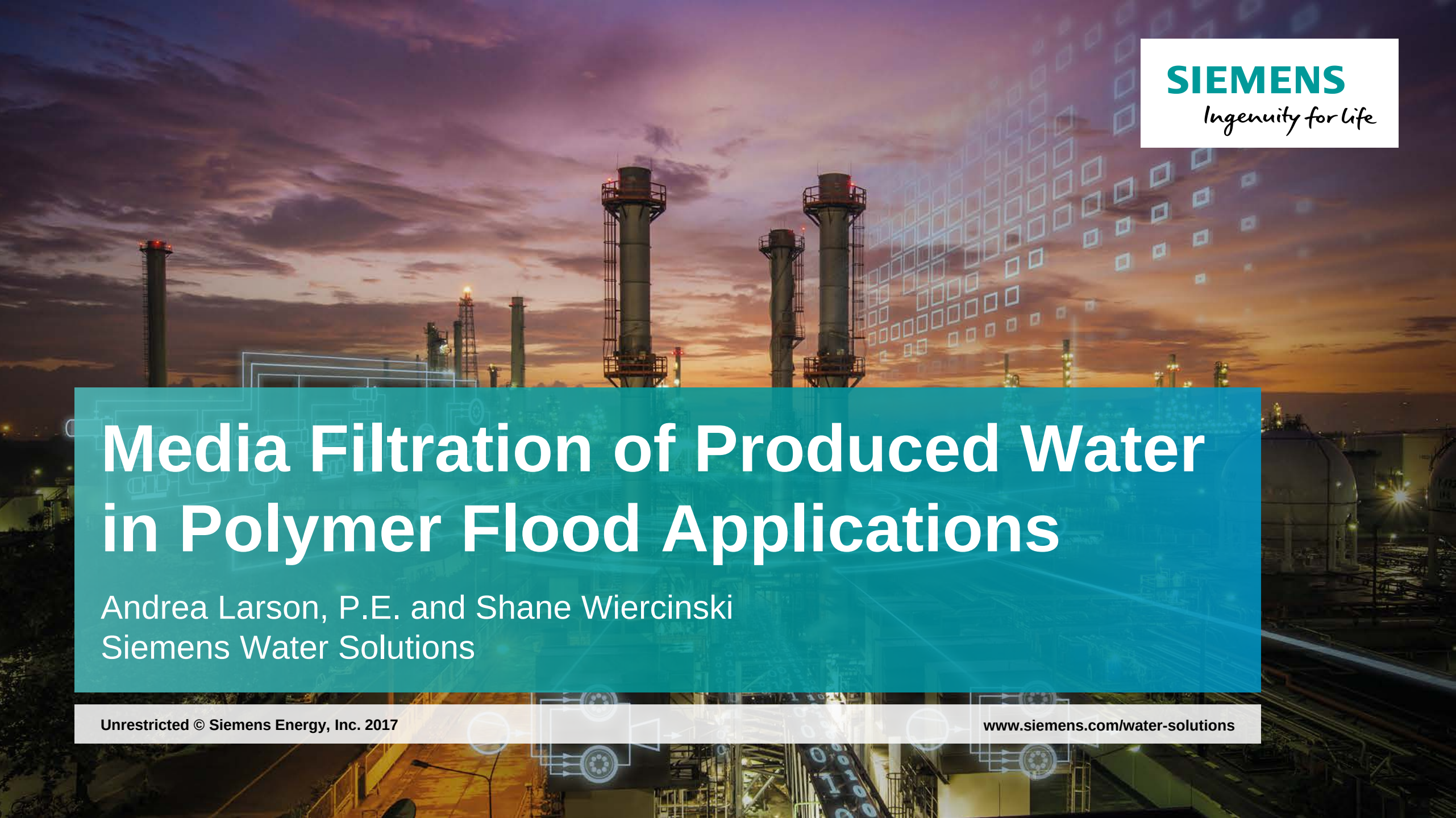

Media Filtration of Produced Water in Polymer Flood Applications

Andrea Larson, P.E. and Shane Wiercinski
Siemens Water Solutions

Global Oil Recovery

It is likely that an oil well will see some type of Enhanced Oil Recovery (EOR) application over its lifetime

- Average global oil recovery recovery:
  - Primary (natural pressure) = 10 - 25%
  - Secondary (waterflooding) = 10 – 20%
  - 55 – 80% of the oil is still in the reservoir!

EOR has been proven to be a financially viable option for extending the life of a reservoir

- Gives oil producers the potential to recover even more oil from an individual well

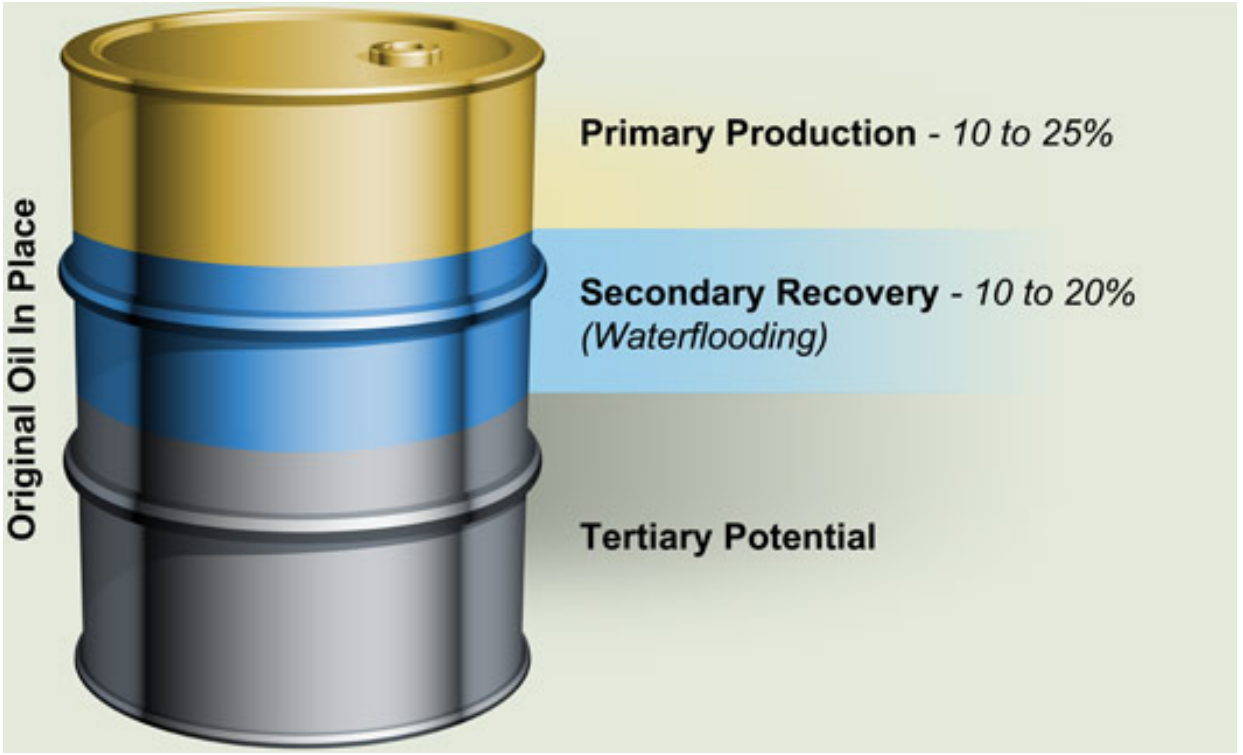

Photo: MidCon Energy

Oil Price and Polymer Price

Will oil producers apply Chemical Enhanced Oil Recovery (CEOR) practices when oil price is low?

