Investigation of PVC Pipe Failure at Terrell State Hospital - Final Report

Submitted to

Terrell State Hospital
Texas Department of Mental Health and Mental Retardation (MHMR)

Submitted by

Guanghua Wei
Song Deng
David Claridge, Ph.D, P.E.
Dan Turner, Ph.D, P.E.

Energy Systems Laboratory
Texas A&M University
College Station, TX 77843

May 2000

Executive Summary

At the request of Terrell State Hospital and MHMR, the Energy Systems Laboratory at Texas A&M University investigated the failure of the PVC pipes serving the chilled water loop at Terrell State Hospital. There were two PVC pipe failures where the PVC pipe bulged out. Based on laboratory test result and trend data from the building automatic control system, it is concluded that the deadheading of building chilled water pump caused the failure. However, it is not clear what caused the building isolation valve to close that resulted in pump deadheading. We are still investigating the cause.

The failed PVC pipe was sent to Materials Performance Inc for testing. Short and long-term mechanical properties were compared for a section from the failed pipe and a new PVC pipe. Results on both tests indicate that the mechanical properties for the failed pipe were similar to that of a new PVC pipe. The possibility of defective PVC pipe material that caused the failure was ruled out.

Several pressure transmitters were installed in various locations throughout the chilled water loop. Monitoring of the chilled water loop pressure did not show unusual water pressure in the loop.

During the course of this investigation, it was found from the building automation system that the failed section of the PVC pipe was located closed to a chilled water pump which had been accidentally deadheading for over 52 hours prior to the second failure. It is concluded that the failure of the PVC pipe was caused by high temperature inside the pipe as a result of pump deadheading. This conclusion is strengthened by high chilled water temperature measured (170°F) after similar chilled water pump deadheading situations occurred in buildings at Texas A&M recently.

Introduction

Terrell State Hospital has a chilled water loop which supplies chilled water to major buildings on the campus. The chilled water pipe is direct buried PVC pipe. In June and July of 1999, there were two (2) PVC pipe failures which occurred at Building 691.

Refer to the schematic of the piping in Figure 1. Chilled water is delivered to Building 691 by direct buried PVC pipes. The PVC pipes come out of the ground and joint the building pipes, see Figure 2. The building pipe is made of steel. There is one building chilled water pump that is equipped with a variable frequency drive for the motor. An isolation valve is installed in the return pipe inside the building.

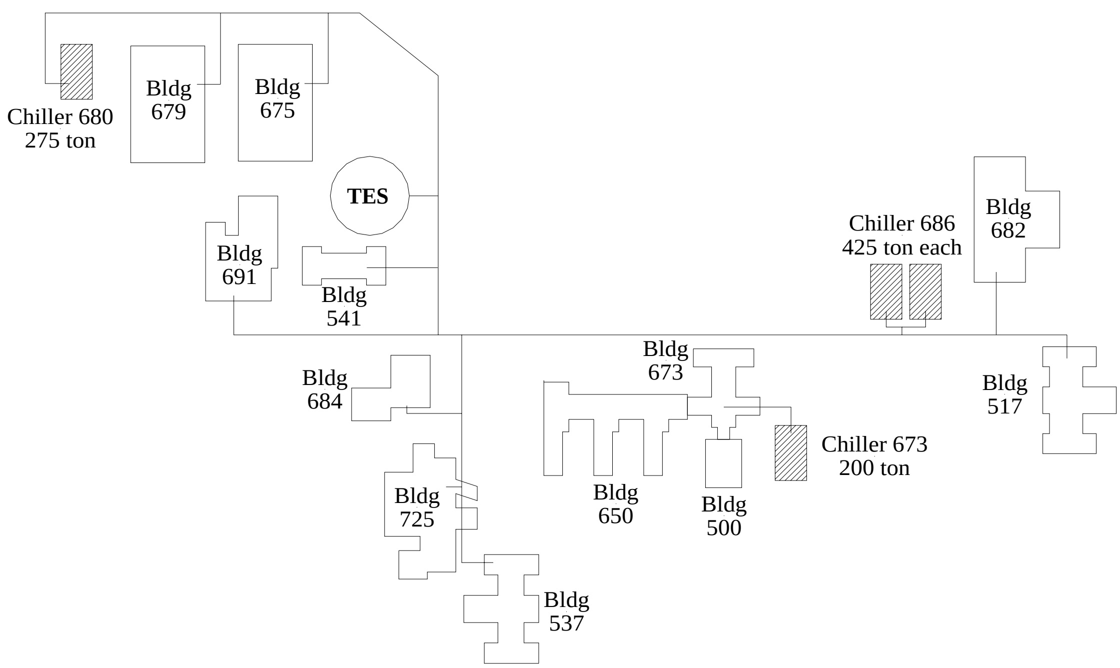

Figure 1. Schematic of the campus chilled water loop.

