Task 5. Treatment Train for Reusing and Recycling Produced Water

Task proposed by The Produced Water Society

The Produced Water Society (PWS) is taking the lead to standardize water-quality specifications for treated produced water and your team is invited to become part of this ground-breaking effort. The PWS seeks to establish a standard for "clean brine" (CB), that has a dependable chemistry and is suitable for reuse in fracturing fluids[1]. By standardizing CB chemistry, produced water (PW) production costs can be greatly reduced, leading to increased reuse of PW[2].

Two significant environmental results will be 1) conserving fresh and brackish groundwater and 2) reducing the volume of saltwater being disposed in deep-injection wells that may contribute to induced seismicity[1].

Background

In conventional oil production, oil is pumped from permeable rock formations, such as sandstones. The permeable layers allow the oil to flow through the formation to the well bore to be recovered. The sands are termed a 'conventional play.' (A 'play' is a geologic formation that is producing hydrocarbons oil and gas.) In recent years, oil companies have expanded their efforts to recovering hydrocarbons in geologic formations that have low permeability, such as shale. Known as unconventional plays, these require horizontal drilling and hydraulic fracturing of the shale to create high-surface-area flow paths that will allow the hydrocarbons to flow to the well bore.

Hydraulic fracturing technology requires large quantities of water for the fracturing fluids and also generates huge quantities of byproduct water. These waters are from flowback of the fracturing fluids as well as from connate water (water that was trapped in the rock prior to drilling). Since flowback and connate waters are often combined in the field, we group them together in the term 'produced water.'

Companies known as water midstream companies have installed pipelines to gather PW from producing plays. Depending on the situation, they either deliver the water to disposal wells, or they treat the water and sell it back to the oil companies to reuse in hydrofracturing operations. Currently, with no standardization for CB, each oil company that purchases PW from the water midstream companies sets unique water-quality specifications. This requires the midstream companies to specialize their treatment processes to meet a myriad of specifications. Each new set of specifications limits the scale of operations for treatment, driving up costs and therefore limiting reuse of the waters, since it is often cheaper in the short run to use fresh groundwater.

Standardizing CB specifications will allow water midstream companies to treat PW at greater scale and, more significantly, they will be able to share CB across their pipeline systems. This reduces the need for costly storage ponds that not only have a large footprint, but often require a greater level of treatment to adjust for natural water quality degradation in the ponds. Hence, establishing a standard for CB will reduce capital costs, production costs, storage costs, and environmental footprint for PW. The PWS has drawn up specification guidelines as a first step toward standardization. The guidelines will be used in this task. See Appendix I for more information about PW.

Treatment Train

This task calls for a treatment train to produce CB of a specific chemistry. A "train" refers to a process in series (that may involve multiple unit operations) that can be replicated. Thus, if one treatment train treats 20,000 bbls per day of produced water, then five trains combined can treat 100,000 bbls per day.

The task targets a 20,000 bbl/day treatment rate that can be duplicated to achieve a 100K bbl/day treatment rate because there is much potential for innovation at the 20K bbl/day rate. However, if a team identifies innovative ways to directly treat the PW at a rate of 100K bbl/day, they may do so. Your team is given the choice of approaches and is encouraged to think out of the box to explore new ways of treating 100,000 bbl/day.

Task 5. Produced Water Treatment Train

Problem statement
Your team will research, evaluate, and design an innovative treatment process for producing clean brine from produced water to the specification guidelines listed by the Produced Water Society (see Table 1).

The goal is to develop a treatment process that meets the proposed standards with a practical, low cost, small footprint solution that can treat 20,000 bbl/day (times five) or 100,000 bbls per day, when utilized for larger-scale treatment.