CEOR is viable even at low oil prices

- The cost of the raw product to make polymer follows the price of oil
- Feedstock for most resins is a by-product of oil and gas processing
- When oil is cheap, so is polymer

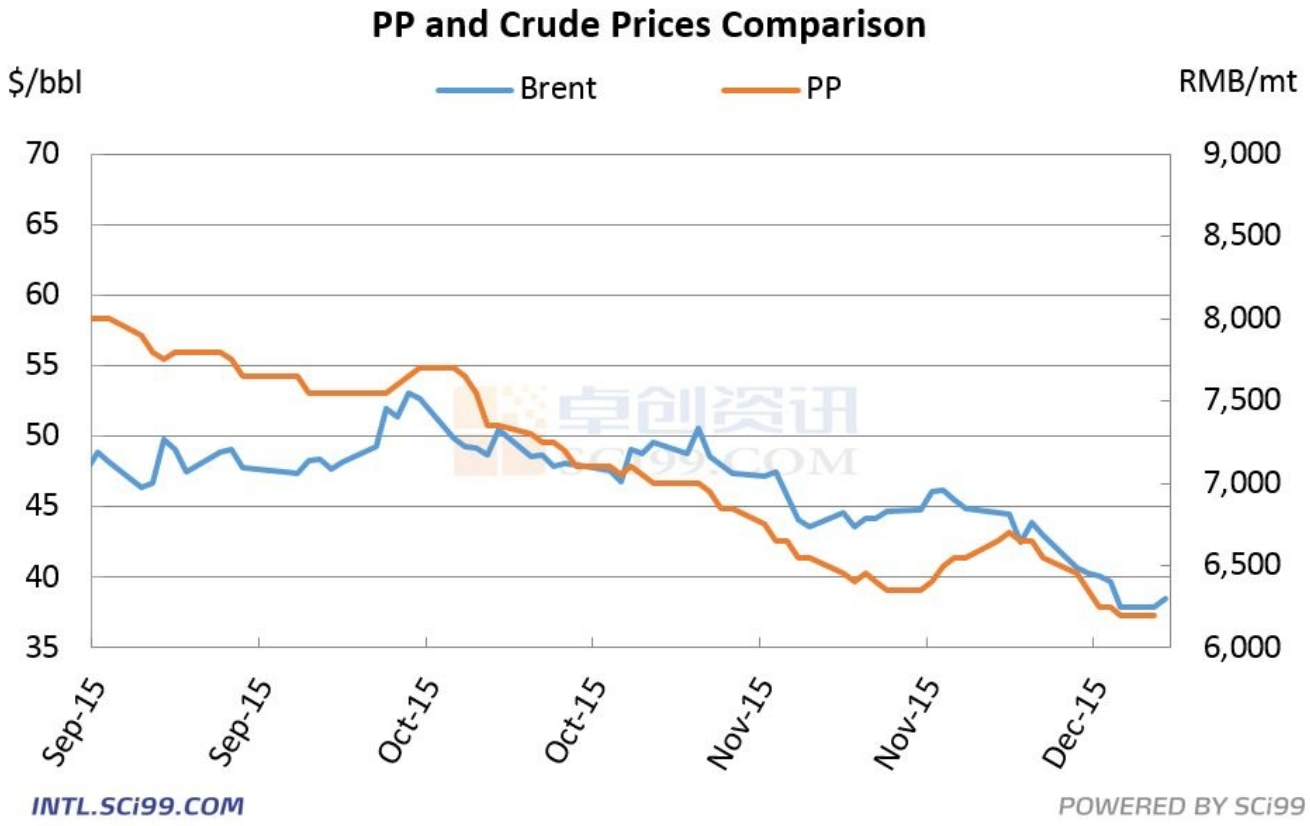

Photo Courtesy of EUROINVESTOR

Polymer Injection and Oil Recovery

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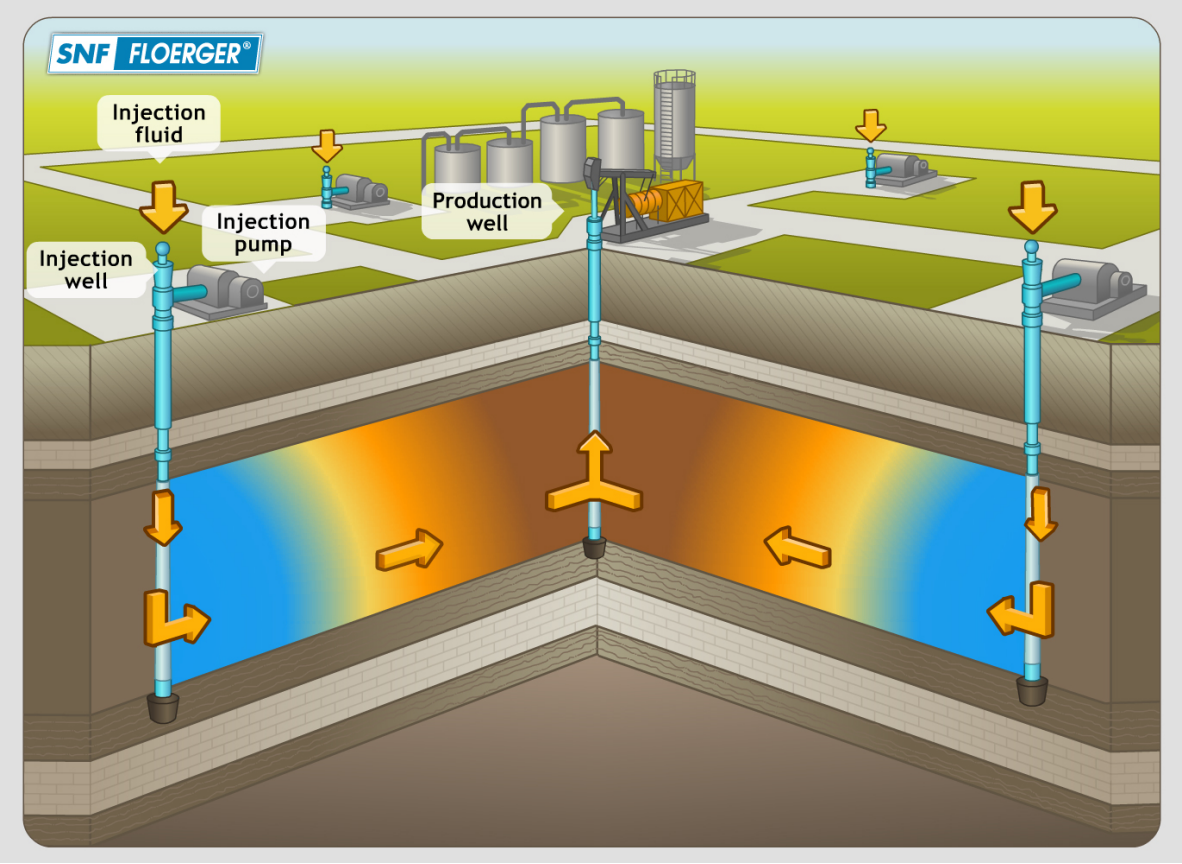
CEOR by use of polymer flooding can be financially rewarding

- Polymer increases water viscosity which increases the pressure to release more oil
- Decreases water cut
- For onshore polymer injection applications about one extra barrel of oil is recovered for every $1-3 spent on chemical injection
- Between 40 and 100 tons of extra oil is recovered for every ton of polymer injected
- Overall polymer costs are 1/3 of what they were 30 years ago



Why Use Polymer When Oil Price Is Low?

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Cost-efficient option for extra oil recovery

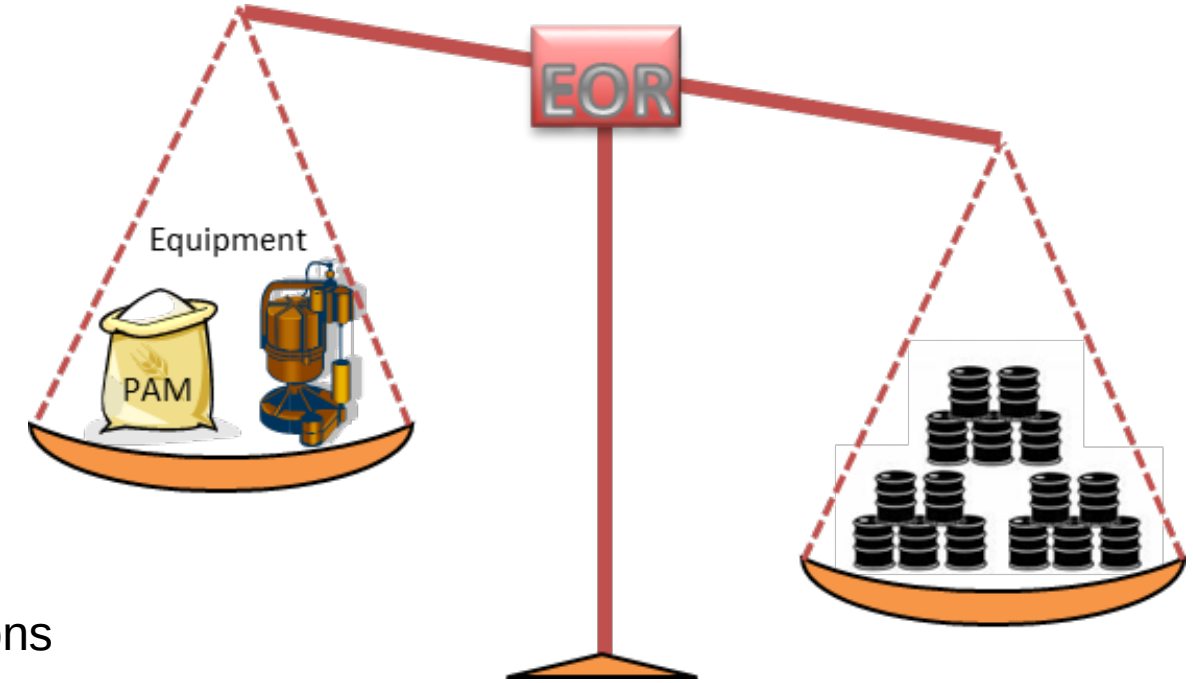
- Cheaper than exploration, less risks involved
- Use existing reserves/reservoirs/infrastructure
- Don’t have to invest in more equipment

