EFFECTS OF TEMPERATURE AND GAS MIXING ON FORMATION PRESSURE, CO_2 SEQUESTRATION AND METHANE PRODUCTION IN UNDERGROUND COALBEDS

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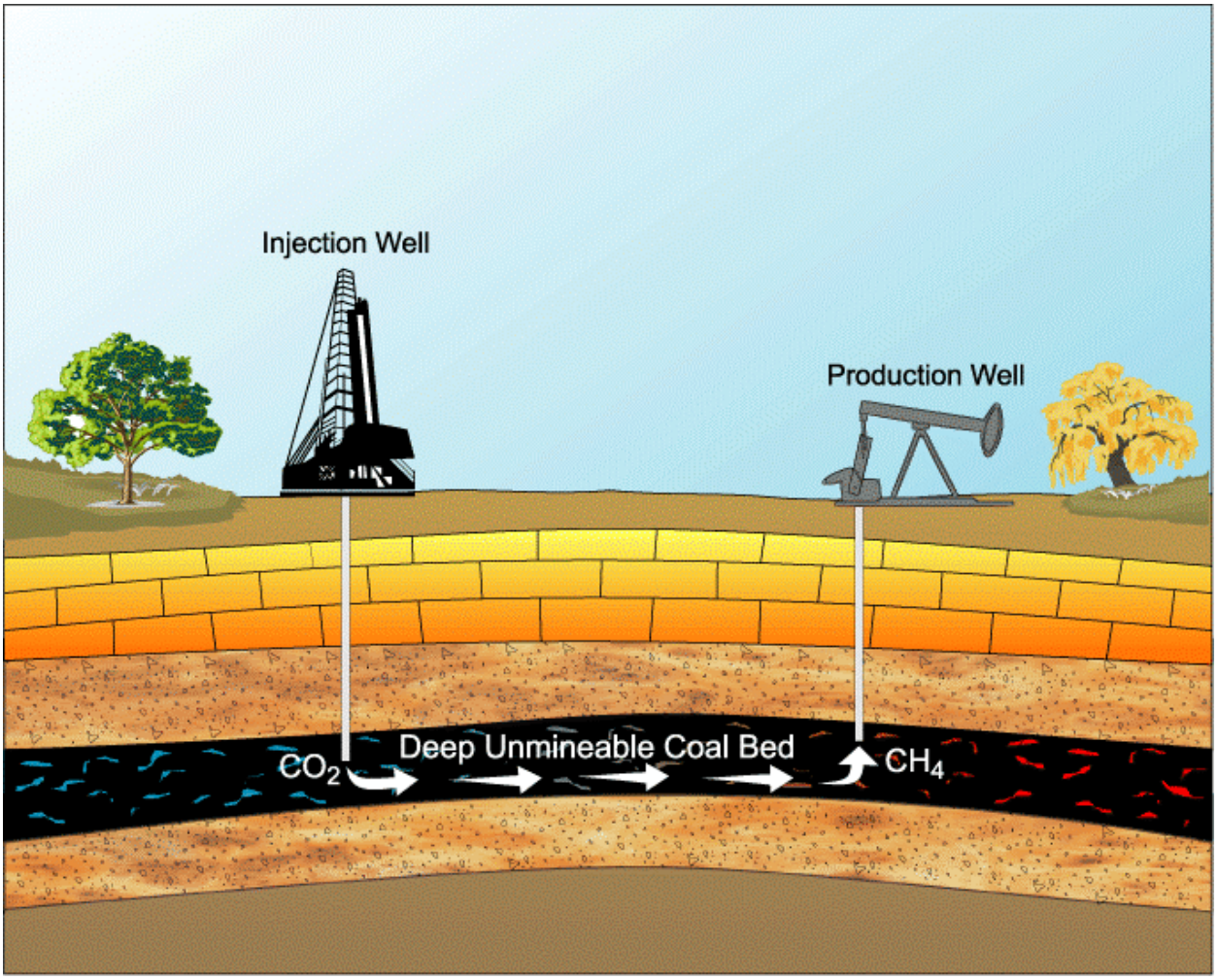
INTRODUCTION

