SERI/TP-254-3157
UC Category: 59a
DE87001166

Polybutylene Pipe Freeze/Thaw Reliability Testing

Robert B. Farrington

April 1987

Prepared for the
ASES Solar '87 Conference
Portland, Oregon
12-16 July 1987

Prepared under Task No. 3062.410
FTP No. 1-624

Solar Energy Research Institute
A Division of Midwest Research Institute

1617 Cole Boulevard
Golden, Colorado 80401-3393

Prepared for the
U.S. Department of Energy
Contract No. DE-AC02-83CH10093

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Printed in the United States of America
Available from:
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

Price: Microfiche A01
Printed Copy A02

Codes are used for pricing all publications. The code is determined by the number of pages in the publication. Information pertaining to the pricing codes can be found in the current issue of the following publications, which are generally available in most libraries: *Energy Research Abstracts, (ERA); Government Reports Announcements* and Index (*GRA* and I); *Scientific and Technical Abstract Reports (STAR);* and publication. NTIS-PR-360 available from NTIS at the above address.

POLYBUTYLENE PIPE FREEZE/THAW RELIABILITY TESTING

Robert B. Farrington, P.E.
Solar Energy Research Institute
1617 Cole Blvd.
Golden, Colorado 80401

ABSTRACT

This paper discusses the ability of polybutylene pipe to withstand repeated freezing and thawing. The test apparatus, test procedure, list of chronological events, and results are discussed. Polybutylene piping has potential use in active solar heating systems and integral-collector-storage systems.

1. INTRODUCTION

The purpose of this work is to determine the reliability of polybutylene pipe when it is repeatedly frozen and thawed. This paper begins by discussing the background of why polybutylene pipe may be a suitable substitute for copper pipe and describes previous test results. The apparatus, test procedure, and test results are then discussed, ending with our recommendations and conclusions.

All solar domestic hot water systems require some type of piping to transport fluid to and from the collector, including integrated-collector-storage (ICS) systems, in which the storage tank also serves as the collector. Among methods of increasing the cost-effectiveness and acceptability of solar energy systems are reducing installation costs, increasing reliability, and reducing initial costs. Polybutylene pipe offers the potential to do all three. It can be installed in long lengths and because of its flexibility can easily be installed around obstacles, unlike copper pipe which comes in shorter lengths and requires soldered fittings to detour obstacles. Polybutylene pipe also costs less than copper pipe, leading to lower initial capital costs. Fewer fittings mean less installation time and potentially greater reliability since there are fewer sources of potentially leaky fittings. Instead of soldered fittings, such as for copper pipes, or fusion welds, such as for chlorinated polyvinyl chloride, polybutylene pipe uses compression fittings with copper or aluminum compression rings installed with a simple crimping tool.

Polybutylene pipe has other advantages over copper pipe. Being a polymer pipe it is not subject to the same type of corrosion and scaling that can plague copper piping. It also has the potential to withstand freezing without damage. However, polybutylene pipe also has limitations. For example, it can not withstand continuous temperatures above 93°C (200°F), which means that it can not be connected directly to a flat-plate collector [which can stagnate at temperatures of 204°C (400°F)]. Likewise, water entering a stagnating collector will be superheated and travel through the pipe at excessive temperatures and pressures causing the polybutylene pipe to fail. Kutscher et al. (1) provide guidelines for minimum lengths of insulated and uninsulated pipe required to prevent the pipe from exceeding 93°C (200°F) when the collector is stagnating. Polybutylene pipe, being flexible, requires more supports for horizontal pipe runs [recommended approximately every 0.5 m (20 n.)] than copper pipe if complete draining is critical, such as for freeze protection.

Some properties of polybutylene pipe are compared to copper and steel in Table 1. Polybutylene pipe is manufactured to conform to ASTM Standard D3309, which specifies that the pipe and associated fittings should have a minimum burst (gauge) pressure of 3.03 MPa (440 psi) at 23°C (73°F). Furthermore, the pipe and fittings should be capable of continuous operation at 82°C (180°F) with a minimum burst pressure at this temperature of 2.21 MPa (320 psi). The pipe should also be capable

TABLE 1. PROPERTIES OF POLYBUTYLENE[a], COPPER, AND STEEL

Property	Polybutylene	Copper	Steel
Density, kg/m^3	912	8910	7870
Specific heat, J/kg °C	1880	385	447
Thermal exp. coeff., 10^{-6} m/m °C	150	17	12
Thermal cond. 0° - 100° C, W/m °C	0.22	389	52
Tensile strength, MPa	28	220	450
Melting point, °C	126	1082	1516
Cost, \$/m[b]	1.02	2.20	-

[a] Compiled from Modern Plastics Encyclopedia, Guide to Plastics.

