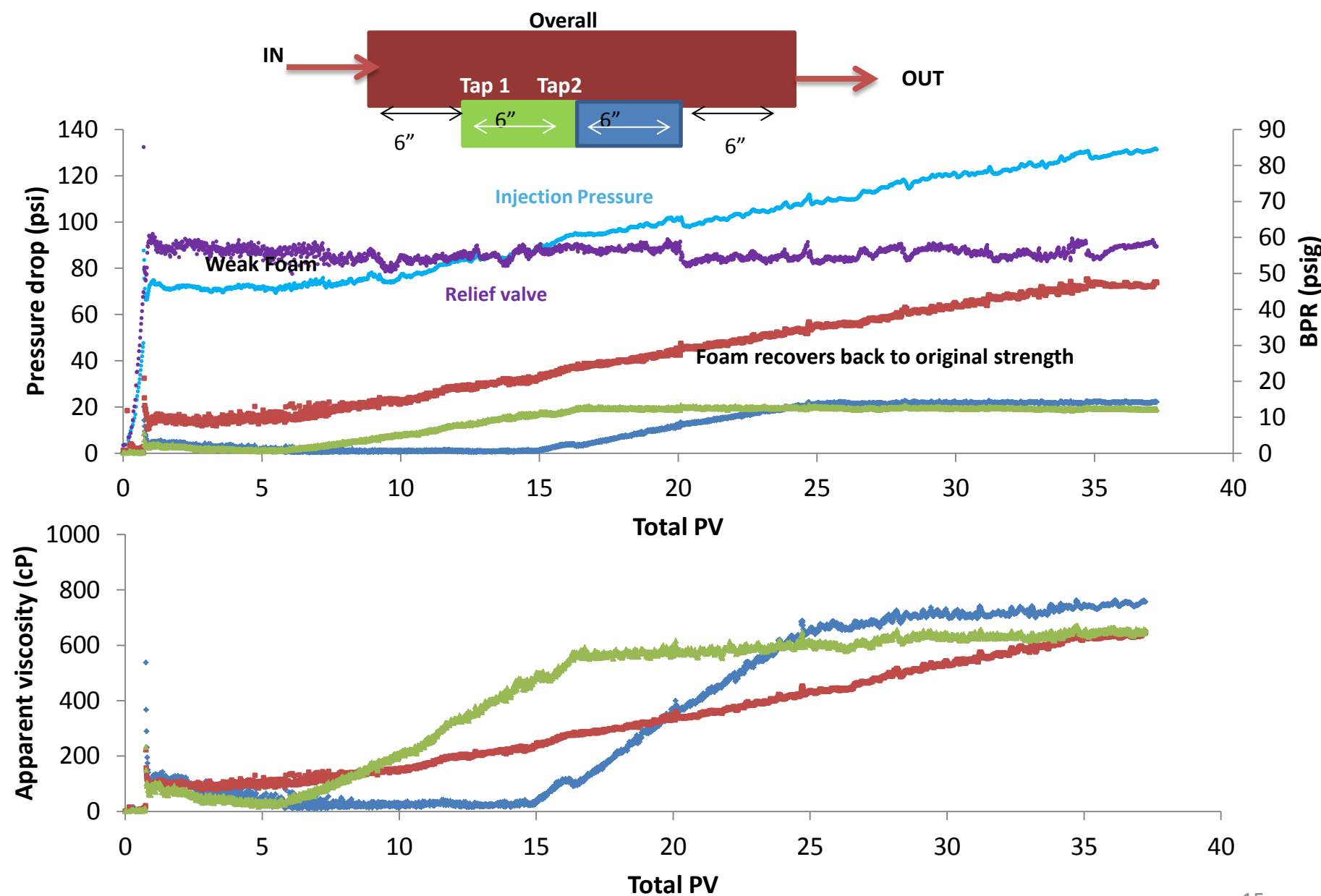


Observations

- 1. The Rhodia A betaine foam has a transition quality of 60%.**
- 2. A:AOS (9:1) foam is observed to be independent of quality.**
- 3. A:AOS (1:9) and Rhodia B foam has transition quality of 90%.**
- 4. Foam shear thinning behavior of the studied surfactant solutions(at transition quality) is observed. However in the case of Rhodia A there is a particular velocity (~ 10 ft/day superficial velocity) below which foam weakens.**

**Surfactant blends A:AOS₁₄₋₁₆ and
Rhodia B foam behavior in presence
of crude oil**

Foam stability with oil (A:AOS 9:1) at ~80-85% quality and ~ 30 ft/day (remaining 63% oil)



Appearance of Sand after Foam(A:AOS(9:1)) Displaced oil

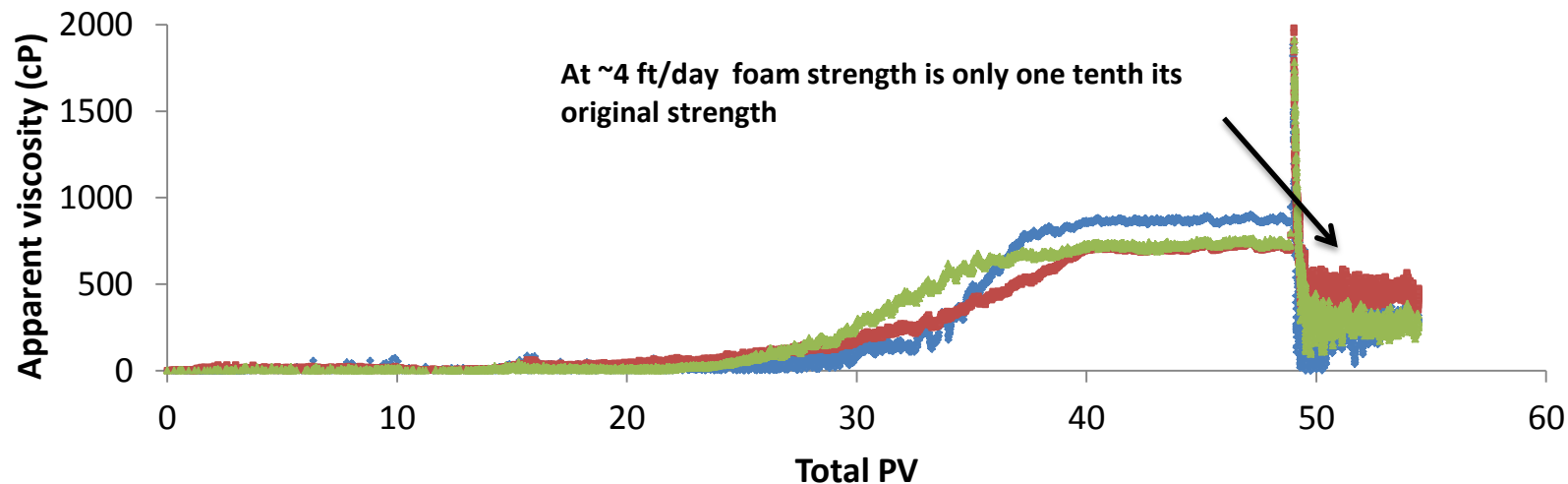
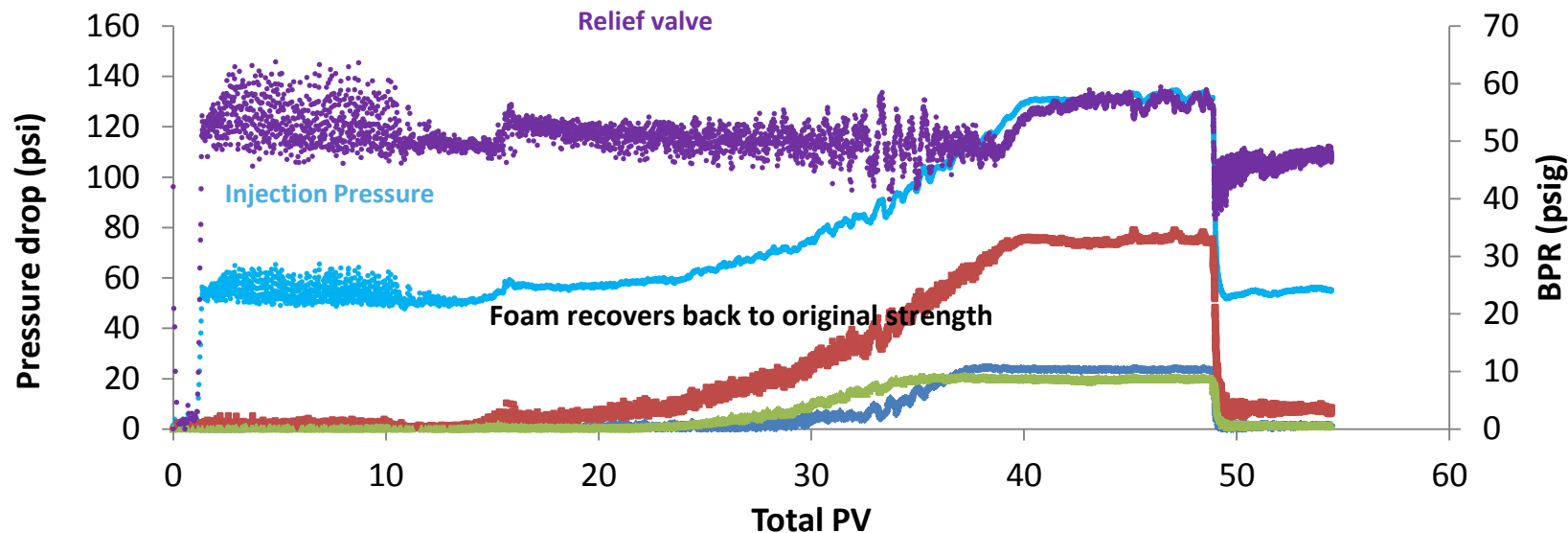
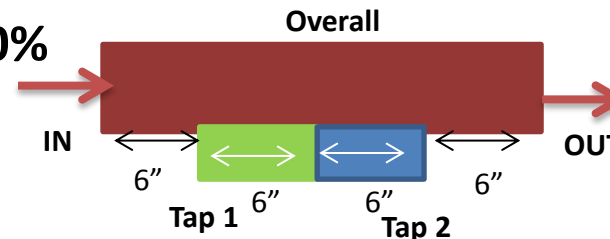


