CHAPTER 1

OVERVIEW OF HOT WATER BOILERS AND HEAT EXCHANGERS

LEARNING OBJECTIVES

At the end of this chapter you should be able to:

- list four materials used in boiler construction
- list and describe three ways heat is moved through a hot water system
- list ten differences between boilers and furnaces
- list the advantages and disadvantages of hot water heat
- list three problems found with boiler heat exchangers

1.1 HOT WATER BOILERS

The function of the boiler is the same as a furnace: to provide heat so that all parts of the home are comfortable. Boilers fulfill this function in a slightly different way than furnaces.

Boilers Don't Really Boil

Hot water boilers, or what some people call hydronic heating systems, don't really boil the water. They typically heat the water to a maximum of 200°F. Normal operating temperatures for many boilers are in the 120°F to 130°F range, depending on a number of factors, including outdoor temperature, design capacity, etc.

Steam Boilers

There are boilers that do boil water into steam. Steam boilers are not discussed in this book.

1.1.1 Materials

Cast Iron

The oldest boilers, and some modern boilers, have cast-iron heat exchangers. Cast iron, incidentally, is a very high-quality material that works very well for water heating systems.

Steel

Many boilers have steel heat exchangers. On some steel boilers, the exterior jacketing is very heavy plate steel. In other systems, the exterior jacket is light gauge sheet steel forming a cabinet that looks very much like a furnace cabinet. In either case, the exchanger steel is heavy gauge.

Steel heat exchangers are considered lower quality than cast iron, since they are more susceptible to corrosion.

Copper

Many modern boilers use copper tubes. Some have aluminum fins on the tubes, and many have cast-iron headers at either end of the copper tubes. Copper is an excellent heat transfer medium, but copper-tube boilers have a shorter life expectancy than steel and considerably less than cast iron.

Alloys

Some boilers have stainless steel or copper-nickel alloy heat exchangers. These systems are relatively new and their life expectancy and long-term performance are not yet known.

1.1.2 How Boilers Work

Several Fuels

Boilers work much like furnaces. Heat is generated by burning coal, oil, natural gas, or propane, for example. Heat can also be generated by electricity. There are electric boilers.

Distributing the Heat

Furnaces use warm air to move heat from the source to various rooms of the house. Boilers use water instead of air to move heat through the house. Furnaces have heat exchangers, and so do boilers. The fire side of the heat exchangers for furnaces and boilers are virtually identical. In a furnace, however, the distribution medium is the house air, and that's what you find on the other side of the heat exchanger. Boilers have water on the other side of the heat exchanger.