[b] Nominal 3/4-in. diameter.

of withstanding a minimum of 100 cycles between 16° and 82°C (60° and 180°F) at a pressure of 0.69 MPa (100 psi). National Sanitation Foundation tests showed that the average burst pressure was 1.9 MPa (275 psi) at 99°C (210°F) and that the pipe sustained a pressure of 1 MPa (150 psi) continuously for 18 months without failure.

Many of these properties of polybutylene pipe were identified by SERI in 1983 (1). One particular advantage of polybutylene pipe was that it was being accepted for cold potable water use by plumbing codes. However, there were questions on how reliably polybutylene pipe and the fittings would survive continual thermal cycling. In 1984, SERI tested the reliability of polybutylene pipe to withstand repeated, frequent thermal cycling between 20°C (68°F) and 93°C (200°F) (2). We tested 10 m (33 ft) of nominal 3/4-in. polybutylene pipe with various types of acetal fittings (elbows, tees, couplings) and valve arrangements. The polybutylene pipe cycled about 24,000 times over a five-month period without any signs of deterioration. The burst pressure after thermally cycling, using 13°C (55°F) water, was over 3.5 MPa (500 psi) for the entire loop and various pipe segments. In only one of the five burst tests did a fitting separate from the pipe, whereas in the other cases, the pipe split. However, acetal fittings are no longer recommended by the manufacturer. Our experience showed us the polybutylene pipe expands and contracts significantly more than copper pipe. This can be seen from the very high thermal expansion coefficient in Table 1. Proper care needs to be exercised in installing pipe insulation to prevent unnecessary tension on the pipe if a rigid insulation (such as polyurethane) is installed when the pipe is warm. A flexible insulation (such as elastomeric rubber) can be compressed when installed and will expand to cover the entire pipe when it becomes warm.

Recently, integrated-collector-storage systems have become more popular (3). These systems are generally used in milder climates but can be used in places with frequent freezing if the pipes to and from the system are protected from freezing. In general, there is little danger of the collector-storage tank freezing. Polybutylene pipe seemed like a good candidate for the piping material because it appeared freeze-tolerant. Therefore, in 1986, SERI began testing the reliability of polybutylene pipe when subject to repeated freezing and thawing.

2. APPARATUS

There are various important considerations when testing the ability of pipe to withstand freezing and thawing. Listed below are some of the parameters that we thought were important.

- Keep the pipe pressurized during the freezing and thawing cycle.
- Use temperatures, rather than equivalent pressures, to include any temperature effects on the chemical structure of the pipe.
- Include a variety of fittings (elbows, tees, couplings) of various compositions (copper, brass, polymer) with aluminum and copper compression rings.
- Install pipes horizontally and vertically.
- Install short and long distances of pipe between fittings.
- Cycle the pipe between realistic temperatures, to include the effect of operating at warm temperatures.
- Flow hot water through the pipes after thawing.

We constructed a test loop, as shown in Figure 1, with 18 m (60 ft) of nominal 1/2-in. polybutylene pipe that included 36 elbows, 10 tees, 8 brass couplings, and 3 polymer couplings. The types of fittings used, with the exception of a brass coupling, are shown in Figure 2. We later added eight more polymer couplings and replaced the three original polymer couplings with brass couplings. The length between fittings varied between 5 and 91 cm (2 and 36 in.). The pipe was plumbed in six parallel loops installed in 4.3 m^3 (15.1 ft^3) chest freezer with penetrations as shown in Figure 1. A 1500-W, two-speed, two-heater-setting electric hair dryer was installed in the freezer for thawing the pipes. The freezer did not have an adjustable thermostat. The heater was set at medium heat and high blower speed.

Dial thermometers were installed upstream and downstream of the freezer to measure the temperature of the hot water into and out of the polybutylene loop during the thaw cycle. A rotometer gave visual indication of the hot water flow rate and a pressure gauge on the upstream side of the polybutylene loop displayed water pressure to the loop during freezing and thawing cycles. A mercury glass stem thermometer, installed at the mid-point of the freezer, gave a visual indication of the air temperature in the freezer. A control system, built to control the freezing and heating cycles as well as leak detection, consisted of a 24-h

