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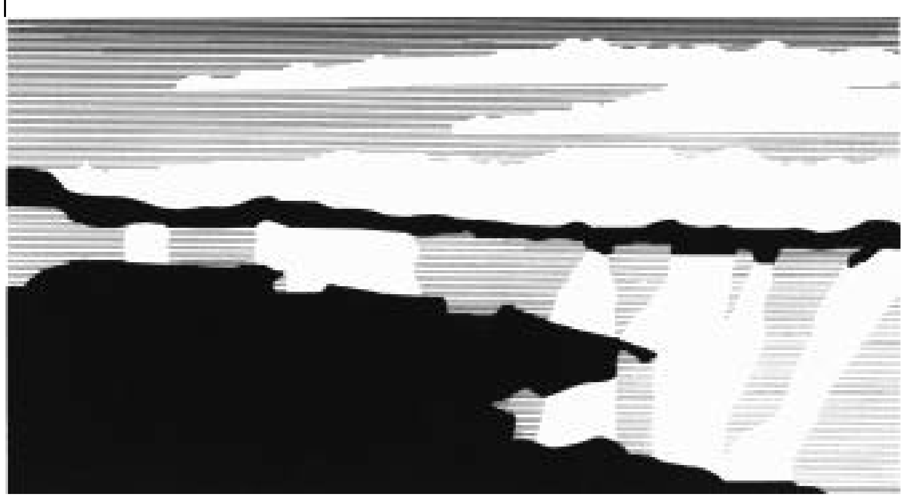

Los Alamos NATIONAL LABORATORY

Temperature Measurements on an HSLA-100 Steel Confinement Vessel

by

R. A. Lohsen

DX-3, Hydrodynamic Applications

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Introduction

Temperature measurements have been made on HSLA-100 steel confinement vessel number 6-2-3-1. These measurements are intended to give a view of the vessel temperature response under conditions similar to operational conditions, starting from worst case. The vessel's temperature must be above the minimum operating temperature when used to contain an explosive event to ensure that the vessel material has the desired crack arrest properties. Several series of temperature measurements have been conducted over 24 and 48 hour periods during February 1998. These tests were intended to demonstrate that after running the heaters in the environmental shelter for some time, (1) the vessel warms up to temperatures well above the minimum operating temperature, (2) that through-thickness temperature gradients are negligible, and (3) that the temperature differences from one part of the vessel to another are small.

Procedure

Several series of measurements of the surface temperature as a function of time were made. In each series, eight type K thermocouples were used. Six were mounted at various locations on the surface of the vessel, whereas one was suspended inside the vessel and one was suspended outside the vessel. An instrument controller and data logger read the temperatures at 15 minute intervals. The vessel is a three port vessel of HSLA-100 steel, of 6 foot diameter, with a 2 inch nominal wall thickness. During these tests, the confinement vessel was mounted in the bottom half of the safety vessel. These together were enclosed in the environmental shelter. Two inch rigid foam insulation was placed over the 16-inch film door and the 22-inch top door. One inch rigid foam was placed over the beam input door because this is all that would fit between the outer face of the nozzle and the inside of the safety vessel. The foam was used so that the heat flow between the outside and inside of the vessel would be by conduction through the wall, and not by convection or conduction through the door openings (Figure 1).

In several of the first series of measurements, the thermocouples were mounted as shown in Figure 1. Six of the thermocouples were paired. Thermocouples 1 and 2 were mounted with one on the outside surface and one on the inside surface of the confinement vessel. They were mounted about two and a half feet to the right of the center of the 16-inch film door, on a line through the center of the door, and about 45 degrees below the horizontal. Thermocouples 3 and 4 were also mounted with one on the outside surface and one on the inside surface of the vessel, about two and a half feet from the center of the 16-inch film door and on a line through the center of the door, about 45 degrees above the horizontal, and to the left. Thermocouples 5 and 6 were mounted with one on the outside surface and one on the inside surface of the vessel, about three feet from the center of the 22-inch top door and on a line through the center of the door in the equatorial plane. Thermocouple 7 was suspended about two feet down from the surface of the nozzle of the top 22-inch door, inside the vessel. Thermocouple 8 was suspended about one foot above the top 22-inch door, outside the vessel. All of the thermocouples were stick-on-surface type. Each was backed by a piece of Molefoam®, so that any local radiative or convective effects would not interfere with the surface temperature measurements. Thermocouples 7 and 8 were attached to pennies to provide minimal, but not zero, thermal mass for the air temperature measurements.

