A Transformative Approach Towards Produced Water: Ensuring a Safe and Sustainable Energy Future

Hearing on"The Energy Water Nexus: Drier Watts and Cheaper Drops"
Subcommittee on Energy
House Committee on Science, Space, and Technology
March 7th, 2019

Raman P. Singh, Ph.D.
Oklahoma State University

Vision

Oil and natural gas production offers significant benefit through job creation, energy for economic and social development, tax revenue, and energy security. Despite environmental challenges in production and utilization, fossil fuels continue to serve as a critical source of energy for the nation and the world. For example, in 2017, 65.8% of the energy consumed in the United States came from such sources. Furthermore, new discoveries continue to revise upwards the estimates of proven reserves. For example, as recently as December 2018, the USGS reported that the Permian Basin's Wolfcamp shale and Bone Spring formation hold the "largest potential oil and gas resources ever discovered." This trend is not going away in the foreseeable future. However, the mitigation of associated hazards, such as induced earthquakes, freshwater consumption, potential contamination of aquifers due to reinjection, and management of greenhouse gases (GHG) such as CO_2 and CH_4, all continue to be a major obstacles.

A transformative approach to the use of water in unconventional oil & gas production is critical to the continuation of the social and economic benefits of fossil fuels while ensuring safety and sustainability, as we transition to more renewable forms of energy. This testimony reflects the vision of a collaborative multi-university effort, led by Oklahoma State University, towards developing technologies that envision a transformative cradle-to-grave carbon- and water-neutral energy platform based on a sustainable fossil fuels future as the bridge to renewable energy. Three technological areas are presented below:

Enhanced Unconventional Recovery of Subsurface Fluids

Despite the significant growth in subsurface fluid recovery for energy production from unconventional resources, recovery factors are still estimated to be <10%. Increased recovery factors will directly reduce the environmental impact of hydrologic fracturing. Hydraulic fracturing, while well adapted and developed for recovery from unconventional oil and gas resources, is not the only way to break rock. Alternative schemes involving dynamic loading have been used in mining and other rock blasting applications, and have been demonstrated in the lab for shale. For hydraulic fracturing, the fracture patterns results from fluid-pressure driven cracking. These patterns depend on the rock fabric and in situ stresses, and cannot be directly controlled by the operator. Also, the pressure fields decay rapid out from the source location. To generate more rock stimulation using current hydraulic fracturing techniques requires high-pressures, use of a large amount of fracturing fluid, and fracturing at multiple sources. An alternative is to augment hydraulic fracturing by dynamic loading conditions. This approach can result in both increased recovered factors and reduce the amount of water needed for hydraulic fracturing.

Produced Water Desalination and Treatment

The reuse of produced water (PW), a by-product of the oil and gas extraction processes, can serve as an alternative water supply for irrigation and other uses. Typically 2–8 m^3 of PW is extracted per day throughout the lifetime of a well and annually, $2.4–3.2 \times 10^9$ m^3 of PW is generated in the United States. Treatment and any beneficial utilization of PW is challenging, as it includes oil, suspended solids, carcinogenic hydrocarbons, trace metals, in addition to a very high total dissolved solids (TDS) concentration ($\sim$5500–300,000 ppm).

Research thrusts are needed to develop a modular desalination systems to enable energy efficient purification of PW to different water quality levels with zero liquid discharge. The levels range from $<$3000 ppm TDS (similar to surface waters) by filtration to $<$300 ppm TDS (drinking water quality) by evaporation–condensation. A modular system is equally suited for centralized desalination with its advantage in economies of scale, and for decentralized systems, which could be scaled to meet local PW needs.

- Pre-treatment by electrocoagulation of PW for removal of metals, colloidal solids and particles, and soluble inorganic pollutants. Enhanced electronic conductivity of high TDS PW is an advantage in this case. We high surface area electrodes which are not limited by the formation of impermeable oxide film, e.g. electrodes made from submicron size powders of different materials. Establishing adequate electronic conductivity between the base-electrode surface and the particles is a key challenge.

- Develop ultra/nanofiltration membranes using alternative materials for desalination. These include low-cost ceramic membranes and laminar graphene oxide (GO) membranes supported over polymer/ceramic substrates.

- Desalination by evaporation followed by condensation involves phase change, and is energy intensive. This can be eased by the use of multi-effect humidification–dehumidification (HDH) approach using vortex tube for heating of dry air and cooling of humid air, and innovative technologies for enhancing evaporation kinetics and energy efficiency. Rapid drying fabrics made with hydrophobic–hydrophilic fibers can be developed to increase gas-liquid surface area to enhance evaporation kinetics.

Using Produced Water as an Alternative to Mining

The above treatment train for PW enables extraction of beneficial industrial chemicals and rare elements from the concentrate streams. The major constituents of PW include chlorides, sodium, calcium, and sulfates that are key feedstocks for the chlor-alkali industry and gypsum production. Trace elements include Li (30–130 mg/L), Sr (300–3000 mg/L) and Mg (80–1700 mg/L). Conventionally, Li is extracted from brines, slowly concentrated by wind and solar driven evaporation over 1–2 years. Competing ions such as Mg must be precipitated by the addition of CaO prior to precipitating the Li as Li_2CO_3 with a Li recovery of 50–70%. Use of various technique for PW desalination and treatment and aid in concentratrating the PW brines prior to Li precipitation. Using a rough estimate, at 50% recovery, we can extract 4500 Mt Li from PW, which exceeds the 3400 Mt imported by the US in 2017.

Challenges

The practical implications of these efforts necessitate an emphasis on engineering system development supported by fundamental science and discovery driven research to address gaps in fundamental knowledge and technology platforms. There are extremely high levels of trans-disciplinary complexity involved in developing and implementing these engineering systems. This necessitates a diverse interdisciplinary team of engineers and scientists working together to observe, understand, and model a multitude of physical phenomena that occur over a wide spectrum of time and length scales. In addition, multi-societal factors require a confluence of engineers, chemists, hydrologists, geologists, geophysicists, geomechanicians, social scientists, economists, legislators, and regulators. Furthermore, meaningful interactions are needed across a variety of stakeholders including universities, local governments, and industry.