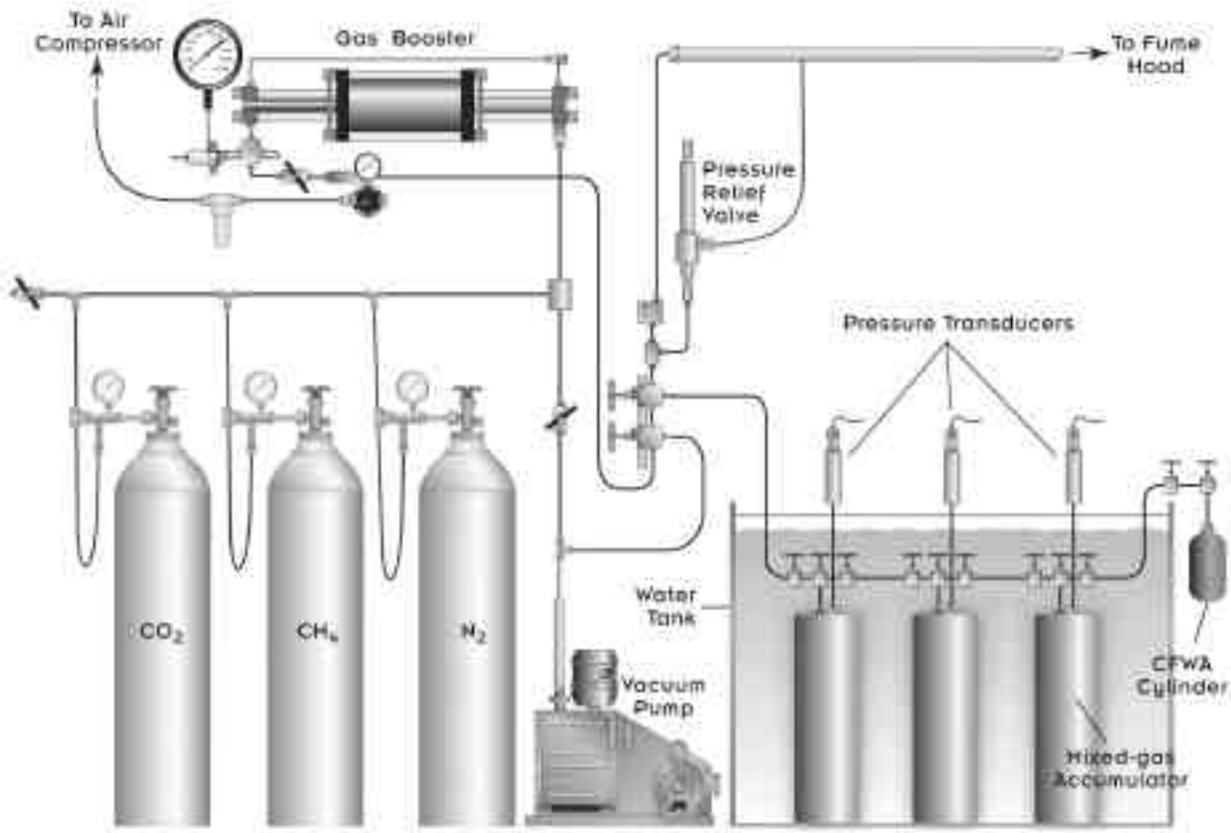
Carbon dioxide (CO_2) injected into subsurface coalbeds replaces adsorbed methane (CH_4) on coal surfaces, allowing the latter to be recovered for commercial use (Fig. 1).

