An Integrated Supercritical System for Efficient Produced Water Treatment and Power Generation

Seyed A. Dastgheib*[1], Ali Ashraf[2], Hafiz Salih[1], Hong Lu[1], SungWoo Nam[2]

[1]Illinois State Geological Survey and [2]Department of Mechanical Science and Engineering, University of Illinois at Urbana-Champaign, Champaign, IL, USA

*seyed@Illinois.edu

Introduction and Background

Water-Energy Nexus in Fossil Fuel Energy

- Current U.S. electricity consumption is ~4 billion MWh and expected to increase ~20% by 2035 [1]
- About 39% of total freshwater in the U.S. withdrawn for the thermoelectric sector [2]
- CO_2 capture may increase the water demand of power generation (depending on the power generation technology) up to two times; climate change may further increase the water demand [3]
- New nontraditional water resources such as produced water may supplement the future water demand of the fossil fuel energy sector

Produced Water

- Produced water is the water from geological formations brought to the surface during fossil fuel production (i.e., oil, natural gas (NG), and coal) or extracted from deep formations used for CO_2 sequestration
- With the large-scale CO_2 sequestration in deep saline formations, large quantities of water can potentially be extracted or produced to manage formation pressure and increase storage capacity
- Produced water can be considered as a resource if it can be treated and transported in a cost-effective manner

Figure 1. Produced water from fossil fuel production and CO_2 Sequestration (potential brine extraction).

Produced Water Quality

- Total Dissolved Solids (TDS) are in a wide range of <1,000 ppm to >200,000 ppm. Salinity mainly from NaCl but other major and trace species also exist [4]
- Significant organic impurities (suspended, colloidal, and dissolved aromatic and aliphatic species) exist in oilfield brines
- TDS of produced water from CO_2 sequestration can be as high as ~200,000 ppm

Produced Water Treatment

Pre-treatment to remove:
- Residual oil
- Dissolved organics
- Suspended solids
- Scale-forming species

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Desalination or the main treatment:
- Reverse osmosis RO (TDS < 50,000 ppm)
- Thermal distillation systems
- Crystallization for zero-liquid discharge (ZLD)
- Others

