LEADERSHIP FOR THE BOILER INDUSTRY

BOILER TYPES FOR STEAM APPLICATIONS

Understanding the Basics & Differences

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ABMA would like to thank Gene Tompkins on ABMA's Technical Team for leading the creation of this publication and Jim Kolbus, Product Manager at Clark-Reliance for partnering with Gene as a contributor, editor and sounding board on this publication project.

This publication shares some typical advantages and disadvantages of different boiler types. While this document is not meant to address the specifics of all boilers, it should offer some general opportunities for customers to select products that best suit their needs.

We welcome your feedback on this publication along with ideas for future contributions from ABMA. Feel free to send any comments to **info@abma.com**.

DISCLAIMER

While this document is technically sound, it is advisory only and to be used as a guide for qualified personnel. This publication is not intended to be definitive, nor are the comments made regarding specific boiler types applicable to every boiler.

This information is provided to help understand the common differences between boiler types and what users should be looking for when evaluating the best boiler for their application. Any use made of the information in this publication is entirely within the control and discretion of the manufacturer and is wholly voluntary.

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This article covers the basic difference between common boiler types for high pressure steam applications in the capacity range of 5,000,000 to 100,000,000 Btu/hr (5-100 MMBTU/hr or 120 - 2400 HP). This size range would be the larger commercial, institutional and industrial applications. This range has been selected because there are many different types of boilers available that are offered by several manufacturers. The goal of this paper is to provide insights into how different boiler designs can impact the efficiency and overall operating advantages of a steam facility.

Low-pressure steam and hot water markets are much different in both performance opportunities and in equipment that can be used in these applications. While the general concepts of efficiency are the same, the actual details provide a much different environment compared to high-pressure

I. Basic Boiler Types

There are two basic boiler styles for steam boilers in this range, Firetube and Watertube boilers. As their names imply, the Firetube boiler has the fire (combustion gases) inside the tube and the Watertube boiler has the water inside the tube. This allows for large variations in product design and manufacturers have taken advantage of this to offer ever expanding options to customers. Over the last few years, these basic styles have expanded to include a wide variety of different boilers, and with each new design comes an opportunity for a better match between the different applications and boiler.

FIGURE 1 *– Firetube Boiler with Economizer (Courtesy of Burnham Commercial Boiler)*

FIGURE 2 *– Industrial Watertube Boiler (Courtesy of Victory Energy.)*

For this analysis, the key issues will be efficiency, response to load, ease of maintenance and space requirements. The value of each of these considerations will vary with the application, so while some people will want to maximize the efficiency because of high fuel costs, others may be driven by limited space, with all other factors becoming secondary.

Each product has its own list of pros and cons, and often a design is done to maximize certain attributes. There are fundamental tradeoffs in the design of a boiler, and you can cut back on one item and expand on another to offer different advantages and performance. This is exactly what has been occurring in recent decades, greatly expanding the products available.

II. Tradeoffs in Boiler Design

There are fundamental tradeoffs in the design of a boiler, and you can easily cut back on one item and expand on another to offer different features, cost and performance. It is important to understand these trade-offs because you want to select the unit that will best serve your application. This is not to say that some boilers will not work for your application, only that some boilers may work better than others. This is especially true today where there are many more types of boilers with different advantages and performance.

Here are some of the key trade-offs in boiler design;

1. **Adding or Reducing Heat Transfer Surface Area:** All things being equal, a boiler with more heating surface will have a higher steady state efficiency. The other advantage of larger heating surface is that if you use oil or a dirty fuel, a boiler will have a longer time between cleanings. The disadvantage of larger surface areas is that it results in a larger more expensive boiler and has a higher heat loss when the boiler cycles on and off (dynamic efficiency).
2. **Furnace Size:** Larger furnaces are easier to fire and depending on the boiler design, it can reduce the thermal stress by lowering some temperatures (like the entrance to second pass tubes in a Firetube boiler). Furnaces size can also have an impact on the emissions capability, with larger furnace sizes making it easier to get lower NOx emissions. A larger furnace also makes the vessel larger and more expensive. These conditions are not absolute, and for example, a pre-mix burner essentially needs no furnace, which is a common design in smaller sizes and for some manufacturers. Also, the Watertube boiler typically has a larger furnace because it is relatively easy and inexpensive to do, where the Firetube furnace is usually smaller.
3. **Using a Pre-Mix Burner:** The flame size of a pre-mix burner is a small fraction of the size required by a conventional burner. Because of this, a separate furnace may not be required, and this can greatly reduce the vessel size. This technology is used in Firetube and Watertube boilers, but is more common in Watertube boilers. It also has the advantage of offering lower emissions by simply increasing the excess air rate although this tends to reduce the efficiency. Pre-mix burners are limited in gaseous fuel, such as natural gas or propane.

4. **Improving the Heat Transfer Rate:** The heat transfer rate can be improved which can increase the efficiency, reduce the heat transfer surface or a combination of both. There are some common methods to do this;

    a. Increasing the flue gas velocity will directly increase the efficiency (up to a point) because more heat will be transferred to the boiler. The downside of higher velocity is that it takes a larger fan and motor to provide this velocity.

    b. Adding turbulators inside the convection tubes of a Firetube boiler will improve the heat transfer, but with a higher pressure drop requiring larger fans and motors to make capacity.

    c. Use tubes that have extended surface on the flue gas side. Heat transfer from the tube to water is easy, but hard for flue gas to the tube. For a Firetube boiler, this means notches in the inside of the tube. In a Watertube, this could mean adding fins to the outside of tubes. Again, all these methods will improve the heat transfer but at the cost of larger fans and motors.

    In all of these, there is also the potential issue of plugging due to the tighter spacing and it is more difficult to clean the heat transfer surface. The extent of the difficulty depends on the type of fuel, with cleaner fuels like natural gas being less problematic.

5. **Adding Economizers:** An economizer is a heat transfer product that will remove heat from the flue gas and add it to the incoming feedwater. It can save a fair amount of energy, and has the added benefit of working with the cooler feedwater, compared to the hotter boiler water, so a boiler with an economizer typically has a higher steady state efficiency. The downside to economizers is that they add cost, complexity and are subject to cold end corrosion.

