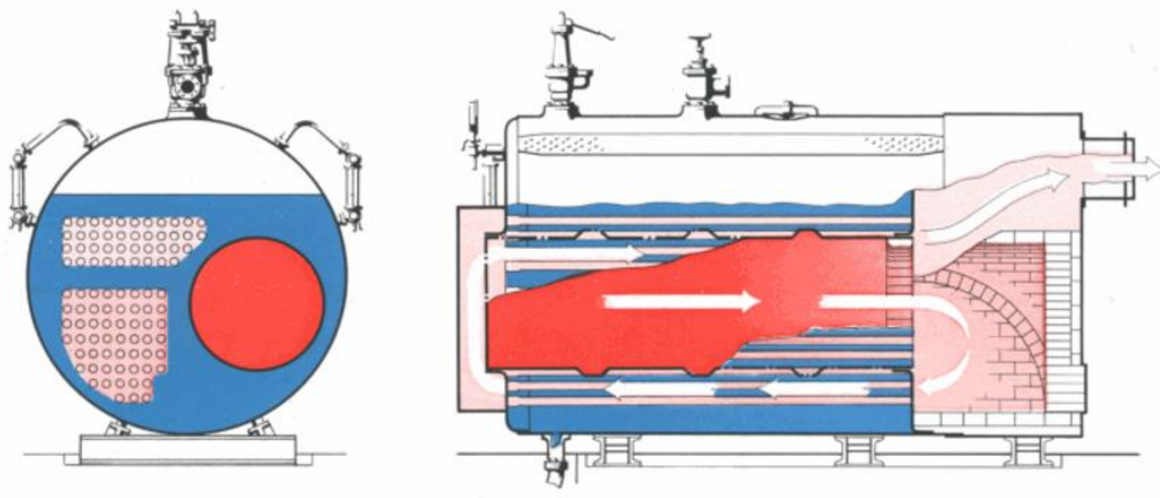

Boiler Plant Operations and Tips

CONTROL

SPECIALTIES, INC.

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Boiler Plant Operations and Tips

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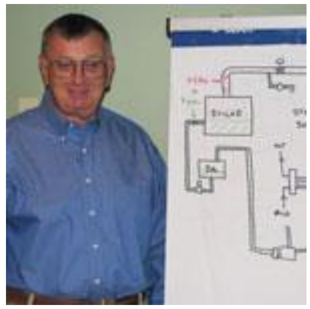
BIOGRAPHY OF EDWARD MOSCHETTI

Edward brings over 50 years of knowledge and experience to the manufacturing, medical, university, and commercial arenas. His education background includes a degree in physics from Muhlenberg College. The last 30 years have been devoted to providing solutions to industrial facilities geared around plant utilities and processes. He has spearheaded energy teams in major corporations resulting in the savings of energy dollars as well as building/designing small to medium size boiler facilities.



Preface

Did you know that as much as 90% of all electricity in the United States is steam-generated? According to the DOE/EIA, nearly half of all fuel consumed by American industry is burned specifically to produce steam. The use of steam includes the heating of raw materials, providing power to equipment, heating facilities and generating electricity. These statistics are strictly based on consumption in the United States. When we factor the worldwide use of steam, the amount of steam consumed is monumental. We have devoted this eBook, with more eBooks to follow, around the generation of steam and its use. We hope you will find some helpful ideas as well as engineering statistics to improve the efficiency of generating and using steam.

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Chapter 1- Why Steam

Chapter 1 Highlights - A steam system is made up of sub-systems such as the boiler plant, distribution system, production equipment and condensate return system. This book will take a sub-system approach to help you to zero in on sections related to your specific questions or interests.

- **Thermal energy (heat) is hard to measure other than something is hot or cold. The measurement decided on was the British Thermal Unit (BTU), which was defined as the amount of energy to raise the temperature of one pound of water one degree Fahrenheit.**
- **With our steam heat transfer media let's examine the BTU and the many sources of a BTU by burning a substance utilizing a great chart from the website Engineering Tool Box.**
- **The most common device used to produce steam is a boiler which burns a fuel which in turn boils water under pressure to produce steam. Stationary boilers helped to power industry and ships while movable boilers became steam locomotives. About 25% of all fuel consumed is used to make steam.**

- **From the Engineering Tool Box website here is a portion of the steam table up to 50 psig to review.**
- **Over a wide range of pressure, the Total Enthalpy remains for a pound of steam about 1200 Btu's per pound, but as the pressure increases, along with the temperature, the amount of energy to boil a pound of water decreases. Stated in a few words, as the temperature rises the amount of energy in a pound of steam goes down!**
- **Thermal energy (heat) flows from hot to cold. The amount of heat which will flow depends on the materials and other factors with temperature difference being a major issue. As a general rule of thumb this temperature difference should be about 50 F. As an example, if we wish to heat something to 290° F we should have steam at a temperature of about 340° F (290° F + 50° F). Steam at 100 psig has a temperature of 338° F-close enough.**

The most abundant compound on planet earth is water which is comprised of the first and third most common elements; hydrogen and oxygen. Without water there would be no life as we know it on our planet. Water fills so many roles in our daily living that one could make a very long list indeed.

Ancients note that when water was boiled it gave off a white vapor, and they actually constructed some elementary machines to demonstrate a fundamental property of steam - it contains energy. In the late 1700's and early 1800's the industrial revolution began to occur with many attempts made to harness the source of energy to do meaningful work. Three industries became early converts to use this new energy source in England. Breweries, mining and transportation with each one having unique requirements:

- The brewing of beer requires the boiling of water with other ingredients under controlled conditions.
- Coal mining in many areas of England required that water be pumped from mines.
- Land and water transportation had an urgent need to find substitutes for horse and wind power.

From these three industries as well as others, knowledge evolved to quantify the properties of steam in a table (called the Steam Table) and develop the concept of a piston being driven back and forth into a wheel to generate rotary motion. Brewing beer became reliable, piston engines evolved to drive mine pumps, and the same steam engines powered both locomotives and ships. The rest is history!

Without energy we would have no modern civilization. To utilize energy we need to be able to understand its properties, quantify them, and then put them to work. Thermal energy (heat) is hard to measure other than something is hot or cold. The measurement decided on was the British Thermal Unit (BTU), which was defined as the amount of energy to raise the temperature of one pound of water one degree Fahrenheit. If you wish to be a home scientist, then measure one pound of water into a sauce pan, put a thermometer in the pan of water, turn on the heat and when the temperatures rises by one degree the energy content of the water increases by one BTU. In the reverse process, if the water temperature were to drop one degree Fahrenheit by placing a bit of ice in the water, then one BTU of work was performed by melting a bit of ice. With this bit of kitchen science we have created a heat transfer media available worldwide, at no cost, and predictable in its properties which we call steam - water in vapor form.

With our steam heat transfer media, let's examine the BTU and its many sources by burning a substance by utilizing a great chart from the website Engineering Tool Box-

Energy Source	**Unit**	**Energy Content (*Btu*)**
Electricity	1 Kilowatt-hour	3412
Butane	1 Cubic Foot (cu.ft.)	3200
Coal	1 Ton	28000000
Crude Oil	1 Barrel - 42 gallons	5800000
Fuel Oil no.1	1 Gallon	137400
Fuel Oil no.2	1 Gallon	139600
Fuel Oil no.3	1 Gallon	141800
Fuel Oil no.4	1 Gallon	145100
Fuel Oil no.5	1 Gallon	148800
Fuel Oil no.6	1 Gallon	152400
Diesel Fuel	1 Gallon	139000
Gasoline	1 Gallon	124000
Natural Gas	1 Cubic Foot (cu.ft.)	950 - 1150
Heating Oil	1 Gallon	139000
Kerosene	1 Gallon	135000
Pellets	1 Ton	16500000
Propane LPG	1 Gallon	91330
Propane gas $60^{o}F$	1 Cubic Foot (cu.ft.)	2550
Residual Fuel Oil [1)]	1 Barrel - 42 gallons	6287000
Wood - air dried	1 Cord	20000000
Wood - air dried	1 pound	8000

http://www.engineeringtoolbox.com/energy-content-d_868.html

Notice that liquid fuels tend to have much higher energy content than solid fuels such as coal. This is one of the reasons why the coal fuel locomotive did not evolve into the coal fueled car. Also notice that electricity, the number one item on our list, does not exist until we convert some other form of energy such as burning a fuel, using light energy in a solar panel, or nuclear power to generate steam to turn a turbine which then turns a generator. The most common device used to produce steam is a boiler which burns fuel, which in turn boils water under pressure to produce steam. Stationary boilers powered industry and ships while movable boilers became steam locomotives. About 25% of all fuel consumed is used to make steam.

