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Forensic Engineering Investigation of Hot Water Boiler and Heater Relief Valve Failures

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Abstract

Heating systems and hot water heaters in residential structures are often neglected in regards to proper maintenance and repair. Although all manufacturers recommend annual Preventative Maintenance on water heaters, furnaces and boilers, oftentimes these appliances are not maintained in accordance with manufacturer or industry maintenance directives and are not seen by professional servicemen until after a failure occurs.

Forgoing preventative maintenance oftentimes allows equipment failures and resulting consequences such as loss of heat, soot, and water damage. Additionally, the lack of maintenance also invites the possibility of more severe consequences including carbon monoxide poisonings, fires, and more commonly in water heaters and forced hot water or “Hydronic” heating systems, pressure vessel explosions.

Short of a gas or propane leak, the most severe type of heating appliance malfunction is due to a pressure vessel explosion or BLEVE (Boiling Liquid Expanding Vapor Explosion) which can cause severe building damage, as well as personal injury.

This paper identifies the system components that commonly fail and go un-noticed by building occupants, as well as service personnel. This paper will also detail typical damage caused by the release of energy due to over pressurization and pressure vessel failure.

Keywords

Water Boiler Explosion, Hot Water Heater Explosion, Temperature Pressure Relief Valve, BLEVE, Safety Relief Valve Failure, Expansion Tank Failure, Bursting, Pressure Vessel Failure.

Background

Besides the damage a natural or LP gas explosion can cause to structures, anyone who has seen a water heater or small water boiler explosion will attest to the damage this type of event can cause.

Boiler explosions caused by the pressure vessel bursting due to excessive pressure is known as a BLEVE or a Boiling Liquid Expanding Vapor Explosion. The National Fire Protection Agency (NFPA) Chapter 921 Describes a BLEVE as:

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"…explosions involving vessels that contain liquids under pressure at temperatures above their atmospheric boiling points. The liquid need not be flammable. BLEVEs are a sub-type of mechanical explosion but are so common that they are treated here as a separate explosion type. A BLEVE can occur in vessels as small as disposable lighters or aerosol cans and as large as tank cars or industrial storage tanks.

A BLEVE frequently occurs when the temperature of the liquid and vapor within a confining tank or vessel is raised to the point where the increasing internal pressure can no longer be contained and the vessel explodes. This rupture of the confining vessel releases the pressurized liquid and allows it to vaporize almost instantaneously."

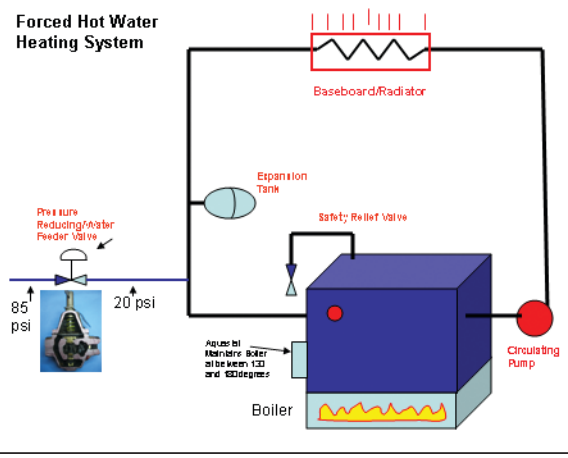
BLEVE explosions have occurred in steam boilers, however, in residential applications are more common in forced hot water heating system boilers.

As can be seen in this photograph, the failure of a boiler pressure vessel results in mechanical failure of the boiler casing, as well as dispersal of hot scalding water. The effects of the pressure release from the pressure vessel can cause shrapnel, as well as impact damage caused by the movement of the boiler.

Mechanical systems in residential settings are more prone to failure than commercial structures for a number of reasons. For larger commercial systems, insurance coverage is by specialized carriers familiar in the risks of mechanical equipment failure. Insurance carriers such as Hartford Steam Boiler or Factory Mutual require many of their commercial clients to participate in an annual examination of these systems which at the same time assesses the functionality of vital components and controls.

A Forced Hot Water Boiler System transfers heat caused by the consumption of burning fuel in the boiler combustion chamber to the water in the boiler.

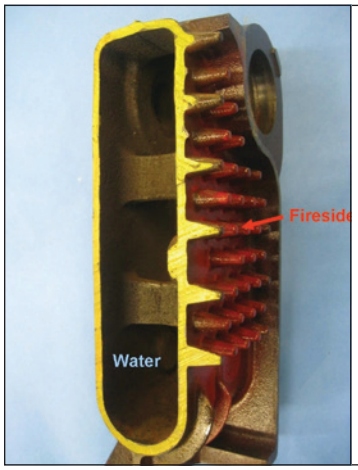
As is illustrated in the diagram to the right, this water is then pumped throughout the dwelling through piping where it flows to baseboards or radiators where the heat is given off to these areas.