Design requirements
Your proposed design should provide specific details and outcomes as follows:

- Design a treatment train for producing clean brine from produced water (specification guidelines in Table 1).
- Include a Process Flow Diagram (PFD) for the selected treatment processes. The PFD must include mass and energy balances (input and output rates, reactants, and reaction rates, etc., as applicable).
- Estimate the capital expenses (CAPEX) to construct a full-scale water treatment train using your selected water-treatment technology either 1) for a treatment train that treats a minimum of 20,000 bbls per day of produced water, with scale-up to 100,000 bbls/day or 2) directly treats 100,000 bbl/day. This includes, but is not limited to, equipment, pipes, pumps, etc. Do not include costs of buildings and appurtenances to the treatment train.
- Estimate the operating expenses (OPEX) (calculated as $/m^3 of clean brine produced) to treat this water (per 20,000/bbl train on an annual basis, including, but not limited to, any consumables (chemicals, sacrificial components, etc.) that may be used, solids disposal costs ($50/ton), energy requirements assuming an industrial electricity rate of $0.09/kWh, and labor rate of $70/hr.
- Determine the footprint required for the full-scale treatment operation.
- Identify and address the fate of any waste products generated by the PW treatment technology.
- Address any intangible benefits of the selected treatment process.
- Discuss your plan's adherence to appropriate federal (USA), state and local laws and regulations. Attend WERC's webinar for helpful tips for addressing regulatory issues. (See website or email us for webinar info.)
- Include a Public Involvement Plan, as applicable (see Team Manual).
- Document success in improving energy efficiency, pollution prevention, and/or waste minimization, as it applies to your project to qualify for the P2E2 Award. Place this in a separate section of the report.
- Address safety aspects of handling the raw produced water and any final products. Safety issues should be addressed in both the written report and the Experimental Safety Plan (ESP). Be sure to attend WERC's webinar for helpful tips for addressing health and safety issues.

Table 1. Common Clean Brine Minimum Specification for Reusing Recycled Produced Water[1,3].

Parameter	**Minimum Specification**
Salinity	Reported after treatment
pH	6.0-8.0
Oxidation reduction potential (ORP)	>350 mV
Turbidity	<5 mg/L (approx. 25 NTU)
Oil	<30 ppm – no sheen
Hydrogen sulfide (H_2S)	Non-detectable
Particle size	Filter <25 micron

Bench Scale Demonstration
Bench-scale demonstrations will serve to illustrate the design considerations listed above. The bench-scale unit should demonstrate a continuous process that can be scaled up to a plant that treats 100,000 bbls per day of produced water.

The bench-scale demonstration, shall include a synthetic solution of produced water of chemistry given in Table 2. The constituents of the synthetic solution are typical for a sample of produced water from the Delaware Shale play.

At the contest, each team will be provided with 18 liters (5-gallon container) of synthetic solution to work with during the bench-scale demonstration. It is not expected that you will use the entire amount of the solution during the contest bench-scale demonstration. After treatment, your team will submit two liters of treated solution for analysis.

To prepare samples for preliminary testing at your campus, follow these steps to make 1 Liter of synthetic produced water using the chemistry from Table 2, below.

1. Use a wide-mouth, semi-transparent polyethylene or polypropylene container.
2. Mix together water phase.
3. Mix together oil phase.
4. Add solids to water phase.
5. Add oil phase to water phase and gently mix.
6. Top off with DI water to make 1.0 L.
7. Just before use, use a homogenizer/mixer to generate small droplets of the oil phase.

Note: Although disinfection is usually an essential pre-treatment step, it will be disregarded for the contest.

Table 2. The bench-scale apparatus shall treat water of the following chemistry[4]

Water phase	**Amount per liter of synthetic solution**
DI water	750 mL
Sea Salt	120 g
Oil phase	**Amount per liter of synthetic solution**
TrueSyn 200 I*, ***	92 mg
Xylene	4 mg
Hexadecane	4 mg
Solid phase	**Amount per liter of synthetic solution**
Fine-grade Arizona Test Dust (Medium Grade)**, ***	50 mg
Sodium Bentonite Drilling Clay (AquaGel by Baroid Industrial Drilling)***	50 mg