From the Engineering Tool Box site here is a portion of the steam table up to 50 psig to review:

Gauge Pressure *(psig)*	Temperature *(°F)*	Specific Volume Saturated Vapor *(ft^3/lb)*	Enthalpy		
			Saturated Liquid *(Btu/lb)*	Evaporated *(Btu/lb)*	Saturated Vap *(Btu/lb)*
25 (Inches Mercury Vacuum)	134	142	102	1017	1119
20 (Inches Mercury Vacuum)	162	73.9	129	1001	1130
15 (Inches Mercury Vacuum)	179	51.3	147	990	1137
10 (Inches Mercury Vacuum)	192	39.4	160	982	1142
5 (Inches Mercury Vacuum)	203	31.8	171	976	1147
0 1)	212	26.8	180	970	1150
1	215	25.2	183	968	1151
2	219	23.5	187	966	1153
3	222	22.3	190	964	1154
4	224	21.4	192	962	1154
5	227	20.1	195	960	1155
6	230	19.4	198	959	1157
7	232	18.7	200	957	1157
8	233	18.4	201	956	1157
9	237	17.1	205	954	1159
10	239	16.5	207	953	1160
12	244	15.3	212	949	1161
14	248	14.3	216	947	1163
16	252	13.4	220	944	1164
18	256	12.6	224	941	1165
20	259	11.9	227	939	1166
22	262	11.3	230	937	1167
24	265	10.8	233	934	1167
26	268	10.3	236	933	1169
28	271	9.85	239	930	1169
30	274	9.46	243	929	1172
32	277	9.1	246	927	1173
34	279	8.75	248	925	1173
36	282	8.42	251	923	1174
38	284	8.08	253	922	1175
40	286	7.82	256	920	1176
42	289	7.57	258	918	1176
44	291	7.31	260	917	1177
46	293	7.14	262	915	1177
48	295	6.94	264	914	1178
50	298	6.68	267	912	1179

Use the following link if you wish to view the full table:

http://www.engineeringtoolbox.com/saturated-steam-properties-d_273.html

Let's define the headers in a steam table in common terms-

- Gauge Pressure (psig) – Atmospheric pressure at sea level is 14.7 pounds per square inch (psi). To eliminate this odd number a pressure gauge reads zero at sea level so all readings of steam system pressures are consistent no matter what the elevation above sea level might be.
- Temperature (°F) – Temperatures
- Specific Volume (ft^3/lb) – The reciprocal of density (lb/ft^3)
- Saturated Liquid (btu/lb) – Water freezes at 32° F becoming ice. By arbitrary definition water at 32° F is considered to have zero (0) energy to the enthalpy (internal energy) at the boiling point of water, 180 btu's per pound, which is calculated by starting at 32° F (0 energy) and raising the water to 212° F which would require 180 btu's (212° F- 32° F).
- Evaporated (btu/lb) – The amount of energy required to transform one pound of water to one pound of steam. Notice at 0 psig it is 970 btu's per pound and <u>decreases</u> as the boiling point temperature and pressure increases.
- Saturated Vapor (btu/lb) – The total of the saturated liquid enthalpy plus the evaporated enthalpy. In some tables this is called the *Total Enthalpy*.

Lots of terms and numbers have been provided - so what is the important take away? Over a wide range of pressure the Total Enthalpy remains for a pound of steam about 1200 btu's per pound, but as the pressure increases along with the temperature, the amount of energy to boil a pound of water <u>decreases</u>. Stated in a few words, as the temperature rises the amount of energy in a pound of steam goes down! Low pressure steam can do much more heat transfer work than high pressure steam with one major caveat - the temperature difference between what is being heated and the steam temperature.

Thermal energy (heat) flows from hot to cold. The amount of heat which will flow depends on the materials and other factors, but temperature difference is a major issue. As a general rule of thumb this temperature difference should be about 50° F. As an example, if we wish to heat something to 290° F, we should have steam at a temperature of about 340° F (290° F + 50° F). Steam at 100 psig has a temperature of 338° F - close enough.

1. Thermal energy is used in a wide range of applications to manufacture products as well as provide comfort during cold weather. Take a moment and glance around your current location and see if you can identify anything you might see which did not use thermal energy to produce it.

2. BTU is the amount of heat to raise one pound of water one degree Fahrenheit.

3. One pound of water yields one BTU of thermal energy when cooled one degree Fahrenheit**.**

4. One pound of steam yields approximately 1000 BTU's when condensed.

5. Steam is a common heat transfer media due to the large amount of heat which can be transmitted through a pipe.

It helps to have some pressure temperature points handy, so long ago I memorized the following which has been a big help over the years –

- Steam at 0 psig is 212° F
- Steam at 25 psig is 250° F
- Steam at 50 psig is 298° F
- Steam at 100 psig is 338° F
- Steam at 150 psig is 366° F
- Steam at 200 psig is 388° F

Note as the pressure increases the corresponding temperatures rise at a slower rate.

A steam system is made up of sub-systems such as the boiler plant, distribution system, production equipment, and condensate return system. This book will take a sub-system approach to help you zero in on sections related to your specific questions or interests.

We covered a fair amount of ground in "Why Steam", and if you hang onto these basics you will be surprised how much you can accomplish in understanding your steam system.

Chapter 2- Boilers

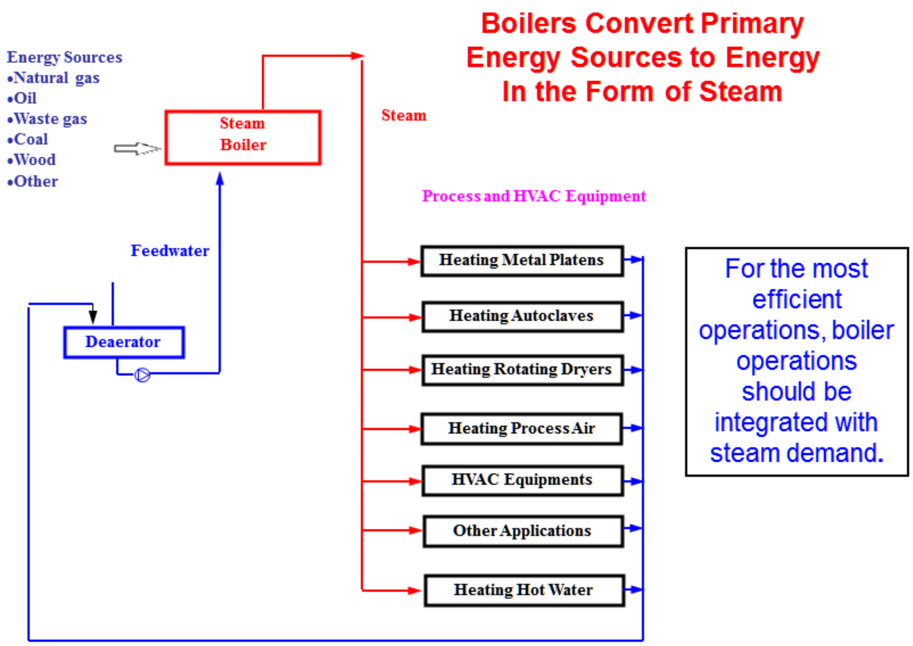
Chapter 2 Highlights – Boilers

- The boiler plant is both the beginning and end of a typical steam system in the sense that boilers produce the thermal energy in the form of steam, and the spent or used steam is sent back to the boiler plant in the form of condensate return.
- Energy data all are equal to one million BTU's
- This chart compares cross over costs using natural gas as the base cost and then using the conversions to arrive at what the equal cost would be for other common boiler energy sources.

- Boilers come in three basic types; firetube, water tube and low volume water tube.

Most steam systems are made up of what we call a closed loop system. Steam is generated in the boiler plant and transmitted to the facility by the pressure of the steam. This provides thermal energy to perform a wide variety of tasks which require energy in the form of heat. As the heat flows into the process, BTU’s flow from the steam which then condenses to form hot water - typically called condensate. Condensate is valuable since it has residual heat, is treated water, and can be returned to the boiler plant and be re-cycled to produce more steam. In open loop systems steam is typically directly injected into the process with no condensate being available for return. Many facilities have both types of applications resulting in a mixed system. Understanding what percentage of steam is used for direct injection is important in analyzing your overall boiler plant operations for efficiency.

The Basic Steam Loop



The boiler plant is both the beginning and end of a typical steam system in the sense that boilers produce the thermal energy in the form of steam and the spent or used steam is sent back to the boiler plant in the form of condensate return.

The common energy unit in a steam system is the BTU and knowing the common versions of BTU’s from different sources allows for cost and efficiency comparisons.

ENERGY DATA ALL ARE EQUAL TO 1,000,000 BTU

- 1 MCF of natural gas
- 1,000 cubic feet of natural gas
- 1 decatherm of natural gas
- 10 therms of natural gas
- 293.1 KW of electricity
- 7.29 gallons of # 2 oil
- 10.93 gallons of propane
- 1,000 lbs of steam
- 29.31 boiler horsepower

Here are some examples of comparing energy costs for different fuel sources using cost examples-

Energy
Cross Over Costs

Gas Cost (MCF)	# 2 Oil (gallon)	Propane (gallon)	Electricity (KWH)
$5.00	$.82	$.46	$.0171

If natural gas costs $5.00 per million BTU's-

•Number 2 oil would have to cost $.82 per gallon
•Propane would have to cost $.46 per gallon
•Electricity would have to cost $.0171 per KWH