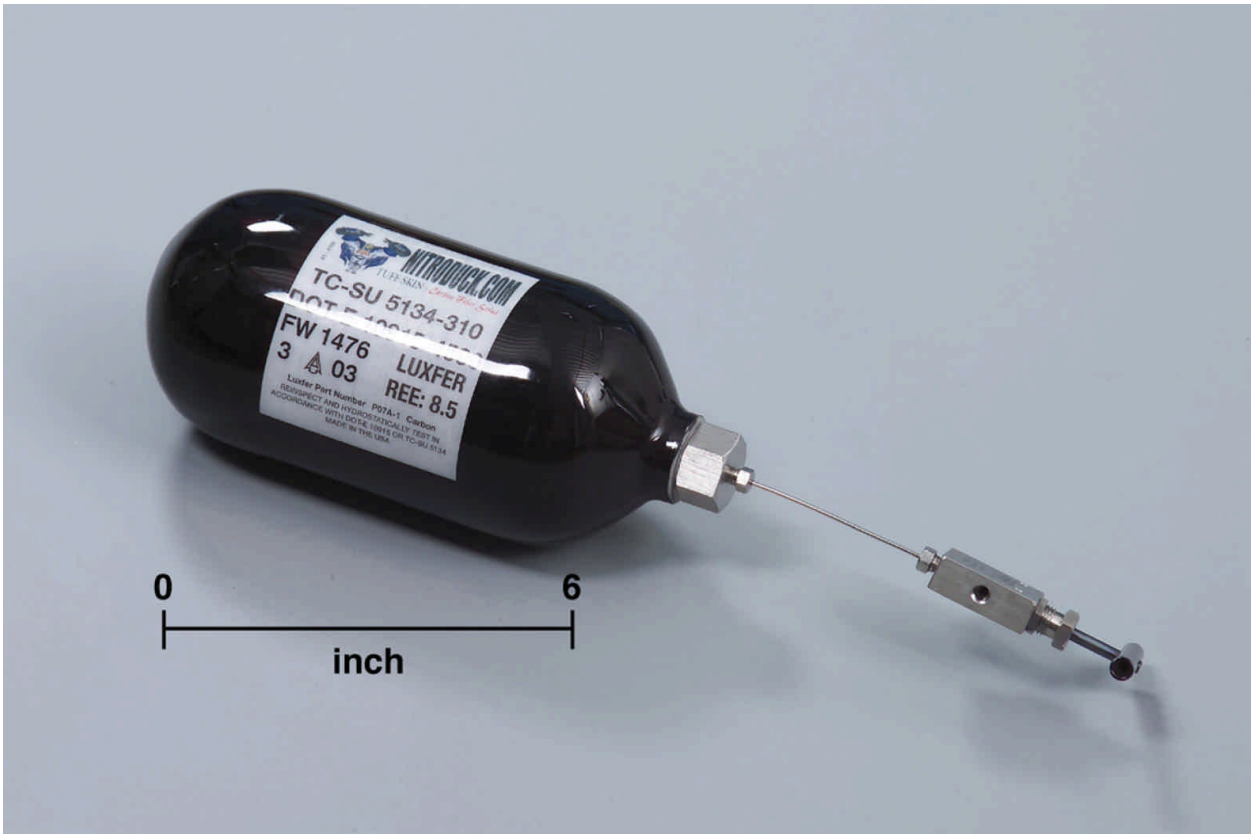


This promising "CO_2-enhanced" coalbed methane technology offers the opportunity to sequester large volumes of CO_2 while simultaneously increasing the efficiency and profitability of natural gas production.

However, much work remains to be done to accurately predict the effects of injecting CO_2 into subterranean coalbeds. Key unresolved issues include: fluctuations in formation pressure caused by CO_2 injection, effects of temperature and gas mixing on rates and levels of CO_2 adsorption on coal surfaces, and swelling/shrinkage of coal due to adsorption of CO_2 and desorption of CH_4.

To determine the effects of temperature and gas mixing on formation pressure and gas behavior in coalbeds, autoclave experiments are being performed to precisely and accurately measure the equilibrium densities of CO_2-CH_4 mixtures at 20-50°C, 0-2000 psi (Figs. 2-4).