III. Firetube Boilers

Firetube boilers have been one of the predominate boiler designs for well over a century, and even today they represent a majority of the high pressure steam generating capacity for units in the normal size range. Not all Firetube boilers are created the same.

Historically, most manufacturers offered Scotch Marine Firetube boilers (horizontal multi-pass with a large furnace) with the same basic design but varied in number of passes (2, 3 or 4-pass) or the furnace turnaround construction (wetback or dryback). These designs had good track records, long life with good efficiency and were easy to operate with a forgiving nature.

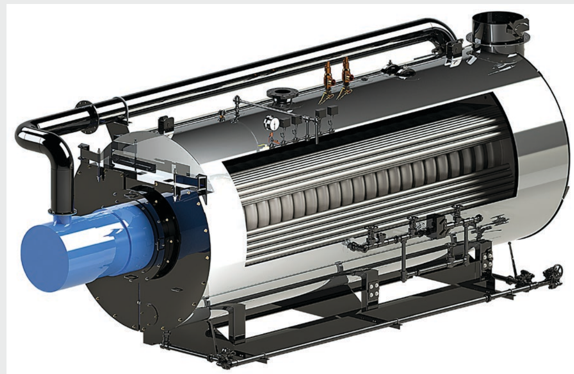


FIGURE 3 *– 3 Pass Wetback Boiler (Courtesy of Victory Energy)*

The Scotch Marine Firetube boiler is made up of a cylindrical shell that has a furnace to contain the combustion and numerous tubes used to extract the combustion heat. Turnaround chambers are used to reverse the combustion gases from the furnace to the tubes, and multiple turnarounds can be used to generate multiple passes. Typical Firetube boilers can have anything from a single pass (no furnace) to 4 passes.

FIGURE 4 *– 4 Pass Wetback Flue Passes (Courtesy of Cleaver-Brooks, Inc.)*

FIGURE 5 *– 4 Pass Dryback Flue Passes (Courtesy of Cleaver-Brooks, Inc.)*

The flue gas turnaround from the furnace to the second pass tubes can be done in two common methods, a wetback and dryback turnaround. Wetback boilers have a water cooled chamber located in the vessel for the furnace turnaround and although it doesn't require regular maintenance, it is difficult to access for inspection, maintenance and repairs. The dryback boiler has the furnace turnaround in a separate refractory chamber attached to the back of the vessel, making vessel access very easy, but it can require more regular maintenance of the gaskets and refractory.

One weakness of a multi-pass Firetube boiler is a problem called “Thermal Shock”. This is actually not a shock, but a difference in thermal expansion and contraction caused by the furnace, tubes and shell heating and expanding at different rates, causing high stresses and fatigue failure. This is prevented by performing a slower warmup cycle to minimize the temperature differences. A similar problem occurs with hot water applications, where sudden changes in the water (return) temperature cause different expansions and contractions. In fact, multi-pass Firetube boilers are not usually used for hot water applications today because of this issue.

A major difference between Firetube and Watertube boilers is that the Firetube boiler has a much larger water and steam content for any given capacity. This is inherent in the design of the boiler, and the reason for most of the differences between boiler types. This large reservoir of water and steam makes the Firetube steam pressure and water level more stable in fluxuating loads. It also requires more energy to heat up to operating temperature and pressure.

THE CLASSIC SCOTCH MARINE FIRETUBE BOILER

The Scotch Marine Firetube boiler is a multi-pass horizontal boiler that typically has the furnace located lower in the shell. It can be 2, 3 or 4-pass with wetback or dryback construction. These boilers are often made with large heating surface, typically 5 square feet per boiler HP.

Primary Advantages of the Scotch Marine Firetube Boiler

1. Most of these boilers are built with a lot of heating surface, usually 5 square feet of heat transfer surface per boiler HP. This provides higher steady state efficiency and a good resistance to fouling. A Watertube boiler will usually have less heat transfer surface, but often add economizers to overcome this difference. This is why Firetube boilers typically have the best steady state efficiency.
2. Because a large diameter shell contains the water and steam, these boilers have a large steam chest and disengaging area that provides good steam quality without the addition of mechanical separation.
3. The furnace can be made large enough to support a variety of different fuels and emission requirements.
4. The large shell space allows for a fair amount of sediment accumulation without hurting the vessel, providing more flexibility in water treatment and blow down maintenance. This is why the Firetube boiler is considered to be more forgiving.
5. The large water content makes the management of water level easier to control, often with just an on-off control or a simple modulating level control, adding to the “more forgiving” concept.
6. The boiler has large energy content (a combination of the steam and water at saturated temperature) that allows it to generate a higher steam flow rate for short periods with minimal steam pressure variations. Applications with large instantaneous flow rates can use this advantage, but there are limits to how much can be done without hurting the boiler or creating steam quality issues, which are detrmined by the manufacturer..

7. Most of the boiler has water or steam on the inner side of the shell, which is much cooler than the flue gases that are on the interior of a Watertube boiler. In many cases, this can reduce the shell heat loss, defined as the "Radiation and Convection" losses.

Primary Disadvantages of the Scotch Marine Firetube Boiler

1. Most Scotch Marine Firetube Boilers require a slow warmup cycle that can take several hours. Multiple pass boilers are subject to "Thermal Shock", and if the warmup cycle is not done properly, failures will occur over time. The larger (longer) the boiler, the bigger the problem, because the difference of growth between the furnace, tubes and shell will be larger.
2. The longer warmup cycle often requires backup boilers to be kept hot for quicker response. This adds cost and complicates the operation of a plant.
3. Because the steam pressure is contained by the large diameter shell, it has a limited pressure capacity, usually around 300 PSI.
4. The large steam and water content means that more energy is required to bring the unit on-line. If the boiler operates infrequently, that energy (or a portion of that startup energy) will be lost in the off time, which is reflected in the lower dynamic efficiency.