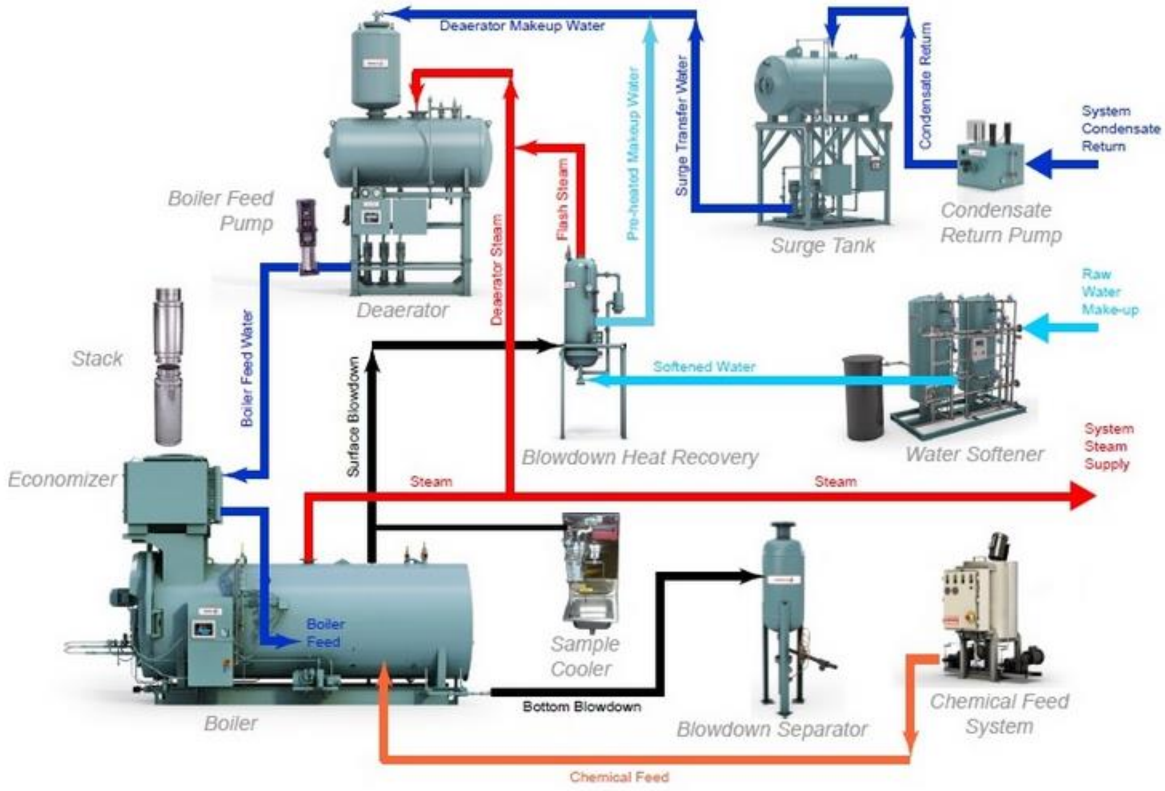
This chart compares cross over costs using natural gas as the base cost and then using the conversions to arrive at what the equal cost would be for other common boiler energy sources.

Energy
Cross Over Costs

Gas Cost (MCF)	# 2 Oil (gallon)	Propane (gallon)	Electricity (KWH)
$5.00	$.82	$.46	$.0171
$6.00	$.82	$.55	$.0205
$7.00	$.96	$.64	$.0239
$8.00	$1.10	$.73	$.0273
$9.00	$1.24	$.83	$.0307
$10.00	$1.37	$.92	$.0341
$11.00	$1.51	$1.01	$.0375
$12.00	$1.64	$1.10	$.0409

As an example, if natural gas cost $7.00 per million BTU's, costs for the other forms would not have to exceed for #2 oil $.96 a gallon, for propane $.64 a gallon, and for electric power $.0239 per Kwh.

Here is an example from Cleaver Brooks of a boiler plant designed to maximize every possibility to achieve maximum boiler plant efficiency. Not every option might suit your budget or technical needs, but knowing what is available is worthwhile.



http://www.econtrol.com/Steam-Boiler-Room-Equipment.htm

Boiler Types

We will exam the boiler plant as a system starting with the boilers. Steam boilers come in three basic types-

1. Firetube Boilers-Typically shaped like a cylinder with fire in the tubes and water in the jacket. Firetube boilers are rated in boiler horsepower (BHP). As an aside, this form of boiler rating dates back to the days of steam locomotives which are firetube boilers on wheels. Imagine being the engine crew running down the rails riding a firetube boiler on wheels at 60 MPH!

2. Water Tube Boilers- Typically a large rectangular box with water in the tubes and fire in the box. Water tube boilers had origins from marine and large stationary applications.

3. Low Volume Water Tube Boilers- Somewhat a recent development with origins in the 1930's and improved over the years. Somewhat brand specific with Clayton and Miura being the most common brand encountered in North America.

For firetube boilers and low volume water tube boilers the conversion is-

$$1\ Boiler\ HP = 34.5\frac{lb}{hr}\, of\ steam$$

Using our conversion of 500 lb/hr = 1 GPM, a 300 HP boiler would produce 10,350 lb/hr of steam which means the boiler would have an evaporation rate of 20.7 GPM of feedwater $(10{,}350 \div 500)$

Watertube boilers are rated in lb/hr. As an example a 25,000 lb/hr watertube boiler would have an evaporation rate of 50 gpm of feed water $(25{,}000 \div 500)$

Chapter 3 Boiler and Steam System Efficiency

Chapter 3 Highlights – A boiler is a pressure vessel with a burner or other energy source used to convert thermal energy from one form to another, as an example, burning natural gas to generate steam.

- Shown is a chart for average steam system efficiency based on a typical energy survey and load balance on a steam system in average condition will yield the following losses.
- If a boiler with a fuel input of 10 million BTU's delivers 8 million BTU's of steam then we consider that boiler to be 80% efficient.
- When fuel is burned the excess results of the combustion process are gases and particles which are not consumed which go up the stack.

- Boilers are blown down at two points. Surface blow down deals with dissolved solids and particles which are present when steam is formed and bottom blow down to eliminate solids which will accumulate in a boiler.
- For most boilers in good condition the radiation losses from the boiler shell are about 4%.
- Boilers should be matched to the load and multiple boilers should be operated with a lead lag control system to minimize radiation losses.

A boiler is a pressure vessel with a burner or other energy source used to convert thermal energy from one form to another; as an example, burning natural gas to generate steam. Efficiency is the comparison of energy input as compared to energy output. In a steam system we need to address the simple question - what efficiency do you want?

Below is a chart for average steam system efficiency. It is based on a typical energy survey and load balance on a steam system in average condition. It will yield the following losses:

Boiler Room Losses

Stack losses	21%
Blowdown losses	4%
Boiler radiation losses	3%
Total Boiler Room Losses	28%

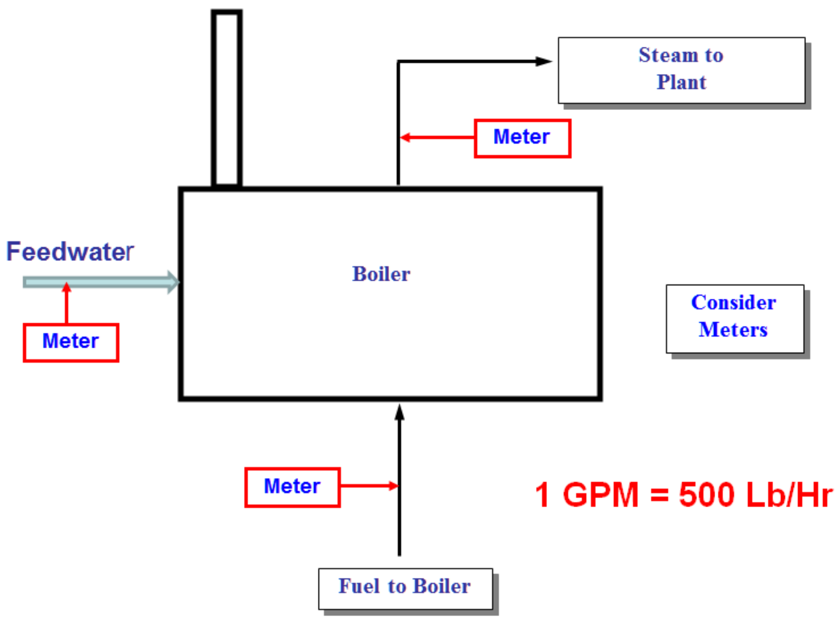
Distribution, Process Equipment, and Return Losses

Insulation losses	7%
Steam leaks	6%
Blowing steam traps	7%
Flash steam losses	13%
Return System losses	9%
Total Distribution Losses	42%
Total Steam System Losses	70%

Placed in perspective, if you are spending $500,000 per year for boiler fuel, only about $150,000 of thermal work is being delivered into your product or process. Notice that there are in fact multiple efficiency numbers to consider, and of course these will vary with system specifics such as boiler type, age, operating pressures, and many other variables.

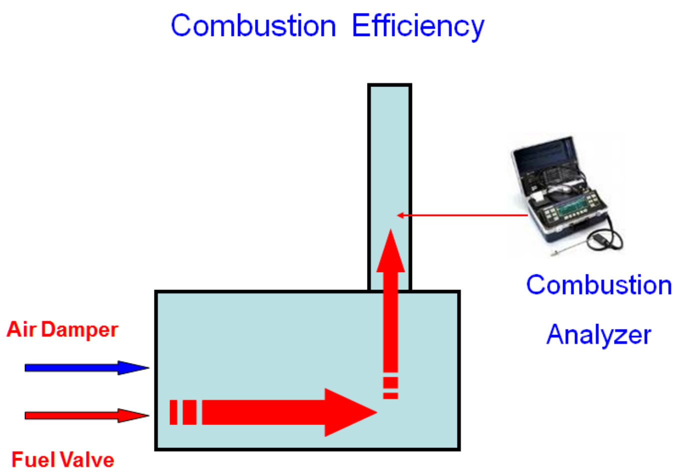
Let's focus in this first portion on boiler room losses. As we discussed, boilers are offered in two basic types; firetube and watertube. The overall efficiency of the boiler, sometimes called the fuel to steam efficiency, is the amount of energy in BTU's delivered, in the form of steam, compared to the number of fuel BTU's consumed. As an example, if a boiler with a fuel input of 10 million BTU's delivers 8 million BTU's of steam, then we consider that boiler to be 80% efficient.

