

**FIRETUBE / WATERTUBE
BOILERS
A
COMPARISON**

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FIRETUBE / WATERTUBE COMPARISON

INTRODUCTION

Two generic boiler designs --watertube and firetube-- are available to meet industrial and commercial steam needs. Choosing the best boiler for each application is critical for the long term success of every project. Proper selection can save the end user hundreds of thousands of dollars over the life of the boiler. It is easy to see why thorough understanding of boiler designs is necessary when it is time to choose. This paper reviews **watertube** and **firetube** boilers and compares their strengths and their limitations.

Watertube boilers contain the water and steam inside a network of mud and steam drums plus the interconnecting bent water tubes. The hot combustion gases used to heat the water circulate outside these tubes. All of this is contained in a large, insulated, and sometimes gas tight enclosure. **Firetube** boilers contain the combustion gases in straight tubes and the combustion chamber while the water and steam circulate outside these tubes. All of this is contained in the much larger outer shell of the pressure vessel.

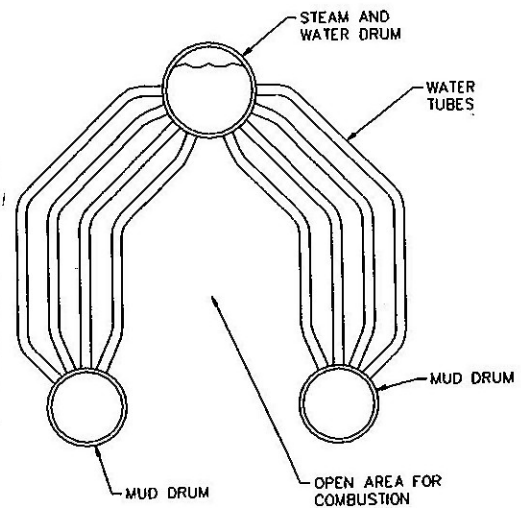
Both units produce steam and share many similarities, but a review of specific design and operating characteristics sets them apart. One difference is the language used to size their output. **Watertube** boilers are most commonly rated or sized in pounds per hour (**pph**) of steam they produce. **Firetube** boilers are rated in boiler horse power (**BHP** or **HP**). To translate between these two languages you need to know only one formula, one (1) BHP is equal to 34.5 pph of steam from and at 212°F.

$$1 \text{ BHP} = 34.5 \text{ pph}$$

Formula 1

WATERTUBE BOILERS

Watertube boilers are available in many different types. Three of these cover 99% of the industrial and commercial applications. First is the 'A' Type boiler, shown in Figure 1. This boiler has a single steam drum and two mud drums. These are interconnected by banks of symmetrical tubes that connect the steam and mud drums in an 'A' shape. The combustion products travel down the large central combustion or radiant zone. At the end of this zone, the

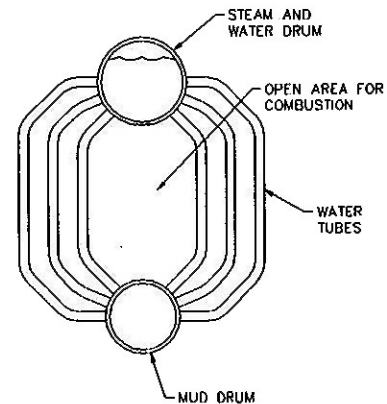


"A" STYLE BOILER

Figure 1

gases split and travel back through the convection tube bundles on each side of the boiler and then out the exhaust. The large open bottom of the 'A' style makes it excellent for solid fuel firing.

