BOILER EFFICIENCY GUIDE

FACTS YOU SHOULD KNOW
ABOUT FIRETUBE BOILERS AND
BOILER EFFICIENCY

FACTS

Forward

Today's process and heating applications continue to be powered by steam and hot water. The mainstay technology for generating heating or process energy is the packaged firetube boiler. The packaged firetube boiler has proven to be highly efficient and cost effective in generating energy for process and heating applications.

Conducting a thorough evaluation of boiler equipment requires review of boiler type, feature and benefit comparison, maintenance requirements and fuel usage requirements. Of these evaluation criteria, a key factor is fuel usage or boiler efficiency.

Boiler efficiency, in the simplest terms, represents the difference between the energy input and energy output. **A typical boiler will consume many times the initial capital expense in fuel usage annually. Consequently, a difference of just a few percentage points in boiler efficiency between units can translate into substantial savings.** The efficiency data used for comparison between boilers must be based on proven performance to produce an accurate comparison of fuel usage. However, over the years, efficiency has been represented in confusing terms or in ways where the efficiency value did not accurately represent proven fuel usage values. Sometimes the representation of "boiler efficiency" does not truly represent the comparison of energy input and energy output of the equipment.

This Efficiency Facts Booklet is designed to clearly define boiler efficiency. It will also give you the background in efficiency needed to ask the key questions when evaluating efficiency data, and provide you with the tools necessary to accurately compare fuel usage of boiler products, specifically firetube type boilers.

Remember, the initial cost of a boiler is the lowest portion of your boiler investment. Fuel costs and maintenance costs represent the largest portion of your boiler equipment investment. **Not all boilers are created equal.** Some basic design differences can reveal variations in expected efficiency performance levels. Evaluating these design differences can provide insight into what efficiency value and resulting operating costs you can expect.

However, every boiler operates under the same fundamental thermodynamic principles. Therefore, a maximum theoretical efficiency can be calculated for a given boiler design. The maximum value represents the highest available efficiency of the unit. If you are evaluating a boiler where the stated efficiencies are higher than the theoretical efficiency value, watch out! The efficiency value you are utilizing may not truly represent the fuel usage of the unit.

In the end efficiency comes down to value. The value of the boiler. The value of the burner. The value of the support provided throughout the life of the equipment.

Cleaver-Brooks, we have built our reputation by manufacturing the highest efficiency and highest value products in the industry. We pride ourselves in providing you with the most comprehensive and reliable service support through our "best in the industry" representative network. When it comes to efficiency, we believe in sticking to the facts. Because the facts say there is a difference between boilers and boiler companies. The value of buying a higher efficiency CB boiler will pay dividends every day, every year, throughout the life of the equipment.

Introduction

Why choose the most efficient boiler?

When you buy a boiler, you really are putting a down payment on the purchase of steam or hot water. The payments to generate the power are ongoing over the life of the equipment and are driven by fuel to steam efficiency and maintenance costs. Even with economical fuel costs, the selection of a high efficiency boiler will result in substantial cost savings. A boiler installation costing $150,000 can easily consume over $1,000,000 in fuel every year at today's energy rates. Future energy rates are sure to be much higher. **Selection of a boiler with "designed-in" low maintenance and high efficiency can provide outstanding savings every year and maximize your boiler investment for today and the future.**

Efficiency is only useful if it is repeatable and sustainable over the life of the equipment. Choosing the most efficient boiler is more than just choosing the vendor who is willing to meet a given efficiency value. **The burner control technology must be proven to be capable of holding the air/fuel ratio year in and year out.** Make sure the burner design includes reliable and repeatable features. How do you tell? Ask any boiler technician who has worked on a variety of boiler/burner designs. **Burners with a high pressure drop design, and simple, robust linkages, are easy to tune and accurately hold the air to fuel ratio.** Burners with low quality damper designs and complex linkage assemblies tend to be more difficult to set-up over the firing range of the boiler and tend to be unable to accurately hold the air to fuel ratio as the boiler operates.

Why choose the most efficient boiler? Because the dividends paid back each year far outweigh any initial cost savings of a less efficient design. **What is the most efficient boiler? One that not only starts up efficiently but continues to operate efficiently year in and year out.**

Replace or Repair

The decision to purchase a new boiler is typically driven by the needed replacement of an old boiler, an expansion of an existing boiler room, or construction of a new boiler room facility.

When considering the replacement of an old boiler, review the following points to make sure you are performing a comprehensive evaluation of your situation.

1. Maintenance Costs

   Review your maintenance costs carefully. The old unit is costing you money in various ways, including emergency maintenance, downtime, major maintenance requirements (past and pending), difficult–to–find and expensive parts requirements, operator time in keeping the unit on-line, and overall vessel, burner, and refractory problems. Many of these costs can be hidden within your overall maintenance budget. **You are paying the price for having outdated boiler room equipment.** But the costs need to be investigated and totaled.

2. Boiler performance

   New packaged firetube boilers have much higher performance standards than older design units. Guaranteed high efficiency, high turndown, accurate and repeatable air to fuel ratio burner control, programmable boiler controls, automatic fuel changeover, automatic excess air trim, ultra low emissions technology, and connectivity to building automation systems are available on premium packaged firetube boilers. The result is automatic boiler control with lower operating costs for your facility. All cost saving reasons to consider a new packaged firetube boiler.

3. Fuel Usage

   If your old unit is designed to fire low grade fuel oil, or if you need to evaluate propane or any other different fuel capability, review the conversion costs along with existing maintenance, performance, and efficiency issues to see if the time is right to consider a new boiler purchase. **Many times an investment is made in an old unit when the costs associated with the next major maintenance requirement will justify a new unit.** The result is wasted money on the old unit upgrade.

4. Efficiency

   Your Cleaver-Brooks representative can help check out the efficiency of your old boiler with a simple stack analysis. The data will give you a general idea of the difference between the fuel cost of the existing boiler and a new unit. Based on the results of the stack evaluation, a more comprehensive evaluation of your boiler room requirements should be performed. Boiler size, load characteristics, turndown requirements, back-up requirements, fuel type, control requirements, and emission requirements, all should be evaluated. The result will be an accurate review of the potential savings in fuel, maintenance, and boiler room efficiency that can mean sub-stantial cost improvement for your facility.

Efficiency Feature Comparisons

All firetube boilers are the same? Not true! The fact is there are key feature differences between firetube boilers.

The efficiency of a firetube boiler is not a mysterious calculation. **High efficiency is the result of tangible design considerations incorporated into the boiler.** Reviewing some basic design differences from one boiler to another can provide you with valuable insight on expected efficiency performance. The following design issues should be considered during your boiler evaluation.

1. Number of boiler passes.

   The number of boiler passes represents the number of times the hot combustion gasses travel across the boiler (heat exchanger). A boiler with two passes provides two opportunities for the hot gasses to transfer heat to the water in the boiler. A 4-pass design provides four opportunities for heat transfer. The stack temperature of a 4-pass boiler will be lower than the stack temperature of a 2 or 3-pass boiler, of the same basic design, operating under similar conditions. Because of this fact, the 4-pass will have higher efficiency and lower fuel cost. This is not an opinion; it is basic heat exchanger physics. The 4-pass design will yield a higher overall heat-transfer coefficient.

   In an attempt to improve heat transfer, many boilers with fewer passes will employ after-the-fact add-on devices within the tubes, or will be tested at less than full firing rate to prove lower stack temperatures. Don't be fooled. Turbulators and similar add on devices may help pass an initial efficiency test, but will cost you in increased maintenance and diminishing performance down the road. In fact, **you do not need high maintenance, boiler tube, add-on devices if the boiler is designed for optimum flue gas velocities in the first place.** Each boiler pass should be designed with a cross sectional area to achieve optimal flue gas velocity, which in turn maximizes heat transfer while also minimizing performance robbing soot build-up within the tubes. When it comes to efficiency, the proof is indeed in the number of passes and optimized boiler pass design.

2. Burner / boiler compatibility

   The term packaged boiler is sometimes used even if a burner manufactured by one vendor is bolted on to a boiler manufac-tured by a different vendor. Is bolting a "Buy-out" burner on a vessel really a packaged boiler? And more importantly, why does it matter? **A true packaged boiler/burner design includes a burner and boiler developed as a single unit, accounting for furnace geometry, radiant and convection heat transfer characteristics, and verified burner performance in the specific boiler package. Development as a truly packaged unit assures the performance of the unit is proven and verified during development.**

   You can install an engine designed for one make of car into an entirely different make of car. The car will probably run and drive reasonable well. But what about performance? Will the car have the same fuel efficiency and reliability as if it had left the factory that way? Is the engine really a good fit for the car, or will there be problems and headaches down the road? If you need service, who do you turn to? The engine manufacturer? The maker of the car?

   A boiler provides the same scenario. The buy-out burner will fire the unit, however **compromises are made in the mating of the burner to the boiler, affecting performance, efficiency, or both.** Can the burner/boiler package achieve high turndown, fuel efficiency, and low emissions? Who will guarantee the performance and who is accountable if it fails to perform? The burner manufacturer? The maker of the boiler? Buy-out burner packaging can result in **compromised performance, higher start-up costs, and increased**

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maintenance requirements. It also can cost you money every time you have a problem and the local service people cannot get factory support. **You may think you saved money with a buy-out burner package. But did you really?**

3. Repeatable air/ fuel control

The efficiency of the boiler depends on the ability of the burner system to provide the proper air to fuel mixture throughout the firing rate, day in and day out, without the need for complex set-up and adjustments. With advances in control technology, consistent, repeatable burner control can now be accomplished in two different ways.

The conventional approach to burner control is commonly referred as single point positioning, where a single control actuator will drive both the fuel valve and combustion air damper in tandem. Most all boilers on the market are offered with this type of burner control system, however not all designs are equal. Many designs utilize complex linkage assemblies with multiple pivots, pins, and other points that are subject to wear and "slop". **These complex designs don't hold precise air to fuel settings over time,** resulting in the need to adjust the burner to high excess air levels to compensate for the inconstency in the burner performance. The fuel the boiler uses, and the monthly bill you pay, are based on the real day to day efficiency of the unit, not the performance on day one. **When evaluating burners, insist on a simple, robust linkage assembly and an easily accessible burner design for true efficiency and real day to day savings.**

With the recent advances in digital control technology, many boilers can now be equipped with two point positioning (parallel positioning) systems, where separate actuators are used to control the fuel and combustion air independently. These systems, when paired with the latest in advanced programmable control technology, allow for **very precise air to fuel ratio control with excellent repeatability.** These systems also allow advanced options such as automatic fuel changover and true combustion monitoring and optimization (flue gas O2 adjustment) similar to a modern automobile, without the need for complex linkages or additional add on devices. When evaluating a parallel position system, insist on robust, high torque actuators that are field replaceable without the need to re-commission the boiler to return to operation. Insist on easy and straightforward set-up, with the flexibility to achieve the optimum air to fuel curve for your boiler, at your location, serving your systems. **A well designed parallel positioning burner system, with the addition of real time combustion monitoring and trim, will achieve the highest level of day to day fuel savings possible.**

The second feature to look for in burner design is the combustion air control damper. Low quality register or blade type damper assemblies tend to have limited control of air at low firing conditions and also tend to be much less repeatable than radial damper designs. **A low quality blade or register damper will affect the burner in the same way as a complex, low quality linkage. The result is inconsistent burner control and the need for higher excess air to compensate.** Insist in a high quality, robust damper to ensure the best day to day efficiency.