OTHER FIRETUBE BOILERS

The Scotch Marine Firetube boiler is historically the most common boiler used for steam generation in the size range of 5 to 75 MMBTU input. The size range of the Firetube boiler line has been increasing over the years, and is now over 100 MMBTU/hr, or about 2500 HP. These larger boilers typically do not have the larger heating surface of 5 square feet/BHP, but use other means to maintain high efficiencies.

There are other types of Firetube boilers, and the most common types are as follows:

1. Ohio Special boilers are units made with a limited amount of heating surface. In the state of Ohio, if the boiler has less than 358 square feet of heating surface, it does not need to have a full-time operator, so designs are made to keep under this limit, while producing 250 HP (10 MMBTU/hr input) or more. They are typically 2-pass boilers with special tubes to improve heat transfer rates.
2. Firebox boilers use similar furnace and tube attachment techniques, but often do not use a round furnace or shells, and are usually limited to low pressure steam and hot water. The boiler tends to be more compact and economical and often used for seasonal heating.
3. More recently, there are boilers that have less than 5 square feet of heating surface per boiler HP in a variety of wetback, dryback and number of passes. These take advantage of the improved heat transfer and the common use of natural gas to get good efficiency in a smaller package.
4. There are vertical firetube boilers that offer the advantage of a much smaller footprint. These units usually are limited to about 200 HP (8,400,000 BTU/hr) in size.
5. There are single-pass horizontal Firetube boilers that use a pre-mix burner and do not need a furnace. Their primary advantage is that they don't suffer from thermal shock, and can be brought on-line and generate steam quickly. They also have less heat transfer surface resulting in a smaller size and footprint.

IV. Watertube Boilers

Watertube boilers have numerous variations in design, mostly because the small diameter tubing is easy to fabricate into many different shapes. There are designs for solid fuels, smaller footprint, truck mounting, lower costs, thermal shock resistance, quick startup and other goals.

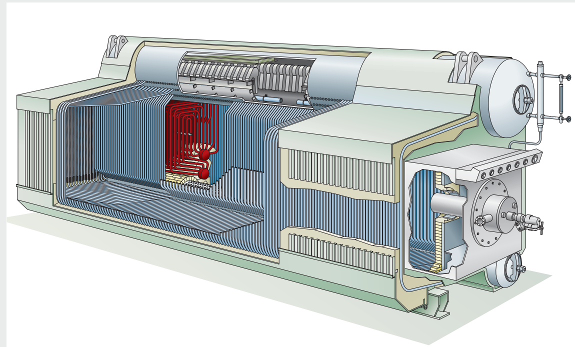


FIGURE 6 *– D Type Industrial Watertube Boiler (Courtesy of Babcock & Wilcox Company)*

The "Industrial Watertube" line is defined as units that have high capacities, high pressure capabilities and the ability to provide superheat. Packaged Industrial Watertube boilers typically go up to about 300,000 PPH, although larger boilers are not able to ship as complete units.

Watertube boilers have the steam and water inside the tubes, so they have much less water content than the Firetube boiler. They also have a much smaller space for the collection of scale and generally require better feedwater because a small amount of scale can block flow through a tube.

Watertube boilers are made up of multiple drums and numerous tubes. The upper drum is called the steam drum and the lower drums called the mud drums. The interconnecting tubes are bent to provide a furnace and convection section. The tubes may also provide some or all of the enclosure of these areas. In Bent-tube boilers, multiple gas passes are made from the bending of the tubes, with no attachment between the tubes, offering great resistance to thermal shock.

One issue with Watertube boilers is sealing the flue gases in the vessel. This is normally done with rigid casing (structural walls that enclose the tubes and provide a gas tight enclosure), membrane walls (tubes welded together to provide a gas tight wall) or a combination of these features. In addition, refractory and insulation are used to protect the drums and tube connections from the hot flue gases. There are many ways to seal the flue gases and often these are provided as sales advantages. Welded membranes, for example, provide an excellent means of containing the hot flue gases, but can make the vessel more rigid and subject to thermal stresses. Tangent tubes offer flexibility in the vessel (a common trait of Bent Tube boilers) but have gas leakage and higher wall temperatures.

Bent Tube boilers have been around for a several decades, and availability continues to grow into larger sizes. They are best identified as units that have shaped tubes used to create multiple passes within the boiler. They typically have a much smaller capacity then the Industrial Watertube, but offerings of up to 100 MMBTU are available. The primary attraction is their small size and lower cost.

The Coil tube boiler is also a special type of Watertube boiler. It is normally made of a single tube coil (or a few coils) that can perform quick startup without the potential of thermal shock. A separate chamber is used for steam separation. These boilers typically have a very low water content, small size and can have a very short startup time for steam generation.

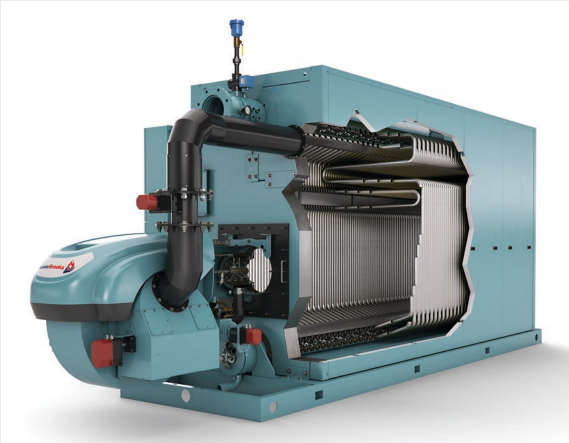


FIGURE 7 *– Bent Tube Boiler*
Courtesy of Cleaver-Brooks, Inc.)

FIGURE 8 *– Coil Tube Boiler*
(Courtesy of Clayton Industries, Inc.)

The Coil tube boiler does require very good water treatment and maintenance to prevent water side scale buildup.

There are many other Watertube designs that are specifically geared towards heat recovery or solid fuel firing and other special applications. In fact, boiler manufacturers provide several unique designs for individual customer applications.

INDUSTRIAL WATERTUBE BOILERS

In this group, the most common Watertube is called "Industrial Watertube" (IWT) boiler. These units are usually in a "D" configuration, but also found in other configurations like an "A" or "O" style. The "A" and "O" series tend to offer the ability to be packaged and shipped in larger capacities as well as very high steam pressures and superheated steam. These boilers have been offered for many years by a variety of different manufacturers and have a proven track record.