Sand with foam



Sand after foam displaces oil

Foam stability with oil (A:AOS 1:9) at ~30 ft/day and ~90% quality
(remaining ~56% oil)



Appearance of Sand after Foam(A:AOS(1:9)) Displaced oil



Sand with foam



Sand after foam displaces oil

Sand with foam



Sand after foam displaces oil



Rhodia A (Betaine)



A:AOS(9:1)



A:AOS (1:9)



Rhodia B (Sultaine)

Comparison of Foam strength and recovery for Rhodia A, A:AOS blends, Rhodia B in presence of crude oil

Summary on internal tap data only

Surfactant	Quality	Superficial velocity (ft/day)	Foam apparent viscosity (no oil)	Foam apparent viscosity strength recovery
Rhodia A (betaine)	80%	~40	~50 cP	~ 5cP and no foam strength recovery even after ~22 PV
A:AOS (9:1)	80%	~30	~1000 cP	Recovers close to 1000 cP tap 1- 16 PV tap 2- 25 PV
A:AOS (1:9)	90%	~30	~1000 cP	Recovers close to 1000 cP tap 1- 34 PV tap 2- 37 PV
Rhodia B (sultaine)	85%	~30	~700 cP	Tap 1- ~32 PV (215 cP) Tap 2-~ 35 PV (420 cP)

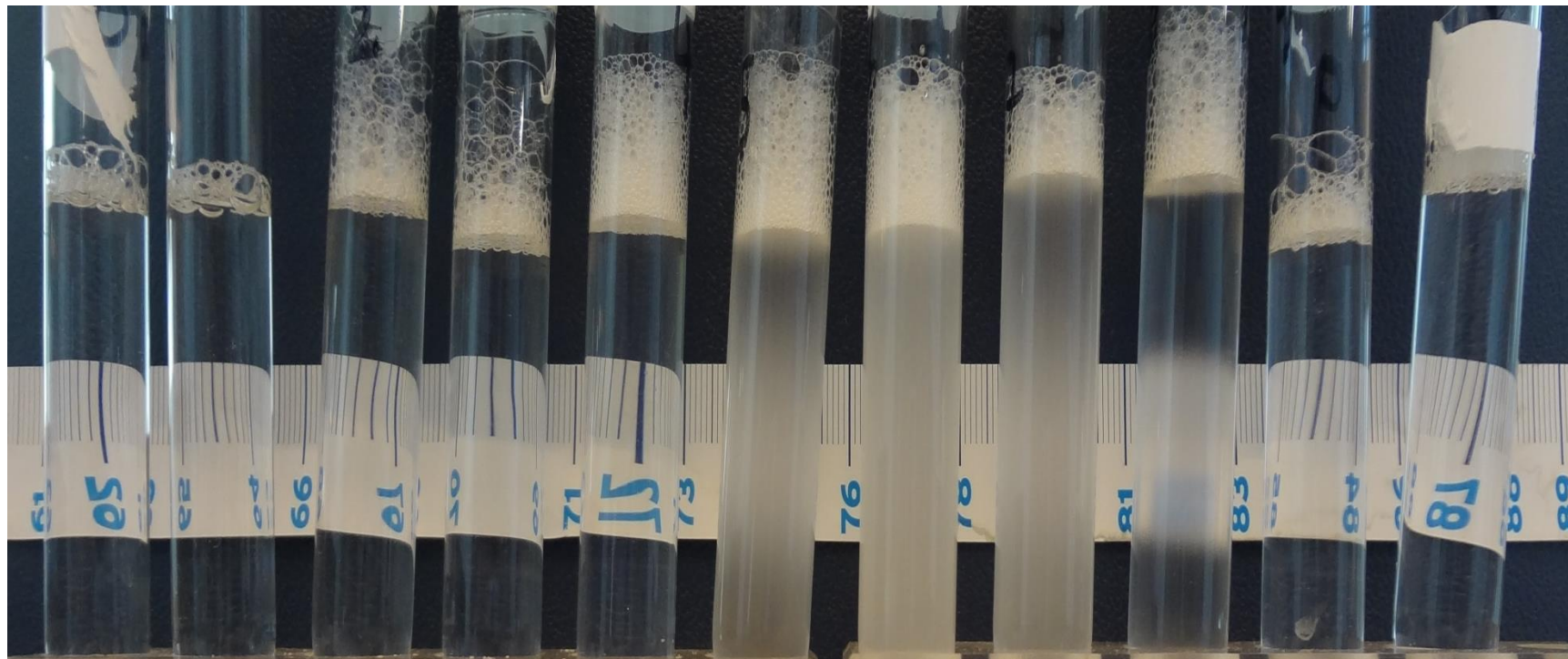
Part II

Foam studies absence/presence of crude oil in Bentheimer core

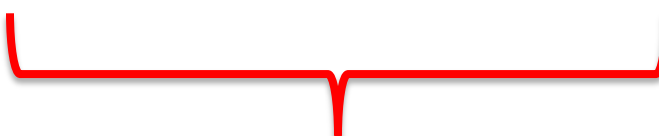
- Lauryl betaine (LB)
- LB: AOS 7:3
- LB:AOS 1:9

Blend Scan (45 °C)

(LB)	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0
(AOS)	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1



Clear

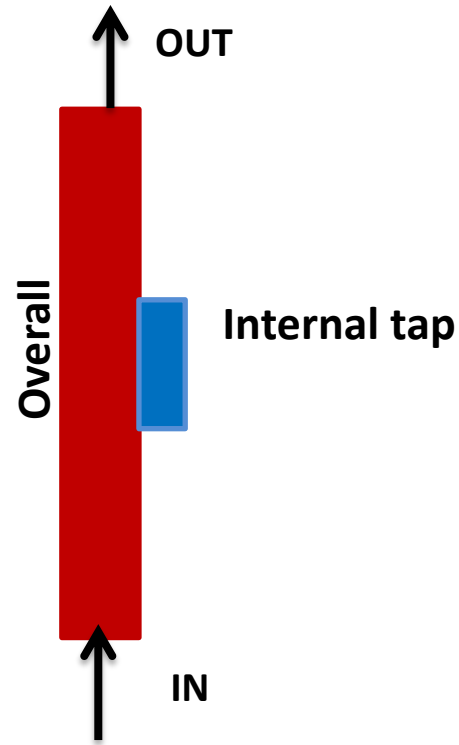


Not Clear



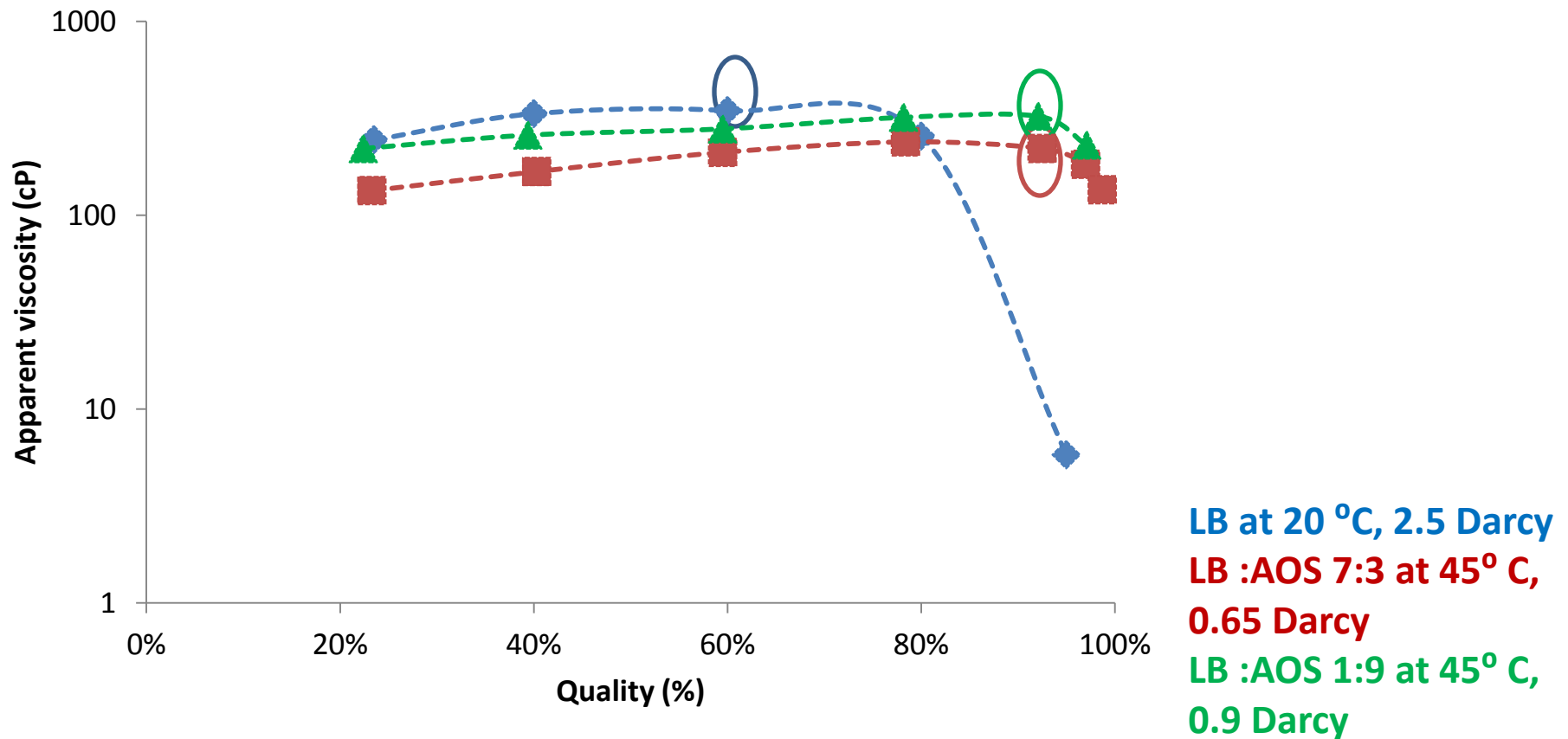
Clear

Schematic of foam set up



In the coming slides all the apparent viscosity data plotted show only the internal tap data. The overall apparent viscosity is $\sim$ close to the internal tap data.