Along with the damper design and the burner control system, the design of the combustion air fan should also be considered. Inexpensive squirrel cage type fans do not provide stable and reliable air control in the way that a backward inclined fan can. A cast aluminum fan assembly is preferred, providing tight tolerances for maximum efficiency and longer fan life. **Without a fan capable of delivering a stable and predictable supply of air, the best burner control and damper designs available are wasted.** This is especially true if a variable speed drive will be used, which is becoming a more popular option to reduce the electrical consumption of the fan and also as an additional means to trim excess air. **The stable nature of a backward inclined fan along with the high efficiency of cast fan construction result in high day to day efficiency and repeatability, resulting in real fuel savings that pay dividends over the life of the boiler.**

4. Heating Surface

The heating surface in square feet per boiler horsepower represents, in general terms, how hard the vessel is working. For the most part, firetube boilers today are designed with **five square feet of heating** surface per boiler horsepower. This standard, set by Cleaver-Brooks, was developed through years of research and testing to achieve high efficiency and add to the life expectancy of the boiler.

With the rapid improvement in computer technology, advanced computational fluid dynamics modeling is now being used to develop designs that deviate from the standard. Firetube boiler designs are available using as little as four square feet of heating surface, while achieving equal or better efficiency than designs with the standard five, without compromising vessel longevity. Precise engineering is crucial to achieve these results. Designs using less than the five square feet standard can only achieve these results through full optimization of all aspects of the heat transfer process, from matched boiler/burner development, optimized furnace design to achieve high radiant heat transfer, optimized tube design, critical placement of the boiler passes within the vessel, and even proper feedwater or return water circulation to further enhance overall heat transfer. Not all boilers are created equal. When considering a design that uses less than the standard, request the facts to back up the performance and longevity claims.

5. Vessel design

Pressure vessel design is regulated by strict ASME code requirements, however there are many variations that will still meet the codes. Proper water circulation, low internal stresses, and easy accessibility for inspection and maintenance are key criteria when evaluating the design of a pressure vessel.

Firetube boilers are available in 2 basic vessel designs, dryback or wetback. The difference lies in the flue gas turnaround area at the rear of the boiler. Each design has it's own advantages and disadvantages as follows:

Dryback – A multiple pass dryback boiler is designed with a rear door with containing internal baffles to direct the flue gas from and to each individual pass. Because the rear door is exposed to the high temperature gasses exiting the first pass furnace, the door must be lined with high temperature refractory to minimize heat loss. High temperature refractory does require inspection and preventative maintenance to ensure peak performance and long life. In practice, the service life of the refractory is installation specific, and is directly related to the proper operation, care, and maintenance of the boiler. Due to the rear door design, a dryback design will be shorter in length that a similar wetback boiler of the same capacity. Also, due to the dryback design, the rear of the boiler contains only one tubesheet, resulting in fewer welds and excellent water circulation. The biggest advantage of a dryback design is that both the front and rear tubesheets are fully accessible for inspection, and allow tube removal from either end of the boiler. This allows easier routine maintenance resulting in lower overall maintenance costs.

Wetback – A multiple pass wetback boiler is designed with an internal turnaround chamber, surrounded by water or steam, to direct the hot flue gas from the exit of the furnace into the second pass tubes. The tubes of the third and fourth pass extend beyond this internal chamber to the rear door, much in the same way that a dryback boiler functions. Because the rear door is not exposed to the hottest flue gasses, there is not a need for high temperature cast refractory. However, because of the internal turnaround chamber, a wetback boiler will be longer that a similar dryback of the same capacity. While the front tubesheet design is similar to a dryback, a wetback boiler has two rear tubesheets to inspect and potentially repair. The internal tubesheet is only accessible through a narrow manway, resulting in more costly and time consuming inspection and maintenance, requiring a confined space permit to perform the work. Because of these characteristics, a wetback boiler is more maintenance intensive that a similar dryback design.

While both dryback and wetback designs have distinct advantages and disadvantages, hybrid designs are available that combine the advantages of both designs without the drawbacks. Such a design, developed by Cleaver-Brooks, is referred to as an intercooled rear turnaround chamber. This design incorporates an internal turnaround chamber design similar to a conventional wetback, however the internal chamber is only surrounded by water on the front and sides. This design incorporates a second, large internal access door to allow full access to the internal turnaround chamber. With this design, the ease of maintenance and compact footprint of a dryback design are achieved in a wetback style package.

In general, the decision on which style of firetube to use comes down to space considerations and maintenance preferences.

Defining boiler efficiency

Combustion Efficiency

Combustion efficiency is an indication of the burner's ability to burn fuel. The amount of unburned fuel and excess air in the exhaust are used to assess a burner's combustion efficiency. Burners resulting in low levels of unburned fuel while operating at low excess air levels are considered efficient. Well designed conventional burners firing gaseous and liquid fuels operate at excess air levels of 15% and result in negligible unburned fuel. Well designed ultra low emissions burners operate at a higher excess air level of 25% in order to reduce emissions to very low levels. By operating at the minimum excess air requirement, less heat from the combustion process is being used to heat excess combustion air, which increases the energy available for the load. Combustion efficiency is not the same for all fuels and, generally, gaseous and liquid fuels burn more efficiently than solid fuels.

Thermal Efficiency

Thermal efficiency is a measure of the effectiveness of the heat exchanger of the boiler. It measures the ability of the exchanger to transfer heat from the combustion process to the water or steam in the boiler. Because thermal efficiency is solely a measurement of the effectiveness of the heat exchanger of the boiler, it does not account for radiation and convection losses due to the boiler's shell, water column, or other components. Since thermal efficiency does not account for radiation and convection losses, it is not a true indication of the boilers fuel usage and should not be used in economic evaluations.

Boiler Efficiency

The term "boiler efficiency" is often substituted for thermal efficiency or fuel-to-steam efficiency. When the term "boiler efficiency" is used, it is important to know which type of efficiency is being represented. Why? Because thermal efficiency, which does not account for radiation and convection losses, is not an indication of the true boiler efficiency. Fuel-to-steam efficiency, which does account for radiation and convection losses, is a true indication of overall boiler efficiency. The term "boiler efficiency" should be defined by the boiler manufacturer before it is used in any economic evaluation.

Fuel-To-Steam Efficiency

Fuel-to-steam efficiency is a measure of the overall efficiency of the boiler. It accounts for the effectiveness of the heat exchanger as well as the radiation and convection losses. **It is an indication of the true boiler efficiency and should be the efficiency used in economic evaluations.**

As prescribed by the ASME Power Test Code, PTC 4.1, the fuel-to-steam efficiency of a boiler can be determined by two methods; the Input-Output Method and the Heat Loss Method.

Input-Output Method

The Input-Output efficiency measurement method is based on the ratio of the output-to-input of the boiler. It is calculated by dividing the boiler output (in BTUs) by the boiler input (in BTUs) and multiplying by 100. The actual input and output of the boiler are determined though instrumentation and the data is used in calculations that result in the fuel-to-steam efficiency.

Heat Loss Method

The Heat Balance efficiency measurement method is based on accounting for all the heat losses of the boiler. The actual measurement method consists of subtracting from 100 percent the total percent stack, radiation, and convection losses. The resulting value is the boiler's fuel-to-steam efficiency. The heat balance method accounts for stack losses and radiation and convection losses.

Stack Losses: Stack temperature is a measure of the heat carried away by dry flue gases and the moisture loss. It is a good indicator of boiler efficiency. The stack temperature is the temperature of the combustion gases (dry and water vapor) leaving the boiler and reflects the energy that did not transfer from the fuel to the steam or hot water. The lower the stack temperature, the more effective the heat exchanger design, and the higher the fuel-to-steam efficiency.

Radiation and Convection Losses: All boilers have radiation and convection losses. The losses represent heat radiating from the boiler (radiation losses) and heat lost due to air flowing across the boiler (convection losses). Radiation and convection losses, expressed in Btu/hr, are essentially constant throughout the firing range of a particular boiler, but vary between different boiler types, sizes, and operating pressures.

Components of efficiency (impact and sensitivity)

Boiler efficiency, when calculated by the ASME heat balance method, includes stack losses and radiation and convection losses. But what factors have the most effect or "sensitivity" on boiler efficiency? As discussed earlier, the basic boiler design is the major factor. However, **there is room for interpretation when calculating efficiency.** Indeed if desired, you can make a boiler appear more efficient than it really is by using a little creativity in the efficiency calculation. **The following are the key factors to understanding efficiency calculations.**

1. **Flue gas temperature (Stack temperature)**
2. **Fuel specification**
3. **Excess air**
4. **Ambient air temperature**
5. **Radiation and convection losses.**

1. Flue Gas Temperature

Flue gas temperature or "stack temperature" is the temperature of the combustion gases as they exit the boiler. **The flue gas temperature must be a proven value for the efficiency calculation to be reflective of the true fuel usage of the boiler.** A potential way to manipulate an efficiency value is to utilize a lower-than-actual flue gas temperature in the calculation. **When reviewing an efficiency guarantee or calculation, check the flue gas temperature.** Is it realistic? Is it near or less than the saturation temperature of the fluid in the boiler? And can the vendor of the equipment refer you to an existing jobsite where these levels of flue gas temperatures exist? Jobsite conditions will vary and have an effect on flue gas temperature. However, if the efficiency value is accurate, the flue gas temperatures should be confirmable in existing applications. **Don't be fooled by estimated stack temperatures. Make sure the stack temperature is proven.**

Figure 1 shows flue gas temperature vs theoretical fuel-to-steam efficiency. This table represents the maximum theoretical efficiency you can achieve at a given flue gas temperature. The table can be used as follows. If a boiler is represented to be 85% efficient firing natural gas, follow the 85% on the left to the natural gas line and down to the flue gas temperature. The result is approximately 270 deg.F. This shows the boiler would have to operate at a 270 deg. F. stack temperature to meet the 85% efficiency, or the efficiency calculation was based on an unrealistically low hydrogen

