Anatomy of a Hydronic Boiler Failure

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Photos provided by Ray Wohlfarth

The contractor called and said he had an opportunity to sell some boilers – it's always a good day when that happens. I met him at his office, and we drove to the small college campus where a maintenance employee greeted us. Inside the boiler room, we saw an old copper boiler that was valved off and isolated. The jacket was removed and leaning against the old boiler. There was also a cast iron sectional boiler with three sections removed, which were laying on the floor of the boiler room. Someone had removed the sections and extended the piping to the now smaller boiler.

"What happened to the sections?" I asked.

"Craziest thing. The sections crack every year," the maintenance man said.

"Why did they crack?" I asked.

The man shrugged his shoulders. "Not sure. Guess they don't make them like they used to."

My "Spidey Sense" started to sound inside my head, and I knew cast iron boilers do not crack without significant help. While I suspected either corrosion or thermal shock, the horizontal crack in each section made me believe it was thermal shock.

Thermal shock occurs when cool water is pumped into a hot boiler. The damage is a result of a wide temperature difference causing rapid expansion and contraction inside the boiler (excessive stresses). Most boilers are designed to handle a 20˚F temperature difference.

"What about the copper boiler?" I asked, pointing to the isolated boiler.

"Oh, that's our backup boiler. It also leaks, and we only use it in an emergency."

"What caused that boiler to leak?" I asked.

"The most common causes of hydronic boiler failures are thermal shock, flue gas condensation, water conditions, combustion air, and inadequate maintenance."

"Not sure," he responded. He explained how they had replaced the heat exchanger assembly on the copper boiler twice before installing the cast iron boiler. This building now had two generations of boilers that were damaged and leaking.

Now came time to put on my detective's cap to determine what caused the problems. This is my favorite part of the job. If the previous two systems failed as a result of thermal shock, mine would suffer the same fate unless I found the cause.

We traced the system piping and made a couple of observations. First, the boiler was used for heating domestic hot water through a water-to-water heat exchanger, so the boiler water temperature remained at a constant 180˚F all year long. The system had circulators and three-way valves for each zone of the building. Three-way valves can damage the boiler, as they allow a cooler temperature to return to the boiler, often resulting in boiler shock. This could have been the cause of the failures. Three-way valves come in two different configurations, mixing and diverting. A mixing valve has two inlets and one outlet, and a diverting valve has one inlet and two outlets. The school used mixing valves to control the water temperature to each zone. The zone control would choose between return and supply water to deliver the proper

Thermal Shock

temperature to the zone. When using three-way valves, most heating systems will require a blending pump to be installed. A blending pump pulls hot water from the boiler and injects it into the return piping to preheat the return water to lower the "Delta T," or temperature difference between the supply and return water temperatures.

"They don't work. We disconnected them," the man informed me, and I noticed all the linkages on the three-way valves were disconnected.

"How do you control the overheating? Are there controls on the room terminal units?" I asked.

He nodded his head.

What I should have asked was, "Do the controls actually work on the terminal units?"

I suggested installing two boilers using primary-secondary piping, which I have found to be less susceptible to thermal shock. I also recommended a separate water heater for the domestic hot water, which was too expensive for their budget. The mechanical engineer for the college agreed with my proposed solution.

Fast-forward 16 months. The contractor called my cell and said, "One of the brand-new boilers is leaking." After allowing him to vent and curse, I offered to meet him at the job site.

Sure enough, one of the boilers had a leaking tube. I walked through the boiler room with my infrared temperature gun scanning for a wide temperature difference and could not find the reason for the thermal shock. Each zone had 180˚F supply water and 160˚ to 170˚F return water.

I hate when I cannot find the cause of a problem. We suspected the domestic water heat exchanger was possibly leaking, allowing cold city water into the hydronic loop. The contractor tested the heat exchanger and found it was not leaking, and we were stumped for an answer. I checked with the factory and they told me the tube was not under warranty since they felt the cause of the leak was due to thermal shock and the boiler being over a year old. I informed the contractor and listened to him curse some more. Once he was calm, I suggested having the tube re-rolled, which he did. The boiler was pressure tested, and it held.