**Sourcing Option: RB Products will ship to you and* charge for shipping only. Contact micah@rbproductsinc.com
***Sourcing Option: Powder Technologies Inc. offers 4 kg for $80. Contact: levi@powdertechnologyinc.com*
**** Contact WERC–we will gladly ship these items to you. They ordinarily come in industrial quantities.*

Contest Analytical Testing Techniques

At the contest, the parameters will be individually evaluated as indicated below.

a) ***Salinity*** —refractometer

b) ***pH*** — pH meter

c) ***ORP***—ORP probe

d) ***Turbidity***—light transmittance probe measuring NTU (nephelometric turbidity units).

e) ***Oil***—EPA Static Oil sheen test.

f) ***Particle size***– visual test for settled solids.

Samples will not be tested for H_2S (hydrogen sulfide), as it is not expected from the synthetic solution.

In addition to the bench-scale demonstration, teams may include video productions, computer simulations, tabletop displays, and scale or architectural models to assist in the presentation; these inclusions can be extremely beneficial to your presentation, but these shall not be substitutes for the bench-scale demonstration.

Technical Report Requirements

The written report should demonstrate your team's insight into the full scope of the issue and include all aspects of the problem and your proposed solution. The report will be evaluated for quality of writing, logic, organization, clarity, reason, and coherence. Standards for publications in technical journals apply.

In addition to the listed requirements, your report must address in detail the items highlighted in the Problem Statement, Design Considerations, Evaluation Criteria, and 2021 Team Manual. The required page formatting has changed this year—check the 2021 Team Manual for more information.

Evaluation Criteria

Each team is advised to read the 2021 Team Manual for a comprehensive understanding of the contest evaluation criteria. For a copy of the Team Manual, Public Involvement Plan, and other important resources, visit the WERC website:
https://iee.nmsu.edu/outreach/events/international-environmental-design-contest/guidelines/.

Additionally, your proposed solution will be evaluated on the following:

- Technical fundamentals, performance, safety and other issues stated in the problem statement
- Potential for real-life implementation
- Thoroughness and quality of the economic analysis
- Originality, innovation, functionality, ease of use, maintainability, reliability, and affordability of the design
- How well the bench-scale represents your full-scale design concept
- The quality of the treated water.
- The process train will be evaluated for treatment rate and efficiency
- Other specific evaluation criteria may be provided at a later date (watch the FAQs).

FAQs/Deadlines

- Teams are expected to watch for FAQs online for any updates in the task requirements. (wercdesigncontest.nmsu.edu)
- Mid-January: WERC will ship any materials that are too difficult to purchase in lab-scale quantities.
- Due 1 February 2021: Experimental Safety Plan (ESP).
- Due 29 March 2021: Written Report.

References

[1] A Common Clean Brine Specification for Reusing Recycled Produced Water – Draft Guidelines, June 2020. Accessed 8/26/2020: https://www.producedwatersociety.com/

[2] Will Water Issues Constrain Oil and Gas Production in the U.S.? Bridget R. Scanlon*, Svetlana Ikonnikova, Qian Yang, and Robert C. Reedy *Environ. Sci. Technol.* 2020, 54, 6, 3510–3519

[3] Trading Water at Terminals, Aaron D. Horn, Shale Play Water Management, Nov-Dec 2019. (Accessed 8/6/2020: https://www.shaleplaywatermanagement.com/trading-at-water-terminals)

[4] Produced Water, Volumes I and 2, John M. Walsh, Petro Water Technology, 2019.

Awards

Each year, the WERC Environmental Design Contest and its sponsors award more than $25,000 in cash prizes. Successful completion of every stage of the design project qualifies each team for the following awards.

1. Full task awards (First, Second, Third Place; minimum amounts: $2500-$1000-$500, respectively).
2. Virtual Desktop Study Awards (awarded independently of the full bench-scale designs). Amounts TBA.
3. WERC Resources Center Pollution Prevention/Energy Efficiency Award ($1000)
4. Judges' Choice Award ($500)
5. Peer Award ($250)
6. Terry McManus Outstanding Student Award. ($500-$1000, according to funding).
7. Additional awards may be announced later.