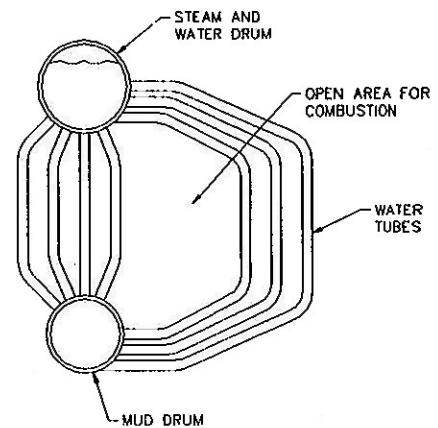
The second design is an 'O' Type boiler, shown in Figure 2. This boiler has a single steam and mud drum. These two drums are interconnected by banks of symmetrical tubes that form an 'O' shape. Like the 'A' type, combustion products travel down the large center radiant zone. At the end of this combustion chamber, the gases split and travel back through the convection tube bundles on each side of the boiler and then out the exhaust. The floor of the combustion chamber is covered with refractory material to protect the mud drum and many of the horizontal tubes from the intense heat of the flame. The typical fuels used in this boiler are gases and liquids.



"O" STYLE BOILER

Figure 2

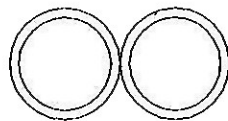
Third--and most common--is the 'D' Type boiler, shown in Figure 3. This boiler has a steam and mud drum. These two drums are interconnected by a bank of asymmetrical tubes forming a 'D' shape. Like the other watertube boilers, the combustion products travel down the large combustion chamber. At the end of this radiant zone the combustion products turn and travel back through the single convection tube bundle and out the exhaust. For some applications, the floor of the combustion chamber may have some refractory to protect these tubes from the intense heat of the flame. The typical fuels used in these boilers are gases and liquids.



"D" STYLE BOILER

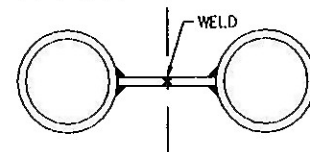
Figure 3

The type of tube construction used in these three boilers affects the boiler construction. Boilers that use a tangent tube wall (see Figure 4) to define the combustion chamber and outer walls will require an outside, gas-tight, enclosure. Because the tubes will move as they heat and cool, open spaces will develop between the tubes that will allow the hot gases to escape from the combustion zone. Some of these gases will leak to the outside of the boiler and some will short circuit directly into the convection zone.



TANGENT TUBE

Figure 4



WELDED WALL

Figure 5

Boilers that use a welded web (see Figure 5) do not require the outside insulation shell to be gas-tight. The welded wall construction provides a gas tight enclosure around the boiler and between the combustion chamber and the convection zone.

There are other types of **watertube** boilers, but their applications are limited to very special needs. Very large custom-designed **watertube** boilers are used by the electric utilities in the production of high-pressure and high-temperature steam to turn electric generating turbines. Specialized flexible **watertube** boilers are built for small, hot-water heating requirements. These types of boilers are not covered in this discussion.

WATERTUBE DESIGN CONSIDERATIONS

The typical water content in **watertube** boiler averages around one-half pound of stored water for every pound per hour of steam for which the boiler is rated. This water content is a function of the small diameter steam drum, the mud drum(s) and the interconnecting water tubes.

The **watertube** boiler design has a heat transfer ratio that typically falls between 0.07 square feet and 0.10 square feet of heat transfer surface per pound of steam per hour produced.

The furnace volume available for combustion varies widely with the three styles of **watertube** boilers. For all three styles, as steam production capacity increases, so does furnace volume--but at a slower rate. For general comparisons, the lower capacity **watertube** boilers will have furnace-to combustion ratios of 95,000 Btu/ft³ to 110,000 Btu/ft³, while higher capacity **watertube** boilers will have ratios that are at or above 180,000 Btu/ft³.

Watertube boilers can be narrow, long, and tall. Available burners for gas and oil firing limit very high capacity **watertube** boiler sizes; they often need to be extra tall to accept the vertical dual burner arrangements that are necessary to reach full heat input.