The first series of measurements was made on February 12 and 13 over a period of 22.5 hours, beginning at 5:16 PM on the 12th. During these measurements, no heaters were used. The vessels and the air in the environmental shelter responded to weather variations.

The second series of measurements began at 8:00 AM on February 17. At 9:30 AM, two of the three air heaters in the environmental shelter were turned on. These heaters are mounted high in the corners of the shelter. They have thermostats and blow warm air out across the upper part of the shelter space. Note that in earlier confined experiment operations, heaters have been placed in the annular region between the safety vessel and the confinement vessel. This was done in order to expedite heating to much higher minimum operating temperatures than will be needed with the HSLA-100 vessels. This was not done in these tests.

Thermocouples 1, 2, 5, and 6 were relocated for the third and fourth runs. Thermocouple 1 was placed on the inside surface of the nozzle opening for the film door. Thermocouple 2 was placed on the surface of the film door nozzle, inside the vessel. Thermocouple 5 was placed on the outside surface of the same nozzle. Finally, thermocouple 6 was placed on the fillet of the shoulder weld, along the side of the nozzle, on the outside surface of the vessel (Figure 2). The third series of measurements began at 1:34 PM on February 19. No heaters were used until 7:55 AM on the 20th. At that time two heaters were turned on, and data continued to be taken until about 4:00 PM.

The fourth, and final, series of measurements began at 9:48 on February 23. At 12:55 PM, the heaters were turned on. Recording was done for more than 48 hours.

The temperature measurement equipment was relocated to a laboratory after these experiments. The eight thermocouples were remounted, with the Molefoam, in two rows of four, on a 4 inch long and 4 inch wide piece of aluminum channel. This arrangement was placed under a cardboard box, and a temperature measurement series was conducted over about 24 hours. There was 5.6°F variation in the room temperature between day and night. The maximum difference in the temperatures recorded between any one thermocouple and any other thermocouple was 0.2°F. The precision of the measurement system is thus 0.2°F. Without the Molefoam and the box, the maximum temperature difference between thermocouples was 0.4°F. This doubling of the difference is apparently because of local convective and radiative effects, which is what the Molefoam was meant to suppress in the absence of the use of thermal wells. Thermal wells would have required destroying the integrity of the vessel wall.

Results

During the first series of measurements, the confinement vessel was subject only to the diurnal temperature change (Figure 3). The maximum temperature difference through the wall was 0.2°F. The maximum difference between the temperatures at any pair of thermocouples and any other pair was 3.5°F (pair 5, 6 and pair 1, 2). At locations higher on the vessel, the temperature is higher–indicative of a temperature gradient in the shelter with warmer air higher in the space. The maximum measured temperature difference between the air inside the vessel and that outside and above the vessel was 14.8°F.

For the second series of measurements, Figure 4, the heaters were turned on at 9:30 AM. After about two hours of warming, the heaters began regulating around 70°F. At 4:00 AM the next morning, something happened and they began regulating around 63°F. This change was probably caused by a change in the pattern of convective air currents in the shelter. A specific cause for this has not been identified. A check of local weather data indicates that there was no precipitation and no sharp change in wind speed or temperature. Over the course of these temperature measurements, the maximum observed difference in temperature through the wall at any of the three locations was 0.7°F. The maximum difference between the temperatures at any pair of thermocouples and any other pair was 11.4°F; again between pair 5, 6, and pair 1, 2. This maximum was observed at 2:30 PM, 6 1/2 hours after the measurement series began. The maximum measured temperature difference between the air inside the vessel and that outside and above the vessel was 41.6°F.

As described previously, four of the thermocouples were moved to locations around the film door nozzle for the subsequent measurements. For the third series of measurements, the vessel was subject to the natural air temperature changes overnight, and then the heaters were turned on and data was taken for slightly less than eight more hours (Figure 5). The maximum difference in the temperatures measured occurred around the nozzle. This maximum was 3.0°F, and occurred between the thermocouple on the inside surface of the nozzle opening and the thermocouple on the shoulder weld (pair 1, 6). The maximum difference observed between the air inside the vessel and that above and outside the vessel was 38.7°F.