Simple implementation

- Only injecting viscous water
- Skid-mounted, pre-designed injection systems
- Use less water to recover the same amount of oil
- Improvements in chemistry leads to more applications

Pilot testing available

- Check injectivity, rates, viscosity
- Evaluate injection equipment
- Assess oil recovery for extrapolation & economics
- Evaluate the produced water treatment technologies



Current Locations and expansion opportunities in CEOR

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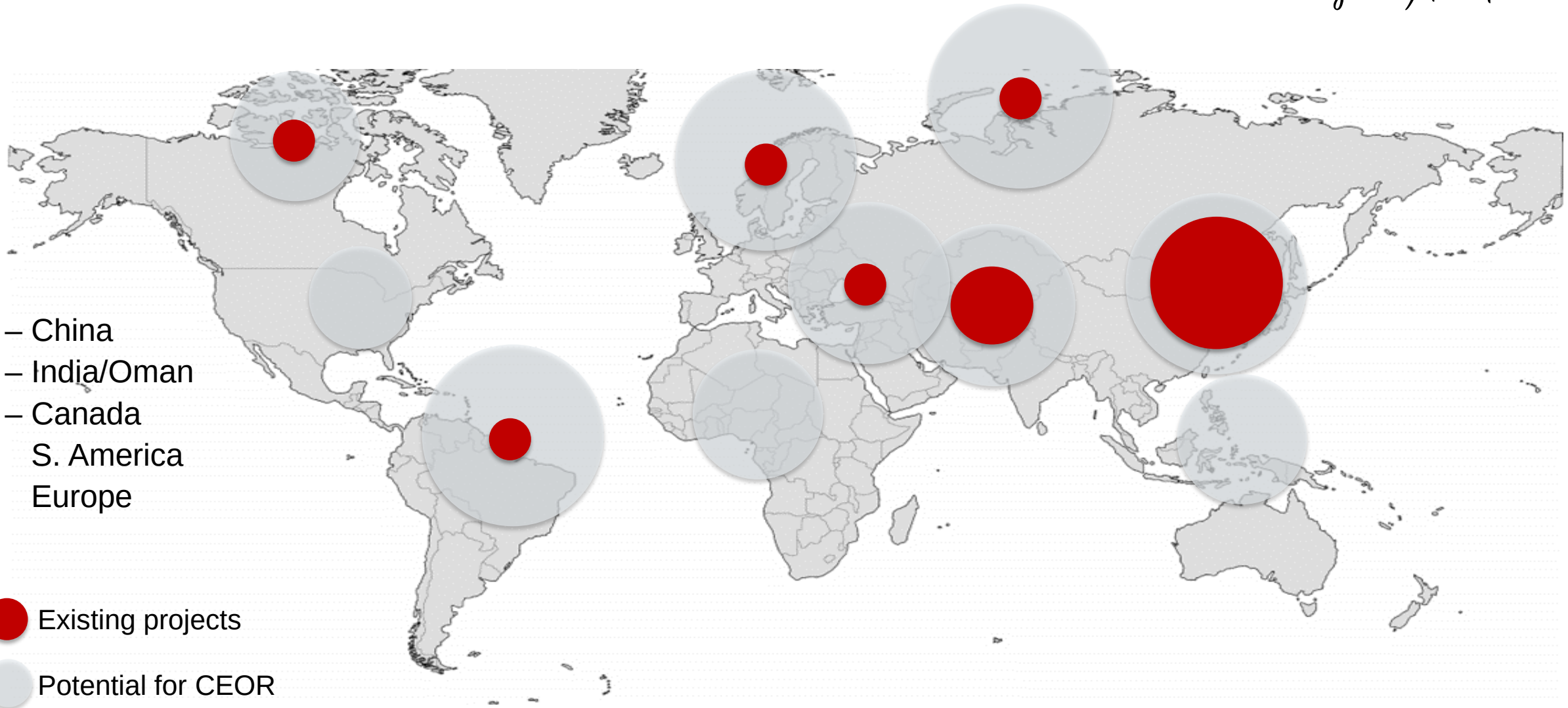

Polymer Flooding – Pros and Cons

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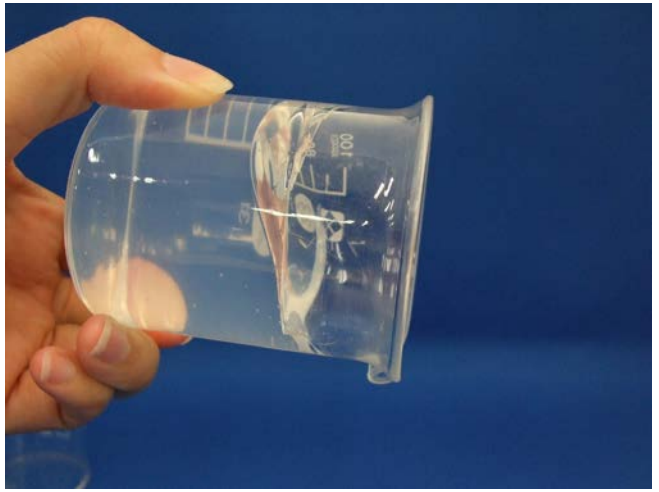
Polymer flooding can be financially rewarding

- Extends the life of a well
- Increases total oil recovery

Presents some challenges

- A portion of the polymer comes back with the produced water
- The viscous produced water creates challenges for conventional produced water treatment technologies
- Current polymers are not biodegradable, so typically reinjected for reuse or deep well injected for disposal



Conventional Water Treatment Can Be Challenging

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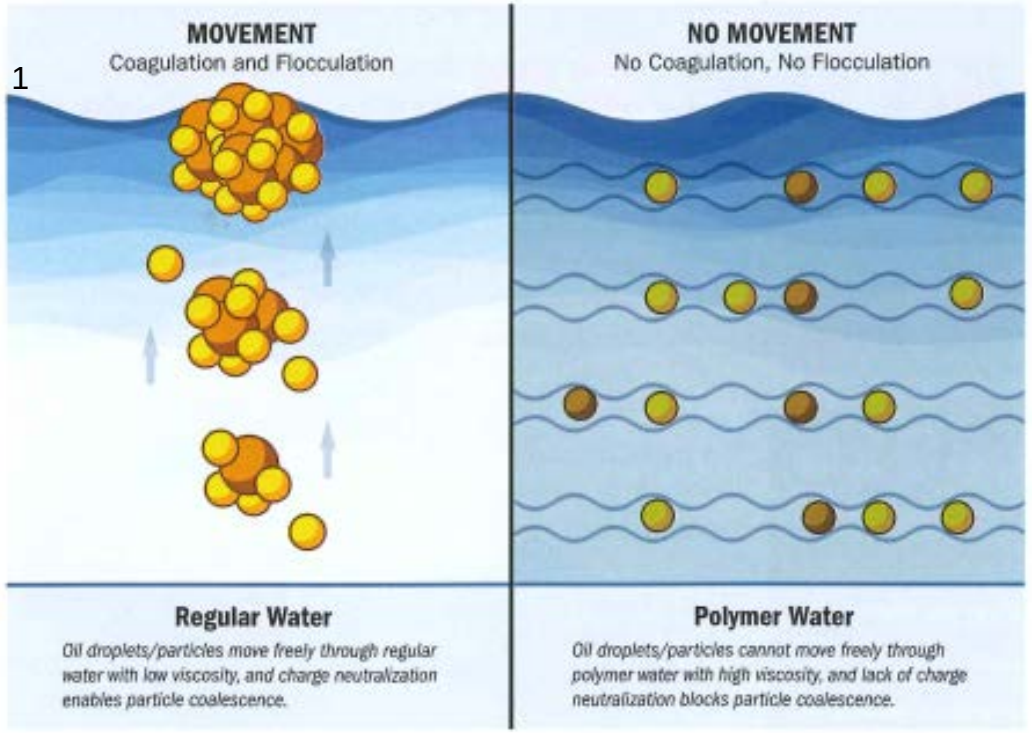
Viscosity is increased and there is a lack of charge neutralization