Primary Advantages of the Industrial Watertube Boiler

1. The primary advantage is their ability for higher capacities, higher steam pressures and superheated steam. If you need any of these attributes, you need a Watertube boiler.
2. The furnace is generally much larger in a Watertube boiler, making it easier to fire. This is somewhat offset by a shape that is not ideal for combustion. A typical Watertube furnace is twice the size of a Firetube furnace,
3. Because the steam and water are contained in relatively small diameter tubes and drums, they can easily handle much higher pressures.
4. The relatively small water and steam capacity means that it takes less energy to warm up the boiler, improving the dynamic efficiency.

5. The small amount of water and steam in the vessel means that changes in load will show up in steam pressure variations more quickly, allowing the boiler to respond to the load change more quickly.
6. The smaller amount of water and steam in a Watertube boiler means that there will be less energy to release if there is a vessel failure, although other issues such as maintenance and steam pressure can be more important.

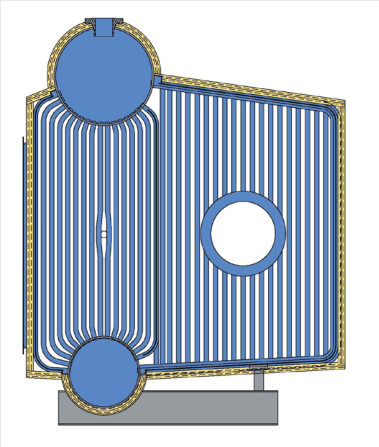


FIGURE 9 *– D Type Watertube (Courtesy Cleaver-Brooks, Inc.)*

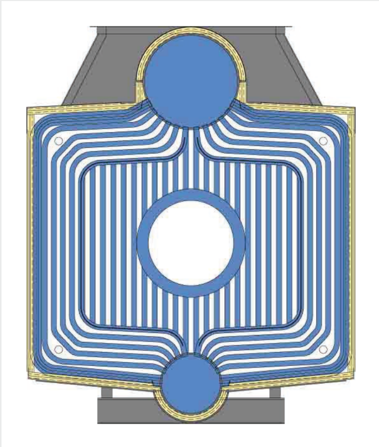


FIGURE 10 *– O Type Watertube (Courtesy Cleaver-Brooks, Inc.)*

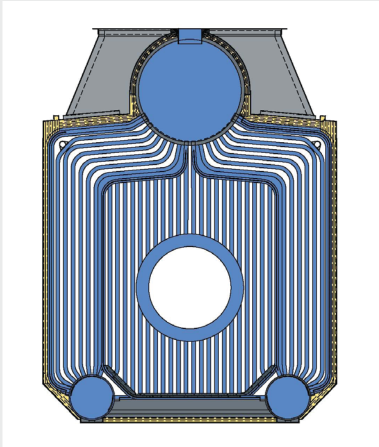


FIGURE 11 *– A Type Watertube (Courtesy Cleaver-Brooks, Inc.)*

Primary Disadvantages of the Industrial Watertube Boiler

1. The tubes are relatively small in diameter and subject to scaling. These boilers do not have a high tolerance to scale buildup and require good feedwater and blow down practice. Scale buildup is always an issue of water quality and maintenance, but some boiler types can handle more scale buildup than others.
2. The heating surface of a Watertube boiler tends to be smaller, such that the outlet flue temperature is typically higher than a Firetube, with lower steady state efficiency. It is common for a Watertube boiler to have an economizer to improve the efficiency.
3. Most Industrial Watertube boilers require a long warmup cycle to prevent uneven heating. This process could take many hours. This is determined by the manufacturer.
4. The water and steam capacity are relatively small and because of this feature, it can be difficult to maintain the water level, especially with big changes in firing rate and steam flow rates. This problem is worse at lower pressures. Often, the level control is done with two or three element controllers to properly manage the water level, which adds to the cost and complexity.

5. The small amount of water and steam in the vessel means that load swings will generate larger changes in steam pressure, as there is less internal energy to absorb the changes.
6. The steam drum is relatively small, and often requires mechanical equipment to obtain good steam quality. This is more of an issue with lower pressures simply because the steam requires a larger space with lower pressures.

BENT TUBE BOILERS

These boilers are usually much smaller in capacity and usually do not offer high pressures or superheat, but there are some manufacturers that offer both high pressure steam and superheat with units up to 100 MMBTU/hr inputs. They are typically made up of tangent tubes that are formed to provide a furnace space and additional gas passes by the bent shape of the tubes. The tubes can be connected to the drums with tapered ferules to simplify tube replacement or the more traditional rolled/welded attachment. The tangent tubes allow for movement without generating stress during warmup, which has allowed this product to become very popular with hot water heating applications. The flexible tube design usually allows the boiler to be operated at full input immediately, providing a short warmup time, usually minutes instead of hours.

Primary Advantages of the Bent Tube Boiler

1. They can be very compact, and often can fit through a doorway in smaller sizes.
2. The tubes are flexible, and not subject to thermal shock. Most units can be started and driven to full rate immediately, to provide steam very quickly.
3. There is a very small amount of water and steam in the vessel, and load changes that can lead to large swings in steam pressure and result in quicker input response to that load change.
4. The small amount of water in the vessel results in better dynamic efficiency, requiring less energy to bring the boiler on line.
5. Units with Ferrule connections can be assembled on the job site, where boiler room access is difficult, without the need for an ASME Code certified welder.

Primary Disadvantage of Bent Tube Boiler

1. The tubes are usually surrounded by insulation, which absorbs the condensation form cold startups. Frequent cold startups can keep the tubes wet for extended periods causing corrosion.
2. These units usually do not have a large amount of heating surface, and tend to have a lower steady state efficiency.
3. The small drum size tends to make steam quality more of an issue, especially when operating at lower pressures.
4. Water level is more difficult to control due to the small water content.
5. Load swings can cause larger variations in steam pressure because there is less internal energy to help absorb the change.