The fourth series of measurements began at 9:50 AM (Figure 6). The heaters were turned on at 12:55 PM. After warming the space, the heaters began regulating around 75–78°F. At 1:00 PM the next afternoon they began regulating around 70°F. This change occurred when a few technicians entered the space, rearranged some of the equipment not associated with these measurements, swept the floor, and generally cleaned up the area. Again, the effect of changing the convection currents can be seen. Over the course of these temperature measurements, the maximum observed difference in the temperature through the wall at any of the three locations was 3.3°F. The maximum measured temperature difference between the air inside the vessel and that outside and above the vessel was 39.6°F. These differences occurred during warming. After 30 1/4 hours, the temperatures measured by all six thermocouples on the vessel were very close to the same, differing by, at most, 0.9°F. At that time, the vessel temperature was then 67°F.

Discussion

As can be seen from the data from the fourth run, after running the heaters in the environmental shelter for some time, the vessel warms up to 37°F more than the 30°F minimum operating temperature for the vessel. The through-wall temperature gradients are negligible, a maximum of 0.7°F during heating. The maximum difference through the nozzle, from the inside surface to the outside shoulder weld, was 3.3°F. The temperature differences from one part of the vessel to another are also small. The maximum observed was 11.4°F. This occurred during heating. When the vessel warmed up to the temperature of the heated air, these differences became much smaller.

These results are consistent with the theoretical estimate of S. Payne, DOE Albuquerque, in that they demonstrate that temperature differences through the wall are much smaller than those which may develop across the surface of the vessel. As can be seen from the data of the fourth run, the temperature of the vessel converges to a single value, with slight differences, after a warming period. The vessel can be heated, if necessary, to a point where thermocouples at opposing points on the outer surface of the vessel measure similar temperatures. There is then extremely high assurance that no through-thickness temperature gradients exist. Therefore, multiple external surface-temperature measurements are deemed adequate.