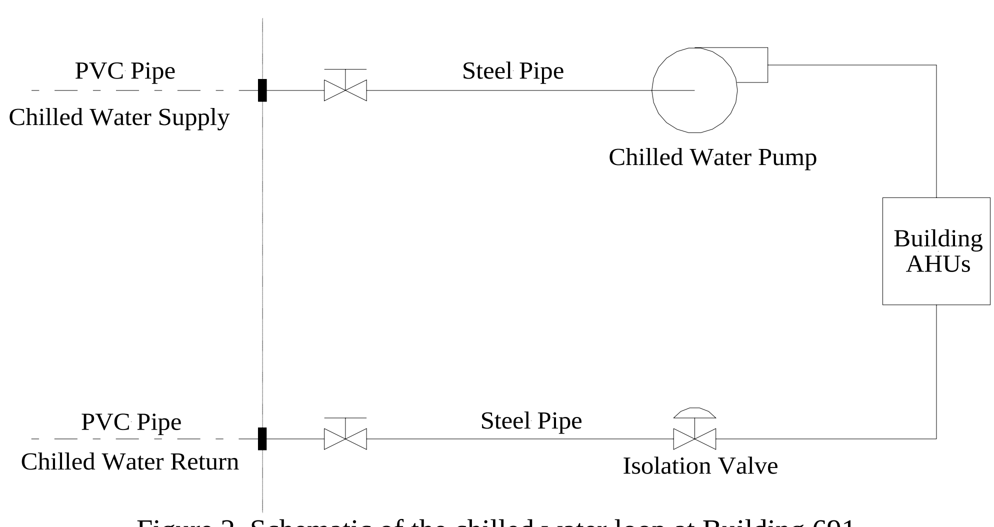

Figure 2. Schematic of the chilled water loop at Building 691.

The first failure occurred at the junction of the PVC pipe and the steel pipe on the chilled water supply side, approximately 50 feet upstream of the building chilled water pump. Figure 3(a) is the picture of the ballooned PVC pipe. The failed PVC pipe was removed and replaced by a new steel pipe about 20 feet long. The second failure occurred at the place where the new steel pipe made the connection with the PVC pipe. Figure 3(b) shows the failed section. Note that the pipe just started to swell.

(a) (b)

Figure 3. Failed section of the PVC pipe with flange in one end.

When the second failed PVC pipe was removed, it was found that one section of the PVC pipe had a lot of bulges inside the pipe. See Figure 4.