When shipping constraints or access to a boiler room requires it, **watertube** boilers can be field assembled. Most boilers are shipped as packaged boilers. The words "packaged boiler" have different meanings for the two types of boiler designs. For the **watertube** boilers, this normally means that the boiler or pressure vessel is assembled with the outside insulating and, perhaps, gas-tight shell. Extensive field labor may be required to install the burner, fuel trains, controls, and boiler trim. For the **firetube** boilers, "packaged" means the boiler pressure vessel is shipped complete with the insulation, burner, fuel piping, controls, and boiler trim. These items are factory installed and tested.

FIRETUBE BOILERS

Firetube boilers are available in many different types. Considering only scotch marine boilers, they are available in one (1) to four (4) pass designs plus

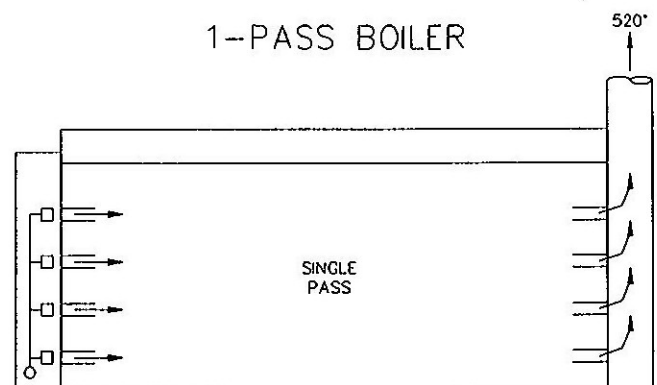


Figure 6

water back or refractory back construction. The number of passes refers to the number of times the combustion products pass through the boiler to transfer heat to the water. Most boilers today are either three (3) or four (4) pass designs, although there are still some single pass boilers manufactured. Figure 6 shows typical one (1) pass boiler and Figure 7 shows a typical two (2) pass boiler.

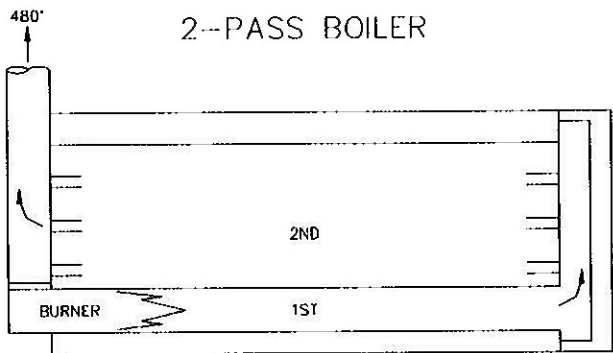


Figure 7

Refractory back and water back boilers (see Figures 8 through 11) differ in their construction at the first turn for the hot combustion flue gas products. Refractory back boilers have only a single rear tube sheet that must work with the vastly different temperatures in a firetube boiler. The single rear tube sheet is subjected to the high thermal stresses of both the very high temperature (1700°F to 1900°F) first turn and a much cooler third turn (450°F to 600°F). Waterback boilers have two rear tube sheets. In operation the high temperature turning area is contained in a fully submerged separate chamber and the second rear tube sheet only sees the cooler, third-turn temperatures. This reduces thermal stress on the tube sheet that may lead to cracking and ensures the end user is not dependent on an expensive and delicate refractory structure to maintain both flue gas separation and boiler efficiency.