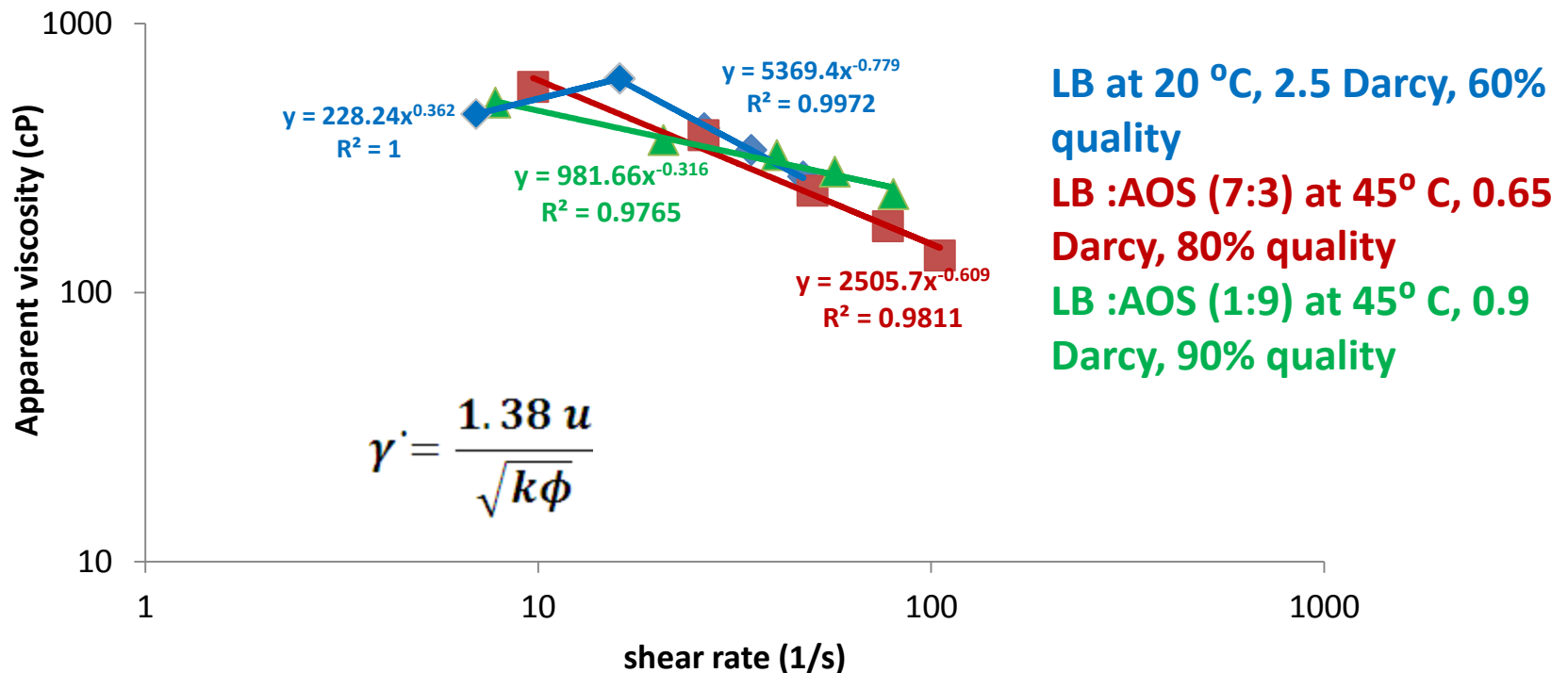
Quality scan at ~ 20 ft/day



The circled qualities show the transition foam quality. For the LB it is 60% and for the LB-AOS blends it is in 80-90%.

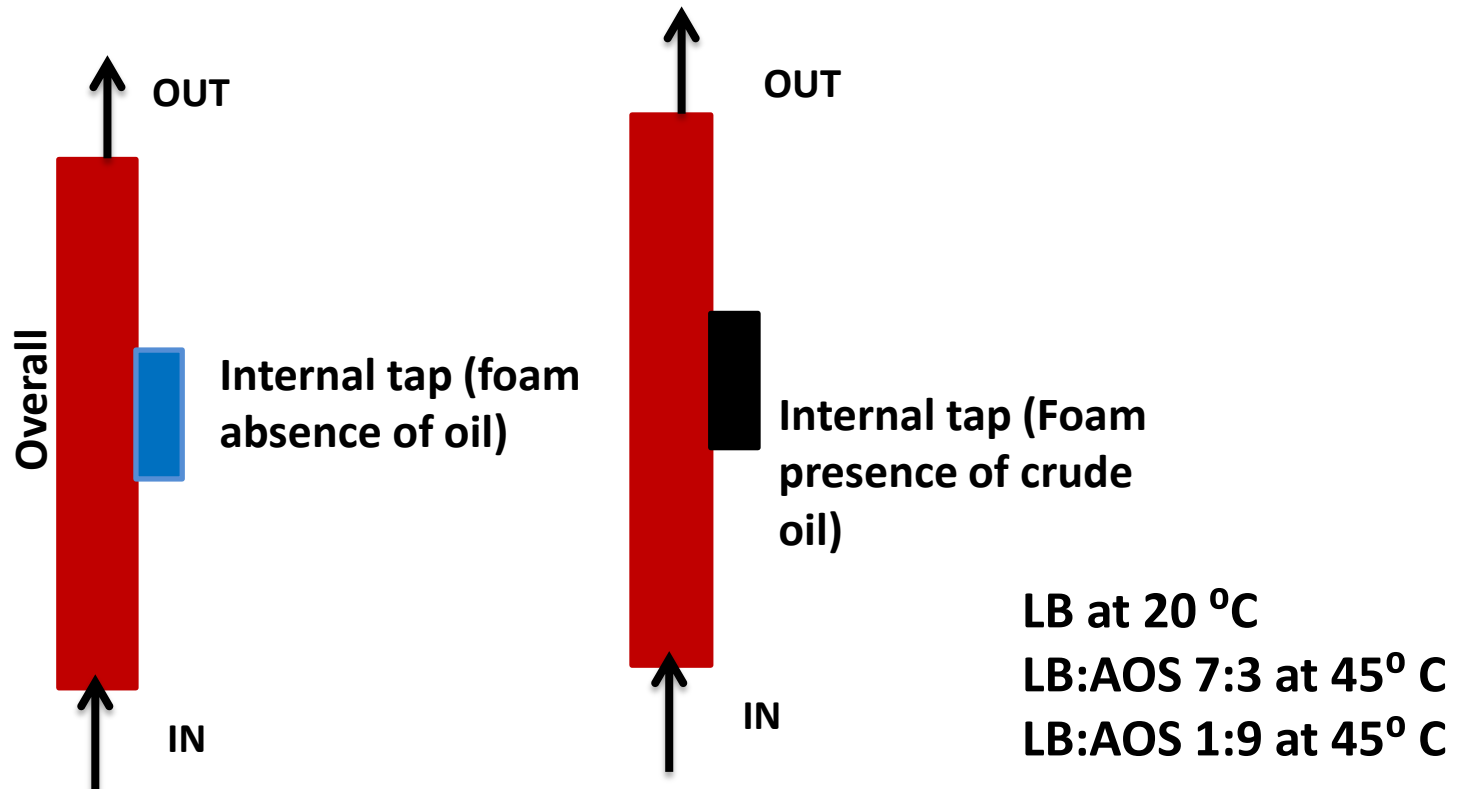
Foam – shear thinning behavior for LB and its blends

Shear thinning at transition foam quality (internal tap data only)



Since the rocks were of varying permeability, shear rate was used to compare the foam strength rather than velocity.