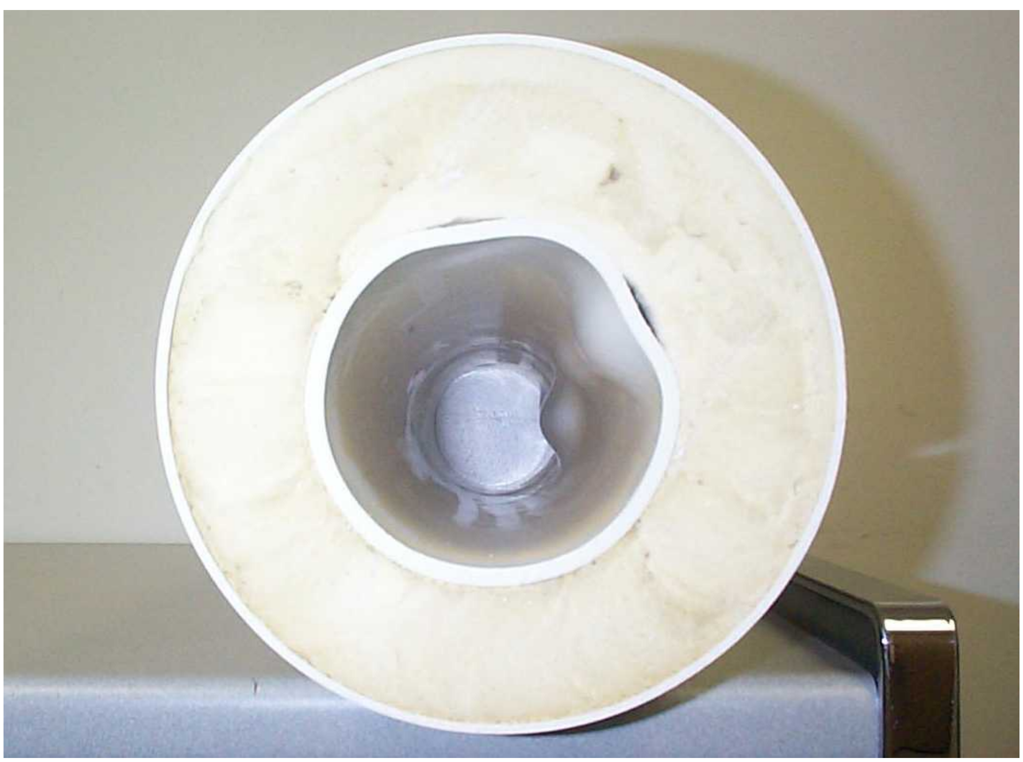

Figure 4. Inside of the PVC pipe cut from places closed to the failed sections.

Testing and Analysis

The failed PVC pipe was sent to a material performance company to determine the quality of the pipe. At the same time, ESL investigated the operating history of the building, the chiller plants, and the thermal storage tank. Chilled water pressures at different locations were monitored and recorded for 2 months. The following are the detailed findings.

Material Testing

The PVC pipe was sent to Materials Performance Inc, a company specialized in material performance testing, for evaluation. Short and long-term mechanical properties were compared for a section from the failed pipe and a new PVC pipe. Results on both tests indicate that the mechanical properties for the failed pipe were similar to that of a new PVC pipe. A complete copy of the test report is attached at the end of this report.

Analysis

There are two CSI controllers inside Building 691. One controller controls the chilled water pump, building isolation valve, and monitors the chilled water temperature and pressure. The other controller, which is a less expensive type, controls all 9 AHUs in the building.

The chilled water pressures at building 691, the main chiller plant, and the thermal storage tank were monitored and recorded for two months. No unusual chilled water pressure was observed at those locations.

Meanwhile, trend log from the control system indicated that the chilled water pump at Building 691 had been deadheading during nighttime and weekends prior to the second PVC pipe failure. The building control program (refer to page 92 of the Continuous Commissioning Report for Terrell State Hospital, ESL 1999) enabled the building chilled water pump based on outside air temperature and the control valve position at roof top unit #9 of Building 691. The building isolation valve was controlled by the building occupancy schedule, which was from 12:05 am to 8:00 pm on Monday and 6:00 am to 8:00 pm from Tuesday to Friday. When the building was occupied or the chilled water pump was enabled, the isolation valve opened. There was a 60-second time delay in the DDC (direct digital control) module that turns on the chilled water pump. In other words, when the chilled water pump was enabled, the isolation valve opened. One minute later, the chilled water pump was turned on. When the building became unoccupied, the AHUs stopped and chilled water control valves closed. Chilled water pump also stopped. The isolation valve would close unless the chilled water pump was commanded to be on.

There were two types of trending available from the control system for every control point: trending with an archive cell and trending without an archive cell. For points trended with archive cells, the historical data can be retrieved from the computer hard drive provided that the trend data is archived regularly. For points trended without archived cells, however, the data is not collected in the computer hard drive. Instead, certain amount of data is stored in the controller panel and can be displayed on the control screen if needed.

Chilled water pump status was trended without an archived cell. Trend plot printed on July 23, 1999 showed that the pump was commanded to be on from July 8 to July 20, 1999, prior to the second PVC pipe failure was discovered (Earlier trend data is not available from the control system). Although the AHUs were supposed to be shut down after 8:00 pm, they were actually running continuously due to control program difficulties (discussed in the next section). Since the building chilled water pump operated according to chilled water valve position, it kept running in order to maintain the cold deck temperature set point. Unfortunately, the isolation valve still operated according to the occupancy schedule. Consequently, the building chilled water pump was deadheading during the unoccupied periods. The maximum deadheading length was 52 hours during the weekend (from 8:00 pm on Friday to 12:05 am on Monday).