V. Economizer – The Great Equalizer

Economizers are commonly used to increase the boiler efficiency. For steam boiler applications, they have an added advantage.

In the boiler, the flue gas is transferring heat to the boiler water which is at the saturated temperature. For example, a boiler operating at 125 PSI, the water temperature would be about 350 °F. A boiler with reasonable heat transfer would bring down the flue gas temperature to about 100 °F above this, or 450 °F.

The economizer transfers heat from the flue gas to the feedwater, typically about 220 °F, and using the same 100 °F difference, it would have an end stack temperature of 315 °F, for a reduction in stack temperature of 135 °F. This would translate into an efficiency improvement of about 3.4%.

Economizers typically are cost effective because they use extended heat transfer surface. Instead of just a bare tube like the boiler, it has a coil attached to the outside of the tube, increasing the surface area and heat transfer surface with only minimal space and tubing increase.

A boiler that does not have great steady state efficiency (or has a higher stack temperature) can simply add an economizer and have better steady state efficiency than a unit with 4 passes and 5 square feet per BHP. It can also have good dynamic efficiency and a smaller space requirement.

The downside of this approach is that economizers do not last as long as a traditional boiler. They suffer from cold end corrosion and plugging. Because the economizer works with the cooler feedwater, it is more at risk for condensation and related corrosion. Also, economizers need a reasonable amount of makeup water, so that the hot condensate does not reduce the ability to absorb heat. And finally, the economizer needs continuous flow to prevent steaming, often requiring a more complicated feedwater system.

VI. IMPACT OF EFFICIENCY

Most manufacturers offer efficiency and other performance data on their boilers which can help make smart decisions in the selection of the best boiler for the application. The problem is that this usually only covers the "Steady State" efficiency, which is based on the boiler operating continuously at some pressure and firing rate. If the load and application have variable loads and down time, other factors come into play which can be more important than the steady state efficiency.

To show the impact of how the difference in steady state and dynamic efficiency, consider a typical Firetube and Industrial Water tube boiler operating at 125 PSIG and each rated at about 60 MMBTU/hr. They are firing at an average of 65% of capacity, normal for a process load. The fuel cost is $8/MMBTU.

If the boiler operates 24 hours/day, 52 weeks per year, the Firetube (which has a higher efficiency) will have a lower fuel cost of about $246,500. However, if the Watertube was equipped with an economizer, it could have a fuel cost that is about $68,000 less than the Firetube. The Firetube could also use an economizer to get a similar fuel cost.

If the boiler only operates 8 hours/day, 50 weeks/year with all other factors the same, then the Watertube boiler will have a fuel cost that is about $5,000 less than the Firetube boiler. This is simply because of the higher heat loss of the Firetube boiler during the off cycle.

The details of this example are given in the Appendix, and the results could easily change depending on the specific details of the operation and the actual boilers.

The point is that if the production schedule is lower, then other factors can become more important.

Some efficiency considerations include:

- Maintenance is a key to retain good efficiency. Lack of maintenance can easily reduce the efficiency by more than 10%.
- Sometimes external considerations can be as important as the efficiency. For example, maintenance costs and extra long startup times may not be worth small gains in efficiency and fuel savings.
- Real efficiency differences in boilers or added equipment (like economizers) can make a major difference in fuel costs when there is a high production use.
- There are other efficiency considerations that are not part of the boiler design, like proper boiler sizing and frequent on-off cycling, which can have a major impact on efficiency.

There are many good references that address efficiency, including ABMA member companies, the Department of Energy and other sources.

VII. HISTORICAL SALES

The following is based on data collected by the American Boiler Manufactures Association (ABMA) over a recent 12-month period. The member companies report their sales to ABMA to gain insight into the market. There are other boiler manufacturers that are not members, but most manufacturers are members.

This data is provided to show how customers typically buy boilers in the 5 – 100 MMBTU/hr size range as well as the overall market. It should be noted that the results change over time. In the past, there would have been a much stronger volume of Industrial Watertube boilers and less of the other types. That is simply because the Firetube, Bent tube and Coil tube boilers have increased their sizes and capacities and have taken more of the larger capacity market.

The data is for Section I (over 15 PSI steam pressure design as defined by the ASME MAWP (Maximum Allowable working pressure)) steam boilers. This data does not provide a complete breakdown of the product types. They are sorted by Firetube and Watertube, but not by type of Firetube or Watertube. Some assumptions were made to break out Bent tube and Coil tube boiler sales from the Industrial Watertube sales.

CHART 1 - *Total Unit Sales all sizes*

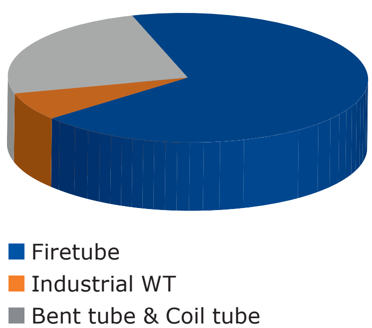


CHART 2 - *Unit sales in 5 - 100 MMBTU/hr*

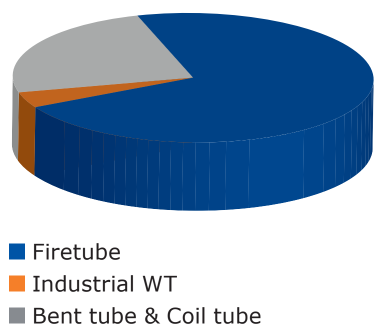
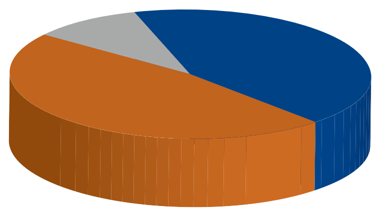


Chart 1 shows the total sales (number of units sold) of all Section I (high pressure) boilers reported to ABMA (all capacities). It shows the much larger volume of Firetube boilers compared to the Watertube types.

It should be noted that ABMA does not collect data on the small commercial and residential boiler capacities, and they are not included here. This chart would be much different if it included heating boilers (Section IV) were included, where Bent tube boilers are more common.