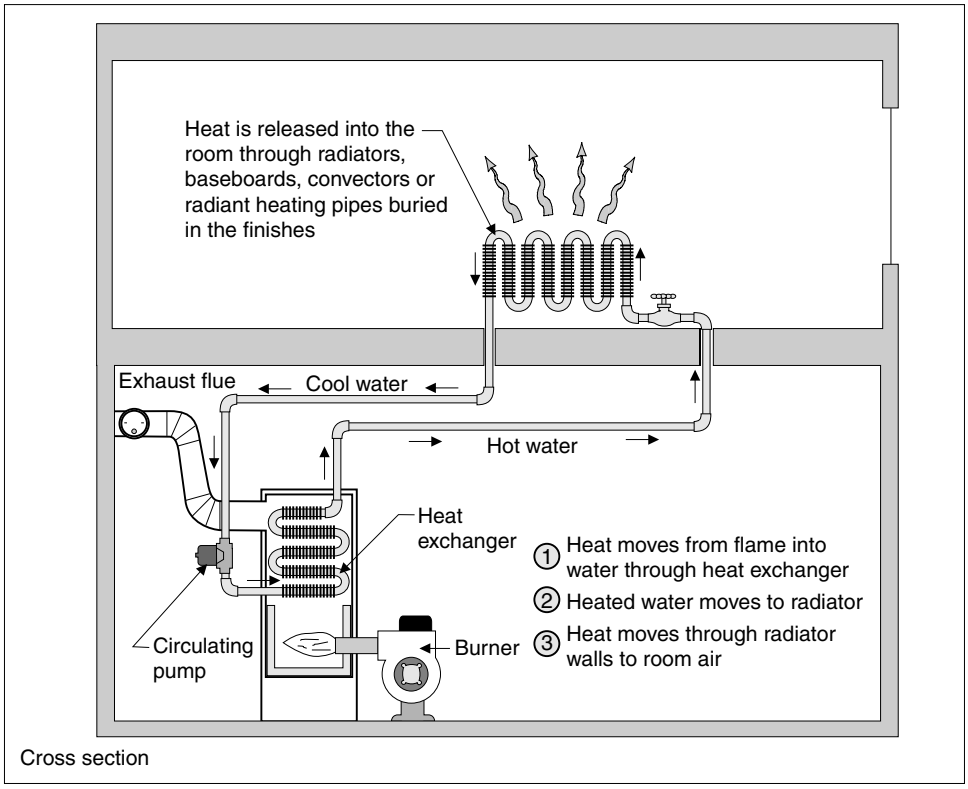
Water Is the Heat Transfer Medium

Heat is transferred from the fire side of the heat exchanger, through the heat exchanger, into the water. The water is piped to the various rooms of the house, where it is released through radiators, baseboards, or convectors (Figure 1.1).

Radiant Heating

In some homes, radiant heating is used where the distribution pipes are embedded in floors or ceilings and heat is released along the entire length of these piping grids, buried in the finishes. In radiant systems, there are no radiators or convectors. There is also a lot less for the home inspector to look at!

FIGURE 1.1 How Boilers Work



Water Circulates

Just as the air in a forced-air system is recirculated, so is the water in a boiler system. Cool water is brought to the boiler, heated, and sent to the radiators. The cool water is returned from the radiators through the piping system, to be warmed again by the heat exchanger.

1.1.3 Heat Transfer Methods

Both furnaces and boilers use conduction to transfer heat from the fire side to the air or water side of the heat exchanger. Furnaces use primarily convection from that point on. Boilers use convection, conduction, and radiation in the distribution system.

Convection

Boilers use convection in two different ways to get heat into a room. Convection helps to move the water through the piping system. Warm water tends to rise and cool water tends to fall, since it's heavier. Gravity water heating systems rely exclusively on convection to move water through the piping system.