There was no interlock between the building chilled water pump and the isolation valve such that the isolation valve verified the chilled water pump status before it shut off. This could also potentially cause water hammers when the building becomes unoccupied, since the isolation valve is an industrial type electricity-driven valve, which was observed to take actions (closing or opening) in a few seconds.

Control Program Problems

The control program failed to turn off the AHUs when the building became unoccupied. The exact cause of this failure is unclear. The building had past history of "corrupted internal program", as described by CSI maintenance personnel and it was listed in the recommendations in the "Continuous Commissioning Report for Terrell State Hospital" (page 96).

Conversations with David Wilhite revealed that there were some wiring problems for power supply to control panels in buildings 650, 675, 679, and 691. CSI maintenance personnel have been to Terrell State Hospital to fix the problem after it was discovered in March 2000 by David. Since one of Building 691's control panel was in the list, the wiring problems may caused the controller to keep reconfiguring itself in order to communicate with the host computer. Control commands from the control program may have been lost during the process. We contacted David and ran a test by putting the control program prior to the PVC failure back into the system and observed the operation. We changed the time schedule to make the building unoccupied, however, the isolation was still open while the pump was running.

Comparison and Analysis with Similar Incidents Occurred at TAMU

We are able to collect some information of two similar incidents happened on Texas A&M University campus, which has a total of more than 14 million ft^2 conditioned area and more than 130 major buildings. As Terrell State Hospital, most buildings receive chilled water from the central plant(s) through campus loops.

Case 1:

One of the two incidents happened in the beginning of January 2000. Right before the incident, some loop work was performed and the building had to be isolated from the campus loops with its isolation valves. Meanwhile, building chilled water pump was turned off. As shown in Figure 5, four valves (2 sets of supply and return valves) were shut to isolate the building, and the manual valve in the building bypass line had been shut at an earlier time. After loop work was done, a different operator was assigned to go to the building to put it back on line, who only opened two of the four closed valves (1 set of supply and return valves) and turned on the building chilled water pump. After a couple of days, hot call came from the building, and hot water temperature was measured in the chilled water line. It was thought that somehow the chilled water lines of this building was cross connected to the campus domestic hot water loop, which normally have a supply water temperature around 150 °F. Later, another team went to the building and checked the valves. One of the two closed valves was opened, and the other one was assumed to be open since the valve could not be turned due to rusty conditions. Finally, this closed valve was identified and opened, and the building was put back to normal operation. The longest recorded pump-deadheading period is about 20 hours (from noon to the next morning 8:00), and the temperature besides the pump was measured to be 170 °F after this.

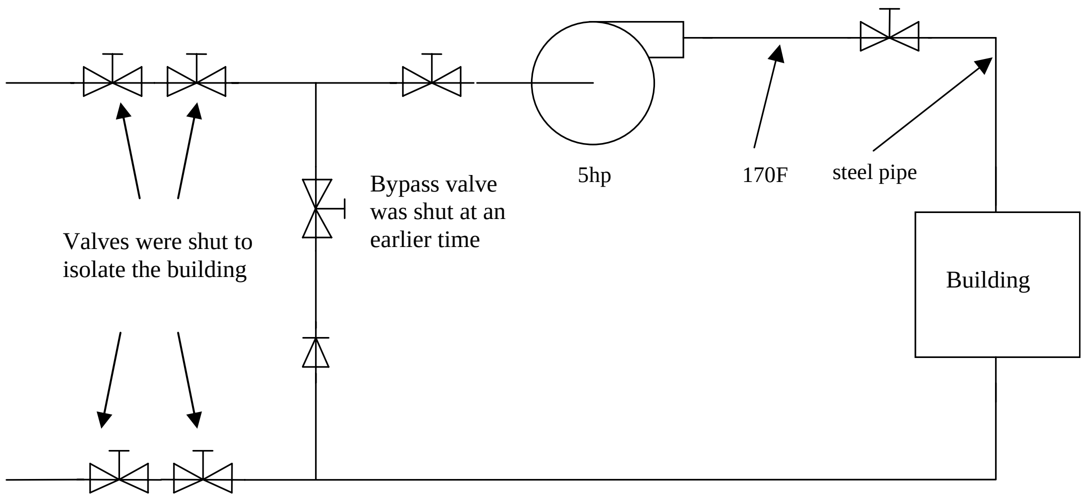

Figure 5. Case 1: deadheading of a 5-hp building chilled water pump caused 170 °F water temperature being measured in the chilled water line

Case 2:

Another incident happened a little earlier in a mechanical lab, where a water loop with a 5 hp pump was set up for some testing. As shown in Figure 6, the discharge side of the pump was built with clear plastic pipe for observation of the local flow pattern and conditions. One day, the pump was left deadheading, and it was told that the clear plastic pipe was resulted to be "melted".