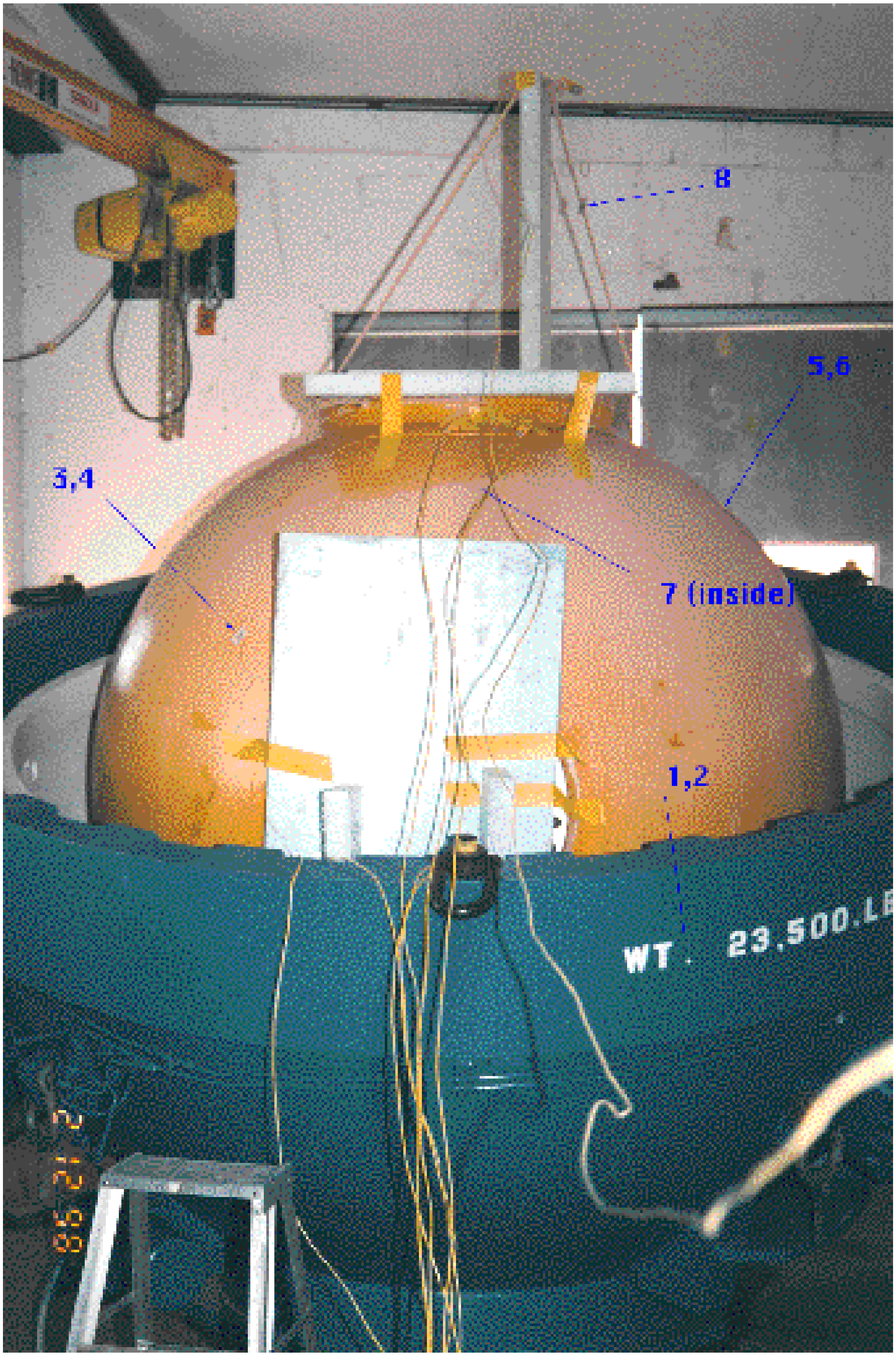

Figure 1. Vessel inside the shelter. The locations of the thermocouples are indicated.