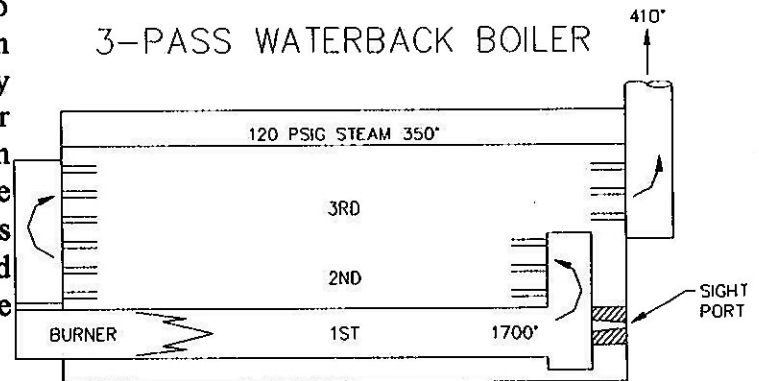


Figure 8

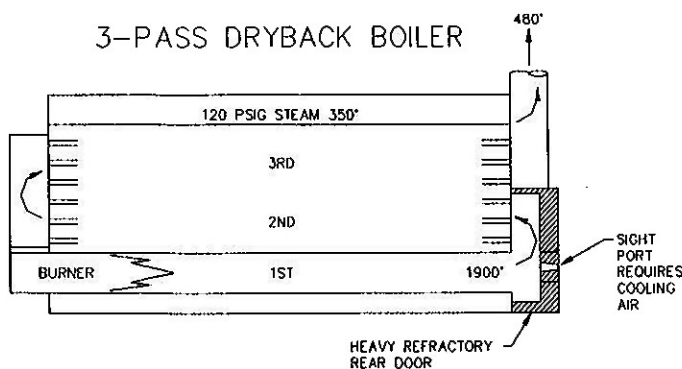


Figure 10

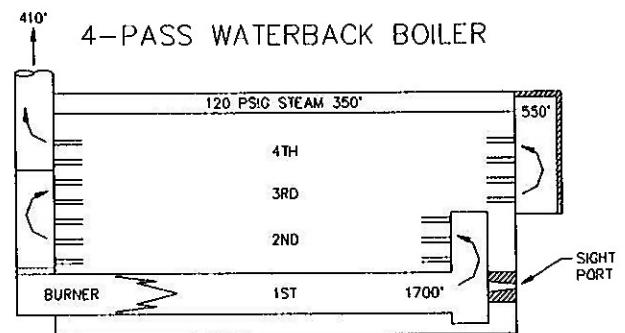


Figure 9

FIRETUBE DESIGN CONSIDERATIONS

The typical water content in these boilers is around 1¼ to 1¾ pounds of stored water for every pound of steam per hour for which the boiler is rated. This water content is a function of the convection tube spacing which dictates the boiler pressure vessel diameter. It is also related to one of the design standards that has developed over time for firetube boilers. That design standard is five square feet of heat transfer surface per boiler horse power. That is the equivalent of 0.145 square feet per pound of steam per hour.

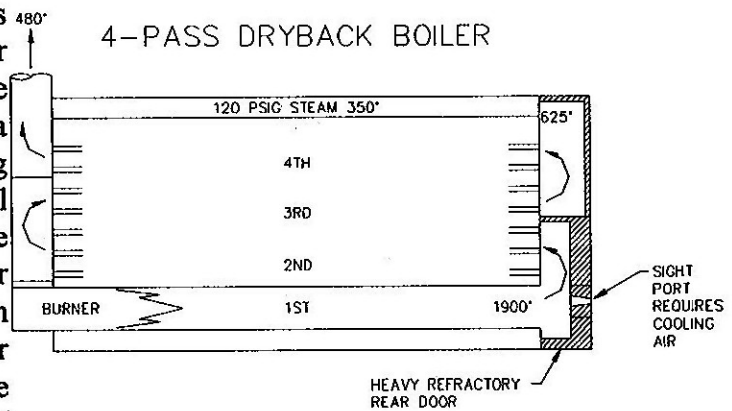


Figure 11

This is another area where the language is different between the two boiler designs. In **firetube** boilers this ratio is given in square feet per boiler horse power. A conversion formula to compare the two types of boiler designs can be developed using the information from formula 1 comparing boiler horse power and pounds of steam per hour.

$$(\text{Square feet of heating surface per pph})(34.5) = \text{Square feet per BHP}$$

or

$$\frac{(\text{Square feet per BHP})}{34.5} = \text{Square feet of heating surface per pph}$$

Formula 2

Using this information, the heat transfer ratios in **watertube** boilers are equal to 2½ square feet to 3½ square feet per BHP.