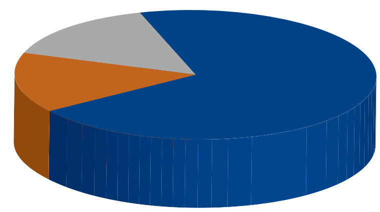
Chart 2 shows the sales volume for just the range of 5 to 100 MMBTU/hr input, the graph changes slightly, but looks similar. The amount of Industrial Watertube boilers has been reduced while the volume of Bent tube and Coil tube boilers has increased. That is simply because most Bent tube and Coil tube boilers are offered within the size range defined, but most Industrial Watertubes are offered in larger sizes.

CHART 3 *- Total Input - all Sizes*



Firetube
Industrial WT
Bent tube & Coil tube

CHART 4 *- Total Input 5 - 100 MMBTU/hr*



Firetube
Industrial WT
Bent tube & Coil tube

Chart 3 shows the total input capacity of all boilers reported to ABMA. Here the Industrial Watertube boilers have about half of the total energy capacity, which is the result of this boiler typically being much larger in capacity compared to the other boilers.

Chart 4 shows the total input for units in the 5-100 MMBTU/hr size range. This greatly changes the shape of the graph, as most Industrial Watertube boilers are larger than this capacity range, and makes the Firetube boiler more prominent in both the number of units sold and the total energy input of those units.

The combination of Charts 2 and 3 best show the boiler volume sales and capacity sales in the 5 – 100 MMBTU/hr size range for high pressure steam boilers. Industrial Watertube boilers would have almost 100% of the sales in larger sizes.

APPENDIX

The following provides details that support the comments made in the earlier sections.

I. PERFORMANCE CRITERIA

When we look at boiler performance, there are several factors that we would consider as part of the overall performance of the unit. Not all performance factors are relevant in all applications, so it is important to understand how the boiler will be used, and which performance factors are key to the application.

1. Capacity

This is simply the amount of energy that can be handled by the boiler. Unfortunately, there are several different units of measure used by the industry, often determined by the type of product. Some common terms are;

BTU per hour input (BTU or BTU/hr); This is the fuel input to the burner. It is usually used on Bent tube or commercial boilers in smaller sizes.
MBH or KBTU/hr; These are common input values expressed as 1000's of BTU/hr. They are normally used to define energy inputs, but can be used for any energy value including output energy.
MMBTU/hr; Another version of the above, except expressed as millions of BTU/hr.
Boiler Horsepower (BHP); This is an expression of energy output, where 1 BHP = 33,474 BTU/hr. This is typically used in the Firetube boiler and small Watertube boilers.
Pounds of Steam per hour (PPH); Larger Watertube boilers generally use a measure of the steam produced, in pounds per hr. at operating conditions. The conversion to PPH varies, as the energy per pound of steam increases with pressure. 1 PPH = 1000 BTU/hr output.

2. Efficiency

Efficiency is a measure of how effectively the boiler converts fuel energy into useful steam energy. It has a major impact on the cost of operating the unit, but it is not the only factor in determining the cost of operating a boiler.

The overall efficiency of a boiler operation can be much more complicated than just looking at some numbers in a chart. This is the same issue faced by everyone attempting to determine the efficiency of any product, including a car, refrigerator or air conditioner. Most boilers have a published steady state efficiency, but this only applies to a boiler that is operating continuously. If you only run for 8 hours a day, cycle on and off and off on weekends, the on-off and startup costs can be important, and have a major impact on the overall efficiency. Your application has a major impact on which efficiency is most important.

Steady State Efficiency (input-output efficiency)

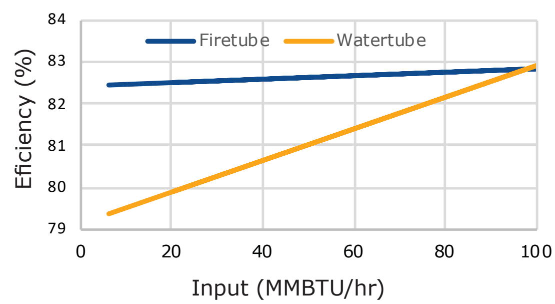
When the boiler is operating at a constant input, and the unit has been warmed up, the efficiency of that unit can be determined, although some assumptions are needed to arrive at a number, and these assumptions may not be correct for your application. The efficiency varies with the firing rate, operating steam pressure, excess air, fuel used, and boiler room conditions.

One of the issues with looking at efficiency is that different assumptions can be used to generate different efficiency results. In particular, the amount of hydrogen in the fuel, the ambient temperature, the operating steam temperature and heat loss through the shell. In comparing different units, these need to be consistent to be of value. Make sure that any comparisons are done using the same assumed values, as these assumptions can have a much larger impact on efficiency than the actual boiler operation.

Dynamic Efficiency

When a boiler is cycled on and off, it uses additional energy to bring the water, refractory and steel up to temperature. When the boiler is cycled off, this energy, or a portion of that energy, is lost to the environment. The physical size of the boiler as well as the amount of water it contains will determine how much energy is consumed in these on and off cycles.

CHART 5 *- Steady State Efficiency*



As an example, a traditional 600 HP Scotch Marine Firetube boiler operating at 125 PSIG steam pressure and operating 8 hours per day, 5 days per week can lose about 30.5 MMBTU/week, which is more than the rating of the boiler.

3. Startup Time

The time it takes to bring a boiler on line, and up to the operating steam pressure will vary with the boiler type. Some boilers are designed specifically for quick startup, and can go from cold to operating steam pressure in minutes. Most traditional multi-pass Firetube and Industrial Watertube boilers will require several hours to bring them up to operating pressure. Some of this time is due to the larger water and material weight that must be heated and some of the time is needed to provide a more uniform expansion of the material as it heats up.

Boilers with short warmup times have tube arrangements that have uniform heat absorption or flexible tube positions in addition to low water and material content. They are offered in both the Firetube and Watertube design.

In an application such as a back-up boiler, this can mean that you do not have to maintain a hot standby boiler, which can be very expensive. If a quicker response is required, a boiler with a small size, and less heat loss can make a big difference in the energy required to provide this back-up boiler.