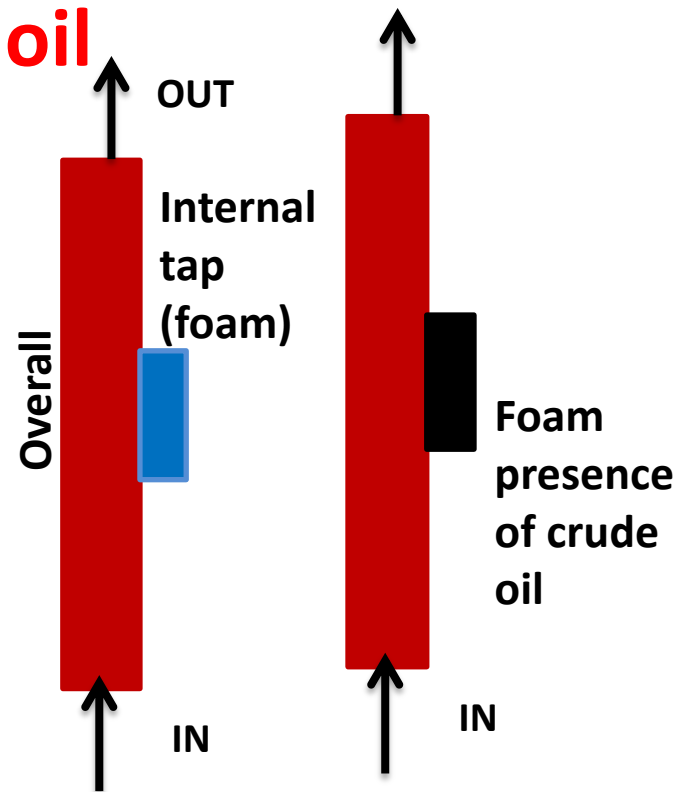
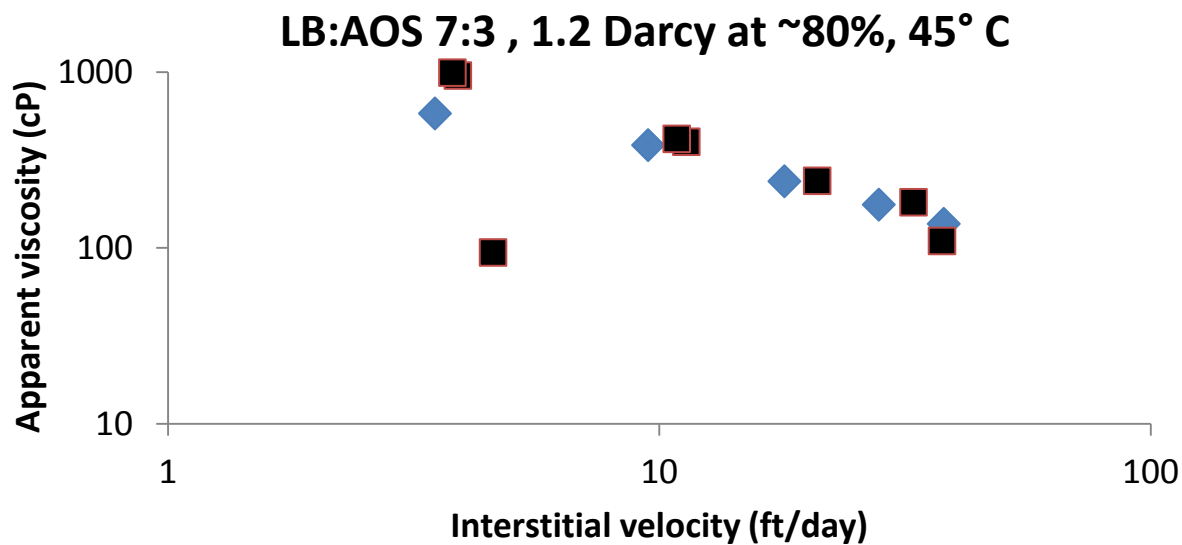
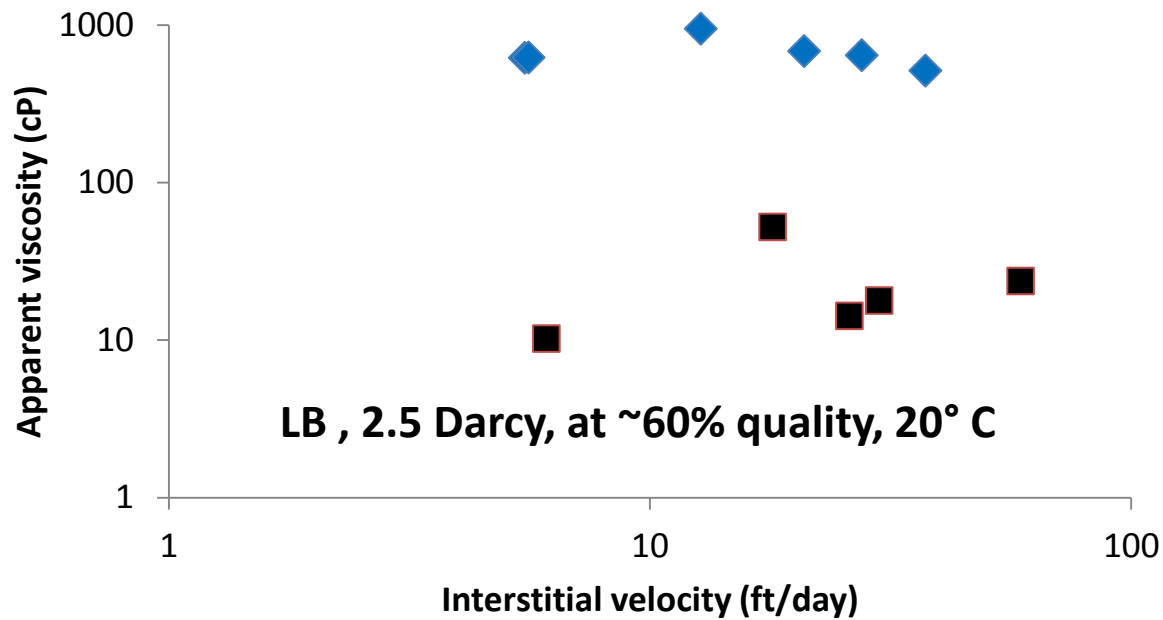
Foam – crude oil experiments



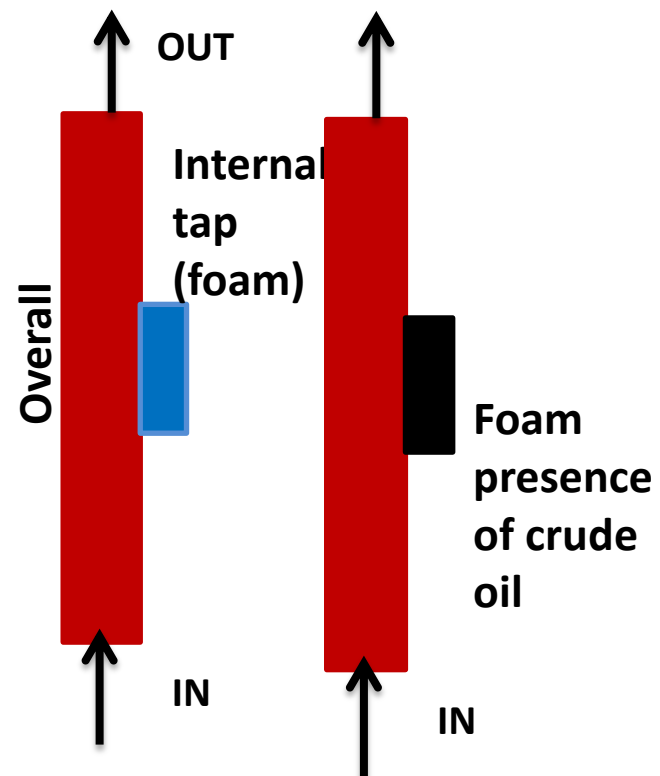
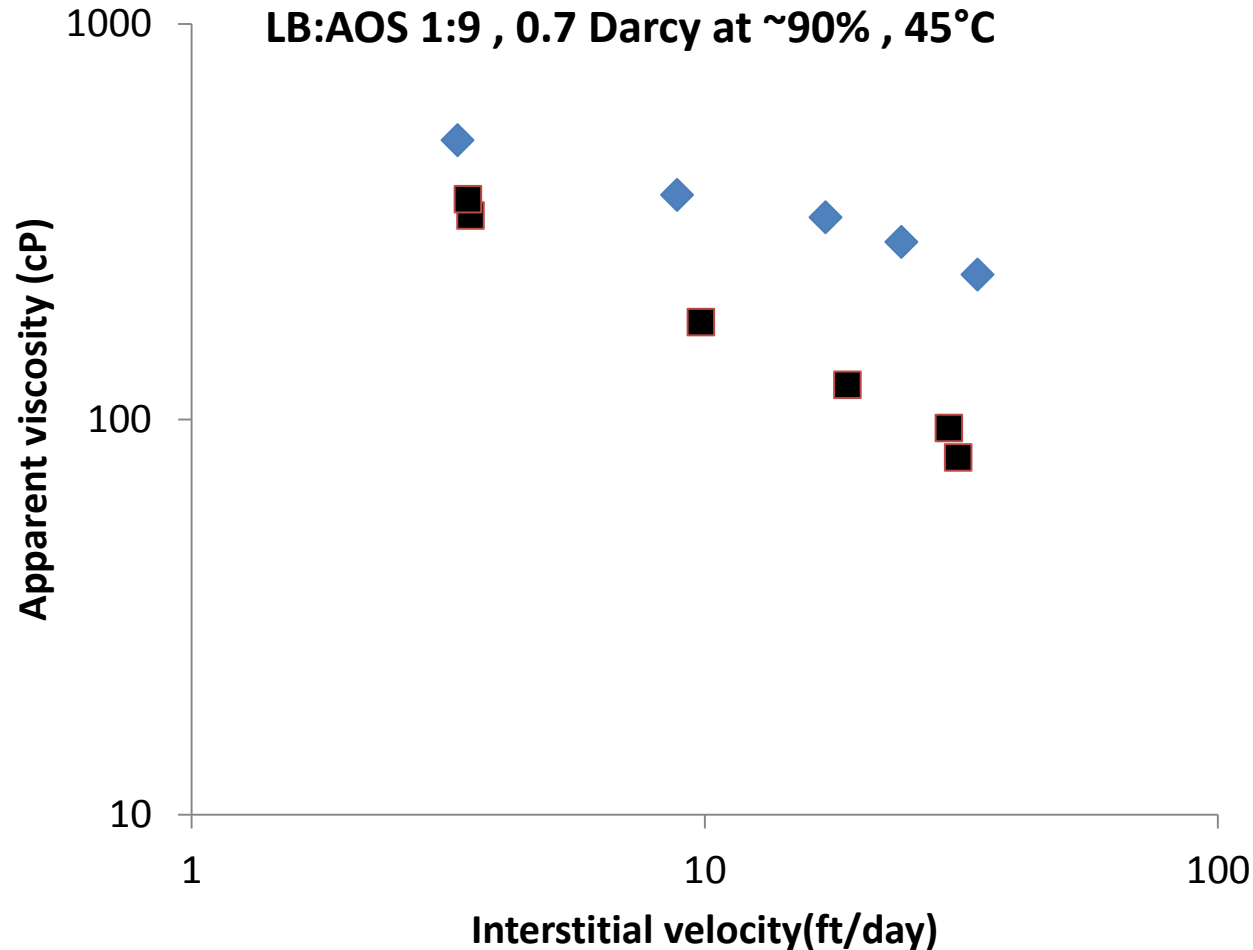
Procedure:

1. Core injected with ~2PV crude oil.
2. CO₂ used to reduce the oil to remaining oil.
3. Water injected till no more oil produced
4. 1 PV surfactant injected till no more oil production seen (At the end of this only ~28-30% oil remains in core)
5. Foam injected (recovers another 6-8% of remaining oil)

LB:AOS Foam with crude oil



LB:AOS Foam with crude oil (contd.)



Summary of foam oil studies for LB:AOS blends

Surfactant	Foam with oil at ~4 ft/day	Shear thinning behavior
LB (20 °C)	Weak	Shows minimum velocity. (Foam weakens below 10ft/day)
LB:AOS 7:3 (45° C)	Yes after attaining strong foam at higher values	Yes (shear thinning)
LB:AOS 1:9 (45 °C)	Yes after attaining strong foam at higher values	Yes (shear thinning)

Acknowledgments

Process in Porous Media Consortium

Rhodia (Solvay)

Dr. Jose Lopez Salinas

Dr. Pasquali and Dmitri

Chang Tian

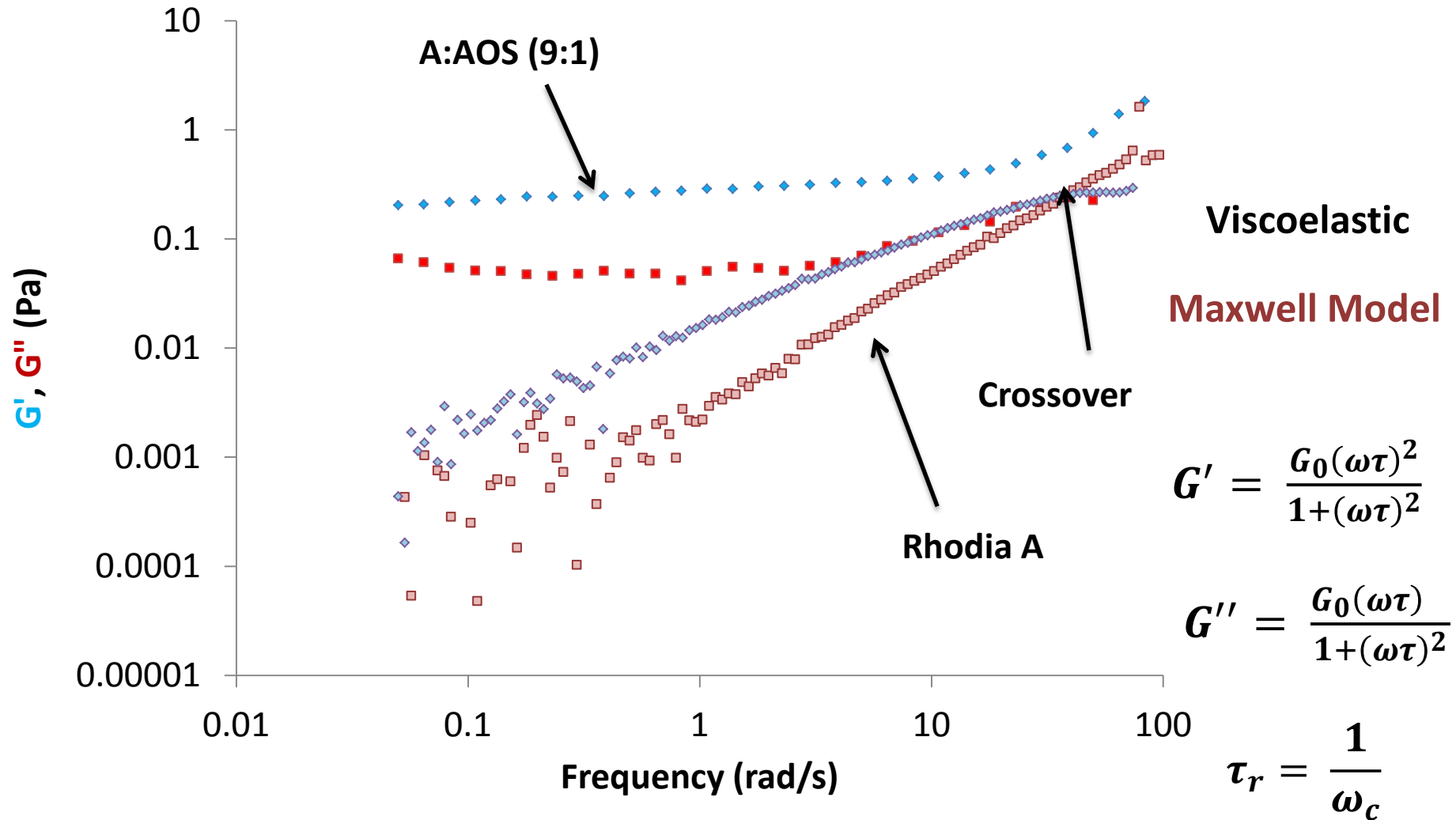
Michiel Slob

Dr. Ali Akbar Eftekhari

Back up slides

Rheology

Comparison of 0.5 wt% Rhodia-A and A:AOS (9:1)