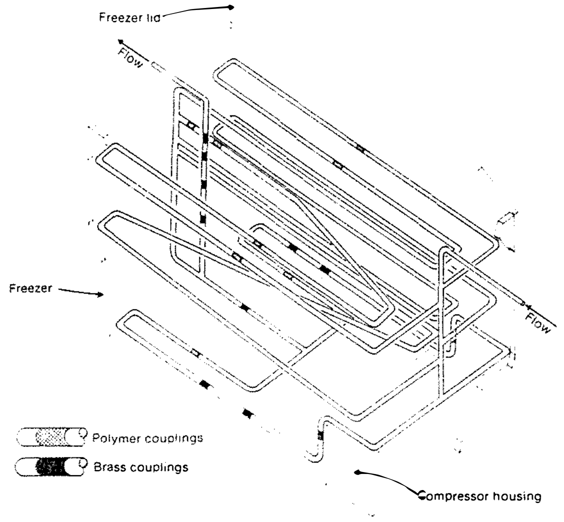

Fig. 1. Schematic of polybutylene pipe arrangement in freezer

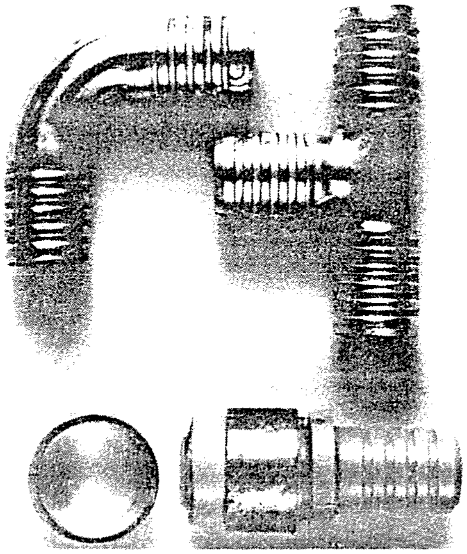

Fig. 2. Types of Compression Fittings

timer, an electro-mechanical counter, a water sensor, and the fault detection system patented by SERI (4). We installed a drain in the bottom of the freezer to channel leaking water to a water sensor and then to a floor drain.

3. TEST PROCEDURE

The test procedure consisted of installing the polybutylene pipe and instrumentation and checking the test loop for leaks. The pipe was frozen overnight and then thawed to check for integrity of the plumbing and operation of the control system. After the loop was verified to operate correctly, we then began to operate automatically with 45 min of heating followed by 7.25 h of freezing, completing 4 cycles per day.

We also conducted extended freezing tests to determine the minimum temperature of the freezer.

4. TEST RESULTS

We began continual testing on May 21, 1986. A typical cycle was:

The pipes froze solid within 3.5 h and thawed in about 10 min. This resulted in typically 10 min of thawing, 35 min with flow through this polybutylene pipe, 3.5 h of cooling down and freezing, and nearly 2 h of being frozen solid. The cycling was a realistic measure of actual freezing, thawing, and operating at moderate temperatures. In each cycle, the pipe froze solid and then reached actual operating temperatures for a solar hot water system.

We performed long-term freezing tests to determine the minimum temperature of the freezer and to determine if a longer freezing period affected the polybutylene pipe. After 49 h of continuous freezing the freezer temperature was -21°C (-6°F), very close to that obtained during the regular freeze cycle. The heater failed on October 13 and was replaced with the same model heater. However, it heated the freezer to a slightly higher temperature, causing the final freezer temperature to reach only -15°C rather than the -20°C reached with the original heater.

A chronology of events is given in Table 2. Our attempt to measure the change in pipe diameter with a micrometer as the polybutylene pipe froze was unsuccessful because the pipe was not round.

The fault detection system detected all the failures and automatically shut off the water pressure to the loop.

5. CONCLUSIONS AND RECOMMENDATIONS

The cycling was a realistic measure of actual freezing, thawing, and operating at moderate temperatures. In each cycle, the pipe froze solid and then reached actual operating temperatures for a solar hot water system. The copper and brass fittings operated without any failures and only had signs of mild surface discoloration of the copper. The copper and brass fittings withstood the freezing conditions even though filled with water at a gauge pressure of 550 kPa (80 psig) and in some locations with only short segments of polybutylene pipe between copper fittings. The polymer couplings with aluminum or copper compression rings were not as reliable as the brass couplings.