4. Steam Quality

Steam quality is a measure of the moisture in the steam. Moisture can be disruptive to the application, and users generally want a very low moisture content. This becomes more difficult in lower operating pressures simply because a pound of steam requires a much larger space. These are the factors usually used to determine what the steam quality will be in a Firetube boiler. Watertube boiler may have additional mechanical means to eliminate the moisture.

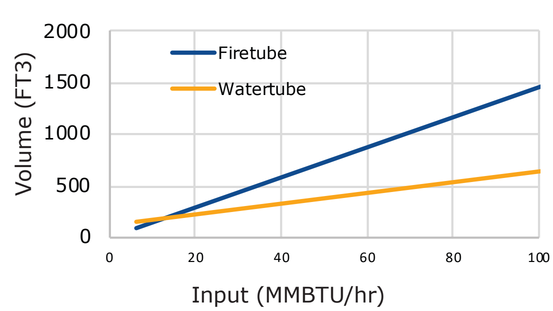
> **Disengaging area**. This is the surface of the water, where the steam passes through into the steam chest. The larger the size, the less opportunity there is to pull water droplets along with the steam.
> **Steam Chest Size**; This is the space that the steam has to move from the water surface to the steam outlet. The larger the steam chest, the slower the steam velocity and the more likely that water droplets will fall out.
> **Internal Steam Velocity**; This is the actual steam velocity within the steam chest, and it can vary by the location and size of the steam nozzle as well as the point(s) of generation. In addition to allowing the water droplets to fall out, a higher velocity, and a longer length of travel can generate "Swelling" of the water level, and even generate slug feeding water into the steam outlet with very high velocities.
> **Mechanical Separation**; A variety of mechanical equipment can be added to boilers to improve the steam quality by providing other means of getting the moisture out of the steam and/or to prevent higher steam velocities from impacting the water level.

The impact of the operating pressure can be much larger than the value of the above performance items. A boiler operating at a relatively low pressure, such as 25 PSI, can have difficulty obtaining dry steam. On the other hand, a unit operating at 300 PSI may find it very easy to obtain dry steam. The reason is that if the internal steam velocity at 300 PSI is 2 ft/s (feet per second), then at 25 PSI the velocity will be 14.4 ft/s. At 2 ft/s, droplets tend to fall out of the steam but at 14.4 ft/s, they will probably be added to the steam, and water swelling can be an issue without mechanical separation. Manufacturers will normally provide larger steam outlets, control valves, safety valves and other components when looking at different operating pressures.

5. Furnace Size

In most boilers, a relatively large furnace is used to contain the fire. The size of the furnace can be important, up to a point. If the furnace is too small, it can be difficult to obtain good combustion. Low NOx emissions and oil firing generally require larger furnace sizes. Likewise, the round furnace in a Firetube boiler can be smaller because the round shape better fits the flame.

***CHART 6** - Furnace Volume*



Firing heavy oil and solid fuels requires an even larger furnace. As Chart 6 shows, the Watertube boiler usually offers a much larger furnace, and is better suited for solid fuels. In some cases, manufacturers have used a hybrid design, with a Watertube section for the furnace and a Firetube section for the convection pass.

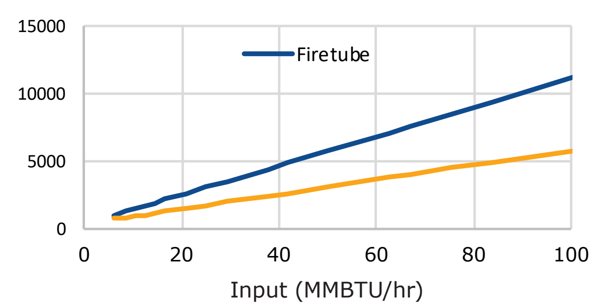
If the boiler uses a pre-mix burner, there often is no furnace because the premix flame size is considerably smaller and does not require a separate large space. This is common in smaller sized boilers, and in some larger boilers.

6. Heating Surface

Traditional Scotch Marine Firetube boilers typically have a lot of heating surface, with the industry standard of 5 square feet per boiler HP historically followed. The Watertube boiler usually has far less heating surface, as shown by Chart 7. The Firetube Ohio Special has considerably less heating surface than the Watertube boiler. In fact, these small heating surface boilers have been around for many years, and support the concept that large heating surfaces are not absolutely required

The opposite of this is that the larger surface area generally provides a higher efficiency. The Ohio Special boilers are not very efficient on their own, but coupled with an economizer, they can have a good efficiency. It should be noted that the large Firetube boilers in the graph do not have 5 square feet per boiler HP, and are 3-pass instead of 4-pass, all of which can lower the efficiency but typically is done to meet shipping requirements.

CHART 7 *- Heating Surface*



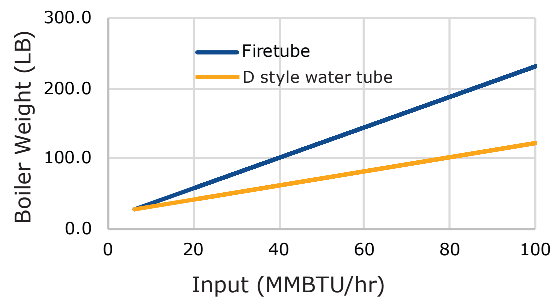
The other common element in the efficiency numbers is that for each general design, the smaller units tend to be less efficient than the larger units. This is usually because the velocities tend to be higher in the large sizes, but is sometimes due to other factors like the manufacturers desire to make them more efficient.

This does show that while the Watertube boiler has less heating surface, it can offer the same or even better heat transfer than the Firetube boiler under certain conditions. The key is that variables like velocity and turbulence can have a larger impact than the amount of heating surface.