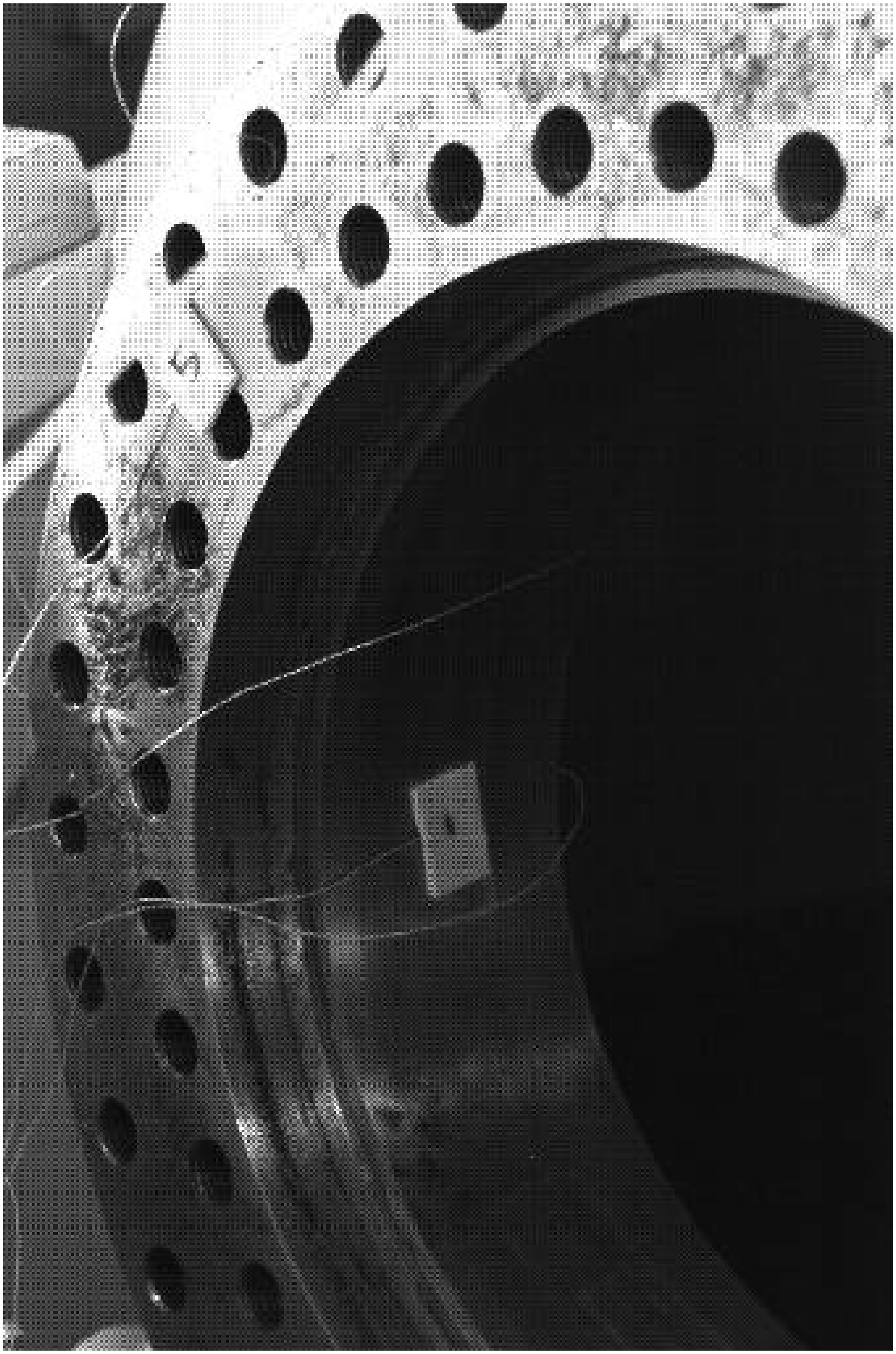

Figure 2. New thermocouple locations for runs 3 and 4.

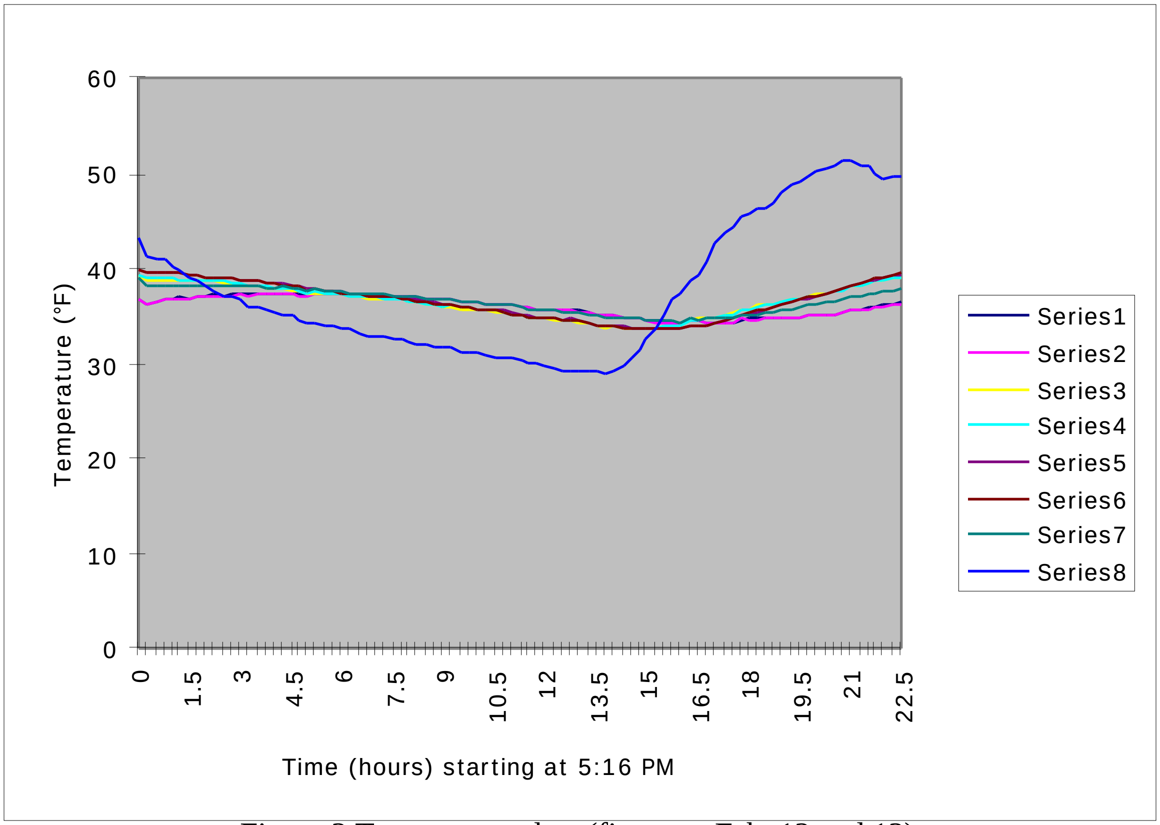

Figure 3 Temperature data (first run, Feb. 12 and 13).