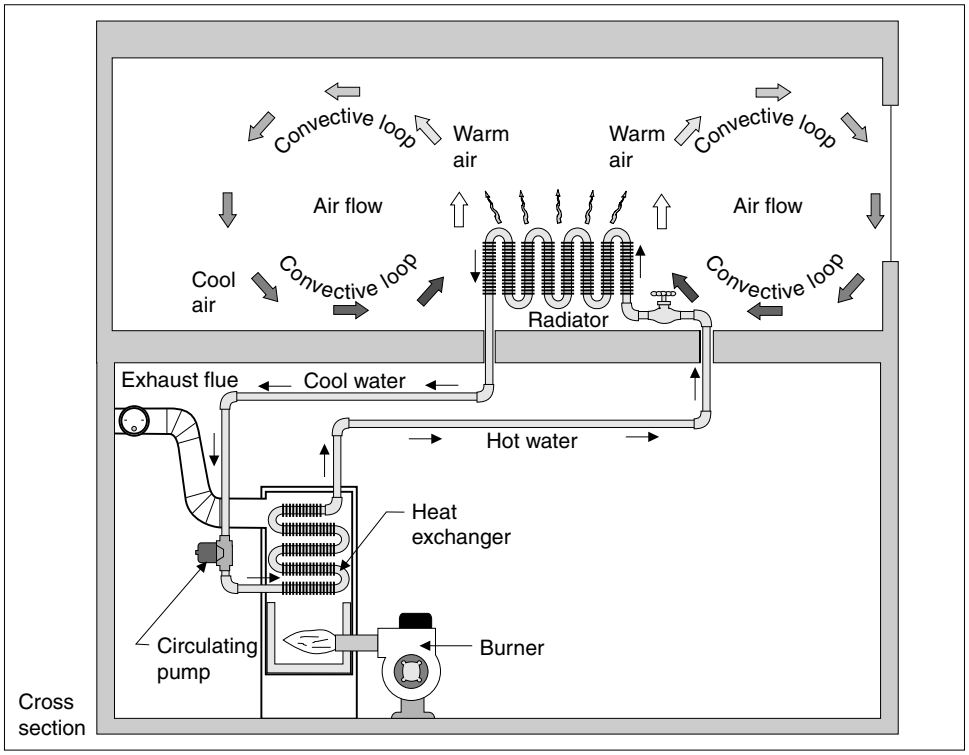
Convective Loops

Boilers also use convection to transfer heat from the radiators into the rooms. Radiators are designed to heat the air in the room. They do this by drawing cool air in at the bottom, warming the air as it passes over the radiator, and discharging the heated air at the top (Figure 1.2). This sets up convective loops of air movement within a room.

Conduction

Boiler systems use conduction to transfer heat from the water into the metal radiators or convectors. This is an extra step in heat transfer we don't find with warm-air furnaces.

FIGURE 1.2 How Radiators Heat the Air Through Convection



Radiation

Radiators radiate heat in all directions into the room, and, unfortunately, into the exterior wall that they are close to. Any warm body radiates heat in all directions to its cooler surroundings. You might think that radiation is the main method of heat transfer for radiators, because of their name. In fact, radiation is less important than convection. This isn't important from a theoretical standpoint but does have a practical impact. Radiators enclosed in covers that restrict the airflow across the radiators don't work as well as radiators that have unobstructed air movement (Figure 1.3).

Less Important than Convection

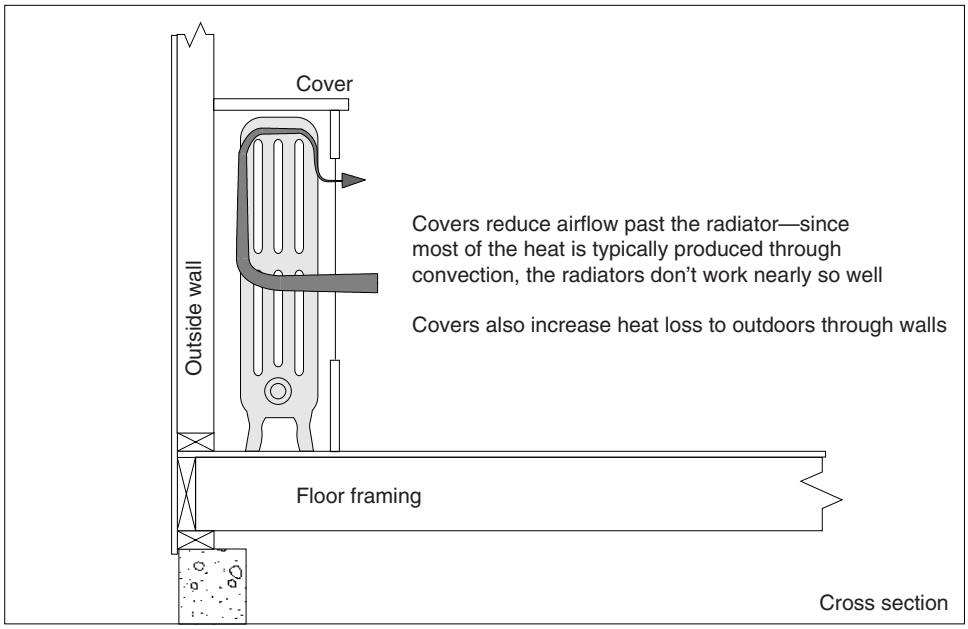
Although we've been talking about radiators, this applies to convectors and baseboards as well.

1.1.4 Similarities Between Furnaces and Boilers

Furnaces and boilers both have—

1. Burners, fuel supplies, and combustion controls
2. Combustion air requirements.
3. Venting systems
4. Heat exchangers
5. Cabinets
6. High-temperature limit switches
7. Thermostats

FIGURE 1.3 Radiator Covers



1.1.5 Differences Between Boilers and Furnaces

The differences between boilers and furnaces that are important to home inspectors are:

1. Boilers have pipes. Furnaces have ducts.
2. Boilers have radiators, convectors, or radiant pipes. Furnaces have registers and grills.
3. Boilers have pumps instead of fans, with pump controls instead of fan controls.
4. Boilers do not have air filters or electronic air cleaners.
5. Boilers cannot have central air conditioning or humidification systems added.
6. Boilers are connected to the house plumbing system (to provide water to the boiler system).
7. There is a control to maintain the boiler water pressure at a desired level.
8. There is often a device to keep the boiler water from getting back into our drinking water.
9. Boilers have a safety device (pressure-relief valve) to prevent water pressure building up in the boiler system.
10. Boilers have an expansion tank to allow the water to expand without creating high pressures when the water heats up.
11. Some boilers have a safety device designed to turn the boiler off if the water level is too low.