FUEL-TO-STEAM EFFICIENCY VS. FLUE GAS TEMPERATURE

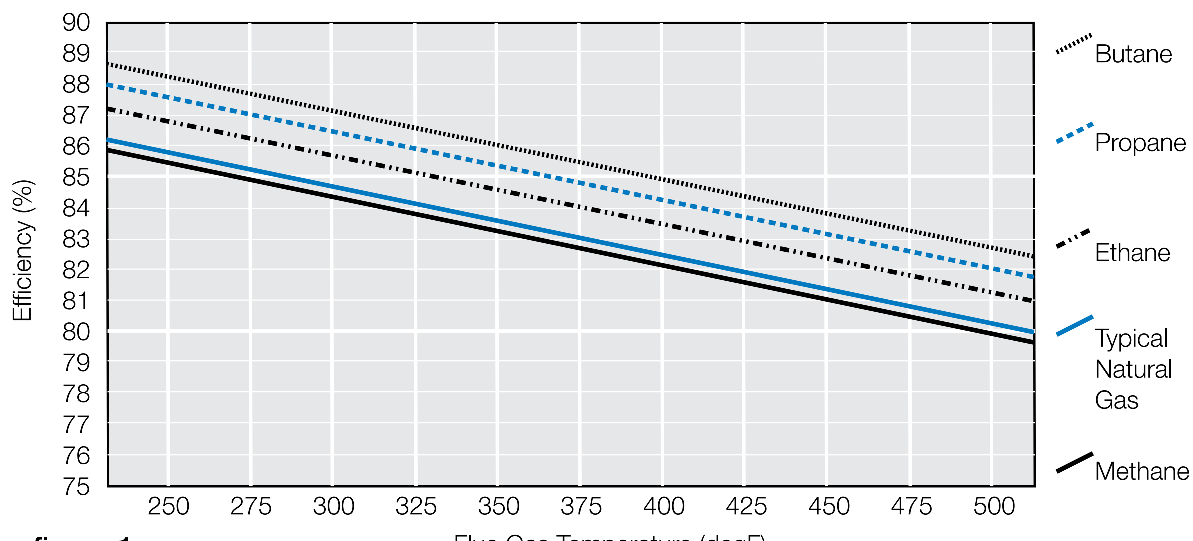


figure 1

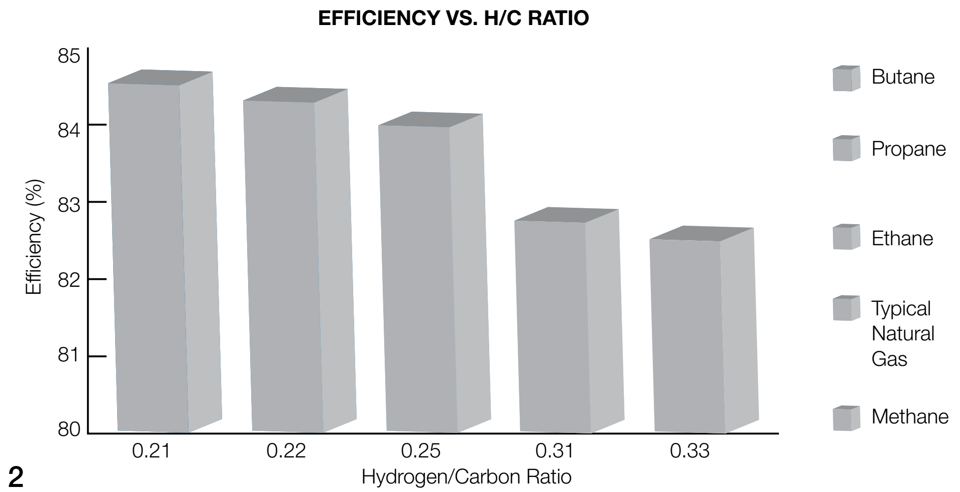


figure 2

content fuel. If a boiler is represented to be 85% efficient on natural gas at a 350° F stack temperature, check the fuel specification. A Boiler cannot operate at 85% efficiency at 350° F stack temperature when firing natural gas per Figure 1.

2. Fuel specification

The fuel specification can also have a dramatic effect on efficiency. In the case of gaseous fuels, the higher the hydrogen content, the more water vapor is formed during combustion. This water vapor uses energy as it changes phase in the combustion process. Higher water vapor losses when firing the fuel result in lower efficiency. This is one reason why fuel oil fires at higher efficiency levels than natural gas. **To get an accurate efficiency calculation, a fuel specification that represents the jobsite fuel to be fired must be used.** When reviewing an efficiency guarantee or calculation, check the fuel specification. Is it representative of the fuel you will use in the boiler? **The representation of efficiency using fuel with low hydrogen content will not provide an accurate evaluation of your actual fuel usage.**

Figure 2 shows the degree to which efficiency can be affected by fuel specification. The graph indicates the effect of the hydrogen-to-carbon ratio on efficiency for five different gaseous fuels. At identical operating conditions, efficiencies can vary as much as 2.5-3.0%, based solely on the hydrogen-to-carbon ratio of the fuel. When evaluating boiler efficiency, knowing the actual fuel specification is a must.

3. Excess Air

Excess air is the extra air supplied to the burner beyond the required air for complete combustion of the fuel. Excess air is supplied to the burner because a boiler firing without sufficient air, or “fuel rich”, is operating in a potentially dangerous condition. Therefore, excess air is used to provide a safety factor above the theoretical air required for combustion. In ultra low emission burners, excess air is also used to eliminate CO production and particulate, and reduce the formation of oxides of nitrogen (NOx) to very low levels by controlling the temperature of the flame. Because excess air is heated by the flame, it takes energy away from combustion, thus taking away potential energy for transfer to the water in the boiler. In this way, excess air reduces boiler efficiency. A quality design will allow firing at minimum excess air levels of 15% (3% as 02) for a conventional burner and 25% (5% as 02) for ultra low emissions burner.*

Seasonal changes in temperature and barometric pressure can cause the excess air in a boiler to fluctuate 5% - 10%. Furthermore, firing at low excess air levels can result in high CO and boiler sooting, specifically if the burner has complex linkage and lacks proper fan design. The fact is even burners theoretically capable of running at less than 15% excess air levels rarely are left at these settings in actual practice. A realistic excess air level for a boiler in operation is 15% if an appropriate safety factor is to be maintained.

* O_2 represents percent oxygen in the flue gas. Excess air is measured by sampling the O_2 in the flue gas. If 15% excess air exists, the oxygen analyzer would measure the O_2 in the excess air and show a 3% measurement.

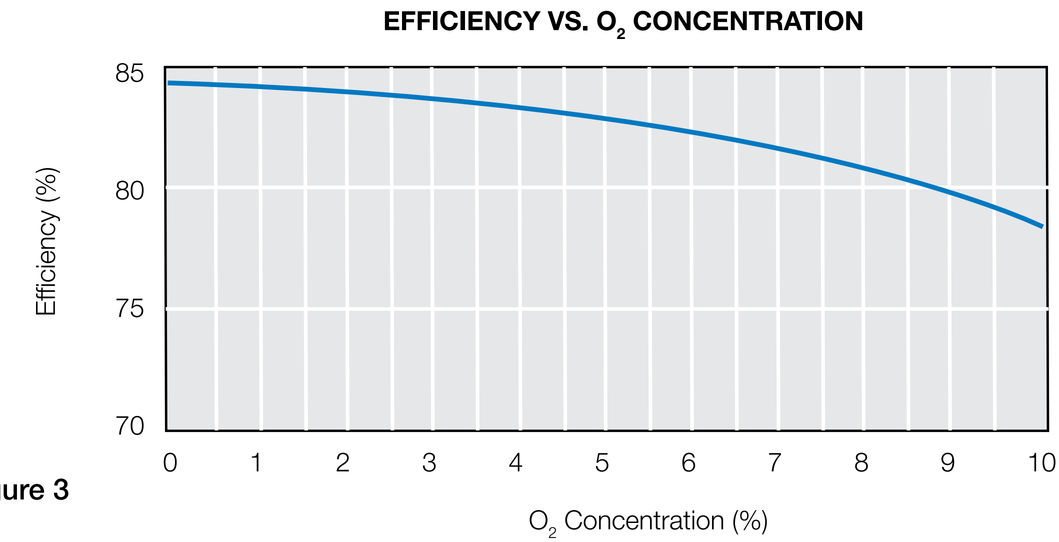


figure 3

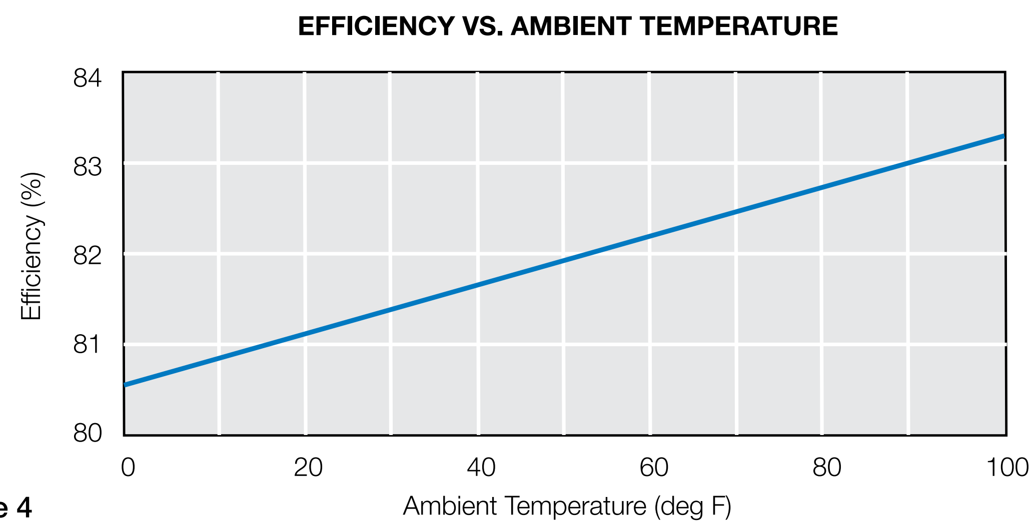


figure 4

When reviewing an efficiency guarantee or calculation, check the excess air levels. If 15% excess air is being used to calculate the efficiency, the burner should be of a very high quality design with repeatable damper and linkage features. Without these features, your boiler will not be operating at the low excess air values being used for the calculation, at least not for long. If less than 15% excess air is being used for the calculation you are probably basing your fuel usage on a higher efficiency than will be achieved in your day to day operation. You should ask the vendor to recalculate the efficiency at realistic excess air values.