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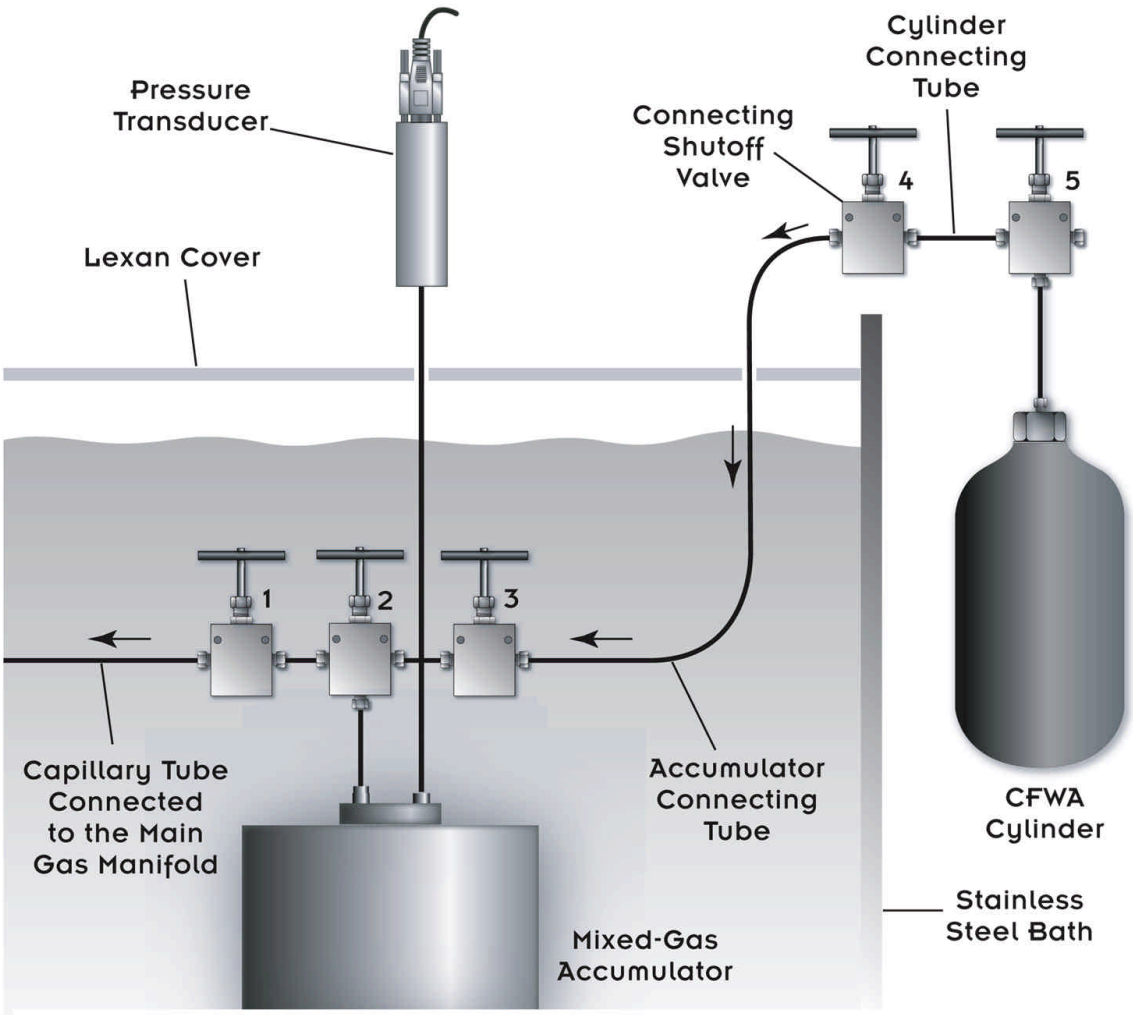

Results of the tests will be used to develop mathematical expressions for application in numerical modeling of the processes and parameters that affect capture and retention of CO_2 in subterranean coalbeds.

BACKGROUND

Evidence is mounting that rising levels of atmospheric CO_2, caused primarily by combustion of fossil fuels, will lead to rapid global warming. To address this problem, numerous nations are developing plans for lowering CO_2 emissions to the atmosphere. The principal approaches under consideration are: improving energy efficiency; making greater use of alternative sources of energy; and creating economically viable technologies for capture, separation, and long-term storage of CO_2. The latter strategy, which keeps large masses of CO_2 separate from the Earth's

atmosphere for hundreds to thousands of years (a concept commonly known as "CO_2 sequestration"), is receiving increasing attention because it permits continued use of fossil fuels to generate electrical power while ensuring that CO_2 releases to the atmosphere are reduced.