Residential equipment, however, is typically covered under a standard homeowner's policy by carriers not concerned about mechanical systems, making the maintenance of these systems solely reliant on the insured and their local heating technician.

Regardless as to whether an appliance is in a commercial or residential setting, the inherent dangers of a control failure still exist and as such, proper maintenance in either occupancy setting is necessary.

System Description Forced Hot Water



Water is heated within the boiler as a result of the boiler's design. Hollow cast iron sections contain water, and hot products of combustion pass in the outsides of these boiler sections, allowing efficient heat transfer. The entire system is pressurized.

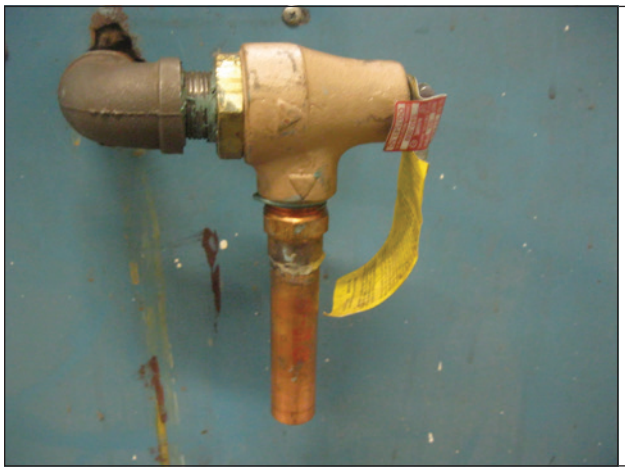
As can be seen in the attached illustration of a pressure reducing water feeder valve, a constant source of make up water is maintained to the system from the water main which is reduced in pressure through a backflow preventing valve and pressure reducing water feeder valve.

Since it has no room for this heated water to expand to, an expansion tank is installed that acts as a reservoir for pressure fluctuations.

Since a forced hot water system is a closed system, it has no room for this heated water to expand to accommodate this, an expansion tank is installed that acts as a reservoir for pressure fluctuation.

There are two types of expansion tanks used in Forced Hot Water Heating systems, a bladder type as depicted in this photograph and a cylindrical compression tank type.

Boiler Safety Relief Valve



In the event that this expansion tank is full or damaged or too small for the system it is servicing, then the boiler is reliant upon the pressure safety relief valve to relieve excessive pressure and prevent the pressure vessel from damage.

As seen in this photograph, these valves are clearly visible from the exterior of the boiler and are intended to be connected directly to the boiler pressure vessel.

Expansion Tank Operation and Failure

An expansion tank is connected to the forced hot water system piping and allows a reservoir of compressed air where system water can expand into and reduce system pressure fluctuations.

One type is one which is air filled and has system water flowing into it allowing it to compress this air. As see in the photograph to the right, these tanks are usually installed in the floor joist between the basement and first floor level. These older tanks were installed in large numbers throughout the 1950's and 1960's and are usually cylindrical in shape.

Older, Compression Tank

A second and more common expansion tank is the diaphragm expansion tank. As seen in the illustration to the left of a tank that has been bisected, this type of tank is divided in half by a rubber diaphragm, which has the system water on one side and is charged with air on the other.

As the water within the system expands, the gas on the opposite side of this diaphragm is compressed.

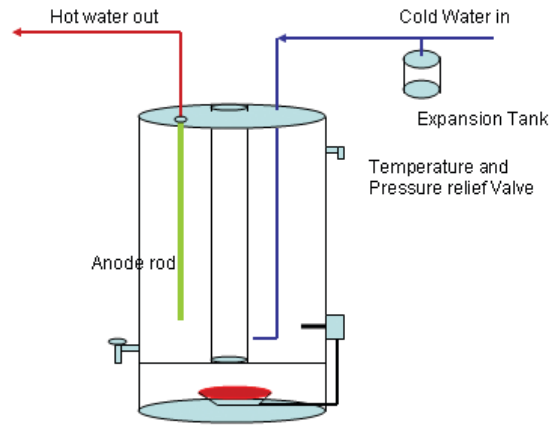
Due to age, improper sizing, and water chemistry, these components can flood completely with water. This prevents any expansion of water and dampening of system pressure, allowing pressures to rise above intended system levels.

Expansion Tank Maintenance

Diaphragm types of expansion tanks should have the air valve tested for pressure to make sure there is a proper charge present. This can be done with a tire pressure gauge. This air valve portion of the tank, as depicted, should not contain water which will flow out of the valve if the valve is depressed. If water is present in this portion of the tank, it should be replaced.