Figure 3 shows excess air concentration vs efficiency. The chart can be used to review the impact of variations in excess air values on efficiency.

4. Ambient Temperature

Ambient temperature can have a dramatic effect on boiler efficiency. A 40 degree variation in ambient temperature can effect efficiency by 1% or more. Most boiler rooms are relatively warm. Therefore, most efficiency calculations are based on 80 deg. F ambient temperatures. **When reviewing an efficiency guarantee or calculation, check the ambient air conditions utilized. If a higher than 80° F value was utilized, it is not consistent with standard engineering practice.** And, if the boiler is going to be outside, the actual efficiency will be lower due to lower ambient air temperatures regardless of the boiler design. To determine your actual fuel usage, ask for the efficiency to be calculated at the lower ambient conditions. Or, use Figure 4 to estimate the effect the lower ambient air levels will have on the boiler efficiency.

5. Radiation and Convection losses

Radiation and convection losses represent the heat losses radiating from the boiler vessel. Boilers are insulated to minimize

MODEL CB 4-PASS BOILER—RADIATION AND CONVECTION LOSSES

Firing Rate (% of Load)	100-350 BHp		400-800 BHp	
	Op. Pressure = 10 PSIG	Op. Pressure = 125 PSIG	Op. Pressure = 10 PSIG	Op. Pressure = 125 PSIG
25%	1.6%	1.9%	1.0%	1.2%
50%	.7%	1.0%	.5%	.6%
75%	.5%	.7%	.3%	.4%
100%	.4%	.5%	.2%	.3%

table 1

Based on
- still air conditions
- 80° F ambient air.

these losses. However, every boiler has radiation and convection losses. **Efficiency is sometimes represented without any radiation or convection losses. This is not a true reflection of the efficiency of the boiler.** Cool surface temperatures on the boiler are an indication of low radiation and convection losses. In this way, the boiler construction and design can have an impact on these losses. Dryback boilers, due to the refractory in the rear door, tend to have cooler rear surface temperatures and therefore less overall losses than a similar wetback design. Likewise, a boiler with an insulated shell will have lower surface temperatures, and therefore lower losses, when compared to a similar uninsulated boiler. **Boilers operating with high surface temperatures are wasting energy every time the unit is fired.**

Radiation and convection losses also are a function of air velocity across the boiler. A typical boiler room does not have high wind velocities. Boilers operating outside, however, will have higher radiation and convection losses.

Table 1 shows expected radiation and convection losses for 4-pass firetube boilers designed and insulated for high efficiency.

Summary

Selection of a boiler with "designed-in" low maintenance costs and high efficiency can really pay off by providing ongoing savings and maximizing your boiler investment. Remember, first cost is a relatively small portion of your boiler investment.

High boiler efficiency is the result of specific design criteria, including:

- **Number of boiler passes**
- **Burner / boiler compatibility**
- **Repeatable air/fuel control**
- **Heating surface**
- **Pressure vessel design**

Boiler efficiency calculations that are accurate and representative of actual boiler fuel usage require the use of proven and verified data, including:

- **Proven stack temperature**
- **Accurate fuel specification**
- **Actual operating excess air levels**
- **Proper ambient air temperature**
- **Proper radiation & convection losses**

When evaluating your boiler purchase, ask your boiler vendor to go through the efficiency calculation to verify it is realistic and proven. Also review the type of boiler / burner being utilized to check if the unit's performance will be consistent and repeatable. **You will pay for the fuel actually used, not the estimated fuel based on the efficiency calculation.** Once the boiler is installed, you can't go back and change the design efficiency of the unit.

The facts regarding boiler efficiency are clear: optimal high efficiency boiler designs are available. You will get superior performance with these premium designs. And efficiency calculations can be verified and proven.

Make sure the efficiency data you are using for your boiler evaluation is **guaranteed** and is accurate and repeatable over the life of the equipment. Make sure your actual fuel usage requirements of the boiler are understood before you buy.

In the end, the time spent evaluating efficiency will be well worth the effort. Insisting on a high efficiency, repeatable design firetube boiler will pay off every time your new boiler is fired, for the entire life of the equipment.

Boiler Efficiency Examples

The following pages are designed to provide the tools you need to calculate and compare boiler fuel costs.

The tables and figures can be used in two ways.

A. You can determine the efficiency of a firetube boiler based on known stack temperature.

B. You can compare fuel costs of firetube boilers operating at different efficiencies.

Efficiency based on stack temperature

Procedure

1. Determine the stack temperature of the boiler. Make sure the stack temperature is accurate and proven!
2. Determine the CO_2 level of the boiler. (If excess air as O_2 is available, O_2 can be converted to CO_2 using figure 5.)
3. Determine the ambient air temperature in the boiler room.
4. Subtract the ambient air temperature from the stack temperature to determine the net temperature and CO_2.
5. Use the “Hays charts” (tables 2, 3, 4) to determine the stack loss based on the net temperature.
6. Add the “Radiation and Convection” losses from table 1. (Note: the radiation and convection losses in the chart are based on model CB 4-pass firetube boilers. The radiation and convection losses from competitive equipment may be higher).
7. Subtract the stack losses and radiation and convection losses from 100 to get the Fuel-to-Steam efficiency.

EXAMPLE

Assume 15 lb. design, 100 HP CB Boiler, fired on gas at 100% of Rating.

Stack temperature is 320° F. and room temperature is 80° F.
(320 - 80 = 240)

You measure CO_2 of 10% with no CO.

From Hays chart, at 240° and 10% CO_2, you get stack loss of 15.2% going up the stack.
(See table 2)

Add .4% for “Radiation and Convection Losses”. (For a CB Boiler, see table 1)
15.2% plus .4% = 15.6%
100 - 15.6 = 84.4% Fuel-to-Steam Efficiency.

Fuel cost comparison of boilers with different efficiencies

Procedure

1. Determine the Fuel-to-Steam efficiency of the boilers. CB efficiencies are shown in tables 8, 9, and 10. (If you do not know the efficciency of existing equipement or competitive equipment, it can be calculated per the prior procedure based on stack temperature).
2. Select the fuel burning rates based on the efficiency per tables 5, 6, and 7.
3. Determine the annual fuel usage based on the annual operating hours.
4. Determine the cost of the fuel used.
5. Calculate the annual fuel consumption and resulting annual cost for each boiler. Compare the results to determine the savings.
6. To determine approximate payback in years, divide the equipment cost difference by the fuel cost savings.
7. For the most accurate estimate of fuel savings and payback, evaluate each boiler at part load performance as well. Estimate the hours per year that the boiler is expected to operate at each firing rate (25%, 50%, 75%, 100% high fire). Using the same procedure, calculate the fuel usage at each firing rate, using the estimated hours of operation for that firing rate and substituting the respective boiler efficiency. Add up the results for each boiler to determine the annual fuel usage and fuel cost.

EXAMPLE

You are evaluating three quotations, each proposing a 400 BHP, 150 lb. design steam boiler to burn No. 2 oil or natural gas and operate at 125 PSIG. The quoted cost, including freight, etc. is $100,000 for Cleaver-Brooks, $91,000 for Alternate #1, and $86,000 for Alternate #2.

The literature for both Alternates guarantees 82% efficiency firing No. 2 oil.

The Cleaver-Brooks FTSE guarantee is 85.5% at 100% load (per table 6).

400 BHP output x 33,475 Btu/BHP = 13,390,000 Btu/hr

No. 2 oil = 140,000 Btu/gallon = $2.08/gallon

Fuel input = $\frac{\text{13,390,000 Btu/hr}}{\text{Efficiency \%}}$ = 16,329,268 @ 82% = 15,660,819 @ 85.5%

Input, gallons = $\frac{\text{Fuel input (Btu/hr)}}{\text{140,000 Btu/gallon}}$ = 116.6 gal/hr = 111.8 gal/hr

Assuming 4000 hours/yr operation at 100% load:

116.6 gal/hr x 4000 hrs/yr x $2.08/gal = $970,112/yr @ 82%
111.8 gal/hr x 4000 hrs/yr x $2.08/gal = $930,176/yr @ 85.5%

$40,036/yr savings with Cleaver-Brooks

Extra cost for C-B Equipment	Payback if 4000 hrs/yr operation	Payback if 3000 hrs/yr operation	Payback if 2000 hrs/yr operation
$9,000 vs. Alternate #1	**0.22 years (2.7 months)**	**0.3 years (3.6 months)**	**0.45 years (5.4 months)**
$14,000 vs. Alternate #2	**0.35 years (4.2 months)**	**0.46 years (5.6 months)**	**0.7 years (8.4 months)**

Conclusion: First cost can be deceiving! Buy the most efficient boiler.

Efficiency vs. Fuel Costs

If you select a boiler because of a lower first cost – and this unit is LESS EFFICIENT than the higher price boiler
– YOU WILL PAY the difference many times over – during the life of that boiler!

NOTE: The percent increase in fuel costs is greater than the nominal percent decrease in fuel-to-steam efficiency!

e.g. A 3% drop in efficiency increases fuel costs 3.8% (85% vs 82%)

e.g. A 5% drop in efficiency increases fuel costs 6.3% (85% vs 80%)

e.g. A 7.5% drop in efficiency increases fuel costs 9.7% (85% vs 77.5%)

e.g. A 10% drop in efficiency increases fuel costs 13.5% (85% vs 75%)

How is this proven?

A 200 Hp Unit has an output of 6,700,000 BTU/Hr.

Assume No. 6 oil @ 150,000 BTU/Gal.

		Boiler "X"	Boiler "CB"
Fuel-to-Steam Efficiency	=	80%	85%
Output ÷ Effic. = Input	=	8,375,000 BTU/Hr.	7,882,000 BTU/Hr.
Input – gal/Hr.	=	55.8	52.5
55.8/52.5	=	6.3% Increase in fuel usage	
	=	6.3% Increase in fuel costs	
		due to 5% decrease in fuel-to-steam efficiency.	

Maintenance vs. Fuel Cost

A good maintenance program consisting of routine inspection and cleaning is essential to maintaining the efficiency of any boiler, and can go a long way towards keeping fuel costs low.

For example, a build up of soot within the tubes no thicker than 1/32 of an inch can reduce the efficiency of the boiler by as much as 12%. As noted in the example above, that can result in over 15% in additional fuel usage.