The most significant observations during the test period were the

1. Appearance of a thin green corrosion layer on some of the copper fittings at 329 cycles. It did not appear to be very serious as it was only a surface discoloration by oxidation.
2. Failure of the coupling between the polybutylene pipe and copper pipe immediately outside the exit side of the freezer at 409 cycles, resulting in a slight leak. This could have worked loose from the rapid opening and closing of the drain solenoid valve located about 20 cm downstream from the fitting. Recrimping the compression ring on the polybutylene pipe solved the problem.
3. Catastrophic failure of all three original polymer couplings at 579 cycles. The failed joints used aluminum compression rings. Apparently the repeated freezing and thawing caused the polybutylene pipe to slowly work off the fitting. One coupling was deeply gouged (see Figure 3), showing the large stress on the fitting as the pipe was slowly worked off. It appears that the polymer coupling is too soft to maintain a good compression fit under severe freeze/thaw cycling. Since these three failures occurred at essentially the same time and for two orientations, this appears to be a fairly uniform process. These fittings were replaced and additional fittings installed.
4. Catastrophic failure of the polybutylene pipe. A horizontal section, shown in Figure 4, split about 1 cm long from freezing after 699

TABLE 2. SUMMARY OF CHRONOLOGICAL EVENTS

Date (Cycles)	Observations
5/21/86 (0)	Constructed and pressure-tested polybutylene loop. Froze polybutylene pipes overnight. Pipes pressurized; no flow.
5/22/86 (0)	9:00 a.m. Freezer temp -21°C. Verified freezing and heating modes. Pipes froze solid within 3 h.
6/02/86 (59)	Pipe supports (wires) collapsed, causing frozen polybutylene pipe to fall. No apparent damage to pipes. Supports were reinforced.
6/03/86	Operated heating cycle with blower heaters off to determine if blower motor alone would give off enough heat to thaw the pipe. Results show that heating is required.
6/23/86 (175)	Began 49-h extended freezing test. Ambient temperature steady at -21°C.
7/24/86 (329)	Thin green film (corrosion) forming on last elbow before polybutylene pipe exits freezer and on first tee of polybutylene pipe after entering freezer. Other fittings appear fine.
7/28/86 (345)	Loss of water pressure in lab. Loop was isolated from the water mains to prevent excessive pressure surge when pressure was restored.
8/14/86 (409)	Puddle forming under freezer. Polybutylene/copper connector, located immediately after polybutylene pipe leaves the freezer, was dripping. Recrimped fitting. Corrosion observed near the top of this fitting and scaling evident near leak and along dripline. Gauge pressure at 690 kPa (100 psig) at times.
8/15/86	Power failure in lab. Isolated test loop to prevent pressure surge when power restored to building water pumps. Reset timer to account for power failure. Recrimped fitting is not leaking.
9/05/86 (558)	Gauge pressure up to 1100 kPa (160 psig) for 30 min. Notified building maintenance of excessive water pressure. Photographed test loop. Corrosion evident on two tees, two elbows. All three polymer couplings, two installed horizontally and one vertically, show evidence of separating. The sides of the couplings that are separating are held by aluminum rather than copper compression rings. Brass couplings do not show any evidence of separating.
9/09/86 (579)	Catastrophic failure of vertical polymer coupling. System shut off automatically. Failure of one horizontal fitting was imminent—it separated when the pipe was moved slightly. The third fitting had crept about one-third of the way out of the pipe, exposing about 5 mm of the fitting. All three polymer couplings were replaced with brass couplings using a combination of copper and aluminum compression rings. Added six additional polymer couplings; four with copper compression rings and two with aluminum rings. Put new element in water sensor. Photographed failed fittings.
9/18/86	A short section of polybutylene pipe immediately in stream of blower has significantly expanded. It has swollen around the compression rings. Blower was moved to avoid directly heating the pipe.
9/30/86 (699)	Catastrophic failure of pipe segment. System shut off automatically. A horizontal pipe in contact with a vertical pipe split horizontally about 1 cm from freezing. The failed pipe sprayed a significant volume of water when pressurized. When water flowed through pipes, reducing the pressure to about 240 kPa (40 psig) in the pipe, it leaked about one drop every 3 to 5 s. Replaced a 5-cm section of pipe using two polymer couplings, one with aluminum compression rings and one with two copper compression rings, and put a new element in water sensor.
10/13/86 (787)	The heater failed and was repaired. Measured pressure, temperatures, and flow rate every 5 min during the heating cycle and pressure and freezer temperature every 30 min during the freezing cycle.
10/14/86 (791)	Heater failed and was replaced. Repeated 30-min time-temp. measurements. Gauge pressure remained at 1310 kPa (190 psig) for 30 min and then dropped.
10/21/86 (820)	Catastrophic failure of a replacement polymer coupling with copper compression rings after 241 cycles since installation. Heater failed after operating without flow through the freezer. Freezer temp. probably approached 100°C.
10/28/86 (821)	Started continual freeze test. Freezer temperature at -21°C.
01/19/87 (821)	Water pressure turned off for 1 day to move cold water pipe.