- Oil/solids can't move freely in the water
  - Difficult to float or sink
  - Stokes' Law shows:
    - Viscosity impact not as significant as initial droplet size, however, still effects the rise rate
- Lack of movement = poor contact/coalescence

Cost prohibitive to break polymer



STOKES' LAW

$$V = \left[\frac{\gamma_s - \gamma_w}{18\mu}\right] D^2$$

where:

V = terminal velocity

γ_s = unit weight of spheres

γ_w = unit weight of liquid

μ = viscocity of liquid

D = diameter of sphere

[1]Source: Daniel Shannon, Cameron Process Systems USA
"How Do You Solve A Problem Like Polymers
E&P Magazine, April 2017

Primary and Secondary Water Treatment Challenges

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Much research has been done on treating a polymer flood produced water with conventional treatment technology

- Hydrocyclones (~50% reduced efficiency)
  - Stabilized emulsions
  - Increased viscosity = Increased Drag
    - Negative effect on gravity separation

- Flotation (~40% reduced efficiency)
  - Stabilized particles won't coalesce or float
  - Short circuiting caused by high viscosity
  - Flotation can be efficient but require >40 ppm chemical dose[1]
    - Not economical

SPE 144 322, 2011[2]

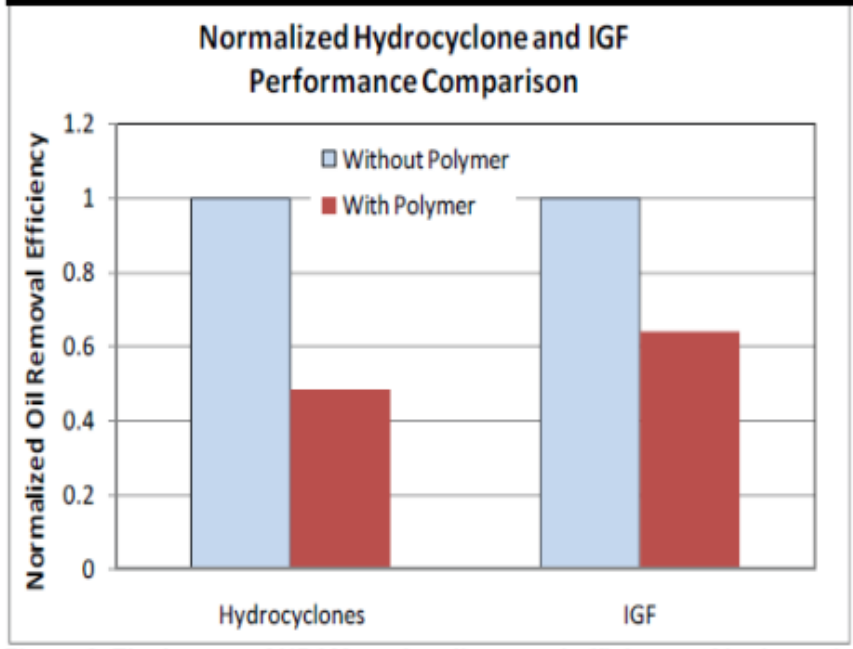

Figure 6. The impact of HPAM on the oil removal efficiency of hydrocyclones and IGF

[1]Mona E. Dadkhah, et. al., Environmental challenges of polymer flooded produced water (PFPW) - Tekna Produced Water Management Conference, Stavanger 2017

[2]Challenges in Processing Produced Emulsion from Chemical Enhanced Oil Recovery – Polymer Flood Using Polyacrylamide
Frank Zheng, Pilar Quiroga, Gary W. Sams, Cameron – SPE 2014

Traditional Media Filtration Challenges

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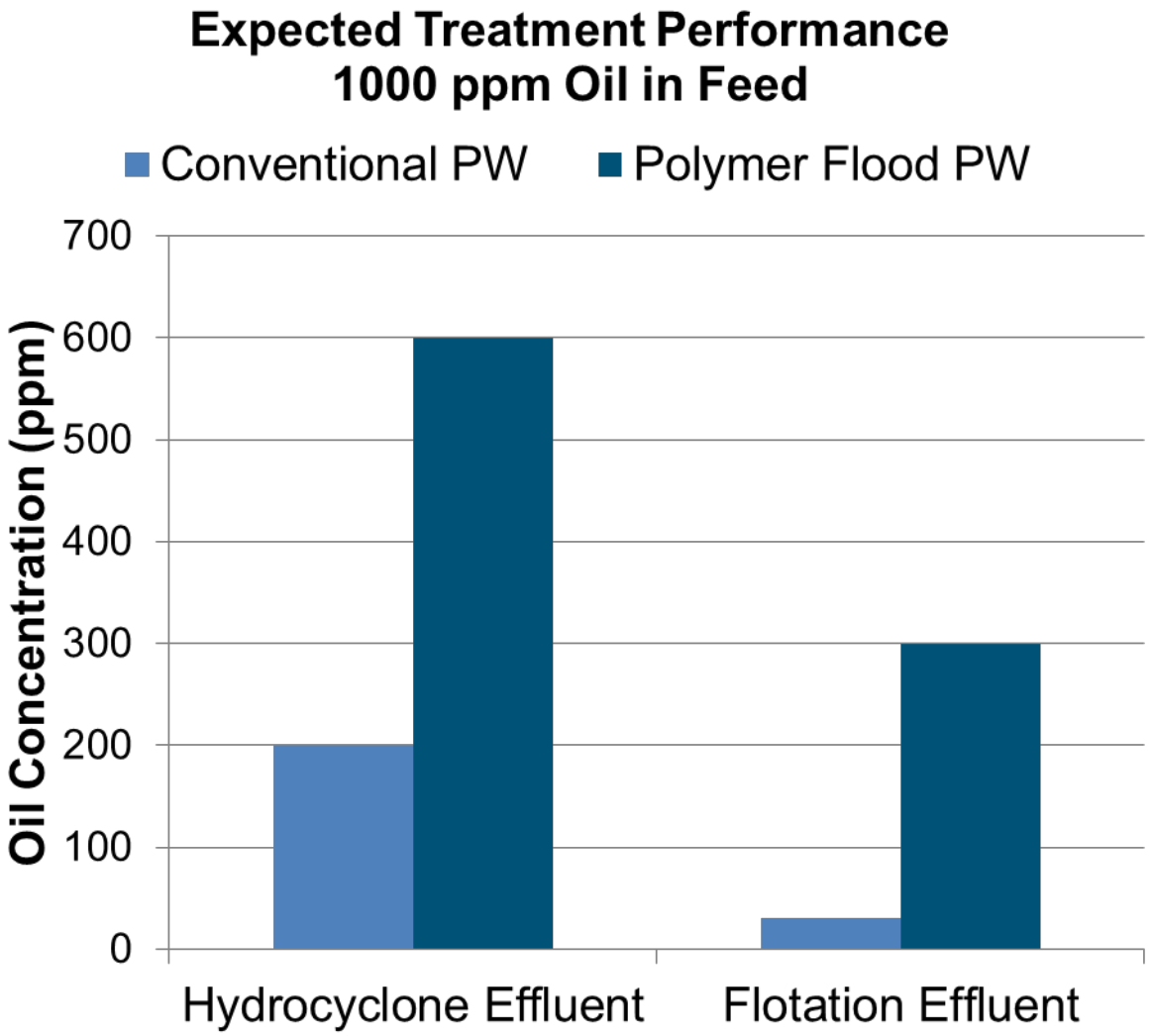
Due to upstream inefficiencies, media filtration is now expected to carry a lot more load

Using efficiencies from previous slide

- Assume 1000 ppm oil going to HC
  - Produced Water WSF Feed = <30 ppm OiW
  - Polymer Flood PW WSF Feed = **~300 ppm OiW**

- Traditional walnut shell filters can't handle this loading
  - High DP = frequent backwashing
    - Every 2 – 4 hours
  - Effluent would require further treatment
    - GAC Columns
    - Disposable Cartridge Filters
    - High OpEx



Siemens – SNF Partnership

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Siemens partnered with SNF in 2015 to review technologies that Siemens could apply to CEOR projects

SNF had done some in-house testing with traditional technologies and saw the same inefficient results

Treatment Goals

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Our goal was to find/develop a technology that:

- Could remove oil and TSS from high viscosity PW at an industry- accepted flux/footprint
- Did not consume the polymer during treatment
  - Did not require chemicals for operation/cleaning

We decided that PerforMedia™ oil removal media would be the technology

- Unique to Siemens
- Not a conventional technology
- Has some properties we thought would be beneficial to treat a polymer flood produced water

What is PerforMedia™ oil removal media?