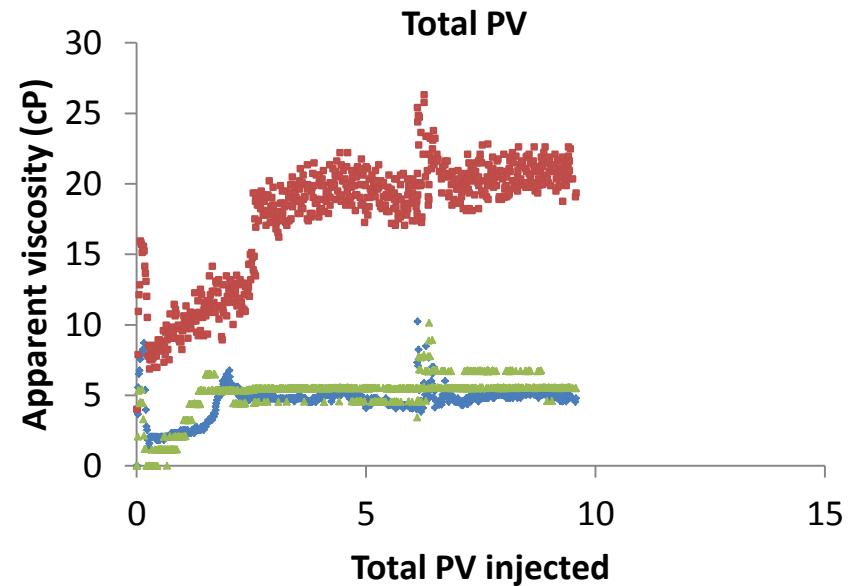
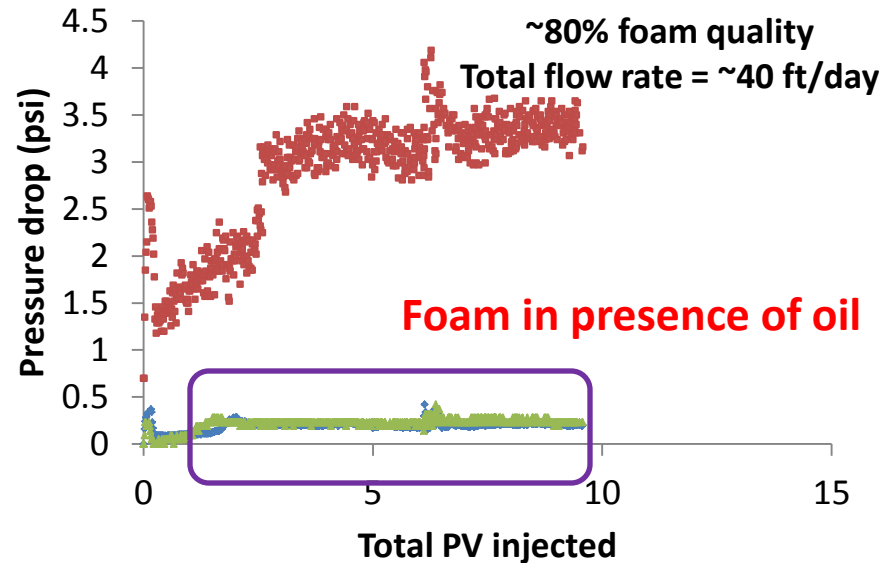
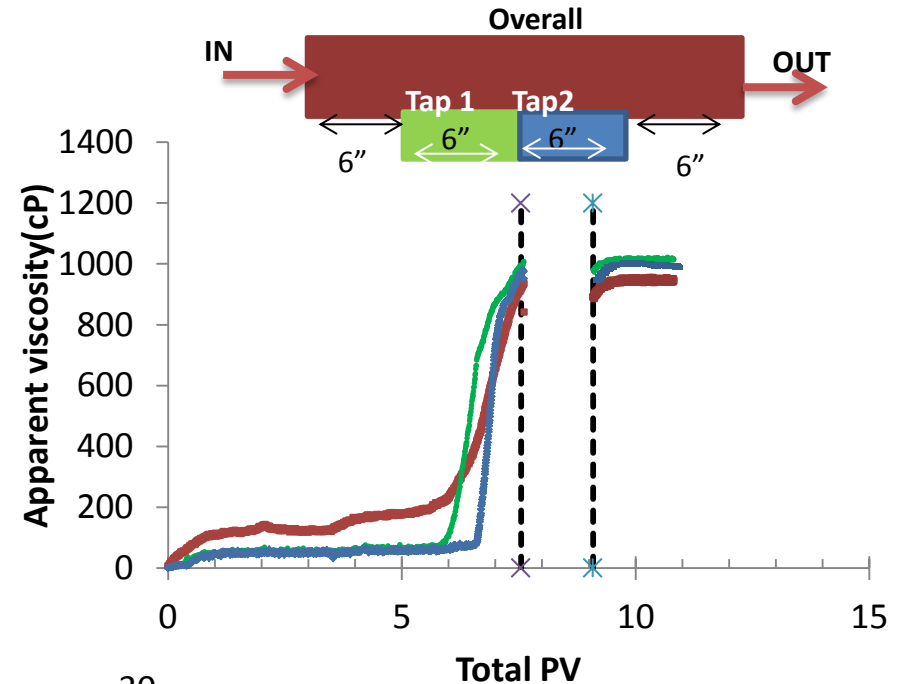
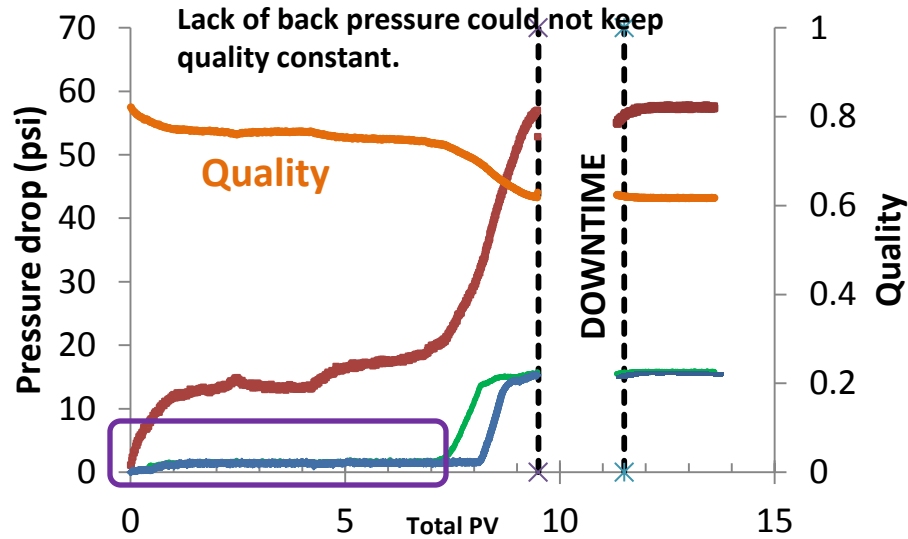
Relaxation time Rhodia A = 0.026 seconds

Rhodia A is weakly viscoelastic

Increase in viscoelasticity is observed on adding a small part of AOS to Rhodia A

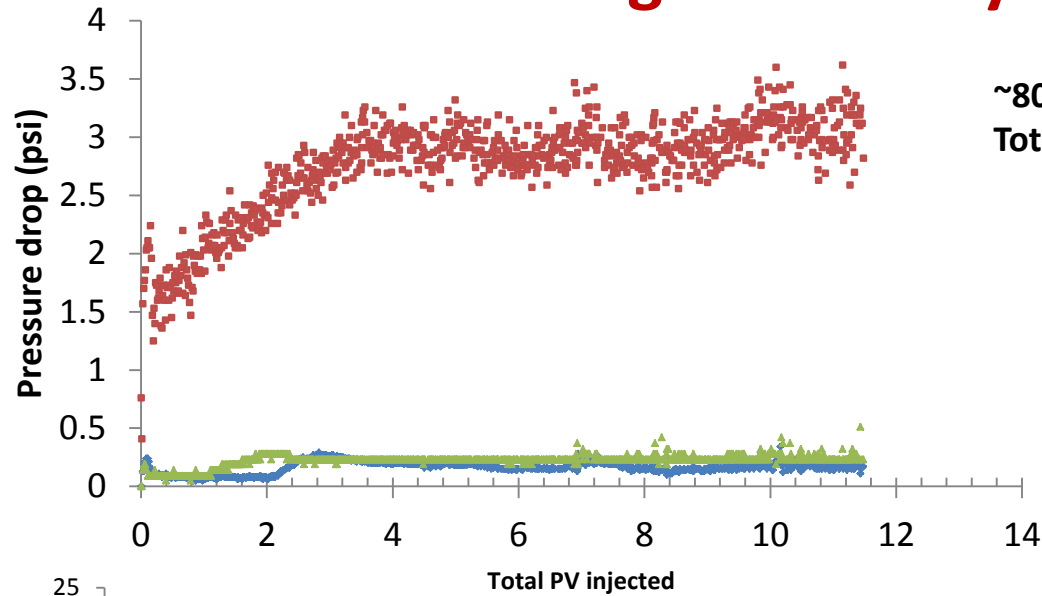
Rhodia A

Foam in absence of oil ~ 30 ft/day



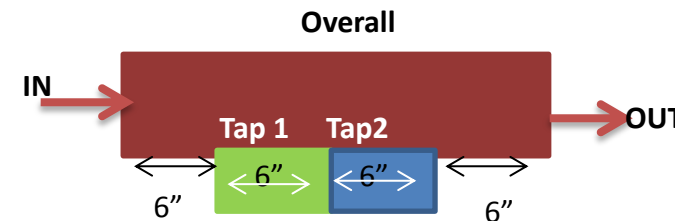
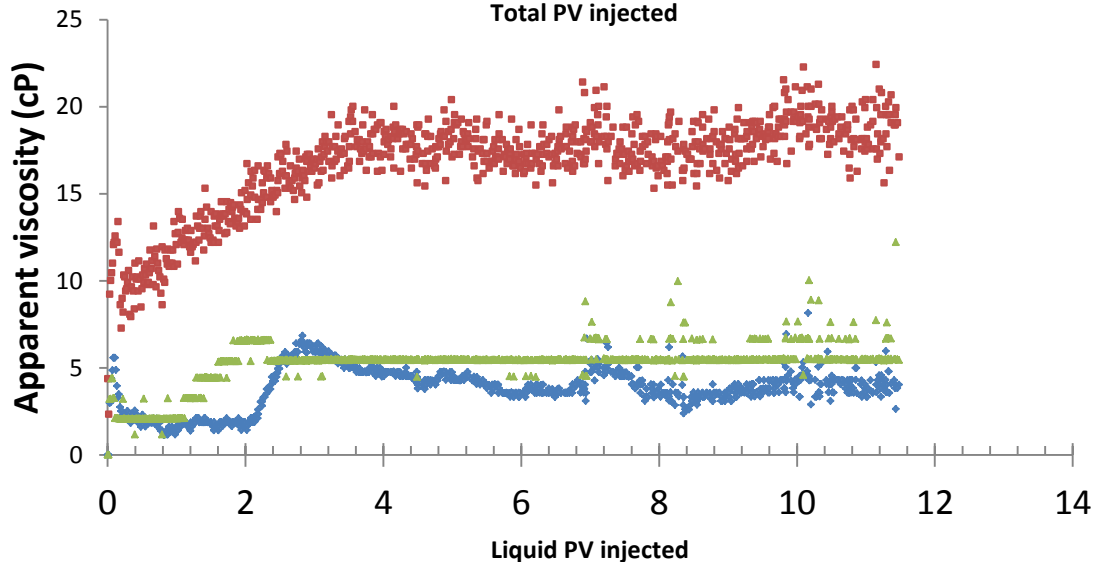
The foam apparent viscosity reduced from ~60 to 5 cP in internal taps(note the quality change due to pressure change- See circled area in purple to compare same quality and velocity)

Rhodia A-Foam strength recovery after oil displacement



~80% foam quality
Total flow rate = ~40 ft/day

To check foam strength recovery after oil displacement .
No improvement of foam strength hence speculated still some oil is left inside pack.



Comments: The foam strength fell down by order of magnitude and did not recover original strength.