Two months later, the contractor called and said, "Both boilers are leaking now." He demanded I meet him on the job site again, as they had no heat. I was greeted by an angry mob; including the director of maintenance, VP of finance, some anonymous woman who took copious notes about everything, the contractor and his lead service technician, and the maintenance man.

Each one took turns offering their reasons for the leaks, questioning my knowledge and the quality of the equipment I sold. (As a side note, I never had a hydronic boiler with a leaking tube in the three-plus decades of selling these particular boilers.)

Again, my infrared temperature gun showed nothing out of the ordinary. After all the bigwigs went back to their cubicles, I was left with the contractor,

Exhaust Fan

"A hydronic boiler is designed to last decades and will do so if it is maintained and installed properly."

his service technician, and the maintenance man. When something does not make sense to me on a job site, I like to get a cup of coffee and go back to the beginning. We sat in the cafeteria and I asked the maintenance man how he controls the temperatures in the building. He informed me his digital control system was inoperative, and he let the system operate on the boiler operating controls. He told me that each room had a unit ventilator with individual controls. I decided to go even more basic.

"Do you ever get a complaint saying the rooms are too hot or too cold?" I asked.

"Oh yeah. All the time," he replied.

"What do you do when that happens?" I asked.

"I shut off the pump for that zone," he said, referring to the three-horsepower circulator for each zone, which fed water to the different wings of the school.

"Wait, you turn the pump off? When do you turn it back on?" I asked.

"When we get a couple of calls saying they are cold, I walk across campus and turn on the pump for that zone," he replied.

I cocked my head, looked at the contractor and his technician and said, "That could be where the cold water is coming from."

They both nodded. Think of it like an iceberg hitting the Titanic.

"Oh, by the way, sometimes the pipes shake and moan when I turn on the pump. Is that normal?" the maintenance man asked us.

"No," we all said in unison.

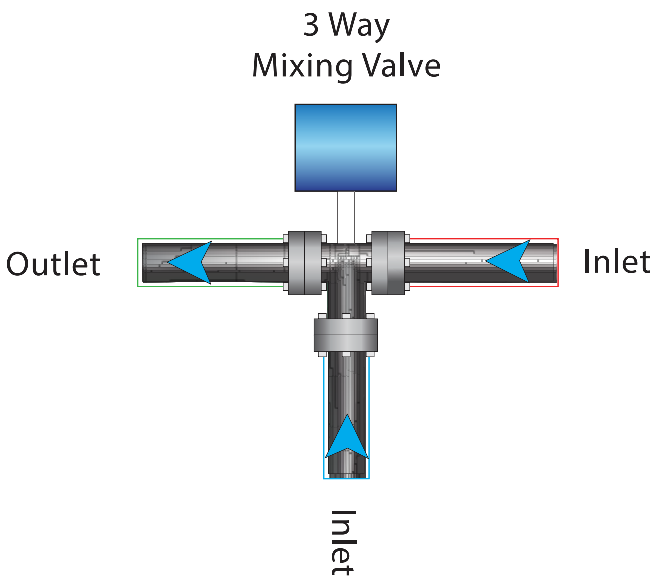
The damage to the boilers was too severe to repair this time, and the owner believed we sold them inferior boilers. I wrote a letter to the contractor explaining the damage occurred as a result of cycling the pumps on and off, but they had their minds made up. I also reminded them this was the third heating system which failed due to thermal shock. The lesson I learned from this project was to ask more questions and investigate further. I should have found the cause of the initial failure before selling new boilers.