Keep a daily log of the flue gas temperature of the boiler to spot potential problems early; an upward trend in stack temperature may indicate that the boiler is in need of cleaning or adjustment. Routine inspections and preventative maintenance will pay for themselves in keeping boiler efficiency up and fuel costs down.

CleaverBrooks

ENERGY CONSERVATION *PAYS OFF*

OPERATING FUEL COST COMPARISON: Job Name: ______________________

Location: ______________________

Date: ______________________

BOILER INFORMATION:

(1) Size: __________ BHp; Op. Pressure __________ PSIG; Fuel: No. __________ Oil

: __________ Gas

(2) Operating Hours/Year: __________ Hours at __________ % of Rating

(3) Fuel Cost: Oil __________ \$/Gal; Gas __________ \$/Therm

FUEL-TO-STEAM EFFICIENCY:	No. 2 Oil	No. 6 Oil	Gas
(4) Cleaver-Brooks, Guaranteed	______ %	______ %	______ %
(5) Other Mfgr. (Estimated) (Guaranteed	______ %	______ %	______ %
(6) Savings (Nominal)	______ %	______ %	______ %

COMPARISON:	No. 2 Oil	No. 6 Oil	Gas
(7) Other Boiler	______ GPH	______ GPH	______ Therms/Hr.
(8) Cleaver-Brooks	______ GPH	______ GPH	______ Therms/Hr.
(9) Savings	______ GPH	______ GPH	______ Therms/Hr.

ANNUAL FUEL SAVINGS WITH CLEAVER-BROOKS:

A) Oil Fuel:

__________ GPH x __________ Hrs./Yr. = __________ Gal./Yr. = Saved!

__________ Gal./Yr. x \$ __________ /Gal. = \$ __________ /Yr. = Saved!

B) Gas Fuel:

__________ Therms/Hr. x __________ Hrs./Yr. = __________ Therms/Yr. = Saved!

__________ Therms/Yr. x \$ __________ /Therm = \$ __________ /Yr. = Saved!

FACTS

CO_2 TO O_2 CONVERSION CHART

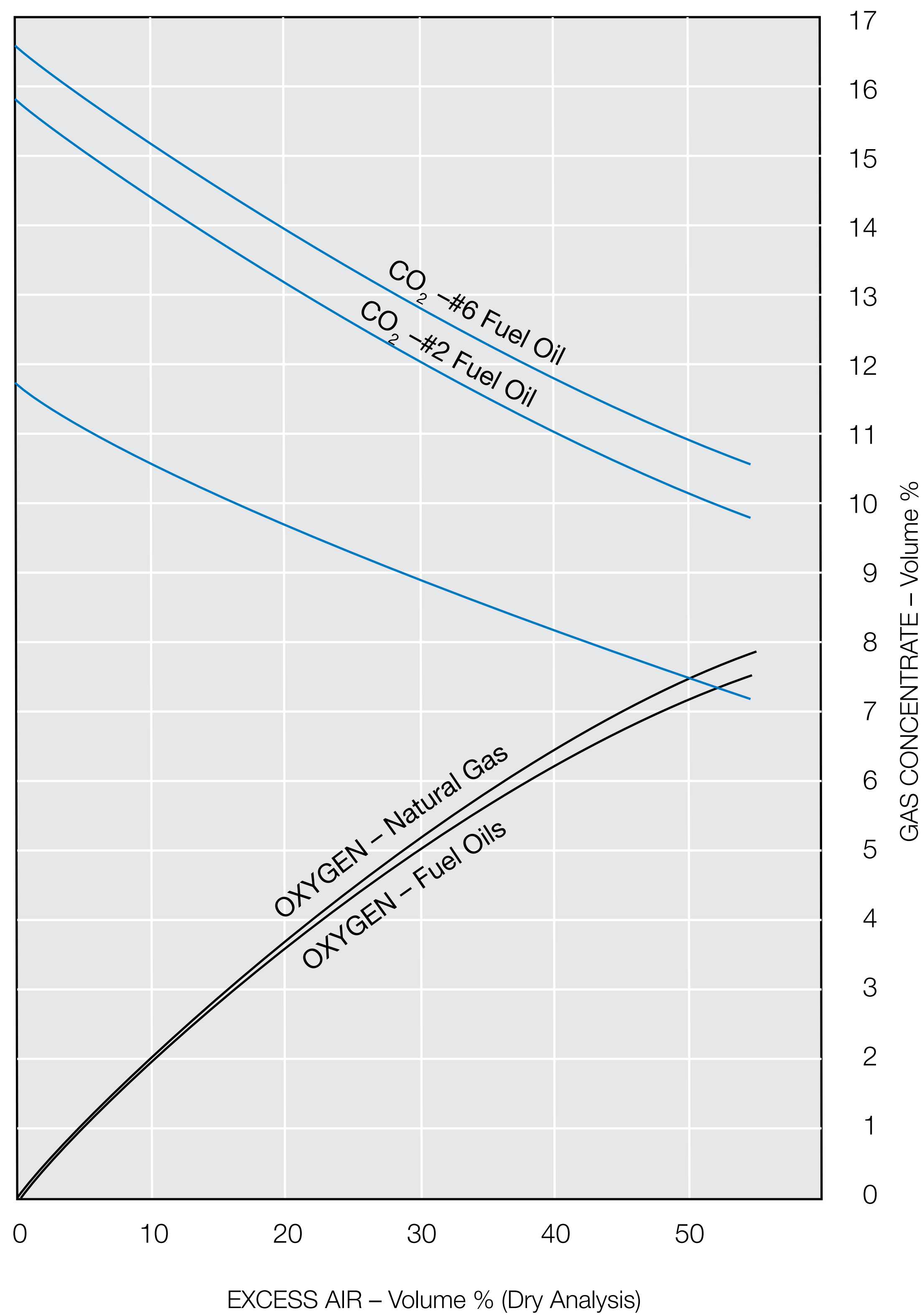


figure 5

Boiler Controls vs. Fuel Cost

Utilizing the latest in advanced, digital boiler controls can net additional savings in operating costs each year. While advanced controls by themselves cannot improve the actual efficiency of the boiler, they can keep the boiler operating at peak efficiency every day. Advanced controls can fine tune the boiler operation automatically to adjust for changes in ambient conditions and boiler load. With high fuel and electricity costs, these minor adjustments can add up to measurable savings, as shown in the example below.

EXAMPLE

Consider the same 400BHP, 150 lb. design boiler firing on natural gas. The boiler operates for 5500 hours per year with the following profile:

1000 hours per year = 20% load
1500 hours per year = 40% load
1500 hours per year = 60% load
1000 hours per year = 80% load
500 hours per year = 100% load

Natural gas cost is $0.83/Therm while electricity cost $0.09/KWh

Under these conditions, the estimated annual fuel cost is $600,585/yr and the estimated annual electricity cost is $3,898/yr.

With the addition of O2 trim, the estimated fuel cost drops to $593,641/yr, for a projected savings of $6944/yr, or 1% of the annual fuel bill.

With the addition of a variable speed drive on the blower motor, the electricity cost drops to $1,365/yr, for a projected savings of $2,533/yr, or a 65% reduction. The majority of the savings occur during part load operation.

STACK LOSS - % - NATURAL GAS

%	DIFFERENCE BETWEEN FLUE GAS AND ROOM TEMPERATURES IN DEGREES FAHRENHEIT																														
CO_2	200	220	240	260	280	300	320	340	360	380	400	420	440	460	480	500	520	540	560	580	600	620	640	660	680	700	750	800	850	900	950	1000
3.0	23.1	24.4	25.9	27.2	28.6	30.0	31.3	32.8	34.1	35.8	36.9	38.2	39.8	41.0	42.2	43.8	45.0	46.3	47.8	49.0	50.0											
3.5	21.2	22.5	23.8	24.9	26.1	27.2	28.4	29.6	30.9	32.0	33.2	34.4	35.8	36.8	37.9	39.2	40.3	41.6	42.8	43.8	45.0	46.2	47.7	48.3	49.8							
4.0	19.9	20.9	22.0	23.1	24.1	25.1	26.2	27.2	28.3	29.4	30.4	31.8	32.5	33.8	34.8	35.8	36.8	37.8	38.8	39.9	40.9	42.1	43.0	44.1	45.2	46.2	48.8					
4.5	18.9	19.9	20.9	21.8	22.7	23.6	24.5	25.5	26.4	27.3	28.3	29.2	30.2	31.2	32.2	33.0	34.0	34.9	35.9	36.8	37.8	38.6	39.8	40.4	41.5	42.6	44.8	47.2	49.8			
5.0	18.0	18.9	19.8	20.6	21.4	22.2	23.1	24.0	24.9	25.8	26.8	27.5	28.3	29.1	30.1	30.9	31.8	32.5	33.6	34.3	35.7	36.2	36.9	37.8	38.8	39.7	41.8	43.8	46.0	48.2		
5.5	17.4	18.1	18.9	19.8	20.5	21.2	22.1	22.9	23.8	24.5	25.2	26.2	26.9	27.8	28.5	29.2	30.0	30.8	31.8	32.3	33.2	34.1	34.9	35.8	36.3	37.3	39.2	41.0	43.0	45.3	47.2	49.0
6.0	16.8	17.4	18.2	18.9	19.6	20.4	21.1	21.8	22.7	23.3	24.1	24.9	25.5	26.2	27.0	27.8	28.4	29.2	30.0	30.8	31.5	32.2	32.9	33.8	34.3	35.2	36.8	38.8	40.4	42.5	44.3	46.2
6.5	16.3	16.9	17.6	18.4	19.0	19.8	20.4	21.1	21.8	22.4	23.2	23.8	24.5	25.2	25.9	26.5	27.2	27.9	28.7	29.2	30.0	30.9	31.4	32.1	32.8	33.5	34.6	36.8	38.4	40.3	42.0	43.8
7.0	15.8	16.5	17.1	17.8	18.4	19.1	19.8	20.4	21.0	21.8	22.3	22.9	23.6	24.2	24.9	25.5	26.2	26.8	27.4	28.0	28.8	29.4	30.0	30.8	31.2	32.0	33.8	35.3	36.8	38.3	40.0	41.8
7.5	15.5	16.1	16.7	17.2	17.9	18.5	19.1	19.8	20.3	20.9	21.5	22.2	22.8	23.3	24.0	24.6	25.2	25.8	26.4	26.9	27.7	28.2	28.8	29.4	30.1	30.8	32.2	33.8	35.2	36.8	38.3	39.9
8.0	15.2	15.7	16.3	16.9	17.4	18.0	18.6	19.2	19.8	20.3	20.9	21.5	22.1	22.8	23.2	23.8	24.4	25.0	25.5	26.0	26.7	27.2	27.8	28.4	29.0	29.5	31.0	32.4	33.8	35.4	36.8	38.2
8.5	14.9	15.4	15.9	16.5	17.1	17.6	18.2	18.7	19.3	19.8	20.4	20.9	21.4	22.0	22.5	23.1	23.7	24.2	24.8	25.3	25.8	26.4	26.9	27.4	28.1	28.6	29.9	31.3	32.8	34.2	35.4	36.8
9.0	14.6	15.2	15.7	16.2	16.6	17.2	17.8	18.3	18.8	19.3	19.9	20.4	20.9	21.4	21.9	22.5	23.0	23.5	24.1	24.5	25.2	25.8	26.2	26.7	27.2	27.8	29.0	30.3	31.8	33.0	34.3	35.7
9.5	14.4	14.9	15.4	15.9	16.4	16.9	17.4	17.9	18.4	18.9	19.5	19.9	20.5	20.9	21.4	21.9	22.4	22.9	23.4	23.8	24.4	24.9	25.4	25.9	26.4	26.9	28.2	29.4	30.8	32.0	33.3	34.5
10	14.2	14.6	15.2	15.6	16.1	16.6	17.1	17.5	18.1	18.5	19.0	19.5	20.0	20.4	20.8	21.4	21.8	22.4	22.8	23.3	23.8	24.2	24.8	25.2	25.8	26.2	27.4	28.6	29.8	31.2	32.2	33.4
11		14.4	14.7	15.2	15.6	16.1	16.5	16.9	17.4	17.8	18.4	18.8	19.3	19.6	20.2	20.5	20.9	21.4	21.9	22.3	22.8	23.2	23.7	24.2	24.6	25.0	26.2	27.2	28.3	29.5	30.8	31.8
12			14.4	14.8	15.2	15.6	16.1	16.5	16.9	17.3	17.8	18.2	18.6	19.0	19.4	19.8	20.2	20.6	21.1	21.4	21.9	22.3	22.8	23.2	23.6	24.0	25.1	26.1	27.2	28.3	29.2	30.3