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Siemens proprietary synthetic media

- Handles up to 500 ppm OiW in the feed
  - 5x more than walnut shells
- <10 ppm OiW in effluent
- Combines 2º and 3º treatment into a single economic step
- No chemicals required for operation or cleaning

- Media is larger than black walnut shells
  - Less prone to plugging and DP excursions
- Operates in same vessel design with same backwash procedure as our current walnut shell filter
- Removes 90% of particles >10 um
  - Includes OiW and TSS
- Less attrition than walnut shells

2015 Siemens – SNF PerforMedia™ Media Testing

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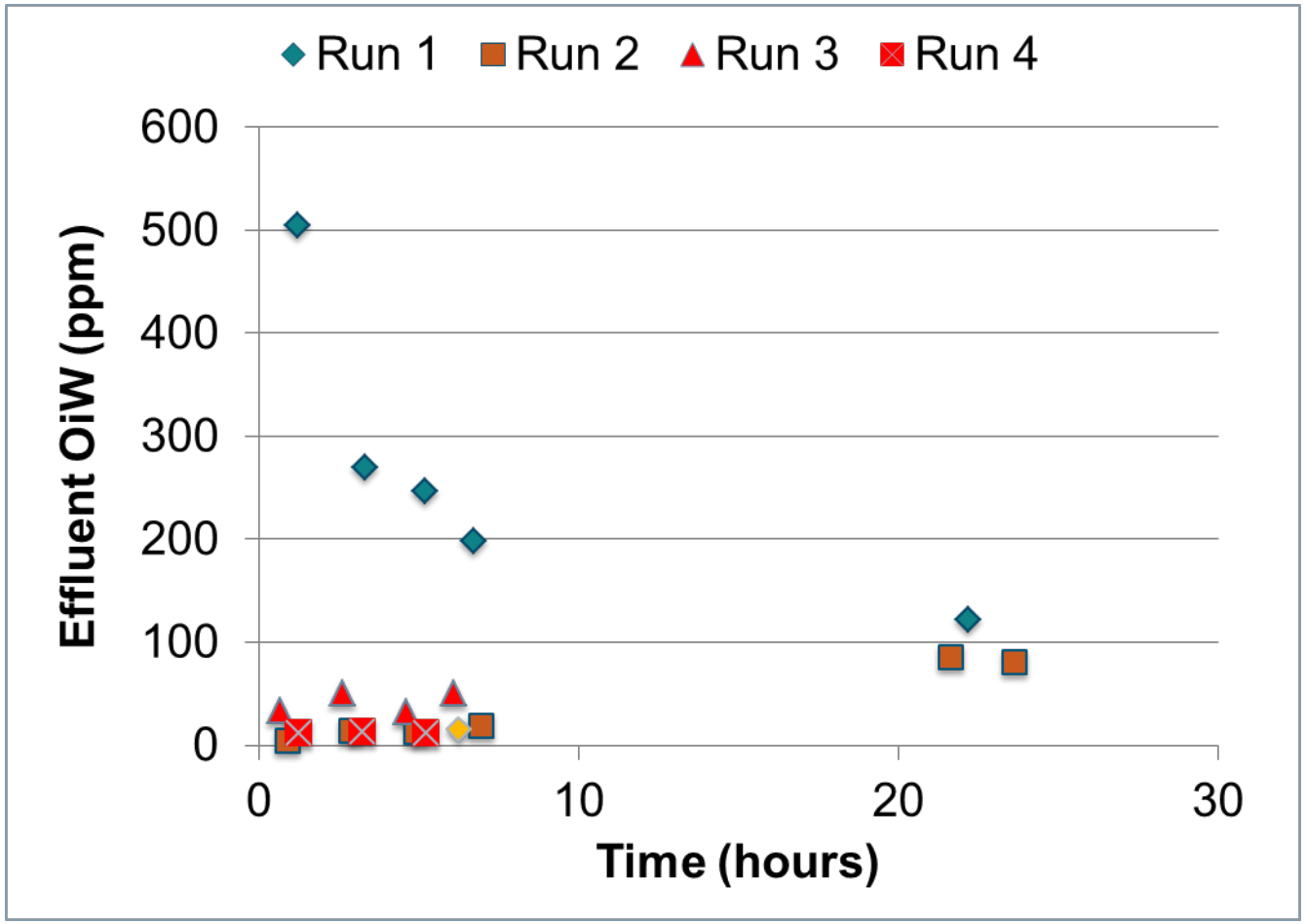
Started in-house proof of concept testing in fall of 2015

- Synthetic produced water was created
  - Injected oil and polymer into heated tap water
  - 500 ppm oil - 1300 ppm polymer (SNF FLOPAM)

Initial results were promising but not great

- 540 ppm OiW in feed
- <50 ppm OiW in effluent
  - Typical PerforMedia™ media performance:
    - 500 ppm OiW in
    - <10 ppm OiW out



Pilot Testing – Problems Encountered

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Manually operated pilot unit, no automated flow control

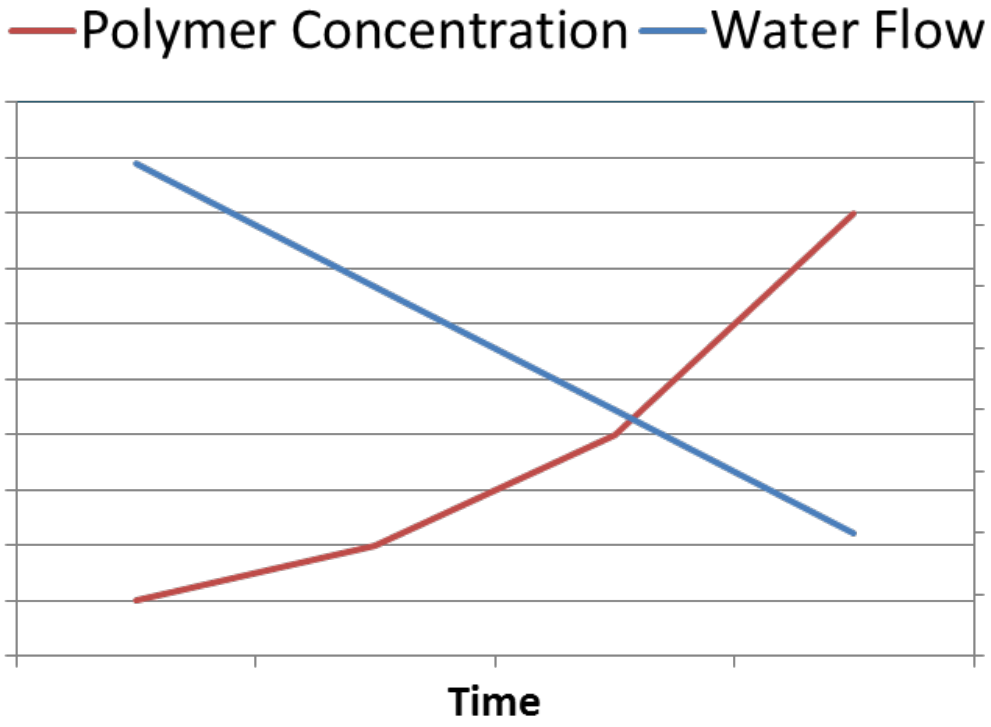
- As DP increased overnight the flow dropped
- Independent polymer pump did not adjust flow
- As a result, the polymer concentration increased while water flow decreased

Polymer had a negative effect on media regeneration

- Our standard backwash procedure was not effective
- Need to make modification to steps and durations to account for polymer

OiW analysis was difficult

- Polymer and hexane would not separate during extraction



2017 SNF - PerforMedia™ Media Pilot Testing

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Results from 2015 pilot study were encouraging

- Decided to dedicate a project to this testing for FY17
- Allow us to dedicate time and money to proper test setup

2017 Modifications

- Obtained crude oil from an active Polymer Flood site in Canada
  - API 21.6
- Upgraded pilot to automated flow control
  - Filtration and Backwash
- Developed method for separating polymer and hexane extraction during OiW analysis
  - Used TD500 handheld OiW meter