Louden and Sugar Creek

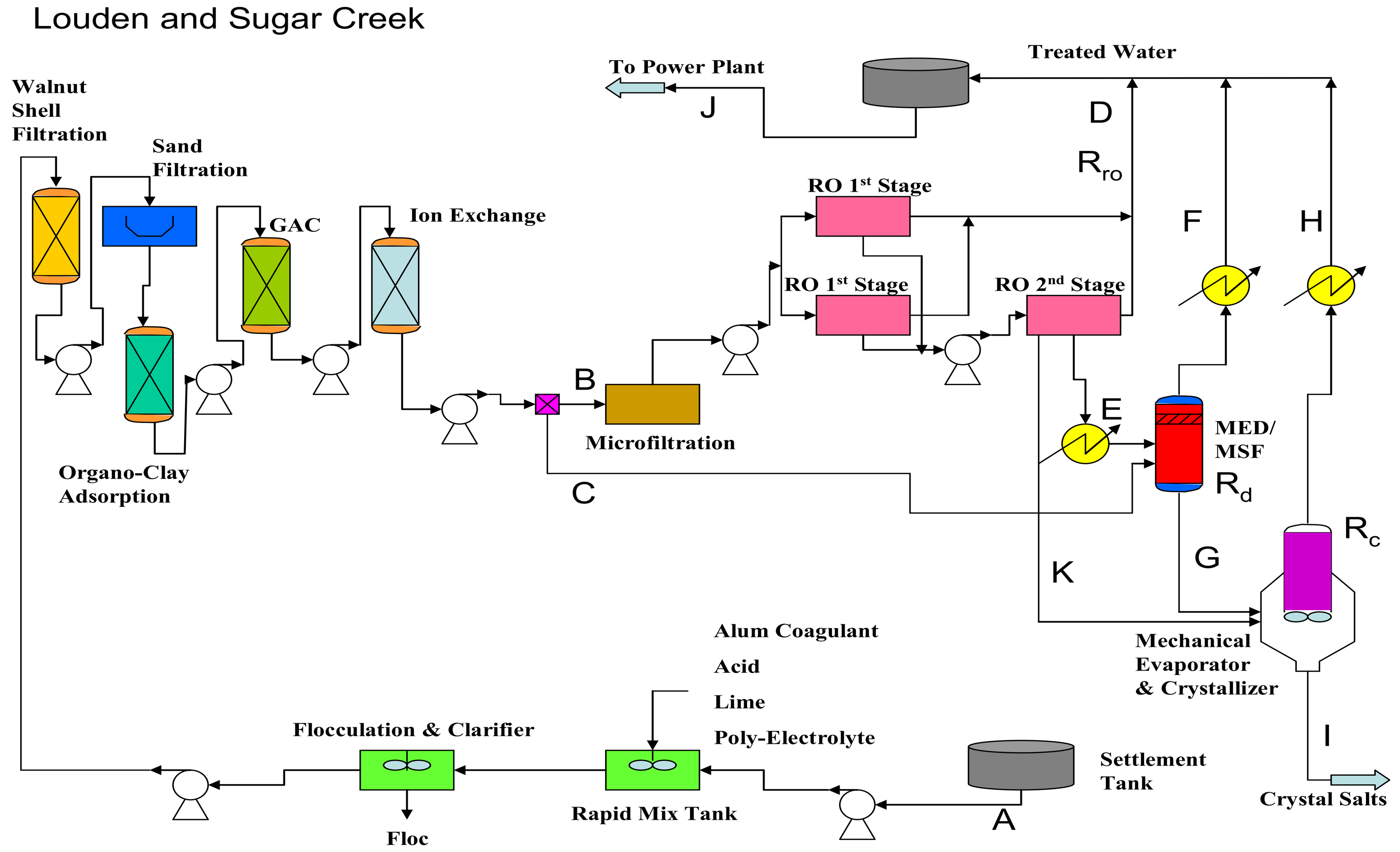

Figure 2. An example of a process for produced water treatment by conventional technologies ([4]).

Project Objectives

Evaluate feasibility of an integrated, supercritical (SC) cogeneration system for cost-effective treatment of produced water from CO_2 sequestration, oilfields, and CBM recovery

Significance and Outcome

- A potential transformative concept for treatment of concentrated brine in a ZLD plant
- Simultaneous water purification and power generation by an integrated SC system using coal or NG as energy source and produced water as the water source
- Higher energy efficiency for treatment of concentrated brine or water-power cogeneration
- Potential of the recovery of valuable minerals

Challenges of High-TDS Produced Water Treatment

- Desalination of brines with TDS > 50,000 ppm by RO needs a huge pressure, far beyond the practical RO limit, to overcome the osmotic pressure
- Current distillation desalination technologies are designed for seawater treatment and are not suitable for high-TDS desalination
- Current technologies are less effective for pretreatment (softening) of high-TDS brine
- Available practical option includes crystallization (for ZLD) at a very high cost. Evaporations ponds cannot produce freshwater and have several issues (e.g., land availability, suitable climate …)
- Emerging technologies such as membrane distillation (MD) and forward osmosis (FO) need to be significantly improved to resolve issues, such as low permeate water flux, weak membrane performance, availability of large volumes of low-TDS water (for FO), membrane clogging by salt crystallization, and generation of more concentrated brine streams (for MD)
- New energy-efficient and cost-effective concepts to purify high-salinity produced water and achieve ZLD are needed

Proposed Integrated Cogeneration System

- Pretreatment → Salt Precipitation at Supercritical Conditions → Steam Polishing → Power Generation → Pure Water Production
- Integration of water treatment and power generation
- SC steam should be polished without condensation and significant energy loss
- Utilization of SC steam for power generation is possible by the proposed approach