table 2

STACK LOSS - % - NO. 2 OIL

%	DIFFERENCE BETWEEN FLUE GAS AND ROOM TEMPERATURES IN DEGREES FAHRENHEIT																														
CO_2	200	220	240	260	280	300	320	340	360	380	400	420	440	460	480	500	520	540	560	580	600	620	640	660	680	700	750	800	850	900	950	1000
3.0	24.1	25.8	27.7	29.3	31.3	33.9	34.8	36.4	38.2	40.0	42.9	44.8	45.5	47.0	49.0	50.8	52.4	54.3	56.0	57.9	59.6	61.5	63.5	65.0	66.8	68.8						
3.5	21.7	23.1	24.8	26.2	27.8	29.2	31.7	32.5	33.9	35.3	36.9	38.5	40.0	41.7	43.1	44.8	46.1	47.8	49.4	50.9	52.2	53.9	55.7	57.0	58.3	60.0	63.8	67.8				
4.0	19.9	21.2	22.5	24.9	25.2	26.5	27.9	29.2	31.7	32.0	33.3	35.8	36.0	37.3	38.7	40.0	41.4	42.9	44.1	45.5	46.9	48.1	49.8	50.9	52.1	53.8	57.0	60.2	63.9	67.1		
4.5	18.4	19.7	20.8	22.0	23.2	24.4	25.6	26.9	28.0	29.3	30.4	31.8	32.9	34.2	35.6	36.7	37.8	39.0	40.1	41.2	42.5	43.8	45.0	46.3	47.4	48.8	51.8	54.6	57.8	60.9	63.9	66.9
5.0	17.2	18.5	19.5	20.7	21.7	22.7	23.8	24.9	26.0	27.1	28.2	29.4	30.3	31.5	32.7	33.8	34.9	35.9	36.8	38.0	39.2	40.1	41.7	42.4	43.7	44.7	47.4	50.1	52.9	55.8	58.3	61.2
5.5	16.3	17.4	18.4	19.4	20.4	21.3	22.3	23.3	24.3	25.4	26.3	27.3	28.4	29.4	30.6	31.4	32.4	33.6	34.5	35.3	36.4	37.4	38.4	39.6	40.3	41.7	44.0	46.5	49.0	51.8	54.1	56.5
6.0	15.6	16.5	17.4	18.3	19.3	20.4	21.2	22.0	23.0	23.9	24.9	25.8	26.8	27.7	28.6	29.5	30.4	31.4	32.3	33.1	34.2	35.0	36.0	36.9	37.9	38.9	41.0	43.5	45.8	48.0	50.3	52.8
6.5	14.9	15.7	16.7	17.5	18.4	19.3	20.1	20.9	21.8	22.7	23.6	24.5	25.3	26.1	27.0	27.8	28.8	29.6	30.6	31.3	32.3	33.0	34.1	34.8	35.7	36.5	38.7	40.8	42.9	45.1	47.5	49.7
7.0	14.4	15.3	16.0	16.8	17.8	18.4	19.3	20.1	20.9	21.7	22.4	23.2	24.1	24.9	25.7	26.5	27.3	28.1	28.9	29.8	30.5	31.4	32.3	33.0	33.8	34.6	36.5	38.6	40.5	42.7	44.7	46.6
7.5	13.9	14.6	15.4	16.2	16.9	17.7	18.5	19.2	20.1	20.7	21.3	22.2	23.0	23.8	24.5	25.2	26.0	26.8	27.5	28.2	29.0	29.8	30.6	31.3	32.2	32.9	34.8	36.5	38.5	40.3	42.3	44.2
8.0	13.5	14.3	14.9	15.7	16.3	17.1	17.7	18.5	19.3	20.0	20.7	21.4	22.1	22.8	23.5	24.2	25.0	25.7	26.3	27.0	27.8	28.5	29.2	30.0	30.8	31.5	33.2	35.0	36.8	38.5	40.2	42.1
8.5	13.2	13.8	14.5	15.2	15.8	16.5	17.3	17.8	18.6	19.3	20.0	20.6	21.3	21.9	22.6	23.3	23.9	24.6	25.3	25.9	26.7	27.3	28.0	28.8	29.4	30.1	31.8	33.5	35.2	36.9	38.7	40.2
9.0	12.8	13.4	14.1	14.7	15.4	16.0	16.7	17.3	17.9	18.6	19.3	20.0	20.6	21.2	21.8	22.4	23.1	23.8	24.4	25.0	25.7	26.3	27.0	27.7	28.3	28.9	30.5	32.1	33.8	35.3	37.0	38.5
9.5	12.5	13.2	13.7	14.3	14.9	15.7	16.3	16.8	17.4	18.1	18.6	19.3	19.9	20.5	21.1	21.7	22.4	22.9	23.5	24.1	24.8	25.4	26.0	26.7	27.2	27.9	29.4	31.0	32.5	34.0	35.5	37.2
10	12.3	12.8	13.4	14.0	14.6	15.2	15.7	16.3	16.9	17.5	18.1	18.7	19.3	20.0	20.5	21.0	21.6	22.2	22.8	23.4	24.0	24.6	25.1	25.8	26.3	27.0	28.3	29.9	31.4	32.9	34.4	35.7
11	11.8	12.4	12.8	13.4	13.9	14.5	15.0	15.5	16.2	16.7	17.2	17.8	18.3	18.7	19.4	20.0	20.5	20.9	21.5	22.0	22.6	23.1	23.7	24.2	24.8	25.3	26.7	28.0	29.4	31.8	32.1	33.5
12	11.4	11.8	12.5	12.9	13.4	13.9	14.4	14.9	15.4	15.9	16.4	16.9	17.4	17.9	18.4	18.9	19.5	20.0	20.5	20.9	21.4	22.9	22.4	22.9	23.5	24.0	25.2	26.5	27.8	29.0	30.2	31.7
13	11.2	11.6	12.1	12.5	12.9	13.4	13.9	14.3	14.7	15.3	15.8	16.3	16.7	17.2	17.7	18.1	18.6	19.1	19.6	20.1	20.5	21.1	21.3	21.8	22.3	22.8	24.0	25.2	26.3	27.5	28.8	30.0
14		11.3	11.8	12.2	12.6	13.0	13.4	13.8	14.3	14.8	15.3	15.6	16.2	16.5	16.9	17.4	17.8	18.3	18.7	19.2	19.7	20.2	20.6	21.0	21.4	21.8	22.9	24.1	25.2	26.2	27.4	28.6
15			11.4	11.7	12.4	12.6	13.1	13.5	13.8	14.3	14.8	15.3	15.6	15.9	16.4	16.7	17.3	17.7	18.1	18.4	18.9	19.4	19.8	20.3	20.6	21.0	22.0	23.1	24.2	25.2	26.2	27.3