The furnace volume available for combustion varies widely from manufacturer to manufacturer. For all **firetube** boilers, as the output or BHP increases, so does the furnace volume. Some manufacturers hold the ratio steady across their full line while others let the ratios vary and become very high with the larger boilers. For general comparisons **firetube** boilers run between 100,000 Btu/ft³ to 120,000 Btu/ft³ with some above 220,000 Btu/ft³.

Firetube boilers are wide and long. Their width is a function of their design. The more conservative the design, the more water storage the boiler typically will have and the wider it will be.

As stated earlier, all **firetube** boilers should be full factory packages to include burner installation, fuel train piping, controls, boiler trim, and a full factory fire test to capacity on the fuels that will be used in the field. In addition, factory testing should be conducted to the standards of ASME Power Test Code 4.1 to ensure the boiler is generating the guaranteed efficiency. In the case of low-emission boilers, a stack gas analysis should be included in the test to confirm the boiler is fully within compliance at all firing rates.

FIRETUBE / WATERTUBE - THE COMPARISON

Initial Cost

With the fluctuating cost of capital, fuel, and maintenance, it is important that boiler selection be based on performance, installation expense, and operating expense, rather than historical consensus or personal preferences. A thorough review of installation expenses, annual fuel expenses and continuing maintenance charges may substantially affect a company's profit statement for the life of the boiler.

The initial cost of a boiler should include the purchase price and installation charges associated with bringing the boiler on line to full production. The purchase price of the **firetube** design is normally considerably lower than the more complex 'A', 'O' and 'D' type **watertube** boilers. In addition, there are the additional construction costs to complete the "packaged" **watertube** boiler to the same level of completion as the factory "packaged" **firetube** boiler. Field labor to install burners, fuel piping, controls, and boiler trim is very expensive. Start-up time required at light off in the field is much longer than the time required to fire a burner that has already proven its operation capabilities in the manufacturer's plant.

Energy Efficiency - Annual Fuel Cost

And, while initial cost is an important consideration, one of the most critical factors in analyzing which boiler to select is its guaranteed efficiency and resulting annual fuel cost. To better understand this portion of the selection process, let's compare equal sized **watertube** and **firetube** boilers.

ANNUAL FUEL COST COMPARISON

<u>Design Parameters</u>	<u>New Watertube w/o Economizer</u>	<u>Firetube w/o Economizer</u>
Output pph;	40,000	40,000
Output Btu/hr:	38,797,525	38,797,525
Design psig:	250	250
Operating psig:	200	200
Feed water temperature:	212°F	212°F
Air temperature:	80°F	80°F
Excess air %:	15	15
Fuel:	Natural Gas	Natural Gas
Fuel Cost:	\$0.35 per Therm	\$0.35 per Therm
Operating Hours	8,000	8,000
Operating Efficiency:		
@ 100%	78% Estimated	82.2% Guaranteed
@ 75%	79% Estimated	82.0% Guaranteed
@ 50%	78% Estimated	81.2% Guaranteed
@ 25%	77% Estimated	80.2% Guaranteed

Fuel Usage Calculations

$$\frac{\text{Output}}{\text{Efficiency}} = \text{Input}$$

$$\frac{38,797,525}{78\%} = 49,740,416 \text{ Btu} \quad \frac{38,797,525}{82.2\%} = 47,198,935 \text{ Btu}$$

$$\text{Therms Used:} \quad \frac{49,740,416}{100,000} = 497.4 \text{ Therms} \quad \frac{47,198,935}{100,000} = 471.99 \text{ Therms}$$