2017 SNF - PerforMedia™ Media Testing – Synthetic Feed

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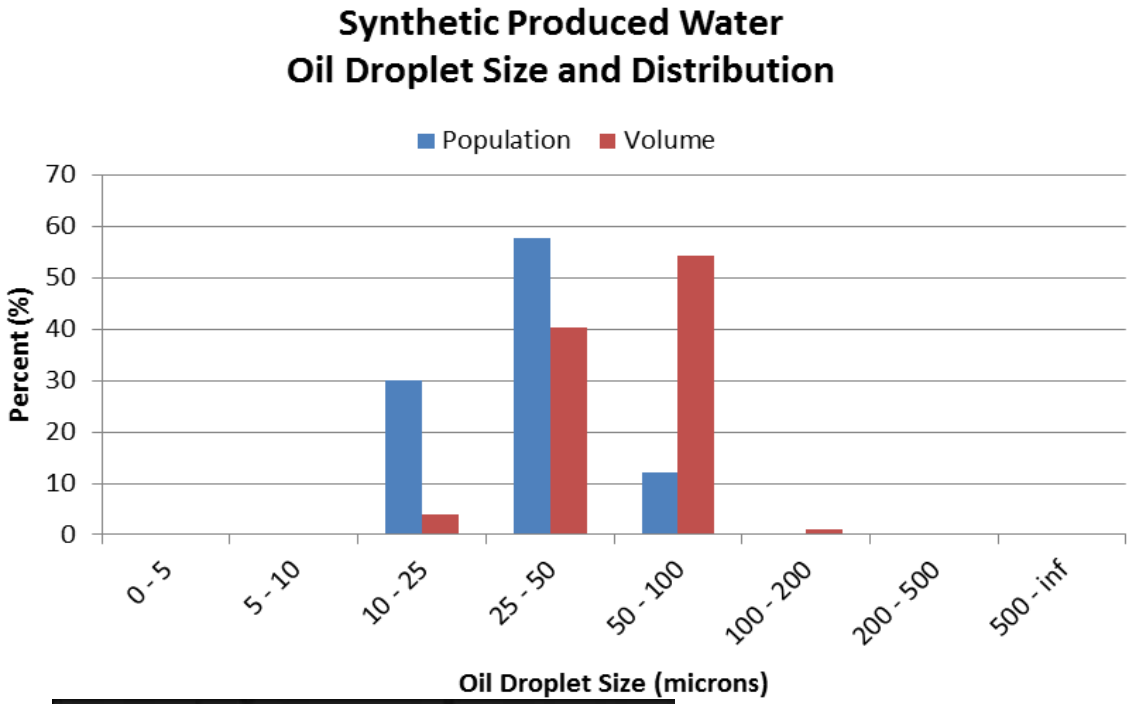
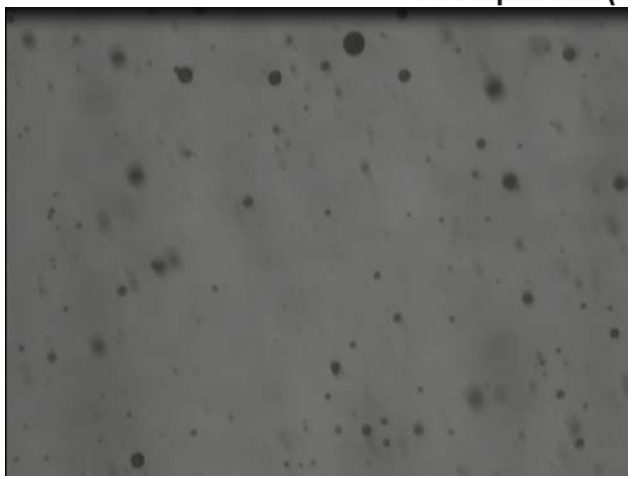
Synthetic Feed

- Crude Oil (21.6 API)
- SNF provided their FLOPAM polymer for the testing
  - ViscoTec high viscosity pump
- Oil/Polymer injected upstream of centrifugal pump that fed the system
- Used Canty particle analyzer to make sure we were creating a representative oil droplet distribution
  - 10 - 100 micron distribution

Downstream $FeCl_3$ dosing system

- Break polymer before it went down the drain
- Prevent sanitary drain plugging





2017 SNF - PerforMedia™ Media Pilot Testing – P&ID

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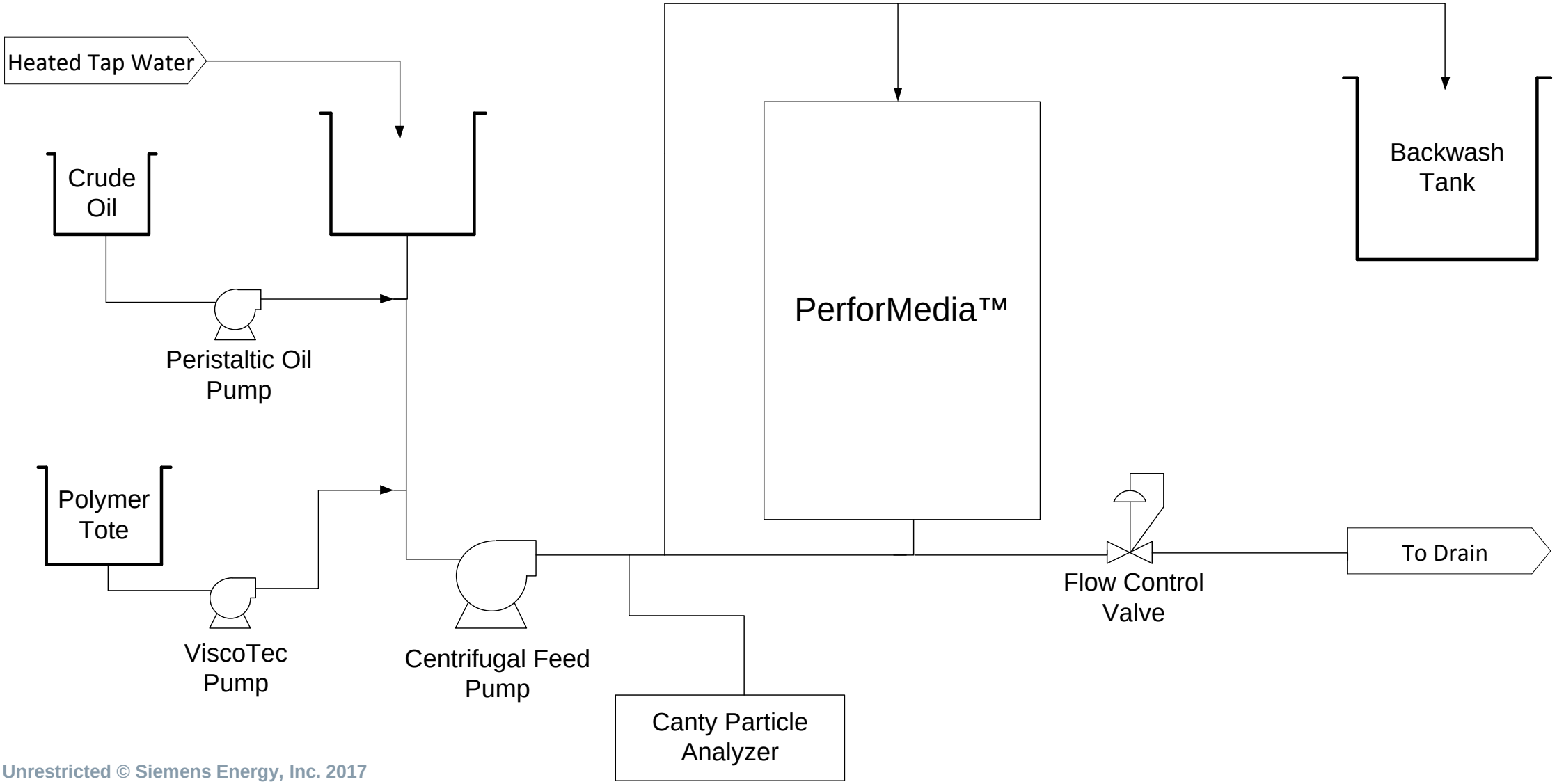