table 3

STACK LOSS - % - NO. 6 OIL

%	DIFFERENCE BETWEEN FLUE GAS AND ROOM TEMPERATURES IN DEGREES FAHRENHEIT																														
CO_2	200	220	240	260	280	300	320	340	360	380	400	420	440	460	480	500	520	540	560	580	600	620	640	660	680	700	750	800	850	900	950	1000
3.0	24.5	26.5	28.5	30.2	32.2	34.5	36.5	38.2	40.4	42.2	44.4	46.4	48.2	50.0	52.3	54.3	56.3	58.2	60.3	62.0	64.1	66.2	68.1	70.1								
3.5	21.8	23.4	25.2	26.8	28.6	30.4	32.1	33.8	35.5	37.4	39.0	40.6	42.2	44.0	45.6	47.5	49.2	51.0	49.4	50.9	52.2	53.9	55.7	57.0	58.3	60.0	63.8	67.8				
4.0	19.8	21.2	22.8	24.2	25.7	27.3	28.8	30.2	31.6	32.5	34.8	36.3	37.8	39.4	40.8	42.2	43.8	45.1	46.9	48.2	49.8	51.2	52.9	54.2	56.0	57.8	61.1	65.0	68.9			
4.5	18.2	19.4	20.8	22.2	23.5	24.8	26.2	27.4	28.8	30.4	31.5	33.0	34.2	35.4	37.0	38.1	39.4	41.0	42.2	43.5	45.0	46.3	47.9	49.0	50.1	51.9	55.0	58.2	61.8	65.1	68.5	
5.0	16.8	18.0	19.3	20.4	21.7	22.8	23.2	25.3	26.6	27.8	29.0	30.3	31.4	32.6	33.8	35.3	36.2	37.5	38.8	39.8	41.0	42.3	43.8	44.9	46.1	47.5	50.1	53.6	56.3	59.8	62.3	65.8
5.5	15.8	16.8	18.0	19.2	20.3	21.3	22.5	23.5	24.6	25.8	26.9	28.0	29.2	30.2	31.4	32.5	33.5	34.7	35.8	37.0	37.9	39.2	40.1	41.3	42.3	43.8	46.1	49.1	52.0	54.7	57.8	60.1
6.0	14.8	15.8	16.9	18.0	19.0	20.0	21.1	22.0	23.1	24.2	25.2	26.3	27.3	28.2	29.3	30.3	31.3	32.3	33.5	34.3	35.3	36.5	37.5	38.3	39.7	40.5	43.0	45.8	48.2	50.9	53.5	56.0
6.5	14.3	15.2	16.1	17.1	18.0	18.9	19.9	20.8	21.8	22.8	23.7	24.6	25.5	26.5	27.5	28.5	29.4	30.4	31.4	32.3	33.4	34.3	35.1	36.1	37.1	38.0	40.2	42.8	45.1	47.6	49.9	52.1
7.0	13.5	14.4	15.3	16.2	17.1	17.9	18.8	19.7	20.6	21.5	22.4	23.3	24.2	25.0	25.8	26.8	27.7	28.6	29.0	30.2	31.2	32.2	33.0	33.9	34.9	35.8	37.9	40.1	42.1	44.4	46.8	49.0
7.5	13.0	13.8	14.6	15.5	16.3	17.3	18.0	18.8	19.7	20.5	21.4	22.2	22.9	23.7	24.6	25.4	26.3	27.2	27.9	28.8	29.6	30.5	31.2	32.1	33.0	34.9	35.9	37.9	40.0	42.0	44.1	46.1
8.0	12.5	13.3	14.1	14.8	15.7	16.4	17.3	18.0	18.8	19.6	20.4	21.2	21.9	22.7	23.5	24.2	25.0	25.8	26.6	27.4	28.2	29.0	29.9	30.6	31.5	32.1	34.1	36.0	38.0	40.0	41.9	43.9
8.5	12.2	12.8	13.6	14.4	15.1	15.7	16.6	17.3	18.0	18.7	19.6	20.3	21.0	21.6	22.5	23.3	23.9	24.7	25.5	26.2	26.8	27.6	28.2	29.1	29.9	30.8	32.6	34.2	36.2	38.0	39.9	41.8
9.0	11.7	12.4	13.2	13.8	14.6	15.3	15.9	16.6	17.4	18.1	18.8	19.5	20.2	20.8	21.6	22.3	22.9	23.7	24.4	25.0	25.7	26.5	27.1	27.9	28.7	29.4	31.1	32.9	34.6	36.3	38.0	39.9
9.5	11.4	12.1	12.7	13.4	14.1	14.7	15.4	16.0	16.7	17.5	18.1	18.7	19.4	20.0	20.7	21.4	22.1	22.8	23.5	24.0	24.7	25.4	26.1	26.8	27.5	28.1	29.8	31.2	33.2	34.9	36.4	38.1
10	11.2	11.7	12.3	13.0	13.7	14.4	14.8	15.5	16.2	16.8	17.5	18.2	18.7	19.4	20.0	20.6	21.3	21.9	22.6	23.2	23.8	24.5	25.1	25.8	26.4	27.0	28.7	30.1	31.8	33.5	35.0	36.7
11	10.6	11.3	11.8	12.4	12.9	13.5	14.2	14.7	15.3	15.8	16.5	17.0	17.6	18.2	18.8	19.4	20.0	20.6	21.2	21.7	22.3	22.9	23.5	24.1	24.8	25.2	26.8	28.1	29.8	31.2	32.5	34.1
12	10.2	10.7	11.3	11.7	12.3	12.8	13.4	13.8	14.5	15.1	15.6	16.2	16.7	17.2	17.8	18.3	18.8	19.4	19.9	20.4	21.0	21.6	22.1	22.7	23.1	23.8	25.0	26.4	27.9	29.1	30.5	31.9
13		10.3	10.8	11.3	11.8	12.3	12.8	13.3	13.8	14.4	14.8	15.4	15.8	16.3	16.8	17.3	17.9	18.4	18.9	19.3	19.8	20.4	20.9	21.4	21.9	22.4	23.8	24.9	26.2	27.5	28.9	30.0
14		9.8	10.4	10.8	11.4	11.8	12.3	12.8	13.3	13.7	14.3	14.7	15.2	15.6	16.2	16.6	17.1	17.5	18.0	18.5	18.8	19.4	19.9	20.4	20.9	21.2	22.5	23.7	24.9	26.1	27.2	28.5
15			10.2	10.6	11.0	11.4	11.8	12.4	12.7	13.3	13.7	14.2	14.6	15.0	15.4	15.8	16.4	16.8	17.3	17.7	18.2	18.6	19.0	19.5	19.9	20.3	21.5	22.6	23.8	24.9	25.9	27.1
16				10.3	10.7	11.1	11.5	11.8	12.3	12.8	13.3	13.7	14.0	14.4	14.8	15.3	15.7	16.2	16.6	16.9	17.4	17.9	18.2	18.8	19.1	19.5	20.6	21.6	22.7	23.8	24.8	25.9

table 4

NATURAL GAS FUEL BURNING RATES (THERMS/HR.) AT VARIOUS EFFICIENCIES

Boiler Size B Hp	Fuel – To – Steam Efficiency																
	60.0	62.5	65.0	67.5	70.0	72.5	75	76	77	78	79	80	81	82	83	84	85
100	55.8	53.6	51.5	49.6	47.9	46.2	44.7	44.1	43.5	43.0	42.4	41.9	41.4	40.9	40.4	39.9	39.4
125	69.8	67.0	64.4	62.0	59.8	57.7	55.8	55.1	54.4	53.7	53.0	52.3	51.7	51.1	50.4	49.8	49.3
150	83.7	80.4	77.3	74.4	71.8	69.3	67.0	66.1	65.2	64.4	63.6	62.8	62.0	61.3	60.5	59.8	59.1
200	111.6	107.2	102.0	99.2	95.7	92.4	89.3	88.1	87.0	85.9	84.8	83.7	82.7	81.8	80.7	79.7	78.8
250	139.5	133.9	128.8	124.0	119.6	115.5	111.6	110.1	108.7	107.3	106.0	104.6	103.4	102.1	100.9	99.7	98.5
300	167.4	160.7	154.5	148.8	143.5	138.6	133.9	132.2	130.5	128.8	127.2	125.5	124.0	122.5	121.0	119.6	118.2
350	195.3	187.5	180.3	173.6	167.4	161.6	156.2	154.2	152.2	150.2	148.3	146.5	144.7	142.9	141.2	139.5	137.9
400	223.2	214.3	206.0	198.4	191.3	184.7	178.6	176.2	173.9	171.7	169.5	167.5	165.3	163.3	161.4	159.4	157.6
500	279.0	267.8	257.5	248.0	239.1	230.9	223.2	220.3	217.4	214.6	211.9	209.3	206.7	204.2	201.7	199.3	197.0
600	334.8	321.4	309.0	297.6	287.0	277.1	267.8	264.3	260.9	257.5	254.3	251.0	248.0	245.0	242.0	239.1	236.3
700	390.6	374.9	360.5	347.2	334.8	323.2	312.5	308.3	304.3	300.4	296.6	293.0	289.3	285.8	282.3	279.0	275.7
800	446.4	428.5	412.0	396.8	382.6	369.4	357.1	352.4	347.8	343.4	339.0	335.0	330.6	326.6	322.7	318.8	315.1

Gas = 1,000 BTU/CF

$$\frac{\text{Output (BTU/Hr)}}{\text{FTSE}} = \text{Input (BTU/Hr)}$$

FTSE = Fuel – to – Steam Efficiency

$$\frac{\text{Input (BTU/Hr)}}{\text{100,000 BTU/Therm}} = \text{Therms/Hr}$$

table 5

NO. 2 OIL FUEL BURNING RATES (GPH) AT VARIOUS EFFICIENCIES

Boiler Size B Hp	Fuel – To – Steam Efficiency																			
	60.0	62.5	65.0	67.5	70.0	72.5	75	76	77	78	79	80	81	82	83	84	85	86	87	88
100	40.0	38.5	37.0	35.5	34.0	33.0	32.0	31.5	31.0	30.5	30.5	30.0	29.5	29.0	29.0	28.5	28.0	28.0	27.5	27.0
125	50.0	48.0	46.0	44.5	42.5	41.0	40.0	39.5	39.0	38.0	38.0	37.5	37.0	36.5	36.0	35.5	35.0	35.0	34.5	34.0
150	60.0	57.5	55.0	53.0	51.0	49.5	48.0	47.0	46.5	46.0	45.5	45.0	44.5	43.5	43.0	42.5	42.0	41.5	41.0	41.0
200	79.5	76.5	73.5	71.0	68.5	66.0	64.0	63.0	62.0	61.5	60.5	60.0	59.0	58.5	57.5	57.0	56.5	55.5	55.0	54.5
250	99.5	95.5	92.0	88.5	85.5	82.5	79.5	78.5	77.5	76.5	75.5	74.5	74.0	73.0	72.0	71.0	70.5	69.5	68.5	68.0
300	119.5	115.0	110.5	106.5	102.5	99.0	95.5	94.5	93.0	92.0	91.0	89.5	88.5	87.5	86.5	85.5	84.5	83.5	82.5	81.5
350	139.5	134.0	129.0	124.0	119.5	115.5	111.5	110.0	108.5	107.5	106.0	104.5	103.5	102.0	101.0	99.5	98.5	97.5	96.0	95.0
400	159.5	153.0	147.0	141.5	136.5	132.0	127.5	126.0	124.0	122.5	121.0	119.5	118.0	116.5	115.0	114.0	112.5	111.0	110.0	108.5
500	199.5	191.5	184.0	177.0	171.0	165.0	159.5	157.5	155.5	153.5	151.5	149.5	147.5	146.0	144.0	142.5	140.5	139.0	137.5	136.0
600	239.0	229.5	220.5	212.5	205.0	198.0	191.5	189.0	186.5	184.0	181.5	179.5	177.0	175.0	173.0	171.0	169.0	167.0	165.0	163.0
700	279.0	268.0	257.5	248.0	239.0	231.0	223.0	220.0	217.5	214.5	212.0	209.0	206.5	204.0	201.5	199.0	197.0	194.5	192.5	190.0
800	319.0	306.0	294.5	283.5	273.5	264.0	255.0	251.5	248.5	245.0	242.0	239.0	236.0	233.5	230.5	227.5	225.0	222.5	220.0	217.5

No. 2 Oil = 140,000 BTU/Gal.

