Integration of Coal Energy Conversion with Aquifer-Based Carbon Sequestration

Approach to Electric Power Generation with Zero Matter Release to the Atmosphere

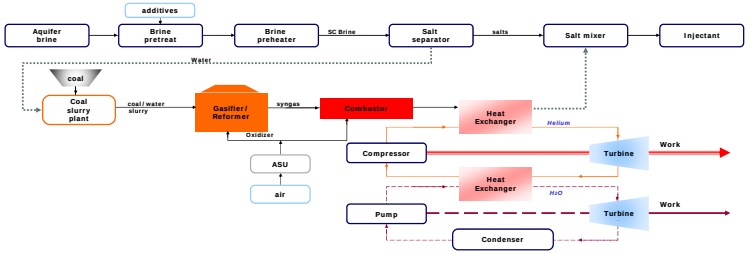
Reginald Mitchell and BumJick Kim, Mechanical Engineering Department, Stanford University

GCEP Global Climate & Energy Project STANFORD UNIVERSITY

Proposed System - The Concept

- Brine from an aquifer is preheated and desalinated before introduction into the system
- Preheated and desalinated water from the aquifer is combined with pulverized coal to form a dilute slurry
- The slurry is partially oxidized in a reformer maintained at supercritical water conditions, producing compounds that are miscible in supercritical water
- Inorganic solids are separated out of the system, carbonaceous solids are recycled to the reformer, the sythesis gas is passed to a combustor
- The synthesis gas is combined with the remaining oxidizer, completing the chemical-to-sensible energy conversion
- The hot combustor products are used to drive a heat engine that produces work, cooling the hot product stream in the process
- The product stream is cooled further via heat integration with the incoming brine
- The previously separated salts are reintroduced into the cooled product stream (or sold if there is commercial value for the salt)
- The cooled solution, a fully equilibrated, single-phase brine solution carbonated to just below CO_2 saturation conditions, is injected back into the aquifer

Proposed System - Aquifer-Based Conversion System Sheme



Why Coal Conversion in Supercritical Water?

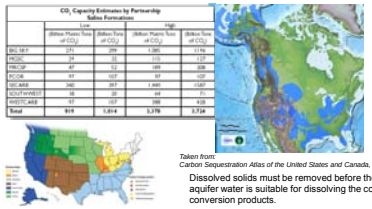
- Nonpolar organic compounds and oxygen are miscible in all proportions in water above its **critical point** (647.3 K, 220.9 bar) and many salts are insoluble. Consequently,

➢ Small polar and nonpolar organic compounds released during coal extraction and devolatilization are completely miscible in SCW.
➢ Large organic compounds released during coal devolatilization hydrolyze in SCW yielding H_2, CO, CO_2, and low molecular weight hydrocarbons, without tar, soot or PAH formation.
➢ Sulfur, nitrogen and many trace elements in coals are oxidized to form insoluble salts in SCW.

- Coal gasification products will be dissolved in **supercritical water**, and any salts can be precipitated from the fluid mixture and removed from the system with the coal ash. There are no gaseous emissions.

Deep Saline Aquifers

- CO_2 capacity estimates in U.S. saline formations range from 1000 to 3700 billion tons of CO_2, sufficient for 86 to 318 years of CO_2 storage at the rate that coal was used for electric power generation worldwide in 2004.



Taken from *Carbon Sequestration Atlas of the United States and Canada, NETL*

Dissolved solids must be removed before the aquifer water is suitable for dissolving the coal conversion products.

Overall Project Objective and Tasks

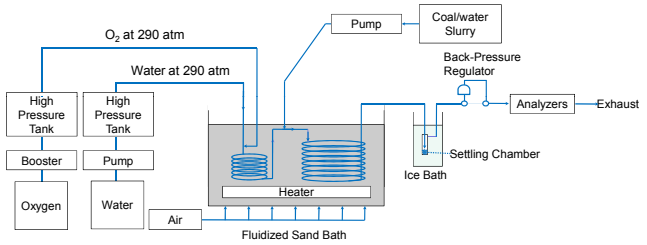
- The overall project objective is to provide the information needed to develop and commercialize the proposed coal-to-electricity scheme with *in situ* CO_2 sequestration.