Throughout this section, we will look at the components that are different from furnaces.

We will talk about these components in three groups:

1. The heat exchanger
2. The controls
3. The distribution system

1.1.6 Advantages of Hot Water Heating Systems

People argue about whether furnaces or boilers are better. We think that both systems have their advantages, and you will never tell a client to replace one heating system for another, unless there are special circumstances.

The advantages of hot water heating systems are that they—

1. provide even heat
2. do not create drafts in rooms, so the rooms tend to be more comfortable
3. are usually quieter than forced-air systems
4. do not circulate odors through the home like a forced-air system
5. have piping that requires less room in walls, floors, and ceilings than ducts—this means fewer and smaller bulkheads built into rooms
6. usually have boilers that are smaller than furnaces of equivalent capacity

1.1.7 Disadvantages of Hot Water Heat

Hot water heating has the following disadvantages:

1. It's more costly to install and service compared with forced-air furnaces.
2. It's more difficult to add central air conditioning, humidifying, and filtering equipment to a home.
3. There is a greater selection of furnaces on the market than boilers. This is especially true at the high-efficiency end of the spectrum.
4. Radiators take up more space in rooms than heating registers.
5. A leak in a hot water system usually means water damage. A leak in a supply or return duct system does no damage.

The bottom line is that hot water heating is a good system. Conversion of any heating system is expensive and disruptive.

One Special Disadvantage

Common Safety Issues

Safety is always a consideration on heating systems. Boilers and furnaces both have safety issues regarding the handling, burning, and exhausting of fuels. In this sense, they are similar.

Explosion Hazard

Boilers have an additional safety concern. If pressurized water is overheated, it can result in a steam explosion. Let's look at how that works.

Water normally boils at 212°F. However, if we pressurize the water in a closed system, it won't boil at 212°F. We can heat the water well past 212° in this closed system, increasing its pressure as the temperature rises. Water at 50 psi boils at 300°F.

Superheated Water

We can get the temperature to 300°F and still the water won't boil. This is **superheated water.** This is important because of what happens when the piping or the boiler fails and the water is released. Let's back up for a second.

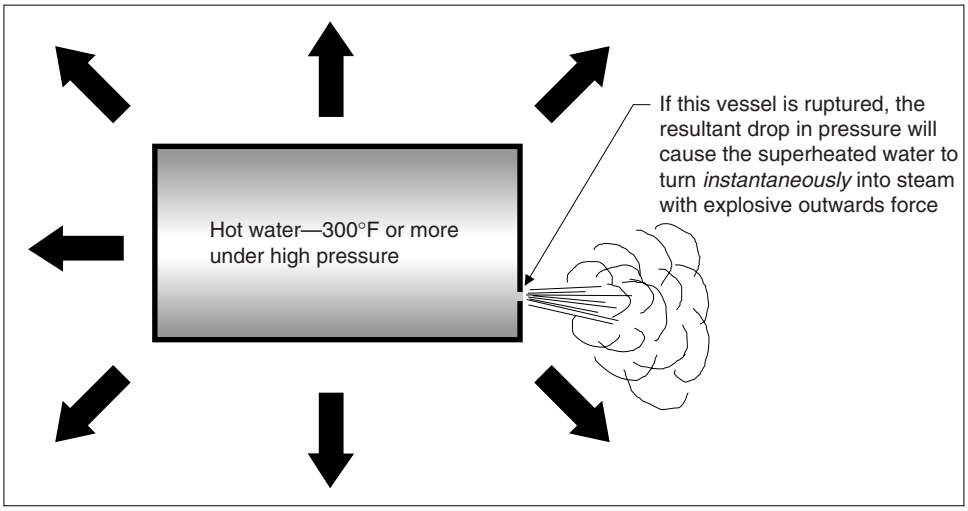
High-Pressure Cold Water—No Problem

If you were to take a tank of room temperature water and pressurize it to 200 psi, there would be a tremendous amount of force in that tank. However, if you ruptured the tank with an ice pick, the tank wouldn't blow up. The pressure would release almost immediately, and water would squirt out for a second and then simply leak out through the hole.