Older cylindrical expansion tanks should not be completely full of water and should be slightly drained if these are overfilled. System water must have an "air space" area within these tanks so that this space can receive any volume of expanding water.

Hot Water Heaters



Tank design based domestic hot water heaters are a second appliance that is subjected to the same effects of water thermal expansion and pressure increase as heating boilers are.

As seen in this diagram, standard domestic hot water systems are an open system that brings in cold water from a water main, where it flows into the tank and then exits the tank through an anode rod fitting assembly that is a sacrificial metal corrosion protection device.

Standard hot water heaters consist of an inner glass lined steel pressure vessel that is insulated with a foam insulating material which is encased in a sheet metal jacket.

Heat is added to the water through a number of means such as oil, LP and Natural gas combustion, as well as electric resistance heaters immersed in the tank water.

Corrosion protection is accomplished by the use of sacrificial anode rods inserted into the tank.

Safety Relief and Pressure-Temperature Safety Relief Valves

Safety Relief Valve Design

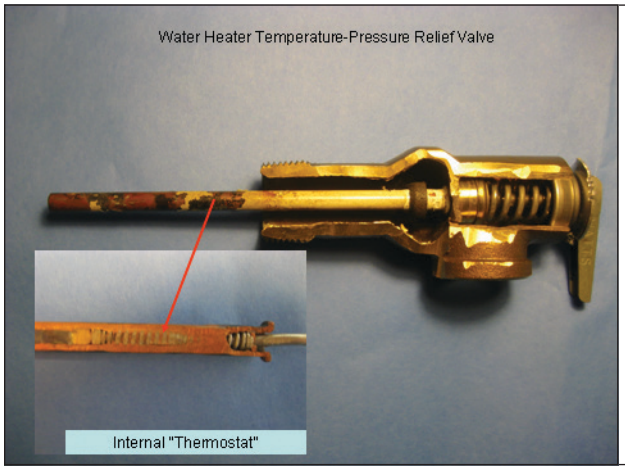
A boiler's safety relief valve, as seen in this photograph, is simply a spring loaded normally closed valve that opens when the vessel pressure overcomes the force of the valve spring. Upon the reduction of vessel pressure, the valve closes.

Depending on the operating pressure of the boiler the valve is protecting, these valves operate in a number of different pressure ranges. Typically, residential pressure relief valves operate at the 30 psi level.

Often times, these valves seize due to their design, as well as maintenance history. Depending upon how these valves are positioned, often times, the seat remains submerged in water, which in turn enhances corrosion causing the valve seat to become corroded to and fused with the valve disc, preventing the valve from opening and accelerating corrosion.

Pressure-Temperature Relief Valve Design

Safety Relief Valve Failure



The Temperature-Pressure relief valve on a typical residential hot water heater is a 150 psi safety relief valve almost identical in design to a boiler's safety relief valve however modified to lift at a higher pressure.

As depicted here, the Pressure-Temperature Relief Valve is also equipped with what is identified as an "Extension Thermostat". This component is a fluid filled cylinder that has a spring loaded pin. In the event of a temperature increase beyond 210 Fahrenheit, this pin is forced into the valve seat and will cause the valve to open. This added feature is designed to prevent scalding and steam build up within the tank.

The safety relief and pressure-temperature relief valves let water escape if pressures in boilers and water heaters exceed the valves rated operating pressure.

These components occasionally open to allow water to exit the system; however, this is usually after the boiler has started after being off due to the end of a heating season or due to a mechanical breakdown.

Water Chemistry and the effects of corrosion will render the moving components of these devices unmovable and seized. These same impurities can also block water flow through the water intake piping eliminating this flow path also.

The effects of corrosion and hardness mineral accumulation must be addressed through preventative maintenance.

Proper Maintenance of Safety Relief Valves

Code Direction

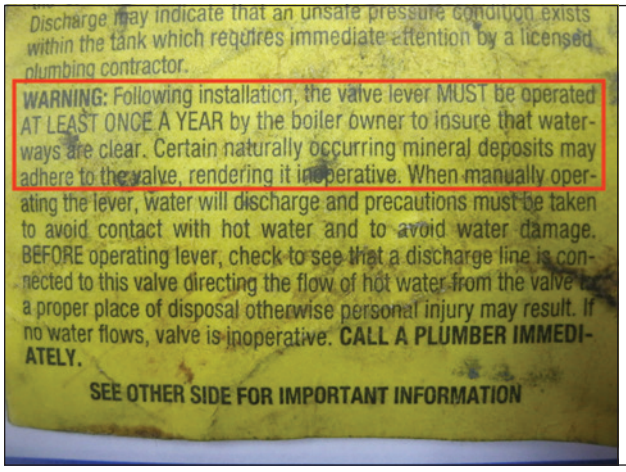
Although code direction is usually addressed towards installation issues, there are several code directives that address the requirement to properly maintain heating appliances and auxiliary components, as well as manufacturer's instructions.

