Task 5. Produced Water: Rare-Earth Element Recovery and Clean Water Production

Task proposed by Los Alamos National Laboratory

Task Sponsored by NGL Water Solutions, LLC

Background
Rare earth elements (REE) are critical materials for numerous technologies including consumer electronics, automotive, energy, and defense [1]. Typically, REE-rich ores are mined and processed to obtain REEs. Given the scarcity of concentrated REE-rich ore mines, alternate sources are explored for obtaining them.

Produced waters from unconventional oil and gas resources and carbon sequestration operations, as well as natural and industrial aqueous streams, including waters from coal mine drainage and coal fly ash leachate, are also attractive potential sources for REE production. Given the large volume of produced and industrial waste water in the US alone (e.g. 21.2 billion bbl. of produced water generated from oil and gas operations in 2012 [2]), energy-efficient treatment of produced water for clean water generation and for recovering critical materials, including REE recovery, is a highly active research area.

Historically, the produced water is disposed of, without consideration of beneficial reuse of the water, but as water becomes scarce and the cost of disposal increases, beneficial reuse of the produced water is becoming economically feasible and environmentally responsible.

A number of rare earth elements can be found in produced water in the U.S. Wyoming oil and gas basins, including lanthanum, neodymium, and europium. In addition, quantities of REEs are predicted in the Permian Basin. Concentrations of REEs found in produced water are typically an order of magnitude higher than those found in the world's oceans, sometimes reaching 1000x that of sea water. Europium is found in the highest concentrations [3]. The concentration of REE in produced water varies depending on the source and can range from ppt to ppm levels. This low concentration of REE makes their recovery a significant challenge. In addition, the stream salinity, pH, and presence of organic and inorganic materials and solids further complicates the treatment process.

Problem statement
Your team will research, evaluate, and design an energy-efficient treatment system to produce clean water while optimizing the collection of rare earth elements from produced water recovered from oil and gas operations. From the produced water, your process should achieve high recovery of the rare-earth elements (minimum 70%) and deliver clean water that meets drinking water standards (500 mg/L concentration of total dissolved solids).

The goals of the designed system are to develop a treatment system that is practical, cost effective, and able to accommodate flow rates of 2000 gallons per day in the full-scale model.

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Design requirements

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

- Design a water-treatment process that will recover a minimum of 70% REEs from the produced water. The REEs should be separated into their individual elements: Eu, La, and Nd,
- Deliver clean water that meets drinking water standards of 500 mg/L total dissolved solids.
- Estimate the capital to construct a full-scale water treatment plant using your selected water-treatment process for a base-case plant that treats 2000 gallons per day of produced water.
- Estimate the operating cost (calculated as $\$/m^3$ of clean water produced) to treat this water on an annual basis. The cost should be adjusted assuming market value of the REE recovered.
- The REE removal process should be effective in the presence of common produced water constituents or methods, and the cost of produced water pre-treatment should be included.
- Address the chemical mechanisms for removing REE. Provide a Process Flow Diagram (PFD) for the selected treatment process.
- Address all intermediate products or wastes generated by your REE removal process. For example, if you choose an adsorption media to remove REEs, address potential regeneration of the adsorption media and methods for recovering the residual product. If the media cannot be reused, provide cost for disposal and replacement.
- Address any intangible benefits of the selected treatment process.
- 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).

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 base-case plant that treats 2000 gallons per day of produced water, given a synthetic produced water solution.

All testing, as well as the bench-scale demonstration, shall include water of chemistry given in the table below. The constituents of the synthetic solution are typical for a sample of produced water from oil and gas operations.

Each team will be provided with 18 liters (5-gallon container) of the synthetic solution to work with during the bench-scale demonstration. Note that this is far more solution than you should need to run your experiment. After treatment, your team will submit 100 mL of treated solution for analysis.

Analyte	**Amount** (mg/L)*
Humic acid as sodium salt (CAS 68131-04-4)	200*
NaCl	127,000
$MgCl_2$	1,550
KCl	500
Na_2SiO_3	26,100
Na_2SO_4	1,500
$CaCO_3$	1,800
$FeCl_3$	150
Neodymium (Nd) as $NdCl_3$	1
Lanthanum (La) as $LaCl_3$	1
Europium ($EuCl_3$)	1

* Quantity may change slightly (watch for FAQs)

Analytical Testing Techniques

- Inductively coupled plasma - mass spectroscopy (ICP-MS) to determine REEs.
- If needed to dissolve REEs, acid microwave digestion will precede the ICP-MS.
- Electrical Conductivity and Total Organic Carbon to assess water quality.

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 shall not be substitutes for the bench-scale demonstration.

Written 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, organization, clarity, reasoning, 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, and Evaluation Criteria.

Evaluation Criteria

Each team is advised to read the Participation Guide for a comprehensive understanding of the contest evaluation criteria. For a copy of the Public Involvement Plan, Participation Guide, 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 proposed technology
- How well the bench-scale represents your full-scale design concept
- The quality of your treated water. The bench-scale processed water will be evaluated for treated water volume, separation efficiency, and time to process
- Other specific evaluation criteria may be provided at a later date (watch the FAQs).

FAQs/Deadlines

- Teams are expected to watch for FAQs related to this task for any updates in the task requirements.
- The Experimental Safety Plan (ESP) is due 24 February, 2020.
- Written Report due 23 March, 2020.

References

[1] Steven Chu, Critical Materials Strategy, US Department of Energy, 2011.
Available: https://archive.org/details/bub_gb_IFrj-IPPvmcC/page/n3. [Accessed 15 August 2019].

[2] US Produced water volumes and management practices in 2012.
http://www.gwpc.org/sites/default/files/Produced%20Water%20Report%202014-GWPC_0.pdf.
[Accessed 15 August 2019].

[3] Quillinan, et al., Assessing rare earth element concentrations in geothermal and oil and gas produced waters: A potential domestic source of strategic mineral commodities, Final Report to U.S. Department of Energy, Geothermal Technologies Office. 2018.
[Accessed 10/01/19 via: https://gdr.openei.org/submissions/960]

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. Task awards (First, Second, Third Place; minimum amounts: $2500-$1000-$500, respectively).
2. Freeport-McMoRan Innovation in Sustainability Award ($2500)
3. WERC Resources Center Pollution Prevention/Energy Efficiency Award ($500)
4. Judges' Choice Award ($500)
5. Peer Award ($250)
6. Terry McManus Outstanding Student Award. (Minimum: $500, according to funding).

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/

NGL Water Solutions