High-Pressure Hot Water—Big Problem

If you took a similar tank and built the pressure up, but also heated the water up to 300°F, for example, the results would be very different. The water wouldn't boil, because it is squeezed into the tank under such high pressure.

FIGURE 1.4 Superheated Water



Since water would like to boil at 212°F at atmospheric pressure, as soon as we release the pressure in that tank, we're going to create steam. When you stick the ice pick into the tank, you relieve the pressure in the same way that we did with the cold water in the tank. The difference is that the superheated water instantaneously boils off into steam as it escapes into the atmosphere (Figure 1.4). It does this so fast that it creates a **steam explosion.**

Steam Explosions

A water heater can easily be shot 300 or 400 feet as the pressure is released. The tank and/or piping forms a deadly projectile. A boiler or tank in the basement of the house, for example, can easily go straight up through a three-story house and have energy left over after it goes through the roof. Obviously, this has the potential to kill someone.

As we talk about hot water heating systems, we'll discuss some safety controls that prevent a superheated water situation and a steam explosion.

1.2 HEAT EXCHANGERS

Just as the heat exchanger is the heart of the furnace, it's also the heart of the boiler.

1.2.1 Function, Materials, and Location

Transfer Heat

Heat exchangers in boilers have the same function as heat exchangers in furnaces: they transfer the heat from the fire into the heat transfer medium. With furnaces, the heat transfer medium is air. With boilers, the heat transfer medium is water.

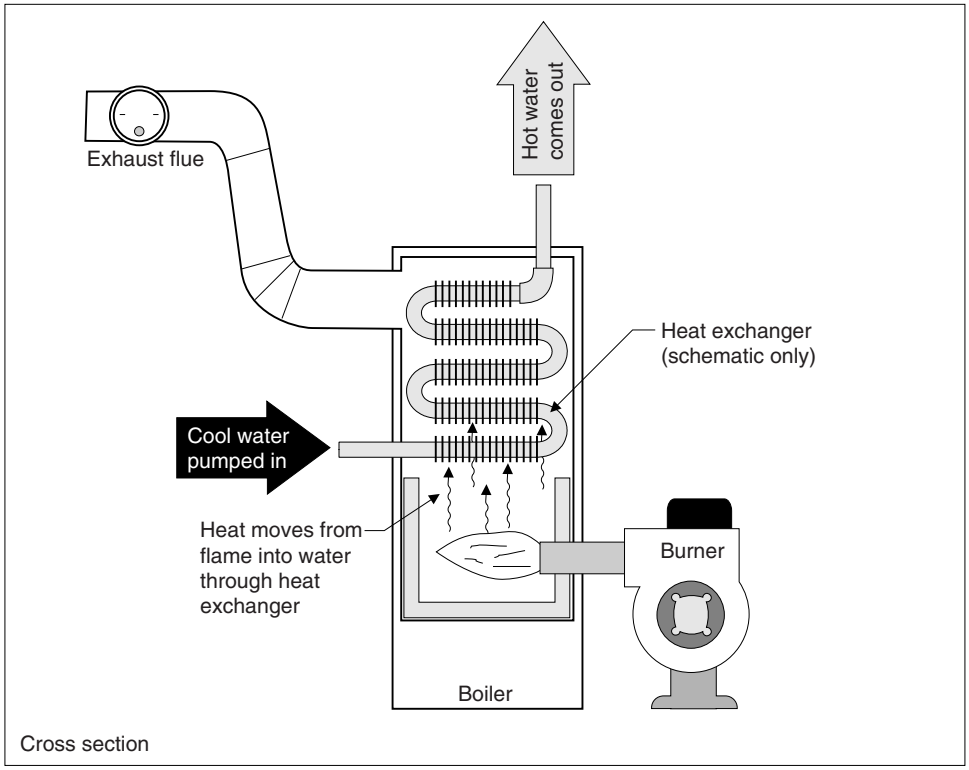
Common materials include cast iron, steel, alloys, and copper.