The American Society of Mechanical Engineering Chapters V & VI call for annual maintenance and the performance of a "pop test" of the pressure relief valve to insure that it is operating properly.

The International Mechanical Code, paragraph 102.3 provides the blanket statement that "Devices or safeguards which are required by this code shall be maintained in compliance with the code edition under which they were installed".

Manufacturers Instructions

Manufacturer's instructions for these components include nomenclature depicted here.



"WARNING: Following installation the valve lever MUST be operated AT LEAST ONCE A YEAR by the boiler owner to insure that the waterways are clear. Certain naturally occurring mineral deposits may adhere to the valve, rendering it inoperative."

This same corrosion process or accumulation of impurities in the valve's inlet or outlet piping can cause the valve to seize or become totally blocked. A seized valve can be identified by performing a "Lever or Pop Test" by lifting the valve handle to make sure it is free of obstructions and will freely move and allow water to flow.


Lever Test on Safety Relief Valve

Although many service technicians do not like to perform testing of the safety relief valve due to the possibility of it not reseating properly, this maintenance must be done to make sure the appliance is safely protected.


Reduced Valve Discharge

Care must also be taken to make sure it is properly installed directly onto the boiler and that its discharge piping is not reduced in diameter or sealed with a piping fitting, contrary to that as depicted in this photograph. This action can also remove impurities that collect in the valve and connecting piping.

The relief valve should be checked for conditions such as showing any evidence of pre-existing and prolonged leakage. As seen in this photograph, the valve discharge piping shows evidence of corrosion, indicating that it is leaking, which should prompt the service technician to examine its condition.

Usually this is in the form of corrosion on the valve or discharge piping. If the valve shows evidence of leakage, flushing the valve and connecting piping with water should remove any impurities. If dripping continues, the valve should be replaced.

BLEVE Explosions are Common after a recent service event

Pressure vessel explosions often occur following a service event in response to a no heat call.

The inherent cooling and contraction of a boiler or water heater's water during this downtime can set the stage for a "time bomb" to develop.

During downtimes the system water cools and reduces the system pressure. Upon repair of the burner or appliance heat source, this water will then rise in temperature and expand. As the system's temperature and pressure continue to rise even further, the system now becomes reliant upon the operation of the safety relief valve.

If the safety relief valve is incapable of lifting, pressures approaching hundreds of pounds per square inch may develop causing pressure vessel failure and the immediate vaporizing of the compressed and heated water within.

Boiler Burst Pressure

In accordance with the ASME Section IV: Rules for the Construction of Heating Boilers, the bursting pressure for a boiler is designed upon the following formula:

P= B/5 X [S/Sa]

B= Bursting Pressure
S = Tensile Strength
Sa = Average tested tensile strength

Residential boilers and hot water heaters are very capable of achieving the burst pressures defined by ASME IV in the event of a safety relief valve failure.

The effects of a burst pressure vessel can be as mild as a small split in the cast iron boiler section or a displaced gasket. The damage can also be very severe including:

Structural Building Damage
Displacement of heavy cast iron boiler
Broken gas lines and fire
Metal Shrapnel Projection
Burns due to scalding water
Injury & Death

Another manifestation of BLEVE damage is not in a failure of the boiler pressure vessel but rather the expansion tank.

Conclusion

The disparity between residential and commercial mechanical equipment maintenance has contributed to an increased rate of failure for residential heating system appliances.

Commonly, periods of system inoperability and the return of these appliances back into service will induce changes in pressures and temperatures not experienced since the end of the last heating season.

During this time, the system will attempt to achieve a thermal and pressure equilibrium in operation.

The typical maintenance deficiency in failing to maintain safety relief valves and expansion tanks allows unsafe conditions to develop with these systems. The failure of safety relief and pressure-temperature relief valves is easily diagnosed and if caught in time can prevent an explosion capable of extensive damage.

It is, however, a simple task to make sure these safety components are functioning properly during annual service events and a task every professional service technician should include into his annual preventative maintenance checklist.

References

The National Fire Protection Agency (NFPA) Chapter 921

American Society of Mechanical Engineering Chapter IV: Rules for the Construction of Heating Boilers

The International Mechanical Code, paragraph 102.3

Watts Industries Instructions, North Andover MA 01845