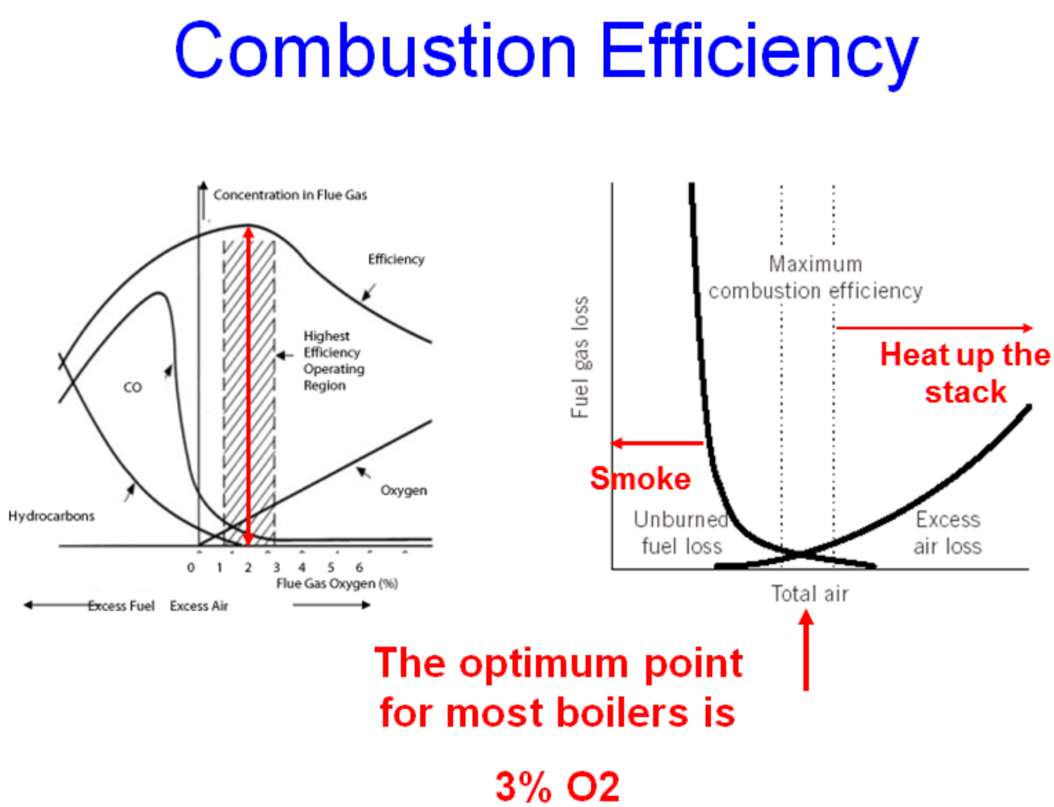
Measuring Fuel to Steam Efficiency



Three primary efficiency issues control the final result - and they include:

- Stack Losses-When fuel is burned, the excess results of the combustion process are gases and particles, which are not consumed and go up the stack. A stack analyzer is used to measure these losses, and for most boilers will show stack efficiency losses in the 76-82% range, depending on the boiler type, fuel burned and boiler loading. The stack analyzer reading is the most often quoted figure for boiler efficiency and typically is 80%. This is part of the fuel to steam efficiency of the boiler.





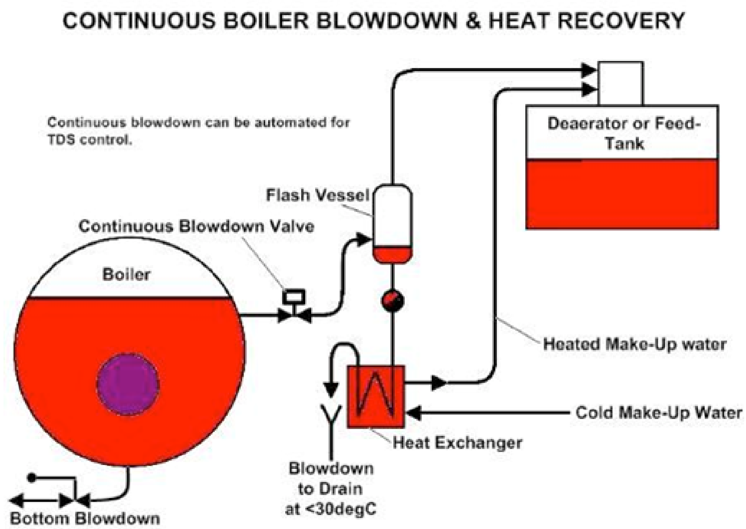
- <u>Blowdown Losses</u>- Boilers are blown down at two points. Surface blowdown deals with dissolved solids and particles, which are present when steam is formed and bottom blowdown eliminates solids which will accumulate in a boiler. Blowdown can be manual, continuous or a combination of both.

Blow Down Considerations

- **As water is boiled, sediment in the water settles and scum rises to the surface.**
- **Surface blowdown deals with the surface contaminants.**
- **Bottom blow down deals with the sediment.**
- **Proper water treatment on a daily basis if critical to the service life of a boiler.**

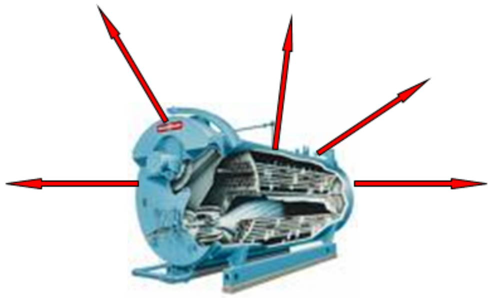
Conductivity based surface blowdown controller

Heat exchanger bottom blowdown heat recovery system



- <u>Boiler Radiation Losses</u> -Temperatures inside a boiler are well in excess of 1000° F, so the boiler has to be insulated for safety concerns as well as to reduce the radiation losses from the boiler. For most boilers in good condition, the radiation losses from the boiler shell are about 4%. Boiler manufacturers will typically provide this specification in their data sheets. Radiation losses are stated as a percentage, with the boiler operating at a 100% firing rate. Since radiation losses are a fixed value under a boiler load, assume a boiler producing 10 million BTU's of steam has a radiation loss of 4%, which leads to a value of 400,000 BTU's. If the boiler later is operating at a 50% firing rate, or 5 million BTU's, the radiation loss remains fixed at 400,000 BTU's resulting in the radiation loss rising to 8% ($400{,}000\ radiation\ loss \div 5{,}000{,}000\ output$). Boilers should be matched to the load, and multiple boilers should be operated with a lead lag control system to minimize radiation losses.

Radiation Loss



Radiation loss is rated as a percentage of 100% boiler output and is typically 4% for most firetube boilers

Since the radiation loss off a boiler does not change, a boiler operating at a 75% firing rate will have a radiation loss of 6% as a percentage of boiler output. At a 50% firing rate, the radiation loss rises to 8%.

The lower the percentage load, the higher the radiation losses become since fuel is being wasted to keep the boiler hot.

Boilers which cycle in and out of operation have very high losses due to radiation and purge losses.

ASHRA Data on the range of potential losses in a boiler plant is as follows-

Boiler Losses

Combustion Efficiency	**75-86%**
Radiation and Convection Losses	**0.3-6%**
Boiler Design and Load Management	**2-7%**
Scale Buildup in Boiler	**7-11%**
Excess Boiler Blowdown	**0.1-1%**
Excess Air	**0-7.5%**
Range of Efficiency	**42.5-76.6%**

(Source ASHRAE Journal September 1994)

A boiler plant represents a sizeable capital outlay and even greater annual operating costs for your business. As an example, for a boiler operating 7,000 hours per year, the cost to provide fuel for that boiler is about 4 times of the cost of the boiler – just for one year! Managing and monitoring the equipment in your facility can result in significant savings and rapid payback of investments in energy efficient equipment and systems.

Chapter 4- Deaerators, Feedwater Pumps and Water Softeners

Chapter 4 Highlights – Deaerators, feedwater pumps, and water softeners are three important elements to protect your boilers and steam system.

- **Deaerators come in two basic versions; atmospheric and pressurized.**
- **A pressurized deaerator uses a closed loop or pressure vessel to raise the water temperature to 225-227° F and maintain the pressure of 5-7 psig to condition the boiler feed water.**
- **A feed water pump draws water from a point by suction, spins it with an impeller, and generates pressure. The pump suction is generally at a pressure less than atmospheric pressure, which means that hot feed water will "boil' inside the pump. This unloads the motor, generates cavitation, destroys seals, and quickly leads to a pump failure.**
- **A pump operating to the left of the red line will give long service, and a pump operating to the right can fail very quickly.**
- **Typical feed water specifications for a boiler are as follows, but confirm your specific values with your brand of boiler.**
- **The carbon dioxide is harmless in the boiler, but free CO_2 will combine with hot condensate H20 to form H_2CO_3, which is carbonic acid. Although considered a "mild' acid, carbonic acid will attack condensate return piping and "rust" the piping until it fails. If you find red brown rust in your return piping you have a carbonic acid corrosion problem. This will cause you many issues with leaks, pipe failures, and equipment damage.**
- **High conductivity, typically above 4,000 microsiemens per centimeter (μs/cm), will cause boiler carryover which results in slugs of water entering your steam system. This results in water hammer that will cause damage or pipe failures and major issues with your steam equipment due to low steam quality.**
- **Steam quality is the numerical percentage of steam to entrained moisture. Pure live steam in a perfect world would have a steam quality of 100%, meaning it is all H_2O in vapor form. A properly operating boiler plant expects steam qualities of 96-98%.**
- **1 GPM=500 lb/hr**

- **The best way to understand the issues that need to be carefully considered to select a boiler feed pump is to look at a real world example. Remember that this example would fit any pump for hot water with low suction pressures.**
- **Having watched many boiler feed pumps fail over the years, we have learned the value of adding a globe valve in the pump discharge harness. This deal limits the amount of water which can flow through the pump under worst case conditions, thereby keeping the pump on the left hand side of the red line.**
- **Stack economizers work best and achieve real savings when installed on boilers which operate steady loads at high firing rates.**

Deaerators

Deaerators come in two basic versions; atmospheric and pressurized. An atmospheric deaerator is a vented vessel and uses chemicals to condition the water. Typically a boiler feed pump is required to transfer feed water in a range of 200-230° F from a deaerator or boiler feed system to a boiler operating at pressures of 15-300 psig, depending on the boiler specifics. The purpose of a deaerator is to condition the water chemically, remove dissolved gases, and heat the feedwater to at least 200° F to prevent doing thermal shock damage to the boiler.