Above Burner

The heat exchanger is usually located above the burner and sees the products of combustion coming off the burner. At the top of the heat exchanger, the products of combustion are typically directed into the venting system (Figure 1.5).

The cool water typically enters the bottom of the heat exchanger and the heated water leaves from the top.

FIGURE 1.5 Heat Exchangers



1.2.4 Conditions

Failures Are Wet

Heat exchangers on boilers are easier on home inspectors than furnace heat exchangers. When a furnace heat exchanger is cracked or has a hole, it's often difficult to tell. When a boiler heat exchanger has a crack or a hole, it's easy to tell. The water leaks out! It may extinguish the burner or result in water spilling onto the floor around the boiler.

Let's look at the specific problems.

1. Leaks
2. Rust
3. Clogged

Leaks

CAUSES

Heat exchangers on boilers leak because the heat exchanger—

- is rusted
- is cracked
- has poor connections

Rust

Rust is a result of oxygen and water attacking the metal. Rust acts more quickly at higher temperatures, so the environment in a heat exchanger is hostile.

Cracks

Cracks result from the thermal stresses on the heat exchanger over a number of years. Cracks may also be caused by a manufacturing defect.

More Cracks

Cracks may also develop from metal fatigue (perhaps because of overheating, sometimes resulting from not enough water in the boiler, or failure to pump the water through the boiler). A boiler that freezes is also likely to have a cracked heat exchanger.

IMPLICATIONS

A leaking heat exchanger typically has to be replaced. Usually you replace the whole boiler when you have to replace the heat exchanger. There are some exceptions, but for the most part, it's safe to say a new boiler is needed when a heat exchanger leaks.

Poor Connections

One exception might be if it is a connection problem. Sometimes sections of heat exchangers are not tightened up securely. Sometimes gaskets fail. In most cases, you won't know and should describe the leaking as a potentially serious problem.

STRATEGY

Look for water. Sometimes it's obvious, but sometimes the leak is quite small and only opens when the heating system is firing.

Dripping and Hissing

One trick is to look inside the burner compartment at as much of the heat exchanger as you can see just after the burner shuts off. Look for dripping water and listen for the hissing sound of water hitting the hot combustion chamber components (refractory, for example) and boiling off into steam.

Listen as Burner Is Shut Off

Sometimes when you open the burner compartment just after the burner shuts off, you'll see a little puff of steam coming out. This generally means that the heat exchanger has one or more small leaks, allowing water to get through the heat exchanger and into the combustion chamber.

Check Outer Jacket

Don't forget to look at the outside jacket of the boiler. Especially on older cast iron and steam boilers, the jacket is part of the heat exchanger. Look for leaks here too. If it is at a seam, it may only be a gasket problem.

Rust

CAUSES

Rust is often caused by condensation from the exhaust products. It's a common cause of corrosion and early failure of heat exchangers, particularly on modern boilers that are substantially oversized.

Damp Environment

Rust may also result from a damp environment that a boiler may find itself in such as a chronically wet basement or crawl space.

Chemicals

Common household chemicals can rust furnace or boiler heat exchangers quickly. These include—

- bleaches
- swimming pool chemicals
- muriatic and hydrochloric acid
- aerosol sprays (eg, hair spray)
- deicing salts
- water softener salts
- paint strippers
- glues, cements, and other adhesives

One side of the boiler is always exposed to water and consequently may rust over time.

Don't Drain the Boiler Water in the Summer

One cause of rusting heat exchangers is the poor practice of draining the water out of the heating system every summer. Some people think this is good for the heating system because the heat exchanger and pipes won't be attacked by the corrosive water all summer long. They also suggest that flushing the water is a good thing.

Oxygen Causes Rust

The reality is that the same water should remain in the boiler year after year. The amount of oxygen available to corrode the cast iron or steel diminishes in a closed system and the water becomes chemically inert over time. Exposing the

metal to oxygen in the air is a bad thing. That's exactly what you do if you drain the water out of the system.