- **Task I. Supercritical Water Coal Reforming**
  Research efforts are aimed at characterizing coal conversion rates under SCW conditions and determining the conditions that maximize the amount of chemical energy from the coal in the synthesis fluid.
- **Task II. Synthesis Fluid Oxidation**
  Research efforts center around the design and operation of the oxidation reactor and the heat exchanger needed to transfer energy to the heat engine.
- **Task III. Aquifer Interactions**
  Research activities are concerned with characterizing the impact of dissolved constituents in the water being returned to the aquifer on aquifer ecology.

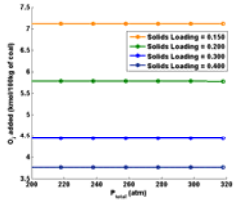
Task I. Supercritical Coal Reforming

- Experimental activities will be undertaken to characterize the rates of extraction, devolatilization, gasification, and oxidation of coals in supercritical water conditions.
- The amount of oxygen required to just drive the endothermic gasification reactions will be determined.
- Conditions that maximize the amount of chemical energy from the coal in the synthesis fluid will be identified.
- Models for predicting thermodynamic and transport properties of key species in SCW media will be developed.
- Models for coal extraction and devolatilization and char gasification and oxidation in SCW environments will be developed.

Experimental Setup



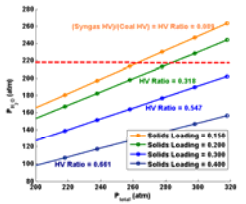
Autothermal Gasifier Operation



- Required oxygen for autothermal operation as a function of slurry solids loading (fraction of solids in water) with no preheating

Water Partial Pressure vs. Total Pressure

Coal composition, by wt. : 79.7% C, 4.2% H, 3,0% O, 1.5%N, 1.5%S



- At 647.3 K, The partial pressure of water needs to be equal to or greater than 218 atm.

Gasifier Synthesis Gas – Real Gas Effects

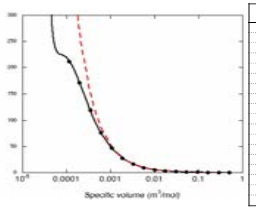
- The Peng-Robinson equation of state is used to describe the variations in pressure with specific volume and temperature.

$$P = \frac{RT}{v-b} - \frac{a\alpha}{v(v+b)+b(v-b)}$$

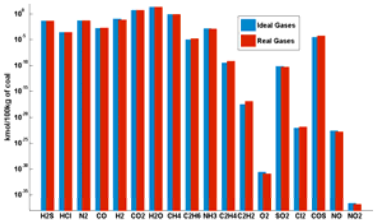
$$a = 0.45724R^2T_c^{2.5}/P_c$$
$$b = 0.07780RT_c/P_c$$
$$\alpha = \left[1+S(1-T_r^{1/2})\right]^2$$
$$S = 0.37464 + 1.5422\omega - 0.26992\omega^2$$

- Fugacity is used as a measure of the nonideality of a real gas.

$$RT\ln f = vdP \qquad \lim_{P\to 0}\left(\frac{f}{P}\right) = 1$$



Fugacity Coefficients, Φ	
H_2S	0.8601
HCl	0.9397
N_2	1.1128
CO	1.1129
H_2	1.0734
CO_2	0.9949
H_2O	0.5169
CH_4	1.0562
C_2H_6	0.9534
NH_3	0.8704
C_2H_4	0.9845
C_2H_2	0.9824
O_2	1.0695
SO_2	0.7856
Cl_2	0.7507
COS	0.8187
NO	1.1014
NO_2	0.9358



Conclusions

Advantages of the proposed aquifer-based, supercritical water coal conversion scheme for electric power generation relative to current and other proposed power generation systems include:

- ✓ maximally efficient power production while storing CO_2 products in indefinitely stable forms,
- ✓ near-zero traditional air pollutant emissions, and
- ✓ size reduction of reactor vessel (compared to conventional pulverized coal-fired systems).

This investigation aims to lay the foundation for an efficient coal energy option with no matter release to the atmosphere and in which all combustion products, in particular, carbon dioxide, are pre-equilibrated in aquifer water before injection into the subsurface.