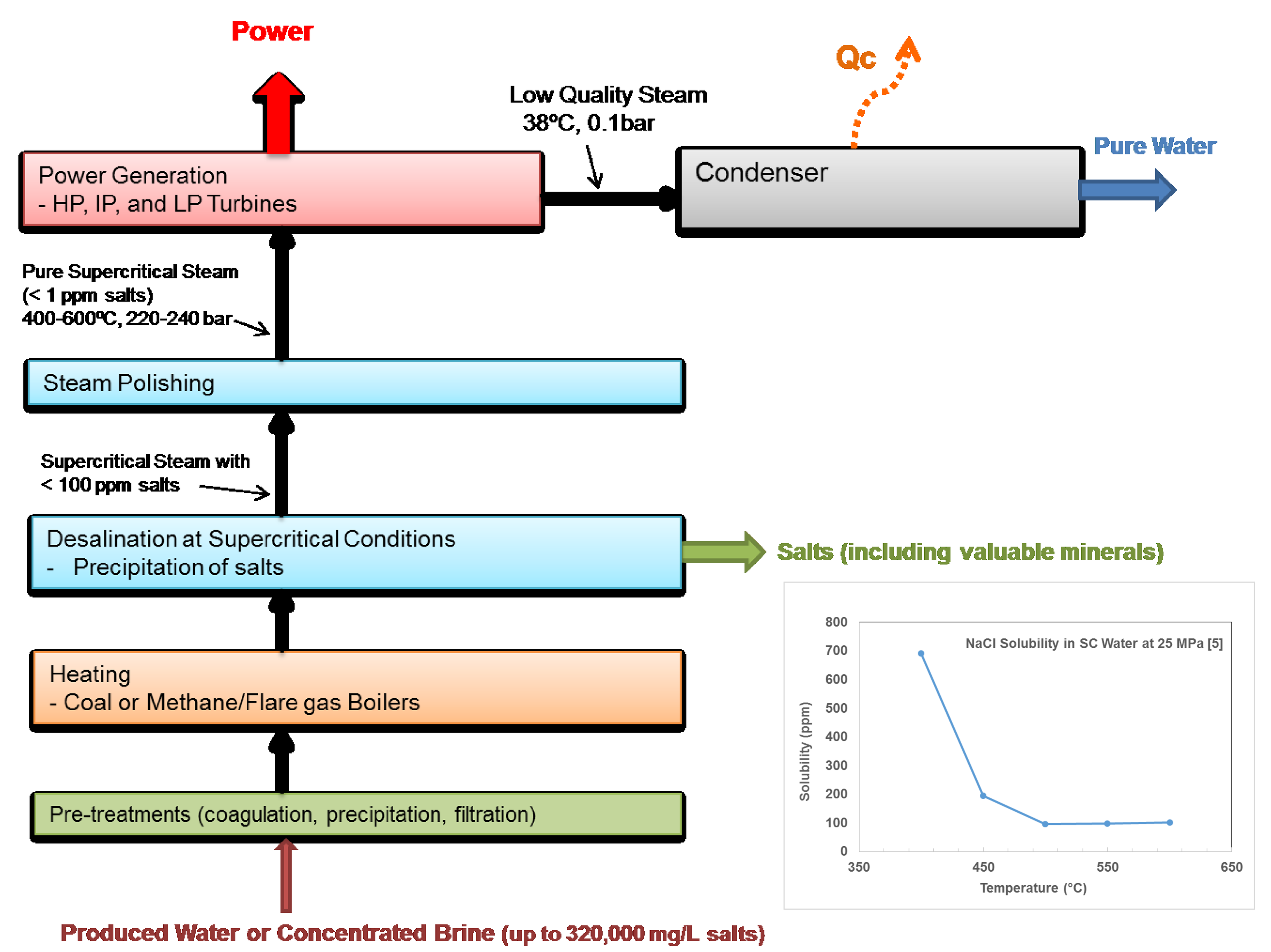

Figure 3. Conceptual diagram of the proposed integrated system for produced water treatment and power generation.

Project Tasks

- Process simulation and techno-economic evaluation
- Design, assembly, and baseline testing of the SC salt precipitation system
- Design, assembly, and baseline testing of the SC steam polishing system
- Development and characterization of advanced materials for the steam purification system
- Pretreatment, desalination, and purification of produced water samples from oilfields, coal-bed methane recovery, and CO_2 sequestration

Results

Process Simulation

- Changed the closed-loop SC steam cycle to an open-loop system (saline water in and condensed pure water out)
- Added SC salt desalination reactor to absorb heat from the boiler
- Highly pure SC steam is sent to turbines to generate power
- Efficiency of the proposed process is only slightly lower than the baseline case
- If a conventional closed-loop cooling system is used, proposed process with saline water input (3% salt) can produce ~5,500 gpm pure water
- Can provide all water needs of the process and generate additional ~1,300 gpm pure water