2017 SNF – PerforMedia™ Media Test Conditions

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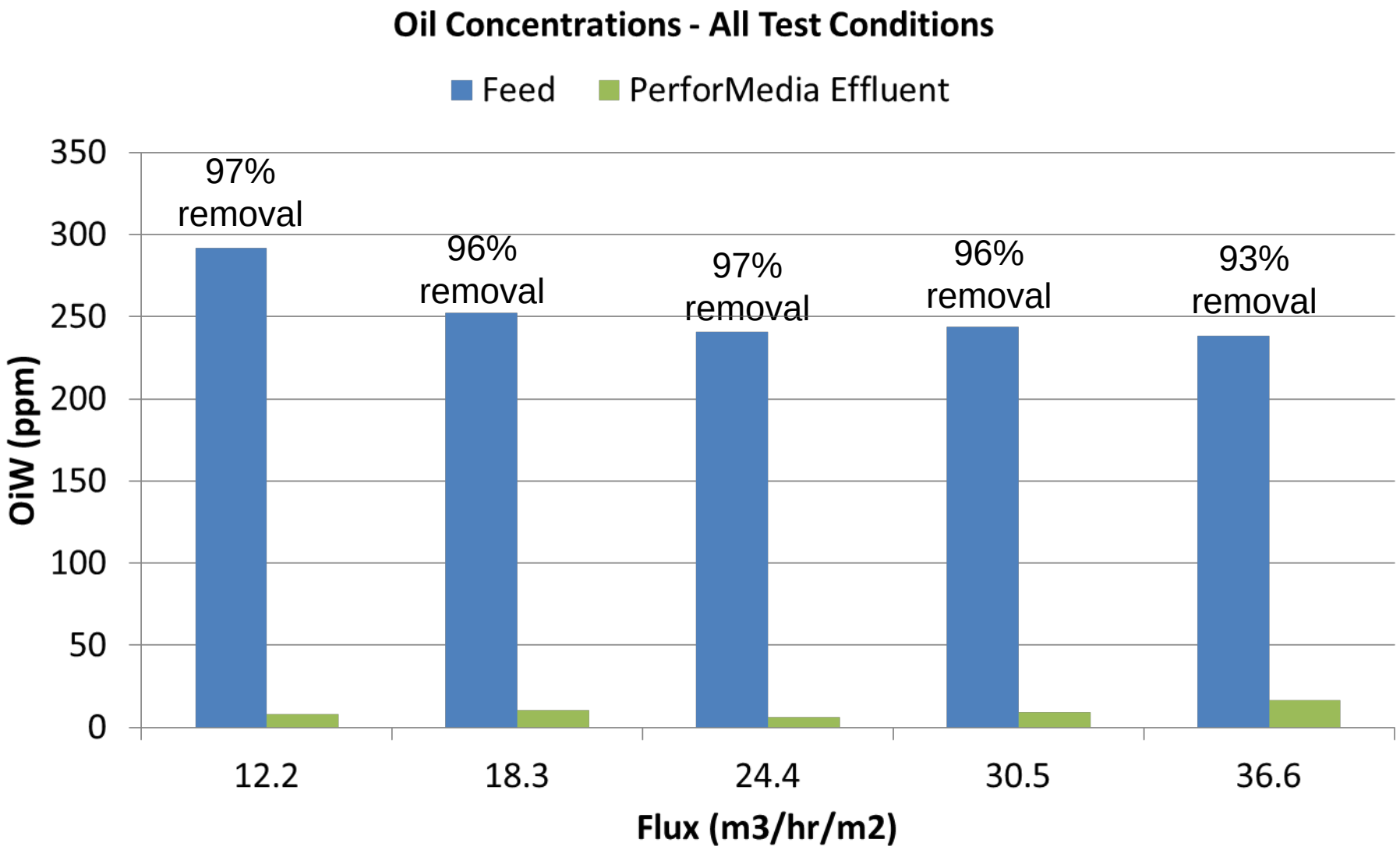
Test Conditions

- All testing done at 70°C
- Feed oil concentrations 250 – 500 ppm
- Polymer concentrations 500 – 1000 ppm

- SNF FLOPAM - not a polymer that would be injected to a reservoir
  - Has properties that were expected of a polymer that would come back in produced water
    - Time spent in the reservoir
    - Pumped a few times
  - Copolymer Acrylamide/Acrylic Acid
  - Molecular Weight: 7 million
  - Anionic
  - 30% hydrolysis

2017 SNF – PerforMedia™ Media – Results



2017 SNF – PerforMedia™ Media – Results

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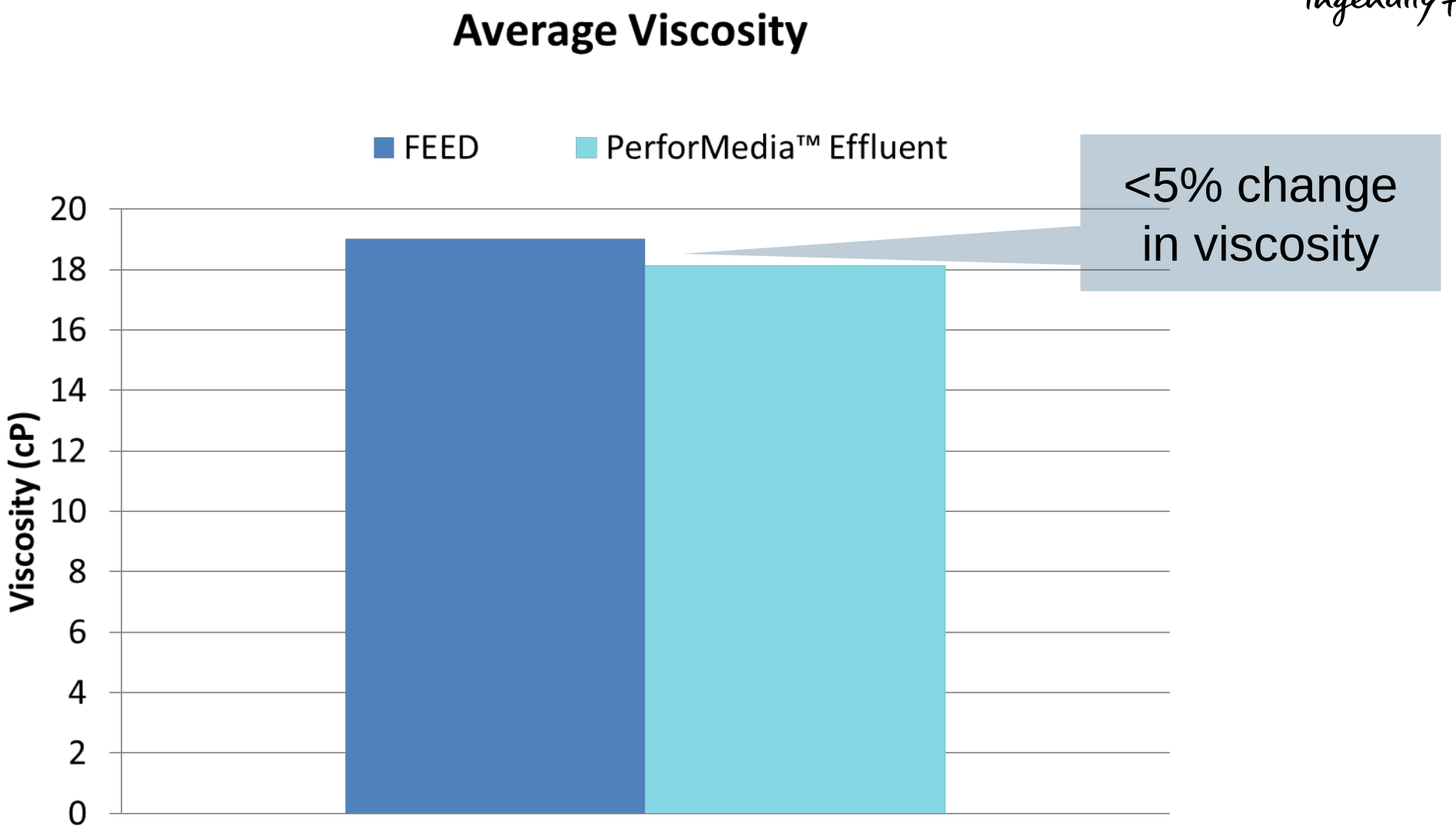

