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November 20, 1990

Mr. Floyd Collins
Program Manager
Office of Buildings and Community Systems
US Department of Energy, CE-133
1000 Independence Avenue, SW
Washington, DC 20585

Re: Comparison of Direct Freeze Ice Slurry Hydraulic Characterization Test Results Obtained Under Phase 2 DOE Contract No. CE-FG01-88CE26559 (CBI Contract No. C9901I) vs. Phase 1 DOE Contract No. DE-FG01-86CE26564 (CBI No. C8533I)

Dear Mr. Collins:

In the Phase II Interim Report No. 1 (DOE Contract No. CE-FG01-88CE26559) submitted August 1990, ice/water slurry hydraulic characteristics were presented which showed a slight increase in system pressure drop when compared with pure water flows at the same conditions. This is in contrast with the results presented in the Phase I final report (DOE Report No. DE88-011597) which showed a significant decrease in the slurry pressure drop when compared with pure water flows at similar conditions. While the Phase II Final Report will discuss the difference in results in detail, Dr. Steve Choi of Argonne National Laboratory requested a brief summary and we are pleased to provide the following information.

The different conclusions from Phase I to Phase II resulted from a different interpretation of the Phase I flowmeter data, duplicated during the Phase II tests. Additional instrumentation pinpointed the limitations of the Phase I flowmeter instrument. Visual observations of the "plug flow" slurry flow patterns made in Phase I were also duplicated in the Phase II tests, confirming that the system was being operated in a duplicate manner.

By way of background, please recall that several changes were made to the test facility between the Phase I and Phase II testing programs. These changes involved:

- o Replacement of the existing variable-speed centrifugal pump with a larger-capacity pump capable of a maximum flow rate of roughly twice the original.
- o Replacement of the oil-lubricated reciprocal compressor with an oil-free compressor, followed by a thorough cleaning of slurry test loop.
- o Installation of seven additional flow meters to provide at least two dedicated measurements of fluid velocity for each of the three test sections.

- o Installation of two additional differential pressure sensors to provide a dedicated pressure drop measurement for each of the three test sections.
- o Installation of a differential pressure sensor to measure the pressure drop across the entire pumping loop.
- o Miscellaneous small changes to the slurry ice generating system to improve efficiency and operational characteristics.

The differential pressure sensors and flowmeters were calibrated in place before data collection began. For the pressure sensors, a Wallace & Tiernam Series 65-120 Portable Pneumatic Calibrator was used to establish the linear output characteristics of each sensor. Two 2700-gallon tanks were used to determine similar calibration data for the fluid flowmeters. The flowmeter calibration work was performed with water as the test fluid. Since the system is a closed loop under partial vacuum, calibration testing with ice/water slurry was not practical.

In the Phase I test series, only one flowmeter was used for all of the tests. This meter was installed in the 6-inch diameter return pipe, approximately 15 feet upstream of the circulation pump. The meter was a Signet MK 565 Mighty-Mag™ Flosensor. This sensor determines the velocity of the fluid by measuring the induced voltage created when a conductive fluid passes through a magnetic field created by the instrument. Although it is not explicitly stated in the technical literature for this device, the sensor is essentially a point velocity measurement. This type of sensor is very sensitive to changes in the velocity profile of the fluid.

At the beginning of the Phase II test series, three Signet MK 515/514 Paddlewheel Flosensors and three additional Mighty-Mag™ Flosensors were installed. Midway through the test series, two additional flow meters were installed. Both of these were full-bore magnetic meters (Rosemount Series 8700 and Endress + Hauser Variomag). These meters use the same induced voltage technique as the Mighty-Mag™ sensors, but the sensing electrodes are placed on opposing sides of the pipe ID. This type of meter provides a cross-sectional average velocity measurement. Figure 1 shows a schematic of the final test facility with the locations of all flowmeters.

In addition to increased instrumentation, the Phase II test series added a second method of data collection. The Phase I test method for obtaining pressure drop data involved three basic steps:

1) the ice slurry generating system was operated to build up to the desired ice fraction for testing,
2) the ice slurry generating system was isolated from the hydraulic characterization system to eliminate sources of interference, then

3) the ice slurry hydraulic characterization system was operated at a constant pump speed until all of the ice was melted. Pressure drop and velocity data was taken during this "melt" period.

The Phase II test series not only duplicated this method, but expanded it to more fully characterize the hydraulic effects. Pressure drop data was recorded as a function of velocity for both cold water and ice slurry. These results were reported in the Phase II Interim Report No. 1. For this letter's purpose of a direct Phase I/Phase II comparison, however, only the "melt" data can be used.