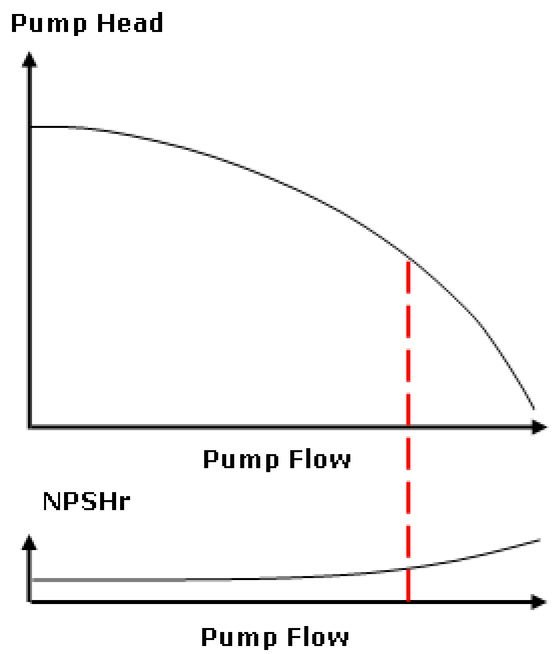
Atmospheric deaerators typically operate in the 190°- 205° F temperature ranges, with no pressure in the vessel.

Steam is typically used to heat the tank. In most installations two feedwater pumps are used to provide back up in the event of failure of the primary pump, which is quite common. Controls are typically an alternator to spread the wear and operation over both pumps. The suction head to the feedwater pumps is the static head only since the tank is vented. The means that the static head or suction head on the feedwater pumps is very low and measured in feet of head pressure.

A pressurized deaerator uses a closed loop or pressure vessel to raise the water temperature to 225°-227° F and maintain pressure of 5-7 psig to condition the boiler feed water. Chemicals are used to adjust the feedwater to proper levels, and the boiling process of the feedwater is used to drive off the dissolved gases present in the cold water.

As with the atmospheric Deaerator, typically two pumps are utilized to provide primary and secondary options with an alternator based control panel. From a pump selection point of view, the selection of the pump based on the discharge requirements is identical, but the suction specifications are different. Water temperatures are now in the 225°-227° F range, but we now have the pressure in the deaerator of 5-7 psig and the static head on the pump to help deal with the potential for cavitation to occur.

A pump draws water from a point by suction, spins it with an impeller and generates pressure. The pump suction is generally at a pressure less than atmospheric pressure, which means that hot feed water will “boil’ inside the pump. This unloads the motor, generates cavitation, destroys seals and quickly leads to a pump failure.



All deaerators and boiler feed systems are mounted on a stand, and the distance from the tank water line to the inlet of the pump is called the **Net Positive Suction Head, NPSH.**

If we examine the generic pump curve, notice as flow increases from the pump, the **Required Net Positive Suction Head (NPSHr)** increases. For most pumps this will occur in the 60-80% of maximum flow through the pump, and the dashed red line represents the danger point which will lead to pump failure.

A pump operating to the left of the red line will give long service and a pump operating to the right can fail very quickly. Since flow and pressure requirements on a boiler feed pump can vary by quite a bit, moving to the right of the red line can occur quickly and without warning. A pump is a passive device in the sense that it will always want to pump as much water as possible, and the current draw on the pump will be a reflection of the amount of water moved by the pump.

Chemical Properties of Feedwater

Cold water enters the boiler plant through a water softener and is fed into the deaerator controlled by a level control. The water is heated to typically 225°-227° F at 5-7 psig in a pressurized deaerator, and 190°-200° F in an atmospheric deaerator, commonly called a feed water heater. Water contains dissolved solids and gases which must be removed to prevent scaling and chemical attack in the boiler. Typical feed water specifications for a boiler are as follows, but confirm your specific values with your brand of boiler.

ITEM	UNITS	BOILER WATER STANDARD RANGE	MAKE UP WATER STANDARD RANGE
pH (AT 25.)		11.0 - 11.8	7 - 9
HARDNESS	$CaCO_3$ mg/L	-0.0-	-0.0-
OXYGEN	ppm	Below 0.5	
P ALKALINITY	$CaCO_3$ mg/L	150 - 600	
M ALKALINITY	$CaCO_3$ mg/L	250 - 800	
SULFITES	ppm	DETECTABLE	DETECTABLE
CONDUCTIVITY (AT 25°C)	µS/cm	1,500 - 4,000	
CHLORIDE	Cl- mg/L	BELOW 400	BELOW 30
SILICA	SiO_2 mg/L	BELOW 250	BELOW 30
IRON AND MANGANESE	Fe & Mn mg/L	BELOW 1.0	TOTAL BELOW 0.5

http://www.iheater.com/miura/literature/ex_engineering_and_installation_manual.pdf

With rare exception, all water contains calcium carbonate ($CaCO_3$), which requires a water softener to eliminate this compound that will scale boilers. Make sure you check the hardness of the feedwater on a daily basis to insure the water softener is operating properly. All water contains dissolved gases, with the two culprits in a boiler being oxygen and carbon dioxide. When water is boiled to make steam, the free oxygen atoms in the presence of the high temperatures in a boiler will pit and destroy the boiler tubes. The carbon dioxide is harmless in the boiler, but free CO_2 will combine with hot condensate H_20 to form H_2CO_3, which is carbonic acid. Although considered a “mild” acid, carbonic acid will attack condensate return piping and “rust” the piping until it fails. If you find red brown rust in your return piping you have a carbonic acid corrosion problem. This will cause you many issues with leaks, pipe failures and equipment damage. The solution rests with proper operation of your deaerator. Condensate should have a conductivity of 0, but a range of 25-50 microsiemens per centimeter (µs/cm) is tolerable.

High conductivity, typically above 4,000 microsiemens per centimeter (µs/cm), will cause boiler carryover which results in slugs of water entering your steam system. This results in water hammer that will damage or cause pipe failure and major issues with your steam equipment due to low steam quality. High conductivity can also create carry over problems resulting in low steam quality.

Steam quality is the numerical percentage of steam to entrained moisture. Pure live steam in a perfect world would have a steam quality of 100%, meaning it is all H_2O in vapor form. A properly operating boiler plant expects steam qualities of 96-98%. How can you check steam quality without a calorimeter? Pure live steam when blown to the atmosphere in the first 1/4” to 1/2” will be a pale blue transparent gas when shining a flashlight through the blow off. A piece of cardboard flicked quickly through the blow off will be dry. If the cardboard is water spotted, your steam quality is below the 96% level. Be careful in doing this visual check and wear proper safety equipment. It is best to check a ½” to 1” connection with a partially open valve. Recognize also that a steam quality of “only” 90% means you are putting 10% condensate right up front into your heat transfer equipment, which will degrade performance and also create failure issues. Many boiler plants have lower than normal steam qualities, so do not assume you are immune from this problem.

The other chemical specifications should be reviewed with your water treatment vendor. A word about water treatment companies-choose wisely and check references if you are changing water treatment companies. Boiler plants are a substantial investment and improper water treatment can create serious damage in a very short period. Be an informed buyer of this very important service. Proper feedwater control and daily tests are critical to the operation of your boiler plant.

Feedwater is fed into a boiler in gallons per minute (GPM), and the boiler produces steam in pounds per hour (lb/hr). How do we convert a volumetric flow rate to a mass flow rate? The magical, ever so valuable, number in any steam system (write it down or memorize it) is –

$$\mathbf{1\ \mathit{GPM} = 500\ \mathit{lb/hr}}$$

Feedwater Pumps and Controls

A tough application for any pump is feeding water to a boiler for the following reasons-

- The water temperature is in the 190°-230° F range.
- The Net Positive Suction Head (NPSH) on the pump is low.
- The pump flow demand can vary widely.

With over 25 years of experience in engineering, designing and installing boiler feed pumps, we have learned by hard trial and error how to avoid many issues which will lead to feedwater pump failure. Being a severe service application, you should also adopt the philosophy that any boiler feed pump will fail; not if - but when. You should also have a spare boiler feed pump either installed or as a spare. For multiple boilers I would recommend that you have at least one more pump on hand than the number of boilers you are operating; assuming all boilers are the same size. If you have boilers of different sizes, or operating at different pressures, then keep a spare pump either installed or in stock.