$$\frac{\text{Output (BTU/Hr)}}{\text{FTSE}} = \text{Input (BTU/Hr)}$$

FTSE = Fuel – to – Steam Efficiency

$$\frac{\text{Input (BTU/Hr)}}{\text{140,000 BTU/Gal.}} = \text{GPH}$$

table 6

NO. 6 OIL FUEL BURNING RATES (GPH) AT VARIOUS EFFICIENCIES

Boiler Size B Hp	Fuel – To – Steam Efficiency																			
	60.0	62.5	65.0	67.5	70.0	72.5	75	76	77	78	79	80	81	82	83	84	85	86	87	88
100	37.0	35.5	34.5	33.0	32.0	31.0	30.0	29.5	29.0	28.5	28.5	28.0	27.5	27.0	27.0	26.5	26.0	26.0	25.5	25.5
125	46.5	44.5	43.0	41.5	40.0	38.5	37.0	36.5	36.0	36.0	35.5	35.0	34.5	34.0	33.5	33.2	33.0	32.5	32.0	31.5
150	56.0	53.5	51.5	49.5	48.0	46.0	44.5	44.0	43.5	43.0	42.5	42.0	41.5	41.0	40.5	40.0	39.5	39.0	38.5	38.0
200	74.5	71.5	68.5	66.0	64.0	61.5	59.5	58.5	58.0	57.0	56.5	56.0	55.0	54.5	54.0	53.0	52.5	52.0	51.5	50.5
250	93.0	89.5	86.0	82.5	79.5	77.0	74.5	73.5	72.5	71.5	70.5	69.5	69.0	68.0	67.0	66.5	65.5	65.0	64.0	63.5
300	111.5	107.0	103.0	99.0	953.5	92.5	89.5	88.0	87.0	86.0	85.0	83.5	82.5	81.5	80.5	79.5	79.0	78.0	77.0	76.0
350	130.0	125.0	120.0	115.5	111.5	107.5	104.0	103.0	101.5	100.0	99.0	97.5	96.5	95.5	94.0	93.0	92.0	91.0	90.0	89.0
400	149.0	143.0	137.5	132.5	127.5	123.0	119.0	117.5	116.0	114.5	113.0	111.5	110.0	109.0	107.5	106.5	105.0	104.0	102.5	101.5
500	186.0	178.5	171.5	165.5	159.5	154.0	149.0	147.0	145.0	143.0	141.0	139.5	138.0	136.0	134.5	133.0	131.5	130.0	128.5	127.0
600	223.0	214.0	206.0	198.5	191.5	184.5	178.5	176.0	174.0	171.5	169.5	167.5	165.5	163.5	161.5	159.5	157.5	155.5	154.0	152.0
700	260.5	250.0	240.5	231.5	223.0	215.5	208.5	205.5	203.0	200.5	198.0	195.5	193.0	190.5	188.0	186.0	184.0	181.5	179.5	177.5
800	297.5	285.0	274.5	264.5	255.0	246.5	238.0	235.0	232.0	229.0	226.0	223.0	220.5	217.5	215.0	212.5	210.0	207.5	205.0	203.0

No. 6 Oil = 150,000 BTU/Gal.

$$\frac{\text{Output (BTU/Hr)}}{\text{FTSE}} = \text{Input (BTU/Hr)}$$

FTSE = Fuel – to – Steam Efficiency

$$\frac{\text{Input (BTU/Hr)}}{\text{150,000 BTU/Gal.}} = \text{GPH}$$

table 7

Model CB / CBLE Boiler

GUARANTEED FUEL-TO-STEAM EFFICIENCIES
NATURAL GAS

BOILER SIZE	OPERATING PRESSURE = 10 psi				OPERATING PRESSURE = 125 psi			
	% OF LOAD				% OF LOAD			
	25%	50%	75%	100%	25%	50%	75%	100%
100	84.4	85.0	84.8	84.4	81.5	82.4	82.3	82.2
125	83.3	83.6	83.4	83.2	80.4	80.9	81.0	81.0
150	84.4	84.6	84.5	84.3	81.5	82.0	82.0	82.1
200	85.0	85.3	85.1	84.9	82.2	82.7	82.7	82.7
250	85.0	84.7	84.0	83.3	82.0	82.0	81.6	81.3
300	85.3	85.3	84.6	83.9	82.6	82.7	82.2	81.9
350	85.3	85.7	85.2	84.5	82.6	83.2	82.8	82.5
400	84.5	84.7	84.6	84.4	81.8	82.2	82.4	82.2
500	85.5	85.7	85.5	85.2	82.8	83.2	83.3	83.1
600	85.7	86.0	85.8	85.6	82.9	83.5	83.6	83.5
700	85.7	86.2	86.0	85.7	83.0	83.6	83.6	83.6
800	85.8	86.1	85.9	85.6	83.1	83.6	83.7	83.5

* See notes.

table 8

GUARANTEED FUEL-TO-STEAM EFFICIENCIES
NO. 2 OIL

BOILER SIZE	OPERATING PRESSURE = 10 psi				OPERATING PRESSURE = 125 psi			
	% OF LOAD				% OF LOAD			
	25%	50%	75%	100%	25%	50%	75%	100%
100	87.8	88.4	88.1	87.7	84.8	85.7	85.6	85.5
125	86.7	86.9	86.7	86.6	83.7	84.2	84.3	84.3
150	87.8	88.0	87.8	87.6	84.8	85.3	85.3	85.4
200	88.4	88.7	88.4	88.2	85.6	86.0	86.0	86.0
250	88.3	88.1	87.4	86.7	85.3	85.3	84.9	84.7
300	88.6	88.7	88.0	87.3	85.9	86.0	85.5	85.2
350	88.6	89.0	88.5	87.8	85.9	86.6	86.1	85.8
400	87.9	88.1	87.9	87.6	85.1	85.5	85.6	85.5
500	88.9	89.0	88.9	88.6	86.1	86.5	86.6	86.4
600	89.0	89.4	89.2	89.0	86.2	86.8	86.9	86.8
700	89.1	89.5	89.3	89.1	86.3	86.9	87.0	86.9
800	89.2	89.5	89.3	89.0	86.4	86.9	87.0	86.8

* See notes.

table 9

GUARANTEED FUEL-TO-STEAM EFFICIENCIES
NO. 6 OIL

BOILER SIZE	OPERATING PRESSURE = 10 psi				OPERATING PRESSURE = 125 psi			
	% OF LOAD				% OF LOAD			
	25%	50%	75%	100%	25%	50%	75%	100%
100	88.2	88.5	88.3	88.0	84.6	85.8	85.9	85.8
125	87.2	87.4	87.2	87.0	84.1	84.6	84.7	84.8
150	88.4	88.5	88.3	88.1	85.3	85.8	85.8	85.8
200	88.9	89.2	88.9	88.7	86.0	86.5	86.4	86.5
250	88.8	88.5	87.8	87.1	85.8	85.7	85.3	85.0
300	89.1	89.2	88.4	87.7	86.3	86.4	86.0	85.6
350	89.1	89.5	89.0	88.4	86.4	87.0	86.6	86.2
400	88.4	88.5	88.4	88.1	85.5	85.9	86.0	85.9
500	89.4	89.5	89.3	89.2	86.5	86.9	87.0	86.9
600	89.5	89.9	89.7	89.4	86.7	87.3	87.4	87.2
700	89.6	90.0	89.8	89.6	86.8	87.3	87.4	87.4
800	89.7	90.0	89.8	89.5	86.9	87.4	87.5	87.3

* See notes.

table 10

NOTES:

1. Efficiencies Based on the Following Fuel Analysis

   Natural Gas:

   Carbon, % (wt) = 68.98

   Hydrogen, % (wt) = 22.31

   Sulfur, % (wt) = 0.0

   Heating Value, Btu/lb = 21,830

   No. 2 Oil:

   Carbon, % (wt) = 85.8

   Hydrogen, % (wt) = 12.7

   Sulfur, % (wt) = 0.2

   Heating Value, Btu/lb = 19,420

   No. 6 Oil:

   Carbon, % (wt) = 86.6

   Hydrogen, % (wt) = 10.9

   Sulfur, % (wt) = 2.09

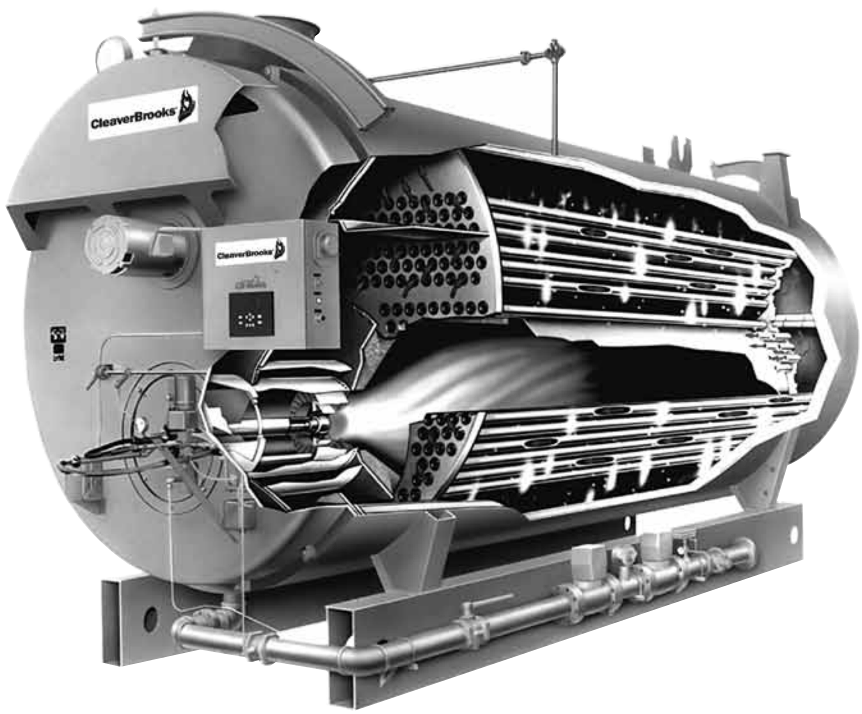
   Heating Value, Btu/lb = 18,330

2. Efficiencies based on ambient air temperature of 80° F, relative humidity of 30%, and 15% excess air in the exhaust.

3. Efficiencies of ultra low emissions boilers (15ppm, 9ppm) will be 0.6% lower than table values due to 25% excess air requirement.

4. Efficiencies include radiation and convection losses as indicated in table 1.

5. Any efficiency verification testing will be based on the stack loss method.



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CB-7767
03/10