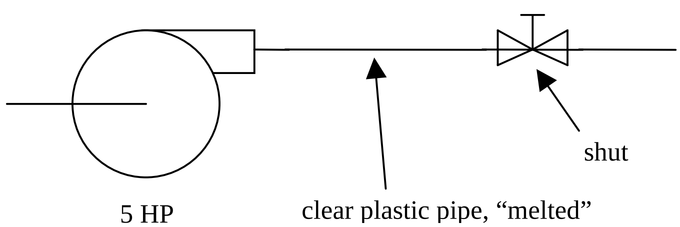

Figure 6. Case 2: deadheading of a 5-hp lab pump caused clear plastic pipe at discharge side "melted"

Comparison of these three cases was summarized in Table 1.

Table 1. Comparison of Pump Deadhead Incidents at TAMU and TSH

Case	Detailed Diagram	Where	Pump Size	Period	Pipe Material	Reason	Normal Water T	Results
1	Figure 5	One Tamu bldg.	5 hp	20 hrs	Steel	Manual valve(s) shut	Chilled water, 44 °F	170 °F measured close to pump
2	Figure 6	One Tamu lab	5 hp	N/A	Clear Plastic	Manual valve shut	City Water, Room T	Clear plastic pipe "melted"
3	Figure 7	TSH Bldg. 691	7.5 hp	58 hrs	PVC/ Steel	Return control valve shut	Chilled water, 40 °F	Caused upstream (about 50 ft away) PVC pipe failure?

EES Software Simulation:
From some study and research, we found the pump-deadheading situation is hard to be simulated. The conduction and convection model is complicated and even hard to define. By making quite a few assumptions, we did a very preliminary simulation analysis by putting together some basic energy balance equations, just trying to provide some ideas.

Field conditions:
1. 4" PVC pipe and steel pipe,
2. 7.5 hp building chilled water pump.

Assumptions:
1. Normal chilled water supply temperature Ts = 40 °F,
2. Deadheading period = 58 hours (Friday 8:00 p.m. until the next Monday 6: a.m.),
3. Pipes were well insulated,
4. 50 % of the electricity consumed by the deadheaded pump (assuming 6 hp) was absorbed by the stagnant water as heat to increase its temperature.
5. The stagnant water temperature increased universally.
6. There is no any kind of heat transfer process between the stagnant water that were heated up and the environment (beyond water, beyond piping, ground soil, air, etc.).

Conclusion:

The heat generated by the deadheaded pump can heat up 3,400 lbs. water from 40 °F to 170 °F, which is equivalent to 620 feet of 4" pipe full of water.

Conclusions

We felt that the PVC pipe failure was caused by the deadheading of building chilled water pump. However, the cause of the deadheading is not clear yet. We will continue to investigate the problem. Meanwhile, it is recommended that we keep the building isolation valve open (has been implemented after the failure) and fix any wiring problems at the buildings.

Appendix PVC Pipe Test Report

Final Report
9/3/99
MPI Reference – 2058-1
MPI Contact – Steve Bradley

INVESTIGATION OF PVC PIPE FAILURE AT A MHMR FACILITY

I. EXECUTIVE SUMMARY

Materials Performance, Inc. has investigated the failure of PVC piping used for water chillers in a HVAC system at a MHMR facility. Short and long-term mechanical properties were compared for a pipe piece sectioned from the failure with a new PVC pipe. Results on both tests indicate that the mechanical properties for the pipe in question were similar to a new piece of pipe in both short and long-term testing at several temperatures. During the course of the investigation, it was learned that the circulation pump may have been dead-headed causing an increase in temperature at the PVC pipe. It is speculated that the increase in temperature and pressure from the dead-heading of the pump lead to the failure of the PVC pipe. We would recommend that a thermocouple and pressure gauge be placed at the failure location under deadheaded conditions to confirm the actual temperature and pressure increases.