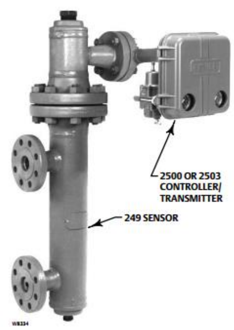
To select and size a boiler feed pump you need three pieces of information:

1. The boiler feedwater pump flow rate.
2. The operating pressure of the boiler.
3. The suction head (NPSH) on the pump inlet.

Feedwater level in a boiler can be controlled by an on/off float type level controller with brand names like McDonnell & Miller or probe controls such as Warrick (Gem Controls).

Either style of this control will turn on the boiler feed pump when the water level is low and turn off the pump when the level is up in the boiler. Off/on control is less expensive to purchase and maintain but is not as good as a modulating level control system. This is especially true for boilers operating over wide load ranges and subject to load demand spikes.

Modulating feedwater control typically utilizes a pneumatic or slide wire level control mounted on the boiler. This will provide a signal for a pneumatic or electric feedwater valve to supply feedwater to the boiler as required. In this type of system, the water level in the boiler is always maintained at the optimum point for the boiler, as opposed to a low and high level for the pump on/off system. In a modulating feedwater control system, the pump(s) run 100% of the time. Continuous run on a pump actually results is less wear than stop and start operation. A common brand for level controls and actuated valves is Fisher.

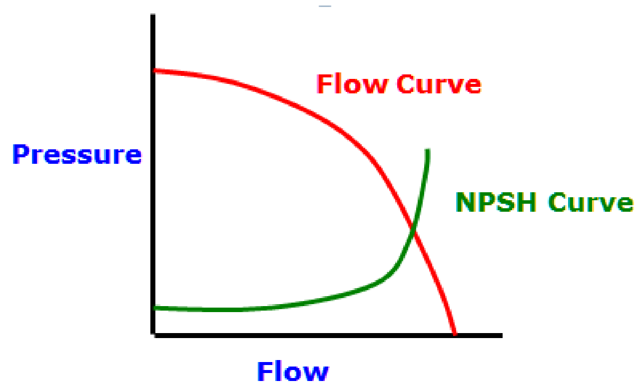


http://www.control-specialties.com/m27-fisher-control-valves.php

For on/off level control on the boiler, take the boiler evaporation rate and multiply it by 2.0 to arrive at the required pump flow rate. For the pump discharge pressure, take the boiler operating pressure and multiply by 2.0. As an example - a 300 BHP firetube boiler operating at 100 psig would require a boiler feed pump to flow 41.4 gpm (20.7 gpm x 2.0) at a discharge pressure of 200 psig (100 psig x 2.0). Some might argue that this is a bit much, but a somewhat oversized boiler feed pump can be dealt with by limiting the flow with proper feedwater piping and set-up, which we will cover shortly. An undersized pump on either or both issues will make for a very bad day - don't ask why we know this!

For modulating feedwater control with continuous run pumps, use the boiler evaporation rate times 1.5 and boiler operating pressure times 1.5. Using our same 300 HP boiler operating at 100 psig the required pump flow would be 31.1 gpm (20.5 x 1.5) at a discharge pressure of 150 psig (100 psig x 1.5).

We now need to deal with the NPSH of the pump. Think of a pump curve as a graphical representation of what performance the pump can produce. Pumps are passive devices in the sense that the supply and discharge pressures govern the operation of the pump.



The graph above represents a typical operating curve to describe pump operations.

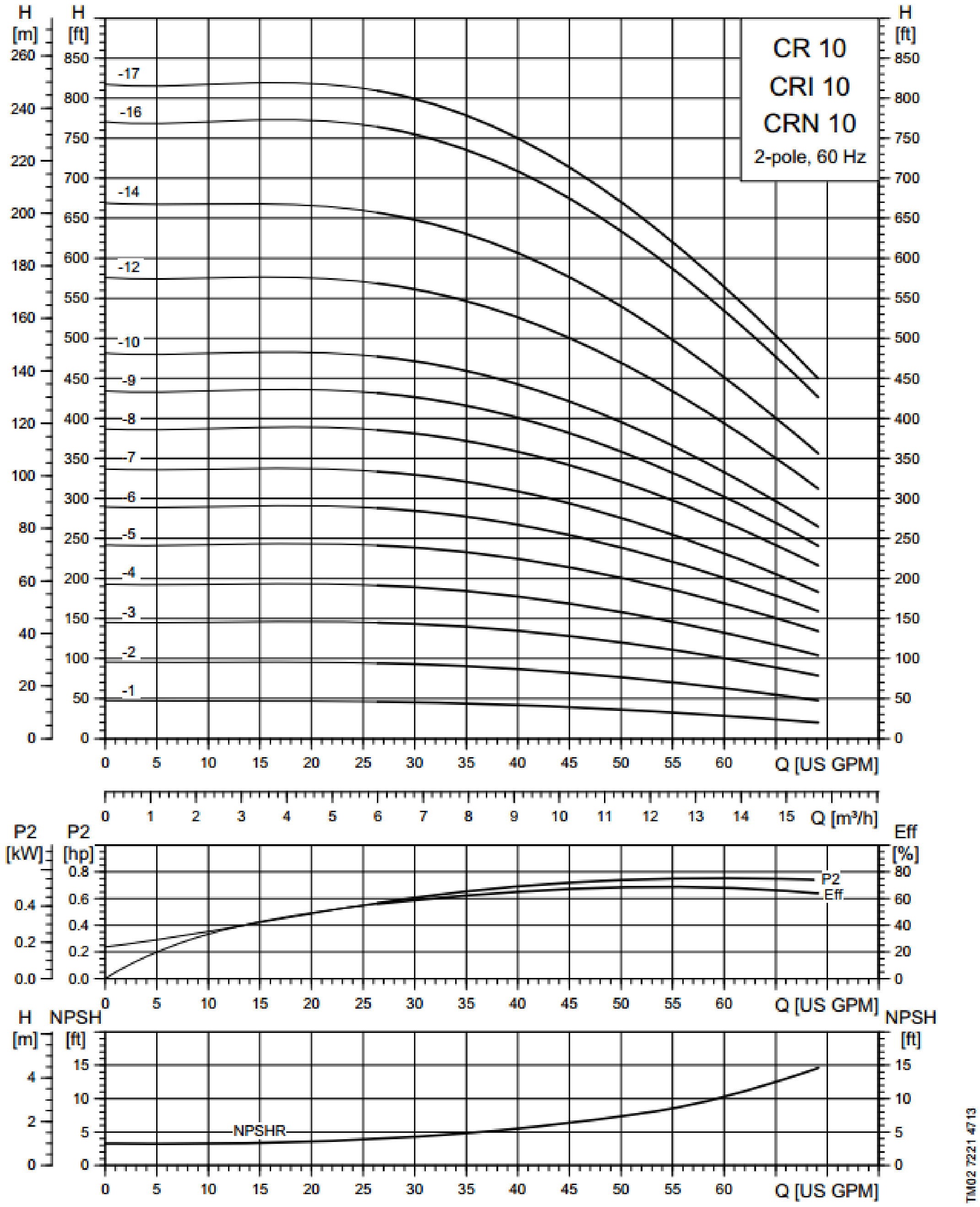
The **red line** is the flow curve of the pump. If we close the discharge valve of the pump cutting off all flow, the pressure at the discharge will rise to its highest value which is the static discharge pressure of the pump. If we remove the discharge piping from the pump and turn it loose, the open flow is at the far right of the **red line** and occurs at no static pressure. The flow curve then allows us to predict the pump flow for any pressure difference between the inlet and discharge connections on the pump. Whenever you install a pump, installing inlet and discharge gauges becomes very important to determine the pump's performance.

The **green line** is the net positive suction head (NPSHr) of the pump. A pump draws water by creating a reduced pressure or suction at the inlet of the pump. A good example is to think of a shop vacuum in operation. For the shop vacuum to operate, a blast of air discharges from the top or side of the unit to permit suction at the hose nozzle. A pump handling water or any fluid operates in the same manner. Water at atmospheric pressure boils at 212° F. As the pressure drops below 212° F, water can boil at temperatures well under 200° F. If insufficient suction head (NPSHr) is present at the pump inlet, then cavitation, which sounds like marbles, will occur in the pump destroying seals and pump internals.

Feedwater Selection Example and Installation Tips

Based on many boiler installations, we have had excellent service using the Grundfos CR series multistage vertical centrifugal pumps. Let's take a moment and examine a typical Grundfos CR pump curve.

CR, CRI, CRN 10



The CR 10 is one in a series of vertical multi-stage centrifugal pumps, so let’s examine the curve for this pump as an example. The top curve shows the number of pump stages offered (called stack kits) from 1 to 17. The CR 10 has a flow range from 0 to 80 gpm at the far right of the curve. The head is expressed in M (meters) or FT (feet). The conversion for head in feet to psig is to divide by 2.33. As an example, a pump with a discharge head of 233 feet would have a discharge pressure of 100 psig.

The middle curve shows the horsepower required along with the motor efficiency. Note that increasing flows increase motor horsepower required.

The bottom curve shows the required NPSH for the pump. Note that it is relatively flat for about 50-60% of the curve and then begins to increase exponentially with increasing flow. Deaerators and feedwater heaters have a low suction head by design. With a pressurized deaerator operating at 5-7 psig, the only added head is the height of the water in the storage tank. For a feedwater heater (atmospheric deaerator), the only suction pressure to the pump is the vertical distance from the pump inlet to the lowest water level in the storage tank.