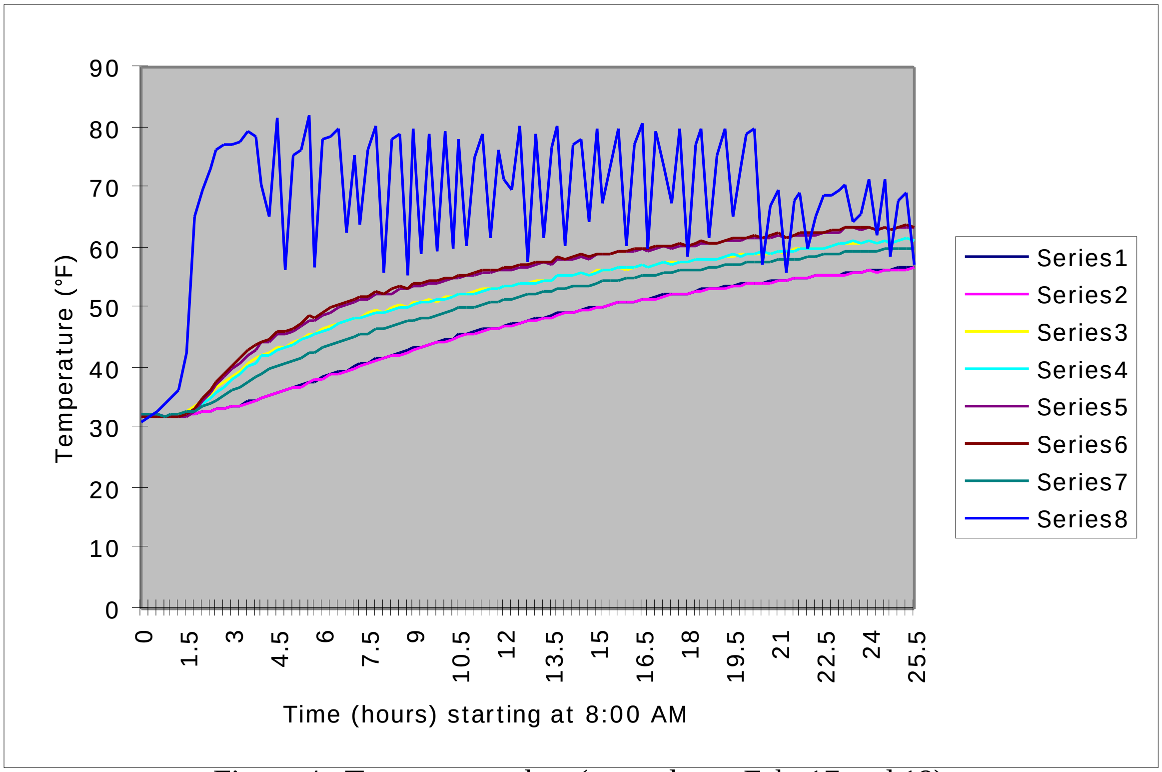

Figure 4. Temperature data (second run, Feb. 17 and 18).