II. TESTING PROCEDURES

Materials and delivery

Pipe sections from the failures were delivered to our laboratories for the investigation. Figure 1 shows a ballooned portion of the pipe adjacent to a flange that connected to a steel pipe. Figure 2 shows the flange connection were the PVC pipe attached to a metal pipe that proceeded to a circulation pump. The flange appeared to be warped due to excess heat.

Figure 1: HVAC water chiller PVC pipe that ballooned and failed.

Figure 2: Flange that connected PVC pipe with metal pipe. It was noted that the PVC flange was warped due to excess heat.

Sample Preparation

Samples were cut from a non-enlarged section of the failed pipe and new pipe in the lengthwise direction. Samples were then machined into ASTM D638 Type I dogbone specimens using a template and a router. The cross-section of each sample was measured using a micrometer. All samples were conditioned at temperature prior to loading.

Testing Equipment

The loading frames use a lever arm mechanism to provide the stress on the sample. The temperature in the environmental chambers shown in Figure 3 were controlled by microcontroller connected to a surface mounted thermocouple attached to the sample.

Figure 3: Creep stands with environmental chamber enclosures used for testing PVC tensile specimens.

III.   TESTING RESULTS

Short-term mechanical properties were determined over a wide range of stresses by performing short-time creep tests, measuring displacement and then calculating strain as a function of time. The samples were progressively loaded to 1500 psi, 3000 psi, 4000 psi, 5000 psi, 6000 psi, and 7000 psi. The loads and the associated stresses were applied for three minutes and then unloaded for 15 minutes. The displacement as a function of time was measured and used to calculate the creep strain as a function of time. These tests were performed at 73 F, 110 F and 150 F. A comparison of the results for the MHMR pipe failure and the new pipe at several stresses are shown in Figures 4-7, respectively. Figure 4 shows several load/unloads performed at 150 F and 1500 psi loading for each of these tests with only one data set distinctly different from the others. Figure 5 shows the same samples after a 15 minute unload with a 3000 psi load applied. Again, only one data set is off from the others with most of the MHMR pipe showing less creep strain than the new material. Figure 6 shows all load/unloads for the MHMR and new pipe at 110 F. Figure 7 shows all load/unload data for the MHMR and new pipe at 73 F. Figures 6 and 7 show that the MHMR and new pipe have about the same creep properties under load at various temperatures.

Long-term creep tests at 1500 psi should approximate the maximum service stress that should be observed in practice. Tests were performed at 110 F and 150 F to estimate the long-term mechanical properties in service conditions and are shown in Figures 8 and 9 respectively. Both graphs show similar long-term creep behavior for the materials.

IV. CONCLUSIONS AND RECOMMENDATIONS

All results except one load/unload test at 1500 psi and 150 F suggest that the properties of the MHMR and new material are similar. This indicates that the pipe failure was not a result of inferior material properties, but due to an external environmental or loading condition.

The long-term ASTM pressure rating of the pipe is 160 psi internal pressure. There is a derating factor which is used to reduce allowable design pressure as the temperature increases. For PVC it is as follows:

80 F	0.88
90 F	0.75
100 F	0.62
110 F	0.5
120 F	0.4
130 F	0.3
140 F	0.22

In other words, if the long-term internal pressure rating of the pipe was 160 psi at room temperature it would be reduced to (160)(.22)= 35 psi at 140 F. If the temperature went higher then the pressure rating would be reduced even further.

During the course of the investigation, it was learned that the circulation pump may have been deadheaded causing an increase in temperature at the PVC pipe. It is speculated that the increase in temperature and pressure from the dead-heading of the pump lead to the failure of the PVC pipe. We noted that the ballooning of the pipe occurred in a section near a flange. Heat generated from deadheading would be highest at this point were the PVC pipe contacted metal pipe. In addition, the pipe at this location was unsupported by foam insulation and an additional piece of exterior PVC piping as was common to the rest of the piping. If temperature and pressure build up occurred, failure would most likely occur at this location. We would recommend that a thermocouple and pressure gauge be placed at the failure location under deadheaded conditions to confirm the actual temperature and pressure increases. Changes in the system design or operation could then be made based on this information.

If you have any further questions regarding the test or conclusions, feel free to contact us.

Best regards,

Steven Bradley