7. Total Contained Energy

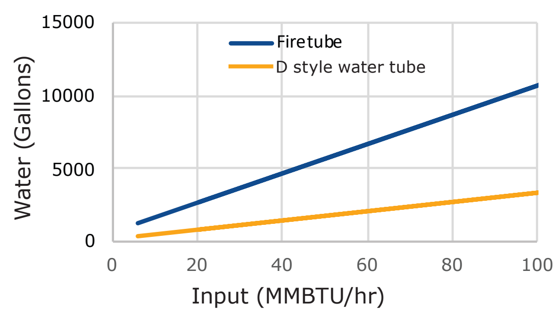
One of the primary considerations in the dynamic efficiency is the amount of energy required to bring the boiler up to steam pressure. This is important because applications that have a lot of "off" time can lose a considerable amount of energy during the off cycle. As a broad general statement, boilers with a lot of heating surface tend to have good steady state efficiency, but due to their larger size, they have more water, steel and refractory to heat up, and a higher heat loss in the off cycle. Boiler designs that are more compact will require less energy to heat up and get to the operating pressure, and will loose less energy in the off cycle.

CHART 8 *- Boiler Weights*



From Charts 8 and 9, it is easy to see that traditional Scotch Marine Firetube boilers have more weight and considerably more water. Obviously, the more water in the boiler, the more energy required to bring that water up to saturation temperature, and start generating steam. Interestingly, water is the primary energy holder. 1000 pounds of water will require 286,700 BTU to bring it up to steam temperature, where 1000 lb of steel only requires 33,950 BTU to bring up to that temperature. The large water content of a traditional Scotch Marine Firetube boiler is shown in Chart 9, and it considerably more than a Watertube boiler.

CHART 9 *- Water In Boiler*



It should be remembered that these charts represent traditional Scotch Marine Firetube and D style Watertube boilers. There are many other Firetube and Watertube boilers that have a much lower water content and physical size, often using different heat transfer methods to get good efficiency with smaller vessels.

Refer to the ABMA Lexicon for a complete listing of all terms used in the boiler industry. Visit abma.com for complete details.

II. AN EFFICIENCY EXAMPLE

To better explain and show the impact of both steady state and dynamic efficiency, we will look at two different applications and how two different types of boilers might meet these needs. In general, the Firetube boiler has better efficiency, especially as shown in this example.

Case 1. Operates 24 hours/day, 7 days/week, 50 weeks/yr.
Case 2. Operates 8 hours/day, 5 days/week, 50 weeks/yr.

In this example, two boilers are considered, a Scotch Marine Firetube boiler (4-pass Wetback with 5 square feet of heating surface per boiler HP) and an Industrial Watertube "D" style boiler, each with a capacity of 61 MMBTU/hr. The energy required to bring these boilers up to the operating steam pressure can be approximated by the charted data. The exact amount of steel that is at the operating temperature is not critical, because steel has a low heat density, and most of the energy is in the water.

The first set of data shows the internal energy within each boiler, and the energy required to bring the boiler up to operating pressure (125 psi in this example) as well as the energy that will be lost to the environment during the "Off" time.

	Firetube	**Watertube**
Model	**Scotch Firetube**	**"D" type**
Max input (MMBTU/hr)	61	61
Normal water weight (lb)	63,130	16,949
Non-water weight (lb)	93,470	66,331
lb of steam in boiler	82.04	61.92
Energy to heat water Kbtu	18,099	4,859
Energy to heat steel Kbtu	1,904	1,351
Energy to heat steam Kbtu	95	72
Total startup energy Kbtu	20,089	6,282

Note: 1 Kbtu = 1,000 BTU

These boilers will be applied to two different applications, one with a heavy load (Case 1) and one with a light load (Case 2). In the first application, the boiler only operates for 8 hours/day, 5 days/week and 50 weeks/yr. When the boiler cycles off, the hot surfaces will release heat to the environment until it has cooled off. The rate of heat loss will decrease as the boiler cools down and the temperature drops. In this example, the Watertube boiler will be more efficient overall, saving $4,990 per year. Interestingly, the higher efficiency of the Firetube boiler will save $12,315 while firing, but the off-time cooling will cost an extra $17,305 to recover.

	Firetube	Watertube
Total heat loss/yr MMBTU	3,534	1,742
Input req'd for this output	4,371	2,208
Fuel cost to cover heat loss	$34,971	$17,666
Operating Efficiency	80.8	78.9
Total fuel costs/yr	$530,971	$525,981
Fuel Savings		**$4,990**

In Case #2, there is no Off time, so the fuel savings due to the higher Firetube efficiency becomes a major factor. While the savings look impressive, the heavy operating cycle generates a much larger fuel cost compared to Case #1.

Efficiency at 125 psi	81.7	77.1
Input MMBtu/hr	61.2	64.8
Fuel cost $/yr	$4,110,232	$4,356,829
Fuel Savings	**$254,597**	

III. SUMMARY COMPARISON

	Scotch Marine Firetube	Firebox	Vertical Firetube	Single Pass Firetube	Industrial "D" Style	Bent Tube	Coil Tube	Electric
Typical max size–BHP	2500	300	250	1000	8400*	1500*	600*	1500*
Typical max size–MBH	105,000	12,500	10,000	42,000	350,000*	63,000*	25,000*	63,000*
Typical max pressure	350 PSI	150 PSI	150 PSI	350 PSI	>1000 PSI	>1000 PSI	350 PSI*	>1000 PSI*
Fuels	Gas & liquid	Gas & liquid	Gas & liquid	Gas	Solid, gas & liquid	Gas & liquid	Gas & liquid	Electric
Relative size	Large	Small	Very small	Small	Large	Small	Small	Small
Relative cost	Medium	Low	Low	Medium	High	Low	Medium	Medium
Maintenance	Low	Low	Low	Low	Medium	Medium	High	Medium
Steady State Efficiency	High	Medium	Low	Low	Medium	Low	Low	High
Dynamic Efficiency	Low	Medium	High	High	Medium	High	High	Medium
Typical Applications	Heating & process	Heating	Heating & process	Heating & process	Process	Heating & process	Heating & process	Heating & process
Comments	High Efficiency	Compact size	Small floor space	Compact & rapid start	High capacity & pressure	Compact & rapid start	Compact & rapid start	No flue gases or combustion

** Higher pressures and larger sizes are offered by some manufacturers.*

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