Annual Fuel Cost Savings

$$\text{Annual Fuel Cost} = (\text{Therms})(\text{Cost per Therm})(\text{Operating Hours}) = \$$$

$$\text{Firetube Boiler} \quad (471.99)(\$0.35)(8,000) \quad = \$ 1,321,572$$

$$\text{Watertube Boiler} \quad (497.4)(\$0.35)(8,000) \quad = \$ 1,392,720$$

$$\text{Annual Fuel Cost Savings with Firetube Boiler} \quad = \$ \quad 71,148$$

In this case the **firetube** boiler will save more than \$70,000 every 8,000 operating hours over a similarly sized **watertube** boiler. Over a 30 year period, this will amount to more than \$2 million in savings...and that is without considering a future value of money.

Maintenance

No review of boiler selection would be adequate without considering maintenance frequency and maintenance expense. Some key areas of concern are the rate of heat transfer and its effect on boiler life, boiler tube replacement, refractory repair, and daily maintenance requirements. Both the **firetube** and the **watertube** boiler must be cooled before any work can begin.

The total wetted surface area of the boiler that is available to transfer the heat of combustion to the stored water and steam is very important. The less square feet of heat transfer surface per boiler horse power or pound of steam produced, the greater the thermal stresses will be on the metal in the boiler. The build up of stresses causes cracked welds, leaky tube joints, and failed tubes.

Most **firetube** boilers with five square feet of heating transfer surface per boiler horse power have an average heat flux of 8,145 Btu/ft². **Watertube** boilers will range from a low of 12,500 Btu/ft² to over 17,760 Btu/ft². With this higher heat transfer rate and the effects of heating and cooling, the **watertube** boiler will be subjected to much greater stresses.

When a tube fails in a **watertube** boiler, the typical repair is to cut the tube out and plug its connections in the steam and mud drums. This logic is to save time and expense, but such a measure does compromise efficiency. **Watertube** boilers, with their specially bent water tubes, require considerable time for the supply and replacement of a failed tube. And if the failed tube is not on the outside where it is easy to service, several good tubes may have to be replaced to reach the defective one. In a **firetube** boiler, the tubes are straight and simple. They are readily available through local distributors. The replacement of any single tube can normally be accomplished in less than an hour.

Many boilers designs, **watertube** or **firetube**, incorporate a great deal of refractory in their construction. The greater the amount of refractory used in the boiler construction, the higher the maintenance cost. The following list shows the more common areas for the two boilers designs to incorporate refractory:

Watertube Boiler

Burner throat
Furnace rear wall
Furnace front wall
Furnace floor
Convection section rear wall
Tube to steam drum furnace side seals
Tube to steam drum convection side seals
Tube to water drum convection side seals

Firetube Boiler

Burner throat
Refractory back (dryback design)
boiler rear door (delicate refractory)

Water and Steam Volume

The volume of water stored in a boiler affects its operation in several ways. The low volume of water stored in a **watertube** boiler allows it to go from a cold start to operating pressure in a shorter time than a similarly sized **firetube** boiler. A cold start is normally only encountered at the boiler's initial start up and in rare cases when a cold boiler is brought on line in an emergency.

The larger water volume of the **firetube** boiler provides it with other features that may outweigh a slightly longer initial cold start up. The larger volume of water will allow the **firetube** boiler to handle wide swings in process steam flow much more easily. A major increase in steam flow is easily accommodated from the larger water volume at saturation temperature and ready to flash to steam. Rapid swings in process steam requirements are very common in many industries as opposed to heating demands that turn on and off.

The larger total water volume of the **firetube** boiler means it has a greater time span between the first indication of a need for additional water and the low water level that shuts the boiler down. A very small volume of water available in the **watertube** boiler between these two levels can lead to nuisance shut downs caused by a low water condition. To avoid this, **watertube** boiler manufacturers must supply expensive multi-element modulating feed water systems. These elaborate systems sense the flow of steam and the change in pressure and begin to feed water to the boiler before the level controls sense a need for additional water. Constant operation of the feed water pumps, required for these systems, increases boiler complexity and electrical cost.