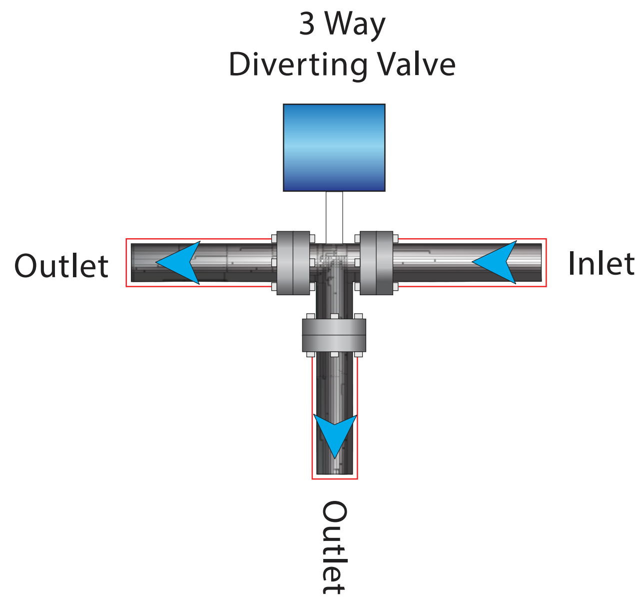
The most common causes of hydronic boiler failures are thermal shock, flue gas condensation, water conditions, combustion air, and inadequate maintenance. As discussed above, thermal shock is caused by a wide temperature difference between the return water and the boiler water. Most boilers are designed for a 20˚ – 30˚F difference between the return water temperature and the boiler water temperature. Thermal shock can also occur when the circulator is undersized or the flow is insufficient.

Since December 1899, most hydronic heating systems have been designed using 180˚F as the design supply water temperature. This means the system should heat the building on the coldest days using 180˚F water temperature. On milder days, the boiler could heat the building using a lower temperature. The majority of hydronic systems use a reset control, which lowers the supply water temperature in inverse proportion to the outside air temperature. For example, the warmer the temperature is outside, the cooler the supply water temperature. When the boiler water temperature drops to below 140˚F, there is a chance of flue gas condensation, which can destroy a boiler, stack, and chimney in a relatively short time. When flue gases condense, several acids form and will destroy the metal components inside the boiler and flue. Each cubic foot of natural gas burned produces:

8 cubic feet of nitrogen
2 cubic feet of water vapor
1 cubic foot of carbon dioxide

The water vapor mixes with the air to form rust and corrodes the fire side of the boiler. The condensed flue gases also form sulfuric and carbonic acids that will eat away the fire side of the boiler, flue, and chimney. Flue gas condensation can also form due to an insufficient burner firing rate. For example,





we had a customer who manually lowered the gas pressure to the boiler below the manufacturer's setting. He turned the non-condensing boiler into a condensing boiler, and it was destroyed in only a few years. A way to see if the flue gases are condensing is to look for rust under the draft diverter or on the fireside of the boiler. A condensing boiler normally uses metal, which is less susceptible to acids and corrosion.

Flue gas condensation can also create a dangerous condition, as the rust flakes can block the flue passages and allow the deadly gas to spill into the boiler room. To limit flue gas condensation, the boiler water temperature must be above 140˚F.

Another issue with hydronic boilers is the condition of the water inside the system. The first thing I like to do is to install a water meter on the makeup water for a hydronic system. The best water treatment is a tight, non-leaking system that is low in oxygen. Fresh makeup water will introduce oxygen and hardness to the system. The hardness will form scale, which will impede the heat transfer of the boiler and prematurely age it. The system pH should be tested regularly, as levels too high or too low could damage it. I recommend consulting with a competent water-treatment professional who will test the system on a regular basis. The water treatment firm should be told if an aluminum boiler is to be used, as these boilers will require different provisions for treatment and glycol.

Each burner requires 12-15 cubic feet of air for every cubic foot of gas burned. The air should be clean and free of toxins. For example, chemicals stored in the boiler room could off-gas and mix with the boiler flame to produce a toxic mixture, damaging the boiler, flue, and chimney. Another consideration is the combustion air required for the boiler. Be sure the boiler room combustion air sizing meets the code for the municipality. Verify the openings are open and not blocked. You also want to look for fans, which could pull the room into a negative condition.

Clearance around the boiler is another safety concern. Boiler rooms become the repository of everything the owner is not sure where to store. A local school stored student records inside the boiler room, right next to the boilers. A slight downdraft caused the flame to roll out and caught the papers on fire.

In the *National Board Inspection Code* (NBIC) Part 2, Inspection, 2.2.10.6, it says: "Establishing proper operation and maintenance of controls and safety devices is essential to safe boiler operation. Owners or users are responsible for establishing and implementing management programs which will ensure such action is taken."

The best part stipulates, "Any defect or deficiency in the condition, operating, and maintenance practices of a boiler noted by the inspector shall be discussed with the owner or user at the time of the inspection."

A hydronic boiler is designed to last decades and will do so if it is maintained and installed properly.