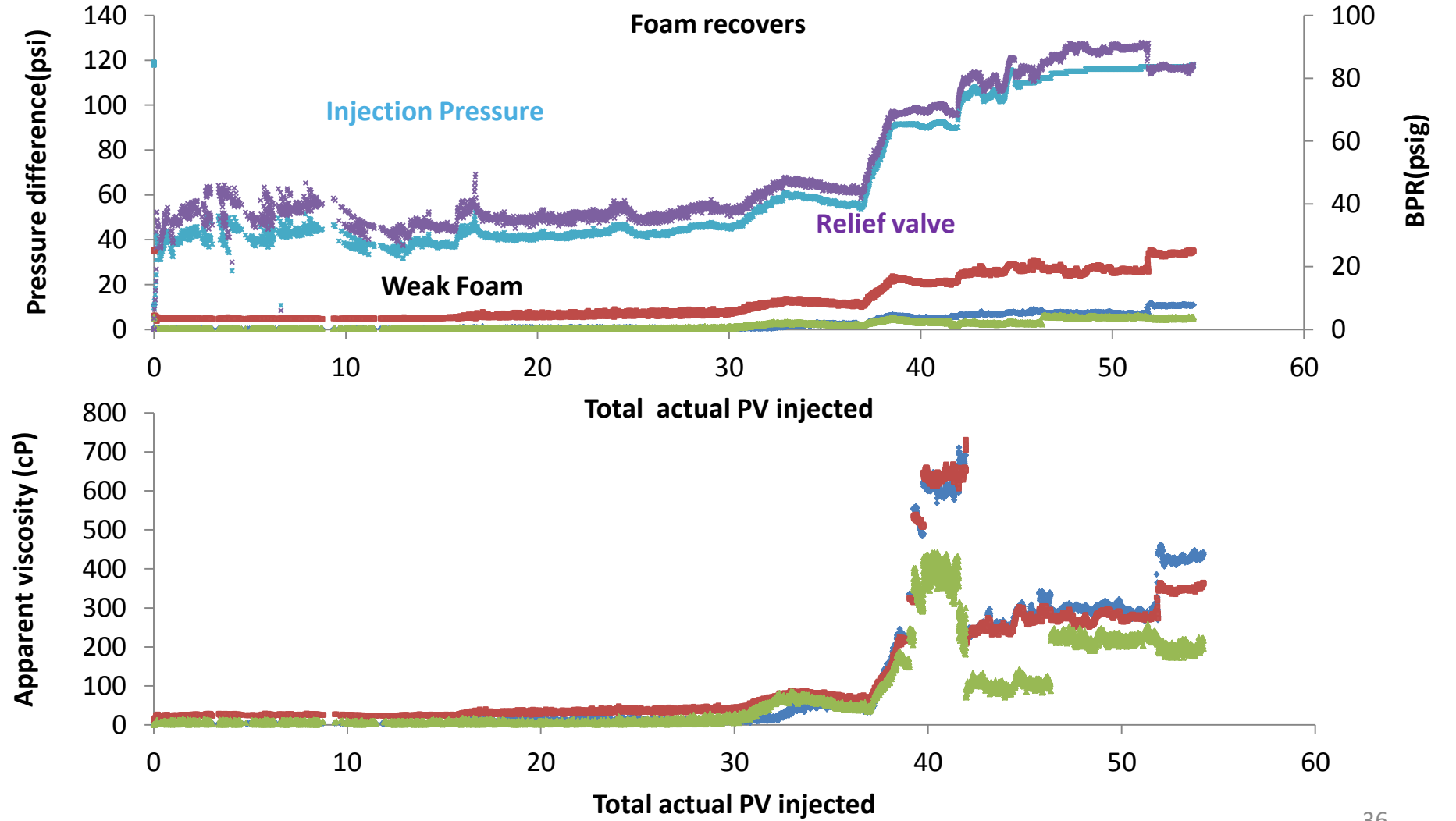
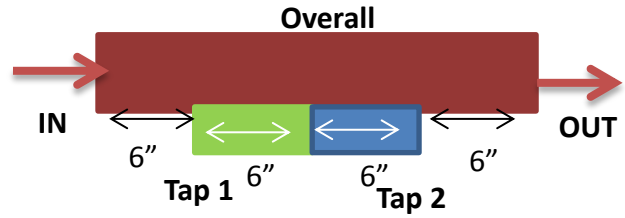
Appearance of Sand after Rhodia A Foam Displaced perhaps ~85% oil



Sand after foamed in the absence of oil

Sand after foamed in the presence of oil

Foam stability with crude oil (Rhodia B) at 85-90% quality at ~30-40 ft/day
(remaining ~40% oil)



Appearance of Sand after Rhodia B (sultaine) Foam Displaced oil



Sand with foam

Sand after foam displaces oil

Foam- oil studies Summary

Foam strength A - ~80% and ~40 ft/day

	No oil	With oil (Perhaps only ~ 15% remaining oil)	Recovery after some oil displacement
Overall	~150 cP	~25 cP	No
Tap 1	~50 cP	~5 cP	No
Tap 2	~50 cP	~5 cP	No

At end of foam flood the sand seems wetted by oil

Foam strength A:AOS (9:1)- ~80 % and ~ 30ft/day

	No oil	With oil (63% remaining oil)	Recovery after some oil displacement
Overall	~1000 cP	~115 cP	Yes to ~original (after 35 PV)
Tap 1	~1000 cP	~46 cP	Yes to original (after 16 PV)
Tap 2	~1000 cP	~20 cP	Yes to original (after 25 PV)

At end of foam flood the sand seems wetted by oil

Foam strength A-AOS (1:9)- ~90 % and ~ 30ft/day

	No oil	With oil (56% remaining oil)	Recovery after some oil displacement
Overall	~1000 cP	~50 cP	Yes to ~original (after 40 PV)
Tap 1	~1000 cP	~20 cP	Yes to ~original (after 34 PV)
Tap 2	~1000 cP	~50cP	Yes to ~original (after 37 PV)

At end of foam flood sand seems almost swept.

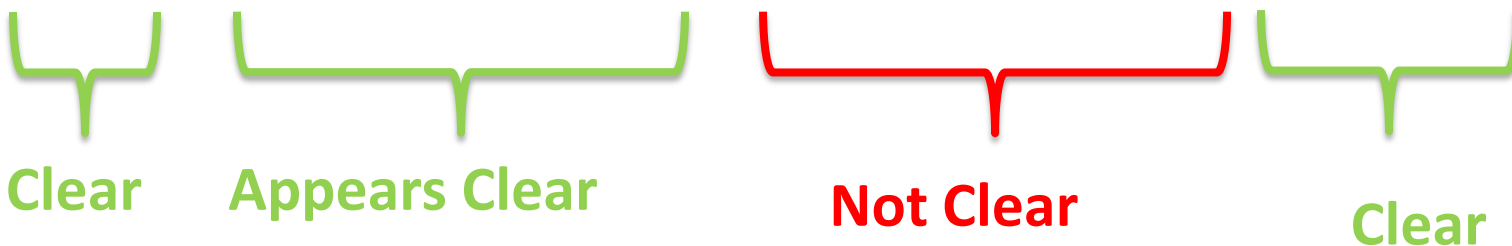
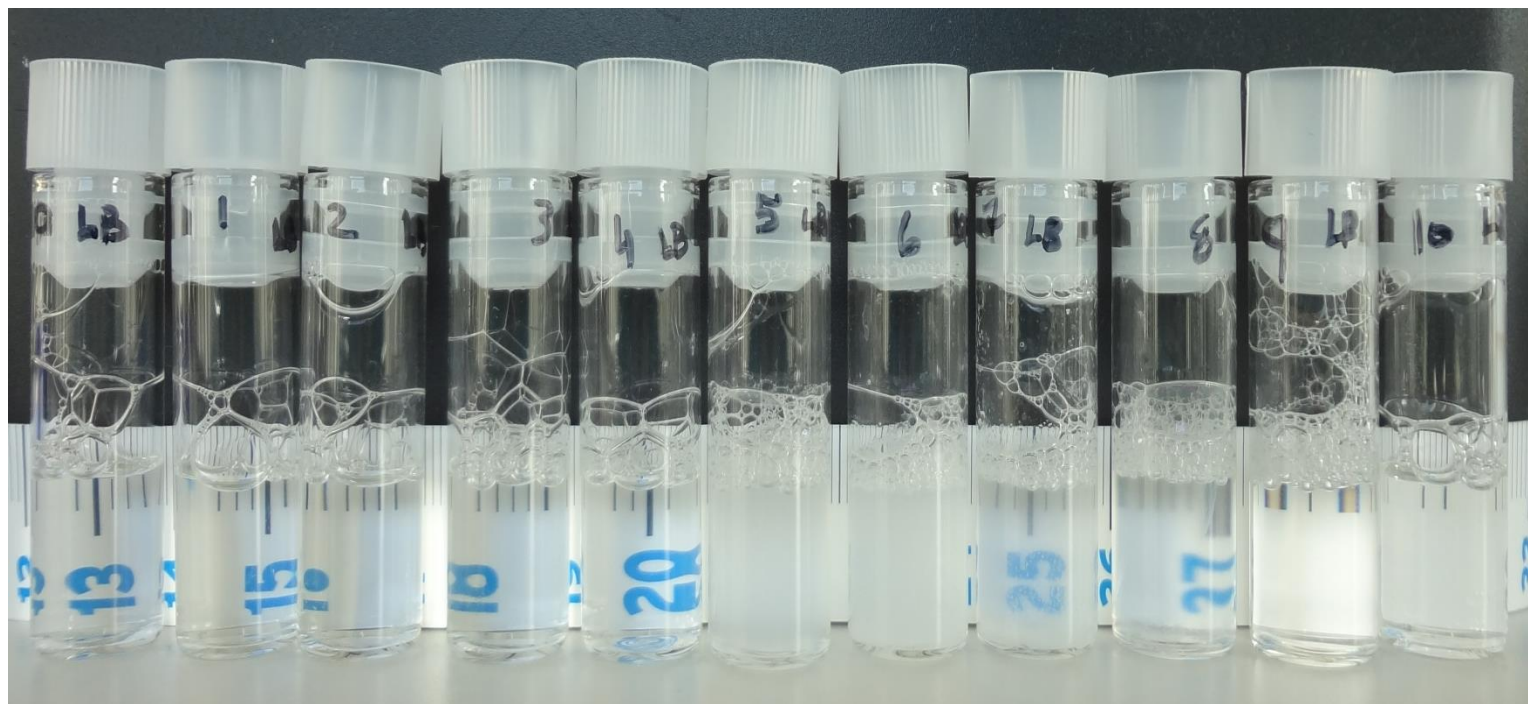
Foam strength B (cP)- ~85% and ~30 ft/day