The small water volumes available in **watertube** boilers make treatment of the water very critical. Proper concentration of chemicals necessary to protect the boiler are more difficult to control. Chemical concentration levels that are too high can create fluctuating or bouncing water that can cause nuisance low water problems, lead to water carry over, and coat the water side of the boiler, leading to a reduction in heat transfer and premature boiler failure. Concentration levels that are too low, lead to boiler corrosion and premature boiler failure. Because concentration levels can change so rapidly in the small water volume of **watertube** boilers, manufacturers usually suggest that large quantities of boiler water be constantly purged to help this potential problem. The loss of high-temperature water adds to the cost of operating a **watertube** boiler.

Dry Steam

Dry steam is very critical for many applications, which usually require 99.5% quality (1/2 of 1% carryover). Steam outlet nozzle design and location are very important to ensure the best possible quality of the steam leaving the boiler. The basic design of the **firetube** boiler places a much greater distance between the water surface and the steam outlet nozzle. The result is 99.5% dry steam from a **firetube** boiler with less complicated internal baffling and without external water separators.

Operating Pressure

Steam operating pressure requirements vary widely. **Firetube** boilers are limited by the materials required to manufacture these pressure vessels to meet design pressures up to approximately 350 psig. As the design pressures go above this level, the thickness of the steel required for the large diameter **firetube** boilers make them more difficult to manufacture and less cost effective for the end user. As steam pressure requirements exceed 350 psig, it is more first cost effective to use a **watertube** boiler. It is not uncommon to have **watertube** boilers designed to operate at pressures of 750 psig or greater.

Super-Heated Steam

The tube layout configurations of **watertube** boilers allow them to be equipped with a steam super heating section. These additional tubes are typically installed prior to the start of the convection section. A great deal of care must be taken with their design to avoid problems, but they work very well for many systems. **Firetube** boilers do not have the ability to provide super-heated steam. There are external steam super heaters designed that can be used with either **watertube** or **firetube** boilers. These units offer better temperature control and easier maintenance, but are typically very expensive. Most external steam super-heating units are designed for gas firing only. A super heating section in a **watertube** boiler can be effective with all fuels used in that boiler.

Fuel Selection

With the many types of **watertube** boilers available, this allows users to choose from a wide range of fuels. The 'A' type boiler with an open floor can easily be fitted with different stokers to burn solid fuels. The 'O' and 'D' types, like the **firetube** boilers, are typically used only for gas and liquid fuels. The larger furnaces of the **watertube** boilers make them more adaptable for some exotic fuels that require the larger combustion volumes.

Conclusion

Of course we have a preference! But we will not even begin to suggest that a firetube boiler is the answer for every need. When you need a large boiler, in excess of 85,000 pounds per hour for a single unit, get a watertube boiler. When you need super-heated steam or pressures above 350 PSI, get a watertube boiler.

But for most other applications we think a firetube boiler -- and a waterback firetube boiler in particular -- is a wiser choice. Here is a recap of our reasons for making that suggestion:

- ✓ They are pretested at the factory.
- ✓ They take less time to install.
- ✓ They are installed at a lower initial cost.
- ✓ Their operating costs are substantially lower.
- ✓ Their efficiency rating is substantially higher . . . and, in the case of Johnston, that is guaranteed.
- ✓ When repairs are needed, the fix is usually fast and relatively inexpensive . . . standard replacement tubes are available from any number of suppliers.

With a normally lower purchase price and substantial saving in installation cost, a **firetube** boiler is clearly the first choice. In any selection, good engineering and financial assessments should continue with a detailed review of annual fuel cost, maintenance cost and many other aspects of the total boiler package.

Watertube boiler . . . ? Firetube boiler . . . ? You are the people who will make the decisions. If nothing else, we hope we have given you what you need to know to begin asking the right questions before you buy or specify.