Water Remediation by Freeze Crystallization

Initial design of freeze, wash and melt units

Overview

The long term goal of this project is to design and build a pilot scale freeze crystallization system for concentration of industrial and agricultural waste water. The full scale system is envisioned to be a stand-alone containerized package that can provide site specific remediation for a wide variety of water streams. The system will produce a water stream of acceptable quality for direct disposal to the environment and a relatively small volume of waste for disposal in an appropriate waste disposal facility. This project will give students experience in process and plant design that will be of use to them in any later industrial career.

Previous student teams have searched the literature for useful data, created a draft process flow diagram, and identified open questions that must be resolved experimentally to establish a firm basis for the mass and energy balances that are necessary for estimating the energy and economic efficiency of the system. The challenges for the 2017-2018 academic year are to (1) design and perform the critical experiments, (2) design the freeze, wash, and melt units, and (3) estimate the costs of building and operating a full scale system. Completion of these goals will require several students working on teams. A minimum of two students will be needed to make useful progress.

Background

In the 1960's H.F. Wiegandt and other members of the Cornell Chemical Engineering Faculty proposed a method of producing potable water from brine, specifically sea water, by the production of ice crystals via direct contact with an expanding refrigerant. As water freezes, dissolved materials are excluded from the crystal lattice leaving a fairly pure water crystal. When the crystals are washed and melted a very low salt content water suitable for human consumption is produced. Wiegandt and his colleagues felt that this could be very competitive with then commonly used flash evaporation method for producing low salt content water from brine in part because producing ice requires significantly less energy than the production of steam.

At present, low ion content water is produced from brines by either multi-stage flash evaporation or reverse osmosis. These methods are poorly suited to the concentration of water streams derived from agricultural or industrial waste water streams. Critical problems for flash evaporation are surface fouling caused by both ionic and non-ionic materials in the water streams and the cost of specialty steels required for corrosion resistance in evaporation systems. Critical problems for reverse osmosis systems are the high osmotic pressures of concentrated ions and the cost of cleaning chemicals and replacement membranes. These problems make conventional approaches infeasible for many kinds of water and in many parts of the world. Freeze concentration may be an attractive alternative.

A significant number of publications on freeze concentration, including much of Wiegandt's work, has been collected and will be made available to students working on this project.

Streams of interest include but are not limited to:

- Sea water
- Crop surface run-off
- Animal Farm waste
- Dairy product and other food processing waste

- Strip mine run-off
- Stack scrubber effluent
- Various kinds of chemical plant waste water
- Hydraulic fracturing return water

Scope of Work

Our intention is to ultimately produce a feasibility study of this process including the design of a pilot scale system and an estimate of capital and operating costs for various water streams. The design will include a flow sheet, mass and energy balance, equipment sizing, equipment layout and detailed designs of the pilot scale freeze, wash and melt units.

We have identified shale gas flowback and produced water as an initial target feed stream because the concentrations of dissolved contaminants are very challenging and there is both social and economic value in developing an alternative to current methods of handling the large volumes of waste water involved in shale gas production.

During the 2017-2018 academic year, the following projects are proposed:

1. Establish by experiment a feasible rate of ice mass production by direct contact with butane and the optimal temperature for production of smooth ice crystals without dendrites over a range of contaminant concentrations.
2. Establish by experiment a feasible washing process to remove contaminants from the ice surface prior to melting.
3. Design a pilot scale freezing unit and estimate the mass and energy balances for operating at pilot and full scale.
4. Design a pilot scale washing unit and estimate the mass and energy balances for operating at pilot and full scale.
5. Design a pilot scale melting unit and estimate the mass and energy balances for operating at pilot and full scale.

Whether all five of these tasks can be accomplished in the academic year depends on the number of students available. We expect two students will be needed for tasks 1 and 2 and at least one additional student for each of tasks 3, 4 and 5.

Schedule

This work is expected to require two semesters to complete, and ideally, a team of several people for each of the five projects outlined above. The first task of each project team will be to evaluate the work load for the team and the individual members and to provide a milestone schedule based on their assessment of the scope of work.

Teams will meet weekly with the oversight committee and make formal progress presentations at each scheduled milestone.

Oversight Committee

M. A. Hurwitz
A. M. Center
Outside experts as available