2017 SNF – PerforMedia™ Media – Results

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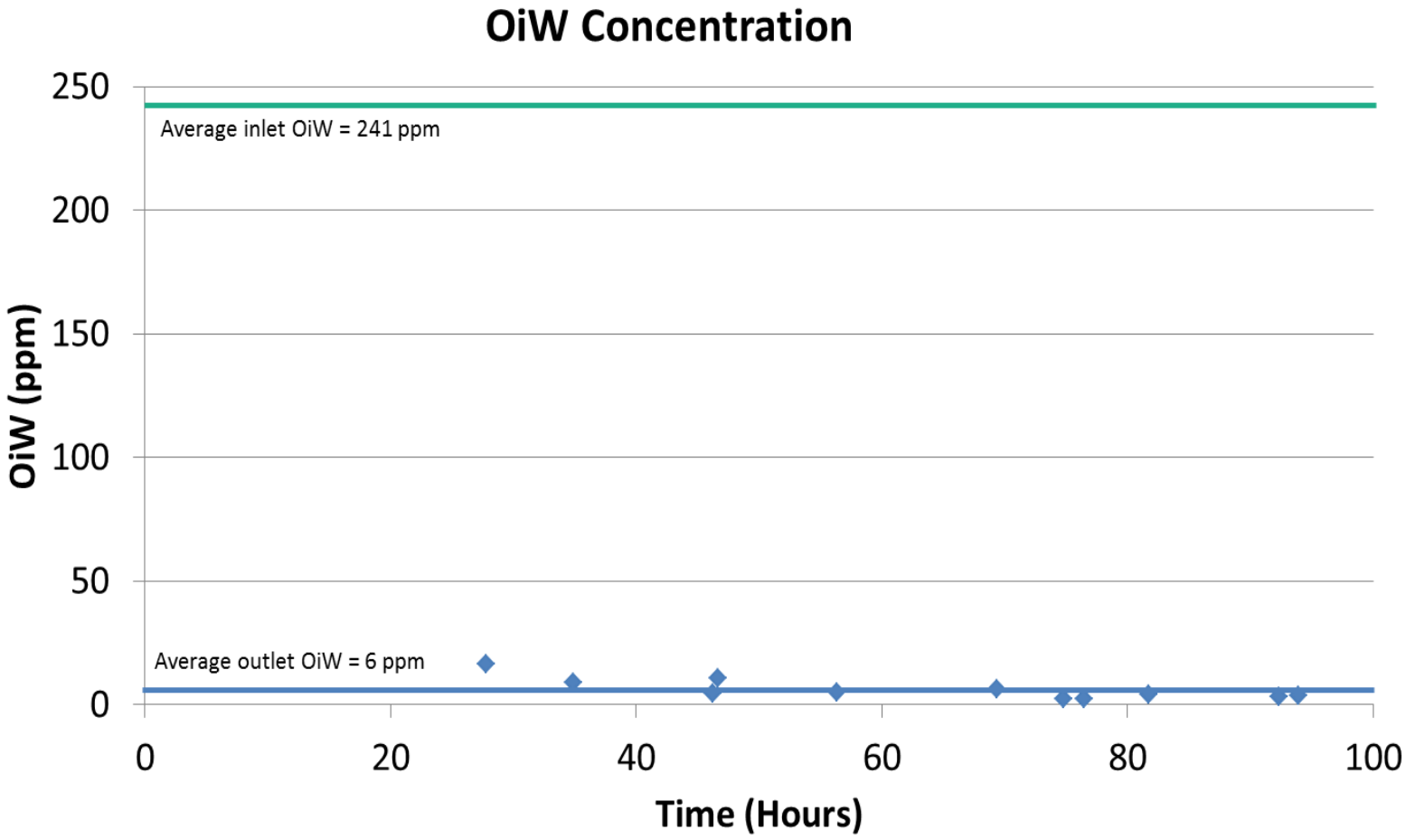
Test Conditions

- Temperature = 70ºC
- Flux = 24.4 $m^3/hr/m^2$
- Feed OiW = 241 ppm
- Feed polymer = 493 ppm
- Effluent OiW averaged 6.2 ppm
- 97% oil removal

The test lasted 3 backwash cycles

- Shows that our backwash system is effective at regenerating the media
- Also DP doesn't increase over time



2017 SNF – PerforMedia™ Media – Results

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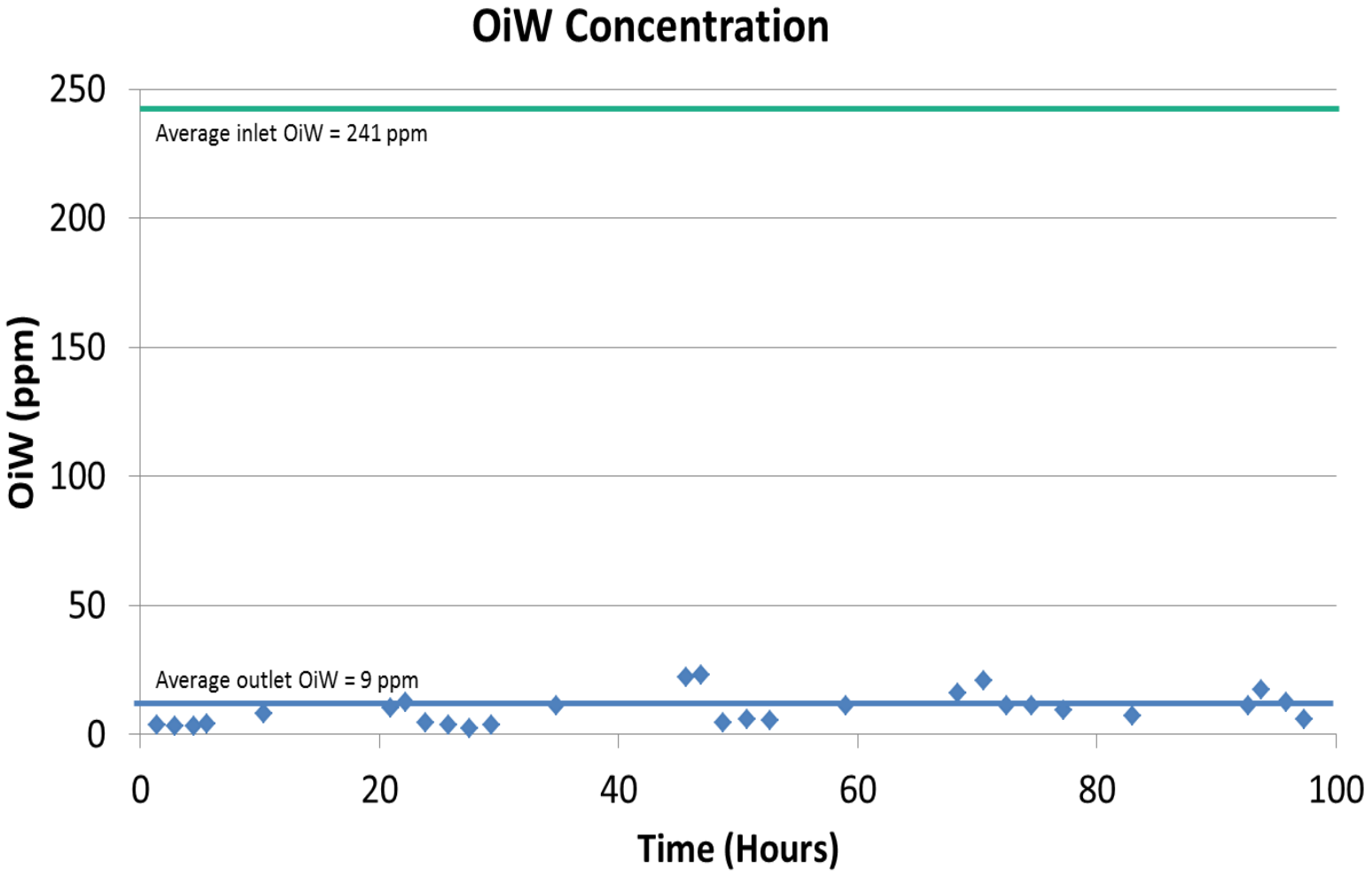
Test Conditions

- Flux = 30.5 $m^3/hr/m^2$
- Feed OiW = 241 ppm
- Feed polymer = 484 ppm
- Effluent OiW averaged 9.5 ppm
- 96% oil removal

Test lasted 3 backwash cycles



Going Forward

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Field Pilot Testing

- Actively searching for industry partners to complete a field pilot study
- Spring 2018 pilot at active polymer injection site in Europe
- We know there are things you can't simulate with a synthetic produced water
  - Polymer and chemicals
  - Suspended solids
  - Feed variability

Pilot Units Available

- Single 6" (15 cm) diameter vessel
  - ~100 BPD
  - ATEX Zone 1 rated, in Norway
- Dual 24" (61 cm) diameter vessel
  - ~2500 BPD Unit
  - Ex-proof only

Conclusions

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Unlike conventional produced water treatment technologies, PerforMedia™ media can be **highly efficient** at treating produced water from Polymer Flood applications.

PerforMedia™ media can operate in the presence of viscous polymer at industry accepted flux while:

- Removing 500 ppm of OiW in the feed to <10 ppm of OiW in the effluent
- Not consuming any chemicals
- Regenerable media
- Recovers >95% of viscosity during treatment

Effluent is a good candidate for re-injection

- Low concentration of OiW/TSS
- Minimal make-up polymer would be required for re-injection

Thanks For Your Attention – Questions?

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