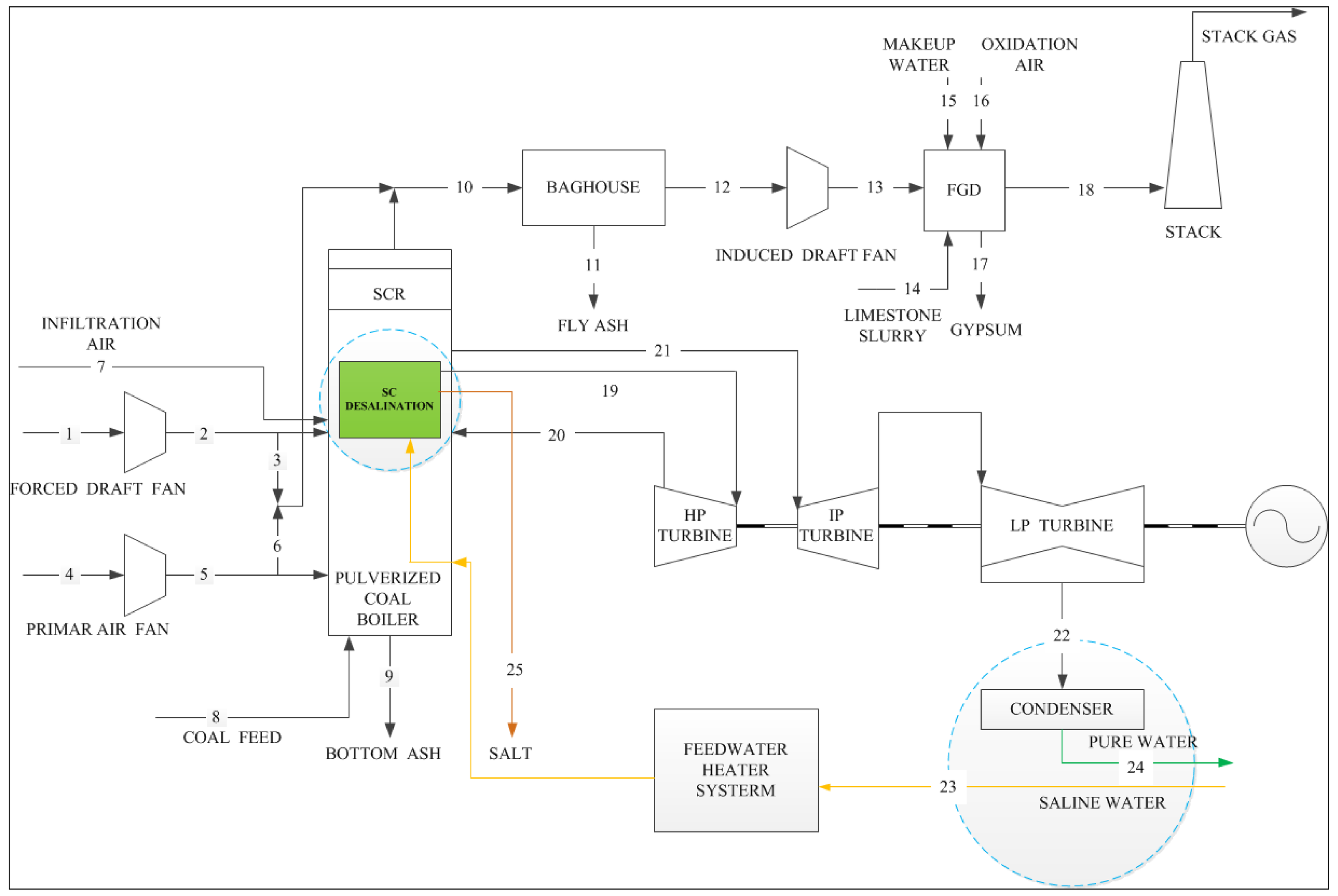

Figure 4. Baseline SC coal steam cycle (Case 11 of [6], modified to an open loop system with saline water as the water source.

Development of Materials and Experimental Systems

- Work is in progress to design and fabricate a SC desalination system
- Advanced carbon membranes are being developed
- A techno-economic analysis is in progress to evaluate the cost-effectiveness of the proposed system

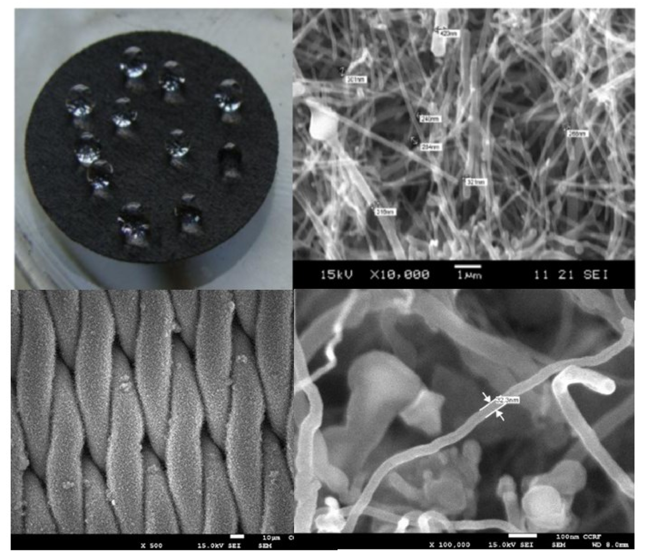

Figure 5. Examples of developed carbon membranes.

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