Oxygen in Water

Adding new oxygen in fresh water is also a bad thing. That's what you do if you flush the system. Therefore, a better practice is to keep the same water in the system year after year to minimize rust on the heat exchanger, the pipes, and the radiators.

IMPLICATIONS

Rust on a heat exchanger leads to leaks.

Rust on the fire side of the heat exchanger reduces the boiler's efficiency, increases the heating costs, and may clog the exhaust gas passages, leading to life-threatening spillage of exhaust gases into the home.

STRATEGY

Rust is the enemy of boilers. Look for rust on the external parts of the boiler, at the combustion chamber, and, using a flashlight and mirror, at whatever parts of the heat exchanger are visible. Look for flaking, scaling rust. Look also for pinhole rusting. Pinholes may be small leaks that scab over with rust scale intermittently; however, they usually mean the heat exchanger is near the end of its life.

Watch for corrosive household chemicals stored near the boiler. These can rust the heat exchanger.

Be Gentle

We don't recommend that you poke aggressively at rust on a heat exchanger with a screwdriver, for example. You may end up with an embarrassing amount of water where it doesn't belong.

Turn Boiler off

If you're going to poke around inside combustion chambers and heat exchangers, you don't want the boiler to come on. Many home inspectors shut the power off before venturing into a boiler. We think that's a good idea. An equally good idea is to turn it back on when you're done!

Careful with Copper Tube Boilers

Typically, you can't get a good look at a boiler heat exchanger without dimantling the system, going well beyond our standards. However, one look at a copper-tube heat exchanger can tell you a great deal. These systems are susceptible to corrosion on the fire side of the heat exchanger, typically because of condensation in the exhaust products (Figure 1.6).

Overheated Heat Exchanger

There is also a potential problem with copper-tube boilers overheating. The copper tubing is relatively thin. It's good at transferring heat from the side to the water. However, if the water inside the tubes gets too hot, the copper will overheat and fail prematurely.

Pump Provides Cooling Water

Copper-tube boilers have a pump that pushes water past the heat exchanger quickly. The total water capacity of a copper-tube heat exchanger is only a few gallons. Many of the old, larger, cast-iron heat exchangers have water capacities in the tens of gallons.

Pump Must Be on When Boiler on

The pump must keep introducing cool water to the heat exchanger to avoid overheating the copper tubing. These systems often have a control that won't allow the burner to come on unless the pump is working.

When you are looking at a copper-tube boiler, make sure the pump is working when the burner is on.

Clogged

CAUSES

The water side of the heat exchanger can become clogged by debris in the water, corrosion of the heat exchanger walls, or both. You won't get to see this kind of clogging, so we won't talk about it much.