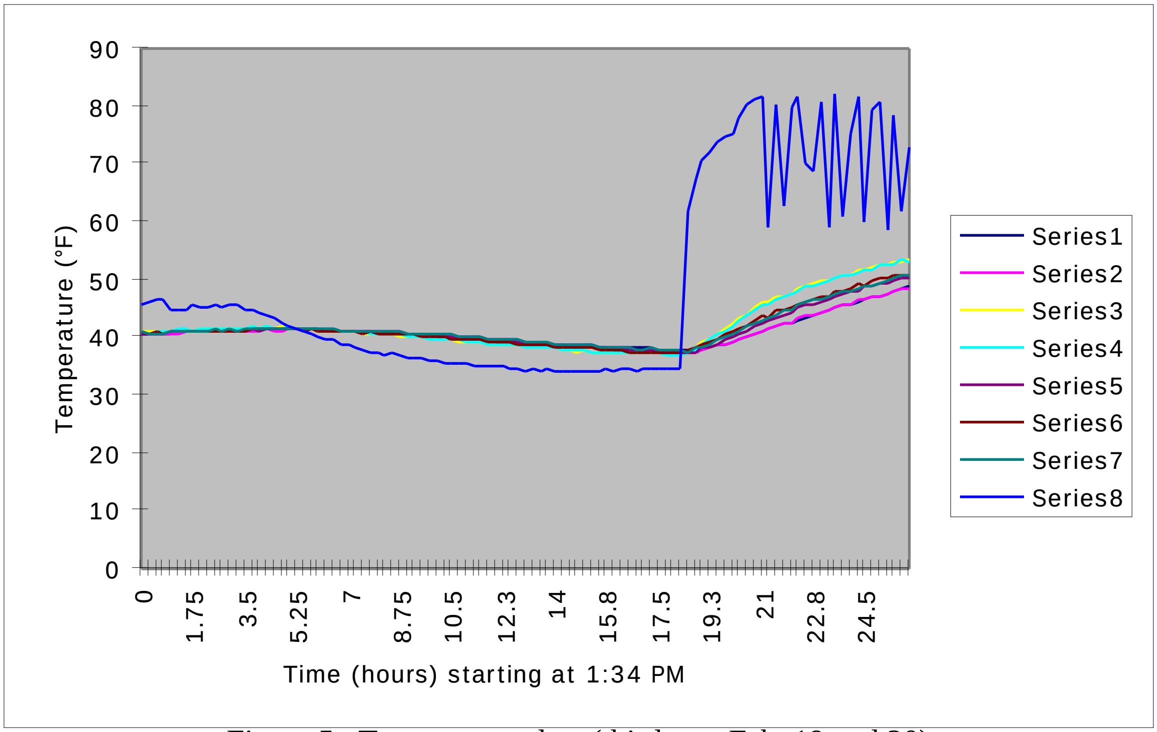

Figure 5. Temperature data (third run, Feb. 19 and 20).

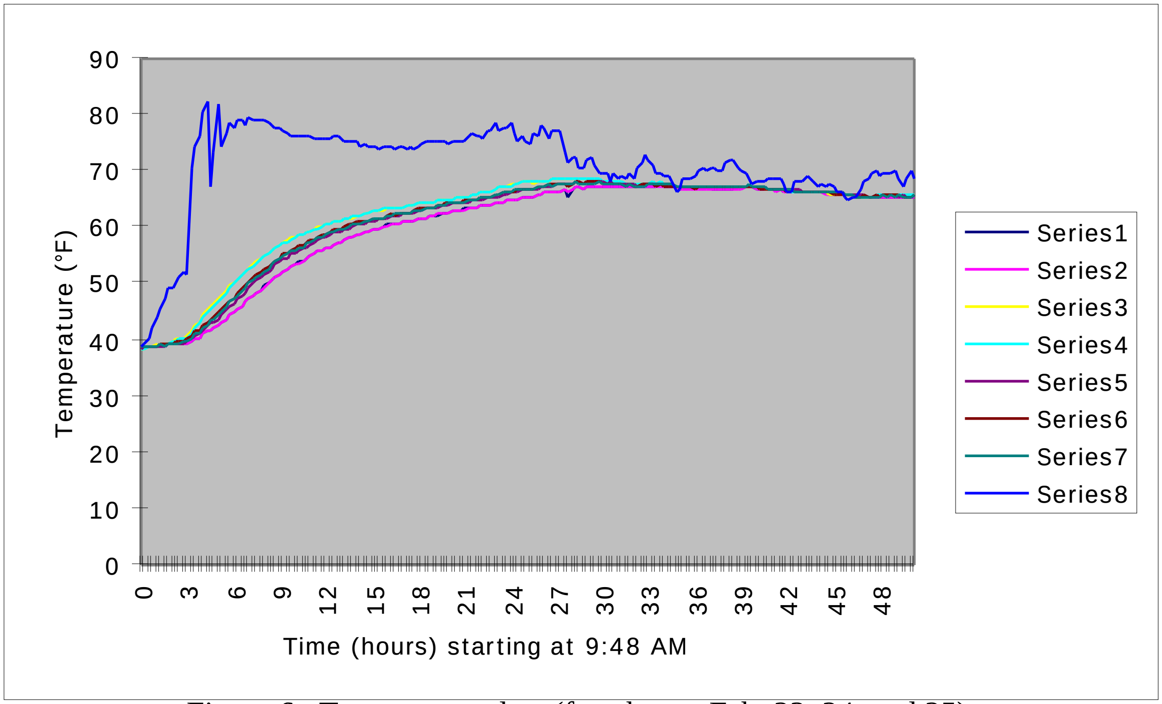

Figure 6. Temperature data (fourth run, Feb. 23, 24, and 25).