A potentially attractive means for terrestrial CO_2 sequestration is injection of gaseous CO_2 into underground reservoirs. The primary candidate sites are active or depleted oil and gas fields, deep brine formations, and unmineable coalbeds. To date, studies to determine the feasibility of geologic CO_2 sequestration have focused on oil and gas fields, and deep brine formations. However, four characteristics of deep, unmineable coalbeds make them extremely attractive for wide-scale CO_2 sequestration. (1) Like deep brine formations, unmineable subsurface coalseams are widely distributed across the U.S. (2) When CO_2 is injected into a coalbed, it efficiently displaces adsorbed methane. Therefore, CO_2 sequestration and coalbed methane (CBM) production are synergistic technologies, the additional natural gas produced by CO_2 sequestration serving to offset the costs of CO_2 injection. (3) CO_2 is more than twice as adsorbing on coal as CH_4, and remains tightly bound to coal surfaces after CH_4 is displaced. Therefore, after being injected into an underground coalbed, there is little risk that sequestered CO_2 will leak to overlying strata, or to the surface. *This is an enormous advantage over CO_2 storage in deep saline formations, where escape of gas through caprock is a serious problem*. (4) Many unmineable coalseams are located near coal-fired power plants, which are large point sources of CO_2. Thus, minimal pipeline transport of CO_2 would be required to deliver it to a suitable site for subsurface injection. In contrast, oil and gas fields, and particularly deep saline formations, are often far removed from fossil fuel-fired power plants.

CBM recovery, accomplished principally by pumping formation water out of a subterranean coalbed, is a mature technology. In contrast, CO_2-enhanced CBM recovery is a recent concept, which has been demonstrated only in pilot tests. Consequently, opportunities abound in fundamental and applied research aimed toward advancing this rapidly emerging technology.

EXPERIMENTAL METHODS AND RESULTS

Preliminary density data for CO_2-CH_4 mixtures were collected at 40°C, 200-2000 psi. Measurements were made by: (1) evacuating (to a pressure <50 mTorr), sealing, and weighing two, 0.74-liter internal volume, carbon fiber-wrapped aluminum (CFWA) cylinders (Fig. 3)—rated for routine use with internal pressures as high as 4500 psi; (2) loading liquid CO_2 into

one of the CFWA cylinders, and gaseous CH_4 into the other; (3) reweighing each cylinder to determine the masses of CO_2 and CH_4 they contained; (4) evacuating the mixed-gas accumulator (Fig. 4) to a pressure <50 mTorr; (5) filling the mixed-gas accumulator with CO_2 to a predetermined pressure between 200 and 1600 psi; (6) reweighing the CO_2-filled CFWA cylinder to determine the mass of CO_2 transferred from the cylinder to the mixed-gas accumulator; (7) recording the temperature and pressure of the CO_2 in the mixed-gas accumulator, and calculating the density of the gas using the mass determined in step 6 and the (premeasured) internal volume of the accumulator; (8) injecting CH_4 into the mixed-gas accumulator until total gas pressure increased by ~400 psi; (9) reweighing the CH_4-filled CFWA cylinder to determine the mass of CH_4 transferred from the cylinder to the mixed-gas accumulator; (10) calculating the composition of the mixed CO_2-CH_4 gas in the mixed-gas accumulator using the measured masses of pure CO_2 and pure CH_4 injected into the vessel (steps 6 and 9); (11) recording the temperature and pressure of the mixed gas in the mixed-gas accumulator, and calculating the density of the gas using the masses determined in steps 6 and 9; (12) repeating steps 8-11 until experimental pressure exceeded 2000 psi; and finally (13) repeating steps 4-12 for a different starting pressure of CO_2 (step 5) in the range 200-1600 psi.

Results of the work are extremely promising, indicating collectively that, at 40°C, 0-2000 psi: (i) CO_2 and CH_4 mix rapidly, regardless of bulk gas composition; and (ii) mixed CO_2-CH_4 gases exhibit strong positive deviations from ideality. The next step in the research is to perform all equipment calibrations needed to accurately determine the densities of CO_2-CH_4 gas mixtures at 20-50°C, 0-2000 psi. Acquisition of publishable results is scheduled to begin in late FY 2004.

ACKNOWLEDGMENTS

The research described in the report is being sponsored by the Office of Fossil Energy, U.S. Department of Energy, National Energy Technology Laboratory, under contract number DE-AC05-00OR22725 with UT-Battelle, LLC.

Figure Captions

Fig. 1. A schematic diagram of CO_2-enhanced coalbed methane (CBM) production.

Fig. 2. A semi-schematic diagram of the densimeter system.

Fig. 3. A close-up photograph of one of the carbon fiber-wrapped aluminum (CFWA) cylinders used to transfer gas into the mixed-gas accumulator.

Fig. 4. A semi-schematic diagram illustrating the method used to transfer gas into the mixed-gas accumulator.