Figure 2 shows representative results obtained in the Phase II test series using the 4-inch diameter test section. Results from the 2-inch and 6-inch diameter sections were similar. It can be seen from this figure that the presence of the ice affected the different meters in different ways. The probe-type Mighty-MagTM flow meter installed in the 6-inch diameter return line (the same instrument used for the Phase I tests) shows a very dramatic increase in the fluid velocity as the ice loading rises from 0 to 10%. After that point, the velocity shows a slight downward trend. This is the same general trend as was described in the Phase I final report. However, the other flow meters show either no change or a slightly lower velocity as ice fraction increases. This difference is apparently due to the effects of velocity profile changes. Discussions with the manufacturer of this meter confirm that it is very sensitive to local changes in velocity and could easily provide this type of result in the presence of a changing velocity profile.

One surprising result shown in Figure 2 is that the two probe-type Mighty-Mag^{TM} meters (6-inch and 4-inch ID pipe sizes) do not show similar results. This is likely due to the meter mounting installation at the 6-inch diameter return pipe. The installation fitting for the meter is designed for schedule 80 pipe, but the 6-inch pipe is approximately schedule 20 (the thickest available clear PVC). This mounting resulted in a probe penetration of almost 19% of the pipe ID, compared with the standard 10% for the other meters. We suspect that this "interior" position of the 6-inch installation may have accentuated the velocity profile sensitivity.

For changing velocity profiles, a more accurate measure of fluid flow rate is provided by an instrument which provides a cross-sectional average of the fluid velocity. The two full-bore magnetic flow meters installed in this system provide such an average. Based on our discussions with flow meter manufacturers and with experts in the field of fluid flow measurement, the accuracy of such an instrument in this application should certainly be within ±5% of the measured value. The Phase II Final Report conclusions will be drawn from the results obtained with the full-bore magnetic flowmeter.

Please recall that, as an alternative, we evaluated a mass flow meter instrument for the Phase II test because of its insensitivity to velocity profile, but could not economically justify it (see our letter of May 3, 1990).

A final issue to be resolved deals with the cause of the observed simultaneous decrease in flow rate and pressure drop at a set pump speed during the melt portion of the test. The answer appears to lie in the performance characteristics of the centrifugal circulation pump. Centrifugal pumps experience a "slip" condition which can be affected by a variety of parameters, including slurry solids fraction. It has been shown by other researchers that increasing the solids loading of a slurry can decrease the capacity of a centrifugal pump at a constant pump speed. Thus, the ice fraction increase caused the pump capacity to drop, which caused the fluid velocity (and its associated pressure drop) to decrease.

Because of the wide variety of changes taking place in the system during the melt portion of the test, a more quantitative measure of the impact of ice fraction on the fluid flow characteristics was found using the variable pump speed tests (Δp vs. velocity) described in our Phase II Interim Report No. 1.

The Phase II final report will of course provide the above information in further detail. If you have any immediate questions concerning this issue, please contact me.

