TITLE: LABORATORY EXPERIMENTS TO SIMULATE CO_2 OCEAN DISPOSAL **DATE:** May 1997

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I. ABSTRACT

OBJECTIVES: The primary objective of this investigation is to obtain experimental data that can be applied to assess the technical feasibility and environmental impacts of oceanic containment strategies to limit atmospheric emissions of fossil carbon dioxide (CO_2) from coal and other combustion systems. These strategies exploit the very large carbon storage capacity of the deep ocean. In a typical system, CO_2 extracted from a combustor is liquefied and transported to the deep ocean (to circumvent the slow natural CO_2 exchange that occurs in the upper layers of the ocean) via a submerged conduit and discharged, usually as a jet. Hydrodynamic instability induces break-up of the jet into droplets which will be buoyant at depths above 3,000 m. Dissolution of the rising droplets may be hampered by a solid hydrate film that forms on the surface of the droplets. The complex mechanisms of liquid CO_2 jet break-up, droplet dispersion and coalescence, and dissolution in the deep ocean environment are not well-understood. The present investigation seeks to address several major deficiencies by the conduct of two categories of laboratory tests which will: (1) characterize size spectra and velocities of the dispersed CO_2 phase in the near-field of the atomized jet; and (2) estimate rates of mass transfer from single rising droplets of liquid CO_2 encased in a thin hydrate shell. The former tests will employ a Phase Doppler Particle Analyzer (PDPA) as the principal diagnostic while the latter will monitor droplet shrinkage by means of close-up video and image analysis.

WORK UNDERTAKEN: To date, the following tasks have been performed:

- A unique pressurized vertical water tunnel was developed to stabilize (in space) buoyant droplets of liquid CO_2 with an opposing flow of seawater. The apparatus provides a means to monitor dissolution that occurs over hundreds of meters of droplet rise in the ocean within the confines of a finite height facility.
- A Phase Doppler Particle Analyzer (PDPA) has been procured and tested. The PDPA optical train was modified to adapt the diagnostic to the test facility.
- Experiments to characterize size spectra and velocities of liquid CO_2 jets under conditions simulating the deep ocean have begun.
- Two international research collaborations were initiated to: (1) develop diagnostics for planned field experiments of CO_2 ocean disposal (with the University of Bergen, Norway); and (2) investigate a concept to sequester CO_2 in the deep ocean through the generation of dense CO_2 hydrates *in situ* (with the National Institute of Materials and Chemical Research, NIMC, Japan).

SIGNIFICANCE TO FOSSIL ENERGY PROGRAM: The U.S. Department of Energy is promoting development of advanced technologies for recovery, reuse, and disposal of CO_2 from coal-fired power stations. This activity is being pursued in consideration of the possibility that stabilization of net CO_2 emissions may be adopted as a policy goal in the U.S., in accordance with the 1992 UNCED agreement. The objective of this advanced technology development program is to identify alternatives which can supplement more cost-effective means of CO_2 control, such as efficiency improvements, energy conservation, and fuel switching. Given the limited reuse options for CO_2, commercial-scale recovery systems may need to be integrated with a disposal technique that will ensure long-term containment. Analyses performed to date have identified the deep ocean as the leading candidate repository for CO_2. These studies, however, have been hampered by a poor understanding of the behavior of liquid CO_2 effluent in the deep ocean. To this end, the present investigation will obtain data on CO_2 jet instability and droplet dispersion, coalescence, and dissolution that can be applied to the development and validation of predictive models to estimate the term of CO_2 sequestration, perform (ocean) environmental hazard assessments, and devise injection methods that ensure rapid dissolution and, hence, long-term containment of the CO_2 from the atmosphere.

PLANS FOR THE COMING YEAR: The following activities are planned for Year-3:

- Complete experiments to characterize droplet spectra and velocities in the near field of liquid CO_2 jets under conditions simulating the deep ocean. The effects of the following parameters will be examined: (1) water temperature and pressure, i.e., simulated discharge depth; (2) jet velocity; and (3) nozzle orifice size and geometry.
- Complete experiments to examine dissolution of single rising CO_2 droplets with hydrate films.
- Continue joint investigations with the University of Bergen and NIMC.

II. ACCOMPLISHMENTS (HIGHLIGHTS)

- A new high-pressure water tunnel has been developed to investigate buoyant liquid CO_2 droplet dissolution under deep ocean conditions.
- A PDPA was designed and procured to perform measurements of liquid CO_2 droplet spectra and velocity in water.
- Preliminary experiments have been conducted to characterize droplet spectra and velocities in the near field of liquid CO_2 jets under conditions simulating the deep ocean.
- Joint research projects were initiated with the University of Bergen, Norway, and NIMC, Japan, to develop diagnostics for future field tests of CO_2 ocean disposal and to investigate an alternative process to contain CO_2 in the deep ocean.

III. ARTICLES AND PRESENTATIONS

With G.C. Nihous, "On the Effectiveness of Oceanic Containment Strategies Applied to Anthropogenic Carbon Dioxide," in *IONICS* (special issue for the International Chemical Congress of Pacific Basin Societies), No. 242, pp. 73-77, 1995.

"Laboratory Experiments to Simulate CO_2 Ocean Disposal," in *Proc. First Joint Power & Fuel Systems Contractors Conference*, U.S. Dept. of Energy, Pittsburgh, PA, 1996.

With H. Teng, C.M. Kinoshita, and G.C. Nihous, "The Effect of Hydrate Formation on CO_2 Jet Instability," *Prepr. Pap., Amer. Chem. Soc. Div. Fuel Chem.*, **41**, No. 4, pp. 1447-1451, 1996.

With H. Teng and C.M. Kinoshita, "Dispersion of CO_2 Droplets in the Deep Ocean," presented at ICCDR-3, The Third International Conference on Carbon Dioxide Removal, Boston, MA, USA, 9–11 September 1996, also in *Energy Convers. Mgmt*, **38**, No. 10–13, pp. 319-324, 1997.

With G.C. Nihous, "Rig Techniques and Experiments," invited paper presented at the 4th Expert Workshop–Practical & Experimental Approaches, Oct. 29-30, 1996, Tokyo, Japan, to appear in *IEA Greenhouse Gas R&D Programme Report on Ocean Storage of CO_2* (W. Omerod, ed.), 1997.

With R.P. Warzinski, P.D. Bergman, and G.D. Holder, "The Effect of CO_2 Clathrate Hydrate on the Ocean Disposal of CO_2: A Review of DOE-Sponsored Research," 213th ACS National Meeting, San Francisco, CA, 13–17 April 1997.

With E.E. Adams, D.S. Golomb, and H.J. Herzog, "The Design of Pilot Scale Releases of CO_2 into the Deep Ocean," to be presented at the 32nd Intersociety Energy Conversion Engineering Conference, IECEC-97, Honolulu, HI, July 1997.