Award amounts listed are minimum amounts and may increase with available funding.

Detailed criteria for each award: https://iee.nmsu.edu/outreach/events/international-environmental-design-contest/guidelines/

Appendices

Appendix I–Produced Water in Oilfield Applications.

Hydrocarbon production from unconventional formations (those that require horizontal drilling and hydraulic fracturing technology) uses large quantities of water and generates huge quantities of byproduct water. The byproduct waters are from two distinct sources: 1) Flowback waters are the initial waters that come back to the surface within 3-4 weeks after a well is producing. These largely consist of the water used for hydrofracturing. They have a complex fracking chemistry and are loaded with shale fines. 2) Connate waters. After 3-4 weeks, most of the water coming up is connate water (water trapped in the rock formation before drilling). Connate waters contain hydrocarbons and fines, but they are less complex and simpler to treat than flowback waters.

When shale plays were first under development, most of these waters were disposed of in UIC Class II saltwater disposal (SWD) wells[1], but early in the shale boom, PW recycling was widely adopted in the Marcellus and Utica plays due to the high cost of transporting PW to disposal wells in Ohio and West Virginia. The practice of PW recycling has been gradually adopted in the largest shale plays: The Midland and Delaware portions of the Permian Basin. There has been very limited PW recycling in other shale plays.

As treatment technologies have improved and scales of operation have grown, it is now often more cost effective to recycle PW than to dispose of it in SWD wells. Improvements such as the development of salt-tolerant fracking chemistry packages has facilitated this change, allowing for the recycling of PW as make-up water for fracturing fluids. Presently, produced water volumes are 200-400% in excess of the annual completion source-water demand in the Delaware portion of the Permian Basin, offering significant opportunity for reuse.

Appendix II—Discussion of Parameters

a) ***Salinity*** —The salinity of CB may vary throughout the unconventional play and can fluctuate in individual wells over the course of their productive lives. In industry, companies are expected to report salinity, but not alter it. For the contest, teams are expected to measure and report salinity values, but treatment processes should not significantly alter initial salinity.

b) ***pH***—The pH parameter can be measured with pH probes.

c) ***ORP***—ORP is a valuable parameter that can be measured with probes. Water with ORP >350 mV should be relatively free of bacteria. This level of ORP should oxidize any dissolved iron to the ferric state, which will precipitate.

d) ***Turbidity***—Measurement of turbidity can be performed with a line light transmittance probe measuring NTU (nephelometric turbidity units). Turbidity is a measure used to determine the level of total suspended solids (TSS). Turbidity does not give any indication of particle size. Large particles would need to be captured in 25-micron solids filters at the point where the CB is transferred to the sales line.

e) ***Oil***—It is in the water treater's interest to capture as much of the oil as possible that comes into their treatment facility, as recovered oil is a revenue stream. Oil can be measured on-line with fluorescence technology, but this is an expensive instrument and must be calibrated when there is any change in source water.

The Static Sheen Test (EPA Method 1617) is adequate for this contest. The 30-ppm oil limit intends to avoid oil sheens on CB storage ponds receiving this water because free-phase oil sheens would require expensive bird protection measures around ponds.

f) ***H_2S***—Operators will not accept CB waters with detectable H_2S. This parameter poses significant risk to personnel, as well as a corrosion risk for facilities. Any hydrogen sulfide in excess of 1 ppm above the water phase will easily be detected by the treatment team. Since this is a bench-top competition, hydrogen sulfide is not expected, but can develop in actual produced waters that are not treated with a biocide. WERC will not test for H_2S at the contest.

g) ***Particle size***—Particle size can be measured with on-line laser spectroscopy, which are expensive instruments. A low-cost and practical approach is to use a Millipore test. For the contest, it is unacceptable to have particles large enough to sink to the bottom of the treated CB. Each team's CB will be allowed to sit overnight to ensure that no large particles precipitate.