Sincerely,

Philip Winters

Philip J. Winters
Principal Investigator

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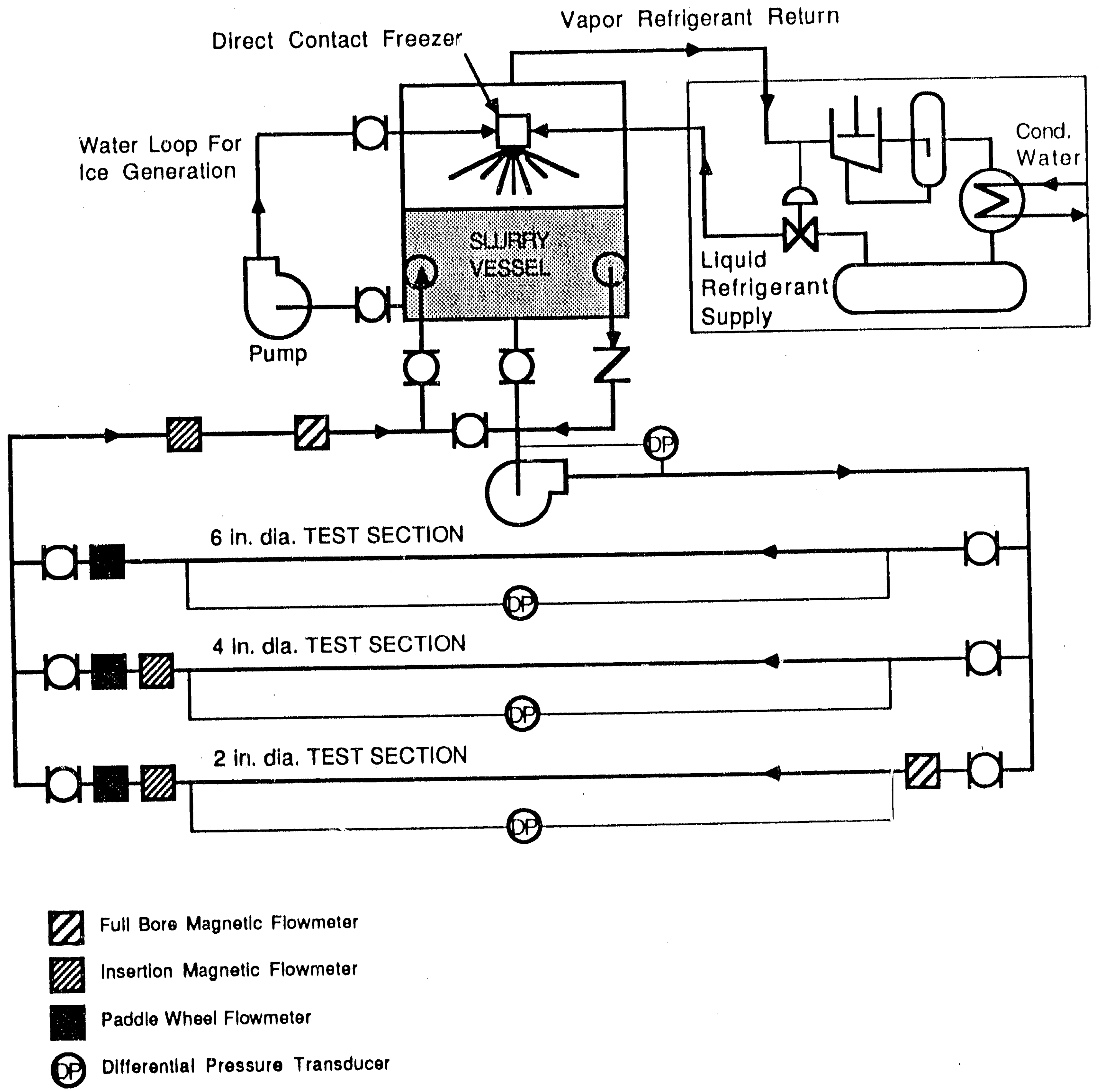
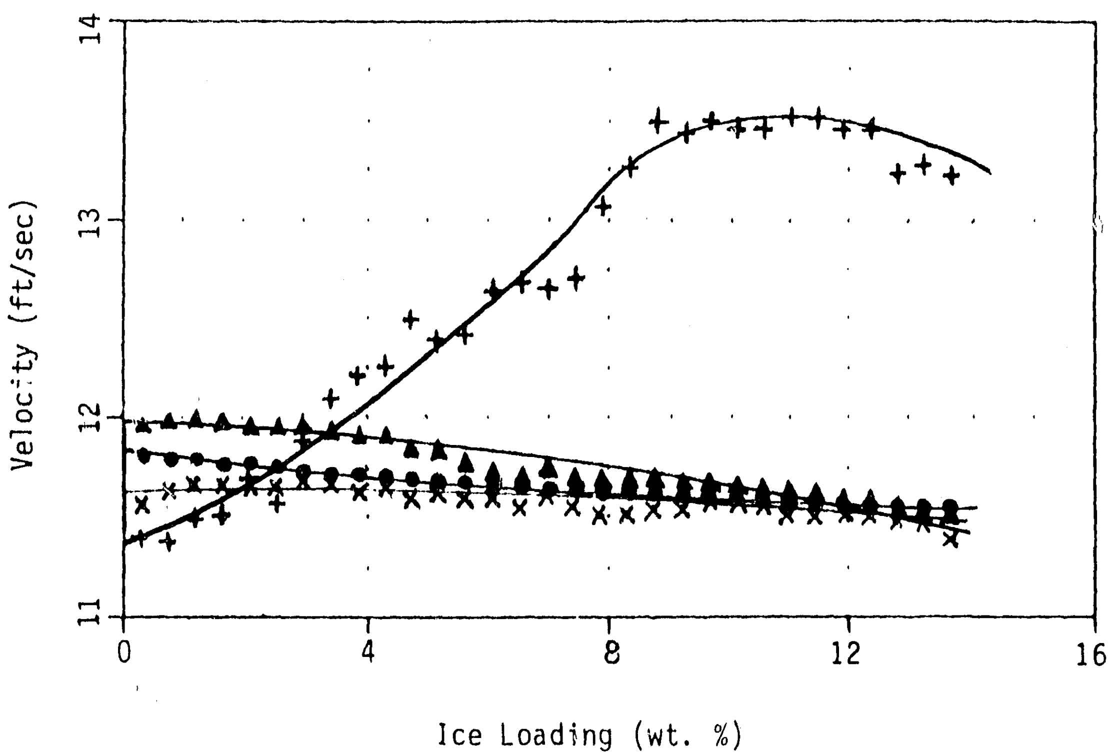


FIGURE 1

EXPERIMENTAL APPARATUS

FIGURE 2

Comparison of Results from Four Different Flow Meters



+ Probe-type Magnetic Flosensor (6-inch diameter line)
● Full-bore Magnetic Flosensor (6-inch diameter line)
▲ Probe-type Magnetic Flosensor (4-inch diameter line)
✕ Paddle Wheel Flosensor (4-inch diameter line)

END

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