	No oil	With oil (40% remaining oil)	Recovery after some oil displacement
Overall	~660 cP	~25 cP	Yes less than original ~340 cP (after ~ 39PV)
Tap 1	~660 cP	~10 cP	Yes less than original ~215cP (after ~ 32PV)
Tap 2	~700 cP	~15 cP	Yes less than original ~420cP (after ~ 35PV)

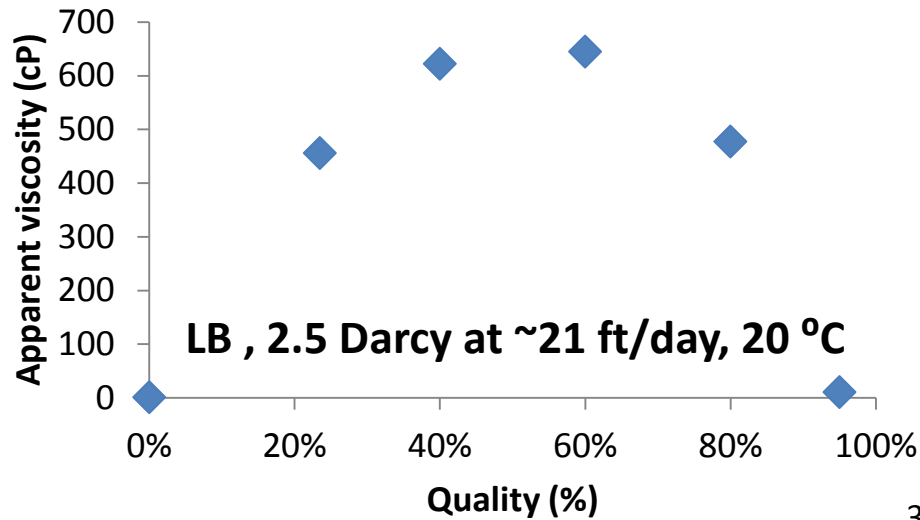
At end of foam flood to displace oil the sand seems cleaned completely

Blend Scan (20 °C)

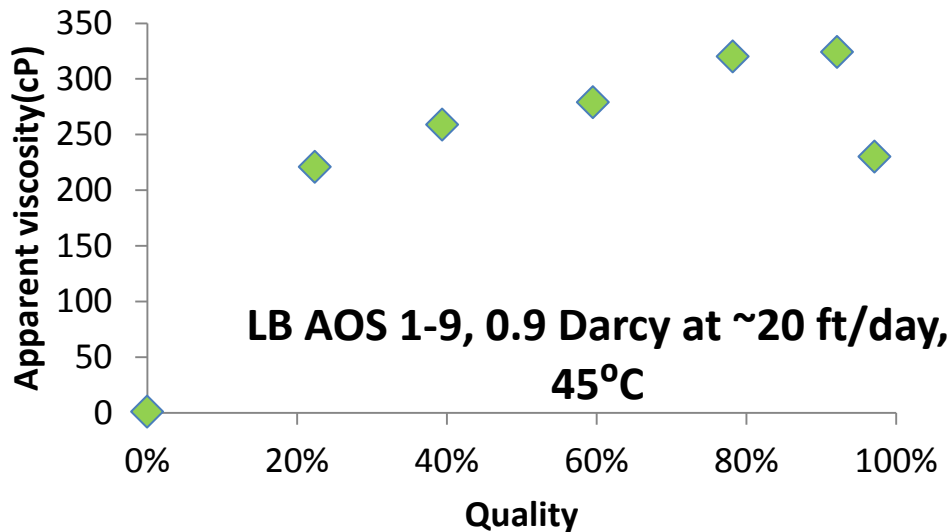
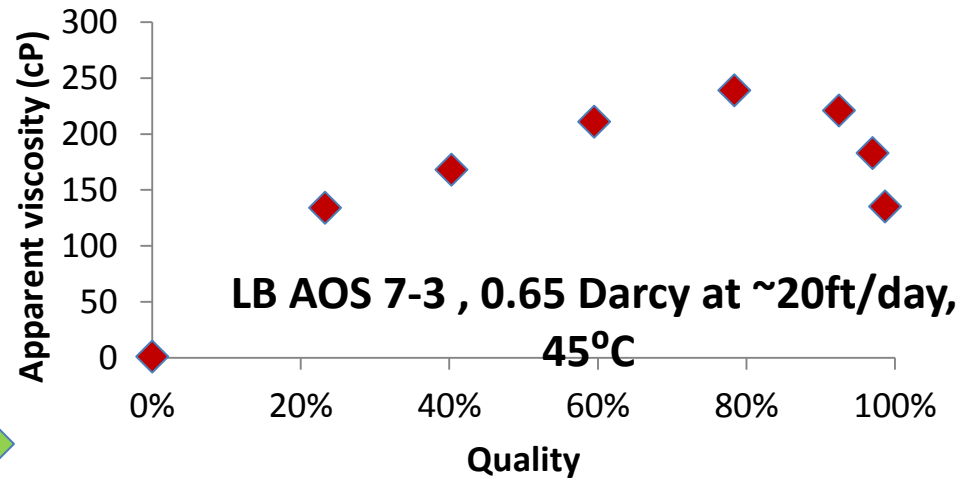
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(AOS)	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1



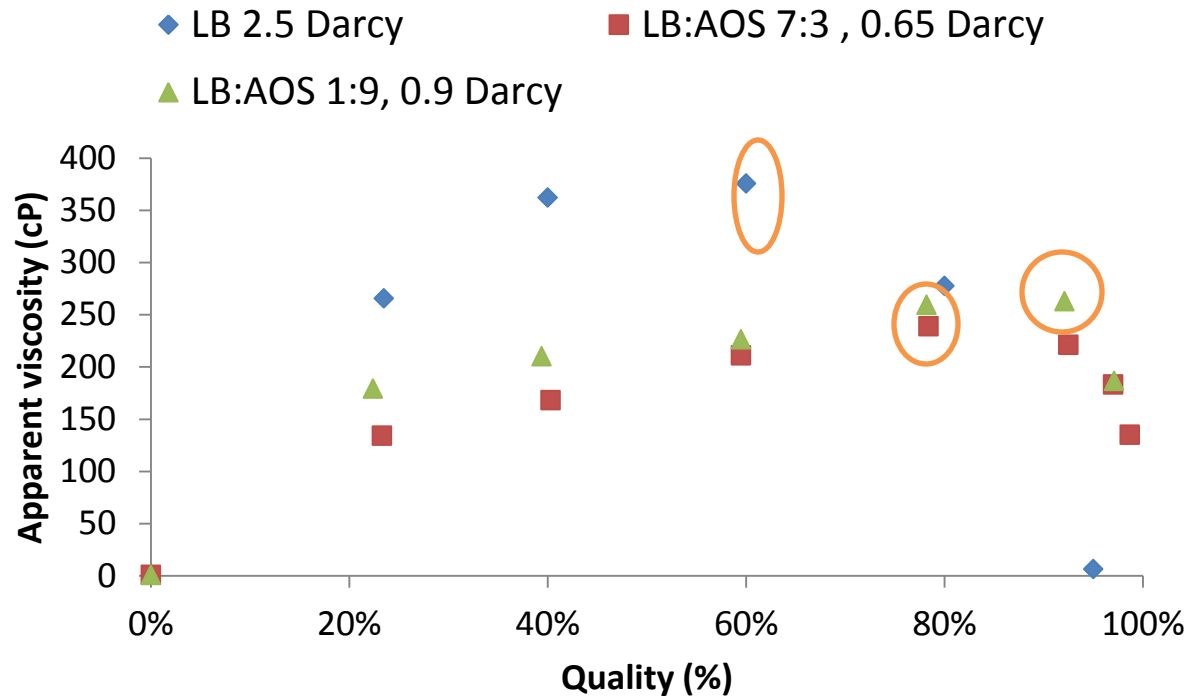
When made in bulk solution slowly
gets cloudy over time



**Quality scan at interstitial
velocity ~20 ft/day(internal
tap data only)**



Comparison of strength as function of shear rate



LB at 20 °C

LB AOS 7-3 at 45° C

LB AOS 1-9 at 45° C

$$n=0.81$$

$$\mu \propto \frac{1}{\dot{\gamma}^n}$$

$$\frac{\mu}{\mu_o} = \frac{\dot{\gamma}_o^n}{\dot{\gamma}^n}$$

$$\dot{\gamma} = \frac{1.38 u}{\sqrt{k\phi}}$$

José Lopez PhD thesis, 2012