DEVELOPMENT OF A HIGH-PRESSURE WATER TUNNEL FACILITY FOR OCEAN CO_2 STORAGE EXPERIMENTATION

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INTRODUCTION

The rising atmospheric levels of greenhouse gases, primarily CO_2, due to the production and use of energy is a topic of global concern. Stabilization may require measures other than fuel switching to lower carbon energy sources, increased use of renewable energy, and improvements in efficiencies. A new way of potentially limiting atmospheric increases of CO_2 while maintaining energy diversity is carbon sequestration which entails the capture and non-atmospheric storage of the carbon emitted from energy production and use. A recent report describes the key areas of research and development presently viewed as necessary to understand the potential of carbon sequestration for managing carbon emissions (1).

One potential storage option is to directly introduce CO_2 into the ocean at depths greater than about 500 m (1,2). Part of the carbon sequestration research program at the National Energy Technology Laboratory (NETL) of the U.S. Department of Energy has involved work in this area (3,4). This work has focused primarily on the impact on this storage option of the possible formation of the icelike CO_2 clathrate hydrate ($CO_2 \cdot nH_2O$; $6<n<8$; referred to hereafter simply as hydrate) as either discreet particles or as coatings on drops of liquid CO_2. All of this prior work was performed in a small (less than 40 cm^3) pressure vessel. While useful data on the formation, dissolution, and relative density of the hydrate were obtained, realistic simulation of the oceanic environment was not possible owing to contact of the species of interest with foreign (glass, stainless steel) materials in such a vessel. These foreign materials can influence hydrate formation and dissolution by acting as nucleation sites and providing unnatural heat transfer characteristics, both important factors in crystallization processes.

To attempt to overcome these limitations and provide a more realistic simulation of the deep ocean environment, a High-Pressure Water Tunnel Facility (HWTF) is being constructed that will permit experimental observations on objects such as CO_2 drops, hydrate particles or hydrate-covered CO_2 drops to be made without contact with materials other than seawater. The HWTF will permit the observation of buoyant objects in a windowed test section through the use of a countercurrent flow of water and special design features that provide for radial and axial stabilization. This paper describes the status of the experimental and theoretical efforts associated with the development of the HWTF.

DISCUSSION

In 1981, Maini and Bishnoi published work on the development of a high-pressure water tunnel to study hydrate formation on freely suspended natural gas bubbles in a simulated deep ocean environment (5). Their design considerations formed a starting point for the work at NETL on ocean sequestration of CO_2. As summarized in their paper, the hydrodynamic conditions necessary for holding an object in free suspension in such a device consist of: 1) the drag on the object should be equal to the force of buoyancy; 2) the axial velocity of the liquid should gradually increase with height to provide stability against vertical displacement; 3) the velocity distribution over a cross section of the liquid column should be axially symmetric with a local minimum at the center to provide stability against lateral displacement; and 4) the flow should be free of large-scale turbulence. To achieve the desired velocity profiles, an observation section with a tapered inner diameter and various flow conditioning devices inserted above and possibly below this section can be used.

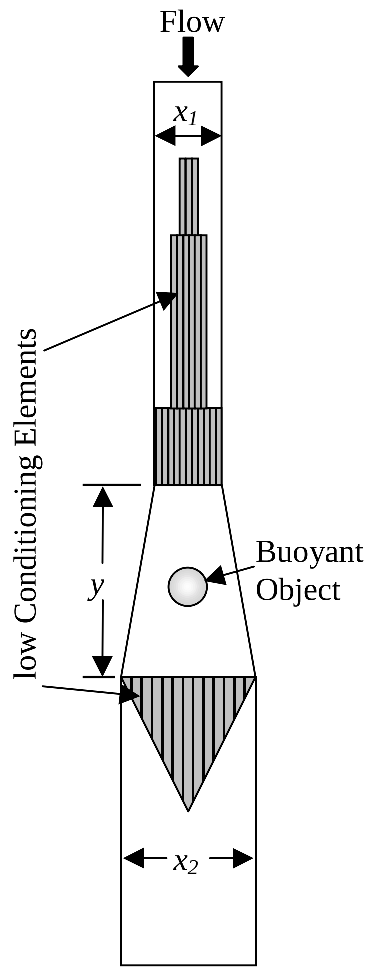

Figure 1. Schematic diagram of a water tunnel device

A simplified schematic drawing of a water tunnel device is shown in Figure 1 (only inner diameters are shown). This device is placed in a flow loop that provides for recirculation of water through the system. For a positively buoyant object, the flow of water or seawater enters the top of the water tunnel and passes through a stilling section (not shown in Figure 1). At the end of the stilling section, a flow conditioning element is placed to provide the velocity profile required for radial stabilization of the buoyant object in the test section immediately below it. The top flow conditioning element shown in Figure 1 represents a bundle of small tubes of different length. Various other configurations are possible. Increasing the length of the tubes in the center results in more head loss in this region and results in flow redistribution with the desired local velocity minimum in the center of the water tunnel. The diameter of the test section increases from top to bottom ($x_2 > x_1$) which provides the downstream axial velocity drop required for axial stabilization. At the exit of the test section, another flow conditioning element may be used. In Figure 1, this lower element depicts another possible tube bundle shape that could be used. A final stilling section is located after the test section (again not shown in Figure 1). Design variables affecting the velocity profile in the test section include the geometries of the conditioning elements and the divergent test section.

Both experimental and theoretical work is in progress at NETL to determine the required design parameters needed for stabilization of CO_2 in a HWTF over the range of anticipated ocean injection conditions. A Low-Pressure Water Tunnel Facility (LWTF) of similar internal dimensions (x_1 = 5.08 cm, x_2 = 6.35cm) has been built to test various designs and provide information for the theoretical treatment of this problem. It consists of the water tunnel which is constructed of plexiglass pipe, a 5.08 cm ID flow loop of PVC plastic pipe, and a variable-speed centrifugal pump for water circulation. An ultrasonic flow sensing system is used to measure the total flow rate in the loop. An S-shaped pitot tube was fabricated and calibrated at NETL for insertion through ports in the test section and is automatically moved across the section's diameter to obtain information related to local velocities. A computer–controlled positioning system translates the pitot tube across the test section and obtains the measurements needed to determine a velocity profile at this point in the system.