To prevent the feedwater pump from going to the right hand side of the curve, resulting in cavitation of the pump and failure, limit the flow on the pump. In other words, park it on the curve.

The best way to understand the issues that need to be carefully considered to select a boiler feed pump is to look at a real world example. Remember that this example would fit any pump with hot water with low suction pressures. To make the selection example relevant we will use a Grundfos CR series multi stage centrifugal pump, since we've had experience with hundreds of installations. The approach we'll use would be similar for any other brand of centrifugal pump.

To set the stage let's go to a specific example-

- Boiler size 300 HP
- Boiler output 10,350 lb/hr of steam
- Boiler operating pressure 125 psig
- Feedwater operation on the boiler is on/off (not modulating)
- Atmospheric deaerator at 200° F
- Stand height of 8' below a 300 gallon tank

With this basic data let us proceed to break down the details to arrive at the specifications we need to select the feedwater pump which includes:

- The pump flow in gpm
- The pump discharge pressure in psig
- The minimum NPSHr required for the pump to avoid cavitation
- The installation details for the pump

We'll do some quick math to get at the pump specifications. You can skip the quick math to arrive at the pump selection if your application is not for a boiler feed pump. The quick math is as follows:

- 500 lb/hr = 1 gpm
- Boiler Evaporation Rate 10,350 lb/hr = 20.7 gpm (10,350 / 500)
- For an off/on boiler feed pump, the pump should be sized for 2:1 of the required boiler evaporation rate. For modulating feedwater control the ratio would 1.5:1.
- For on/off control the required maximum on the pump = 41.4 gpm (2 X 20.7)
- For on/off feedwater control the pump discharge pressure should be the operating pressure 2 times the boiler pressure (2:1). For modulating feedwater control 1.5:1.
- For our example the discharge pressure = 250 psig (2 X 125)
- 2.33' = 1 psig
- The discharge pressure of the pump = 582' (2.33 X 250)
- The suction head is 5' of elevation.

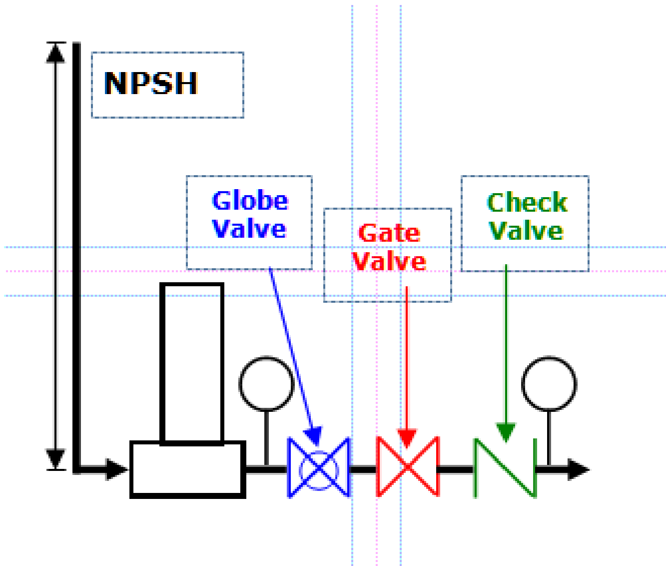
The pump selection specification is 41.1 gpm of water at 200° F with a discharge pressure of 582' and a suction head of 8'.

Our pump selection would be a CR-10-14 based on our sizing calculations. Boilers operate over a wide range of conditions from cold start up with no pressure in the boiler to sudden demand surges which, during peak periods can exceed the boiler output. Notice that the pump as selected has an NPSH of 6', so we are just below the minimum required of about 8'.

A pump is a "dumb" device given that it will pump as much fluid as the suction pressure will allow the pump to discharge into. On filling the boiler the pump will go as far right as possible and pump in the region of 70-80 gpm of water. On a surge demand, which might drop the boiler pressure 5-10 psig, the pump output could increase and exceed the NPSH for our selection, allowing the pump to cavitate and lead to seal or total pump failure.

To prevent the pump from going right on the curve we need to limit the flow to no more than 40-42 gpm. Flow control devices can be purchased which will accomplish that purpose. The option we've found over many years is simpler and works very well.

Referring to the sketch shown below, install on the discharge side of the pump, in sequence, a pressure gauge, globe valve, gate valve, check valve, and another pressure gauge. In our example, with both valves open and cold water flowing through the pump, gradually close the globe valve until the pressure gauge ahead of the globe valve reads 250 psig (585' of head pressure). With the globe valve we have provided a restriction on the discharge side of the pump limiting the flow of the pump and keeping it within the limits of the NPSH curve. The gate valve can be used to isolate the pump for service and the globe valve should be tagged with a plate indicating do not open or close this valve. In our installations we go one step further and remove the globe valve wheel handle.



Having watched many boiler feed pumps fail over the years, we have learned the value of adding a globe valve in the pump discharge harness. This limits the amount of water which can flow through the pump under worst case conditions, thereby keeping the pump on the left hand side of the red line. You can go a step further, which we do, and measure the amp draw on the pump motor and compare to the amp draw required by the pump for 40 gpm.

By studying the pump curve, knowing the NPSH dimension on the pump suction and the amp draw for a given pump, we can park the pump on the curve by throttling the globe valve to add artificial head on the discharge side of the pump, limiting maximum flow through the pump.

This simple piping arrangement along with pressure gauges and an amp meter allow for much better set up of your boiler feed pump.

Pump Bypass Lines

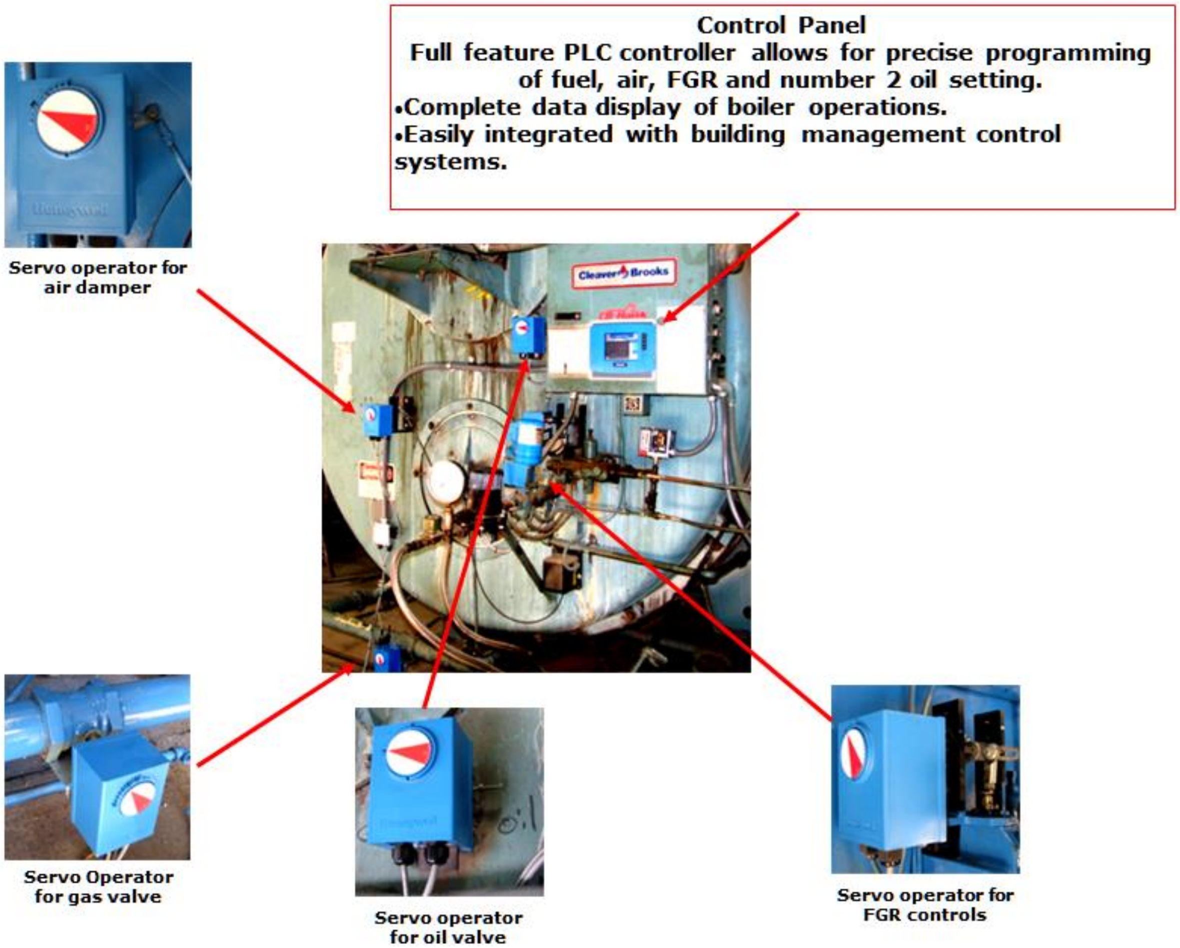
Sufficient flow through a pump is required to ensure that adequate cooling and lubrication of the pump is maintained at all times. Inadequate cooling and lubrication will result in overheating, bearing wear, friction between the seal faces, seal leakage, and ultimately cause premature pump failure. A bypass line should be installed if there is any possibility the pump may operate under its minimum flow requirements. The bypass line should run from the pump vent or discharge pipe back upstream of the pump as far as practical or into a tank to allow sufficient cooling of the liquid.