TABLE 2. SUMMARY OF CHRONOLOGICAL EVENTS (Concluded)

Date (Cycles)	Observations
02/13/87 (821)	Restarted cycling test. During continual freeze temperature steady at -22°C. Cycling twice/day, 45 min htg/cycle.
02/25/87 (859)	Two polymer couplings beginning to separate. One separated 3 m, other 5 mm.
03/18/87 (923)	Heater failure. Three polymer couplings separating: 4 mm, 6 mm and 6-1/2 mm. Left freezer on freeze cycle.
04/06/87 (923)	Installed new heater. No further separation of polymer couplings during continual freeze. Restarted cycling 2/day.
04/17/87 (975)	Catastrophic Failure. Vertical section of pipe was scored by a light gauge retaining wire and developed a 1-cm-long split during freezing. Polymer couplings noted at 854 and 925 cyclings are now separated 7 mm, 8 mm, and 5 mm. Their failure is imminent; test was stopped.

cycles. The pipe clearly failed from freezing as evident from a slight bulge around the split. The split section was very near to a vertical pipe and may have rubbed against it during the freezing and thawing cycle. However, it is not obvious that such contact would result in failure of the pipe wall. There was no discernable erosion of the surface or evidence of contact between the pipes. The section was replaced. After 975 cycles a horizontal section of pipe also split about 1 cm from freezing. it appeared that the end of a light-gauge support wire repeatedly scored the pipe during freezing and thawing.

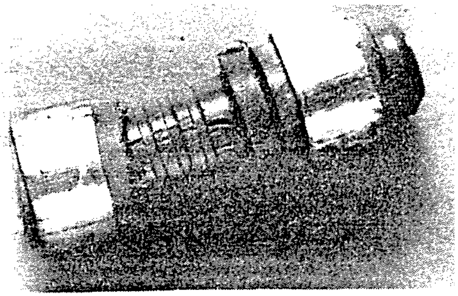

Fig. 3. Failure of Polymer Coupling

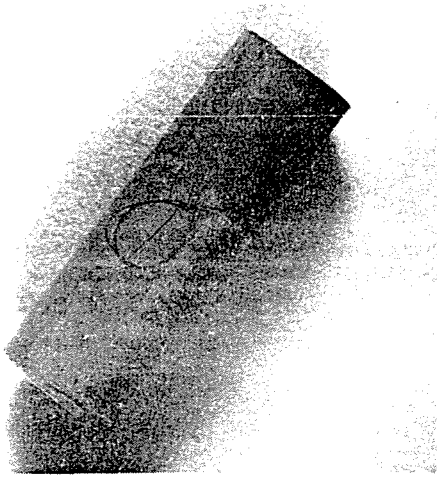

Fig. 4. Freeze Failure of Polybutylene Pipe

It is clear from this rather severe testing that polybutylene pipe, when properly installed, can easily withstand moderate, infrequent freezing. In severe winter climates it should be protected from frequent freezing when filled with water until further testing can demonstrate that polybutylene pipe can withstand frequent, severe freezing and thawing. Our testing has shown that brass connectors are more reliable than polymer connectors under severe freezing and thawing conditions. We recommend that polymer couplings not be used in polybutylene pipe loops since brass couplings are available and appear to be more reliable. The copper and brass fittings performed very well during the freeze/thaw cycling and seem well-suited for this application. Care must be exercised so the pipe does not rub against sharp or rough materials during freezing and thawing. Such conditions may score the pipe and lead to subsequent failures.

6. ACKNOWLEDGMENT

This work was funded by the Solar Buildings Research and Development Program, U.S. Department of Energy.

7. REFERENCES

(1) Kutscher, C. et al., *Low-Cost Collectors/ Systems Development Progress Report*, SERI/PR-253-1750, Solar Energy Research Institute, Golden, CO, (1984).

(2) Farrington, R., *Failure Testing of Active Solar Energy Components*, SERI/TR-253-2187, Solar Energy Research Institute, Golden, CO, (1984).

(3) Lewandowski, A., et al., *A Cost and Performance Comparison of Drainback and Integral Collector Storage Systems for Residential Domestic Hot Water*, SERI/RR-253-2594, Solar Energy Research Institute, Golden, CO, (1985).

(4) Farrington, R., *Reliability Testing of Active SDHW Components, Part III: Development of a Fault Detection System*, SERI/TR-253-2605, Solar Energy Research Institute, Golden, CO, (1986).