Water-Side Rust or Debris

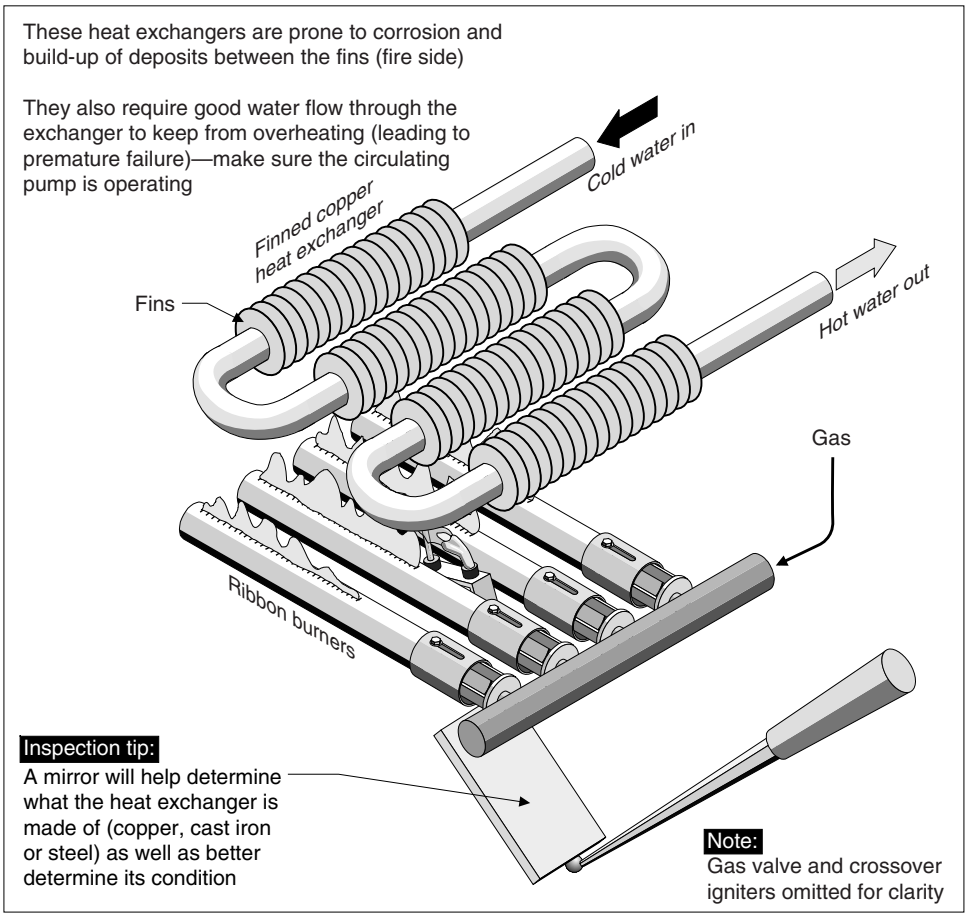
Fire-Side Soot

Soot may also clog the fire side of the heat exchanger in the exhaust flue passages. This is usually because of poor burner adjustment, a defective burner, or a lack of maintenance.

Fire-Side Rust

Rust can clog the fire side of the heat exchanger too, usually from condensation.

FIGURE 1.6 Copper-Tube Heat Exchanger



IMPLICATIONS

This can result in reduced efficiency of the heating system. A soot buildup on the heat exchanger, for example, restricts the heat transfer, resulting in more heat going straight up the chimney.

It can overheat the heat exchanger if the exhaust flow across the heat exchanger is restricted.

In severe cases, it can lead to spillage of exhaust products back into the house through the burner.

STRATEGY

With a mirror and flashlight, look for black, sooty deposits on the heat exchanger. These should not be seen at all on gas burners, and, although some soot can be expected on an oil burner, watch for measurably thick buildups.

Look for rust on the heat exchanger that can completely obstruct the fins on a copper-tube boiler.

Spillage

Check for spillage of combustion gases as you would on any burner. One cause may be a restricted heat exchanger passage.

Cleaning

Where you have identified a partially clogged or heavily sooted heat exchanger, you're probably looking at a maintenance item rather than a replacement item. This is a far less serious condition in most cases than a leak or severe rusting of a heat exchanger.

CHAPTER REVIEW QUESTIONS

Answer the following questions on a separate sheet of paper, then check your results against the answers provided in Appendix E. If you have trouble with a question, refer back to the chapter to review the relevant material.

1. How do boilers use conduction to transfer heat from the flame to the air in the room?

2. Copper-tube boilers typically have

- **a.** better heat transfer characteristics and longer lifespans than cast-iron boilers.
- **b.** better heat transfer characteristics but shorter lifespans than cast-iron boilers.
- **c.** worse heat transfer characteristics but longer lifespans than cast-iron boilers.
- **d.** worse heat transfer characteristics and shorter lifespans than cast-iron boilers.
- **e.** roughly similar characteristics to cast-iron boilers.

3. Which of the following is a similarity between furnaces and boilers?

- **a.** Piping
- **b.** A low-level safety device
- **c.** High-temperature limit switches
- **d.** Backflow preventers
- **e.** A pressure-relief valve

4. List five advantages of a hot water heating system.

5. List five disadvantages of a hot water heating system.

6. Explain briefly how we can get superheated water in a hydronic heating system.

7. Heat exchanger diagnosis on boilers is easier than on furnaces because the heat exchanger will leak when it has failed.

True False

8. Explain briefly why you don't want to drain the zboiler water in the summer.

KEY TERMS

superheated water steam explosion