The liquid from the bypass line must have the opportunity to cool down before re-entering the pump in order to prevent overheating of the pump. For this reason, never run the bypass line directly back to the pump inlet. A properly sized bypass is one that satisfies the pump's minimum flow requirement, as stated on the submittal data sheet for each pump. Grundfos offers bypass orifices, sized for each pump model and illustrates their installation in the Series C Installation and Operation manual included with each pump. Please note that during periods of full demand the combined flow through the system and bypass must not exceed the maximum flow rate of the pump.

Chapter 5 - Boiler Combustion Controls and Economizers

Every boiler requires a system to manage the fuel air ratio for optimum combustion. The most common form of system still in wide spread use is a mechanical system using linkages and cams to adjust for proper fuel to air ratios. As an example, a single fuel boiler firing natural gas would have a modulating gas burner supply valve mechanically connected to an air damper. Cams would be provided so the fuel air ratio could be adjusted at high and low fire for optimum combustion. The cam would allow for some further adjustments for intermediate settings. A combustion analyzer would be used to make the setting. As you add on a second or third fuel alternate, the linkage grows in complexity since additional fuel valves have to be tied to the system. Add flue gas recirculation and the complexity of the system is really no longer feasible. This is a system dating back to the 19th century and prone to all the issues associated with complex mechanical systems.

Mechanical combustion systems are hard to maintain, drift in adjustment, and leads to extra fuel being burned to operate your boilers. With the advent of industrial computers, systems have evolved which replace the mechanical linkage with servo operated valve positioners tied to a PLC based control system with display. These systems are typically called Link-Less Boiler Controls systems, and typically improve combustion efficiency 3-5%.

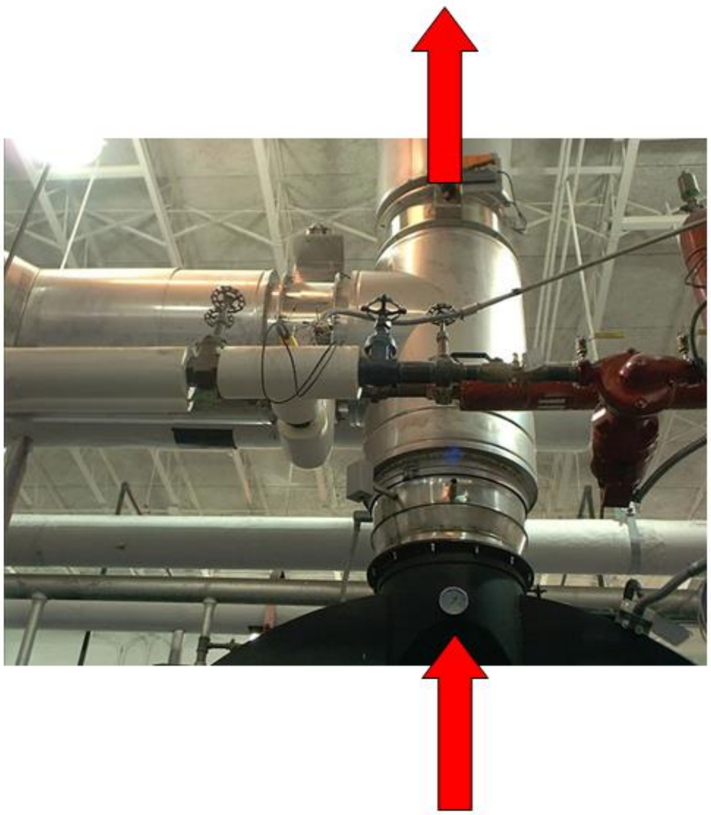


Benefits of microprocessor-driven linkage less burner controls include optimized combustion, repeatability, improved safety control, maximum turndown, fuel and energy savings, and reduced emissions. Modern linkage less control systems include combustion sensing equipment, precise modulators for fuel and air and, ideally, an exhaust gas analysis feedback system, or oxygen trim.

Stack Economizers

Stack economizers can typically reclaim 2-4% of the energy which goes up the boiler stack and be used to heat water, generate low pressure steam and heat other fluids. Typically the stack temperature for a steam boiler operating in the 100-150 psig range is in the 375°-450° F range. A properly sized economizer will drop the flue gas temperature to a range of 270°-290° F. Dropping much below 270° F will result in condensing the products of combustion and will create acids in the stack which can damage the boiler and the stack. Caution should be used in sizing and selecting a stack economizer.

Boiler Stack Economizers



Boiler stack economizers will typically increase combustion efficiency by ~ 4%.

The typical temperature drop across a stack economizer is ~ 100 F.

The heat removed from the stack gas is used to boost the feedwater temperatures into the boiler or preheat boiler feedwater.

Stack dewpoint must be carefully considered to prevent acid formation in the stack.

Stack economizers work best and achieve real savings when installed on boilers which operate with steady loads at high firing rates. Applying an economizer to a boiler operating with a load range of less than 60-70% will tend to not produce good results or savings. They are also at risk of dropping the flue gas temperature too low, resulting in early failure of the economizer and potentially damaging the boiler and stack.

Chapter 6 - Comments and References

Boilers represent a substantial capital investment and also incur high operating costs due to the fuel they consume. A boiler plant represents a great opportunity to reduce your annual operating costs by carefully monitoring key indicators in the facility.

Some suggestions on monitoring include-

- Although somewhat costly, measuring steam flows and fuel consumption can be of real value if you look at monthly totals and compare the energy consumed as compared to the energy delivered to your facility. That ratio, or percentage, can vary widely, so the best result is to establish a baseline for your facility and then look for changes and decreases in the ratio.
- If you have multiple fuel boilers, be an energy shopper and compare costs to produce steam from your energy options.
- For most steam systems operating 24/7, one of the most important numbers is 720 - the number of hours in a 30 day month. Small losses add up quickly so a small loss costing you $10.00 an hour will amount to $7,200 per month and $86,400 per year. A loss of water in your boiler plant or steam system due to leaks, bad traps, and other issues resulting in an increase of only 1 gallon a minute of extra feedwater will be a loss of 60 gallons per hour, 43,200 gallons per month, and 518,400 gallons per year. Small hourly losses mount up very quickly, so if you manage the small stuff you can achieve substantial savings.
- Feedwater monitoring of both chemicals and hardness are critical to the life of a boiler. Shop wisely and carefully for a reputable water treatment company and shop for knowledge, honesty, and excellent service rather than by price. A bargain in water treatment costs could wind up costing you and your company a lot of money, so be an informed buyer.
- Steam traps are a topic all to its own and will be covered in an EBook on steam systems. Few steam traps are typically used in a boiler plant, but the few that are used are very important. The steam trap or traps installed on your main boiler header are very important and should be checked at least quarterly. All boilers, under the right circumstances, can carry water into the steam system. I would suggest that the main boiler header trap or traps be sized to handle 10% of the maximum output of the boiler plant. This will prevent a carryover event allowing water to enter your steam system.
- Monitor the pressure and temperature of your deaerator on a daily basis to prevent oxygen and carbon dioxide which can damage your boiler and steam system. Most pressured deaerators should operate at 5-7 psig of pressure and 225°-227° F. Feedwater heaters should operate at 195°-200° F.
- Boiler feed pumps are a difficult application for any brand and style of pump. Work under the assumption that your boiler feed pumps <u>will</u> fail, not <u>if</u> they will

fail. Maintain either spare parts or spare pumps for your boiler plant. Repeated feedwater pump failure is a symptom which should not be ignored, and you should take the time to look for underlying causes. If the pump has been in service for a reasonable period look, for outside causes such as steam trap failures in the system which will result in elevated return temperatures, leading to cavitation on the pump. Look for red brown rust which is an indication of carbonic acid attack and caused by a deaerator not removing the carbon dioxide from the boiler feedwater. Make sure your pumps are in the proper operating spot on the pump curve and restrict flows though the pump if it is tending to run out on the curve.

- Check all safety valves quarterly and insure that they are in proper working order. A failure of a safety valve could result in a boiler explosion which will do damage well beyond what you might expect. Be safe and wise with your safety and relief valves.
- Make sure your operating personnel are properly trained and updated on all operational and safety procedures. A properly trained boiler plant operator is a very important part of your company's operating team, so hire wisely, train, and pay them a wage rate commensurate with the important role that they play in your facility.
- Find and hold on to a boiler service company you trust and are available 24/7 for questions and service.
- Overview of Boiler and Steam Systems - Power Point. http://www.control-specialties.com/t287-boiler-steam-system-seminar.php
- EPD/EPA Boiler Tune Up Forms. http://www.control-specialties.com/t264-epd-epa-boiler-tune-up-forms.php
- Hot Water and Hydronic Heaters Compared. http://www.control-specialties.com/t301-hot-water-and-hydronic-heaters-compared.php
- Boiler Efficiency Spreadsheet – Video. http://www.control-specialties.com/t249-boiler-efficiency-spreadsheet.php

Boilers have been around in one form or the other for over 200 years. The advent of sophisticated controls and computer driven management systems have really opened up wonderful new opportunities to help improve your boiler plant operations while reducing emissions.

This concludes our eBook on Boiler Plant Operations. We hope it has given those of you who are involved in managing the boiler facilities in your plant enough information to go forward. This will allow you to make the most prudent decisions necessary to operate safely and efficiently. As we all know, making steam is just the beginning. You must now transmit your product, i.e., steam, to the user in the most consistent and efficient means possible.

We will cover the use of steam in our next eBook.