BOILER ROOM BASICS

PRINCIPLES OF COMBUSTION

The process of combustion is a high speed, high temperature chemical reaction. It is a rapid union of an element or a compound with oxygen that results in production of heat – resulting in a controlled explosion. Combustion occurs when the elements in the fuel combine with oxygen to produce heat. All fuels, whether there are solid, liquid or in gaseous form, consists primarily of compounds of carbon and hydrogen called hydrocarbons. Sulfur is also present in these fuels.

PRODUCTS OF COMBUSTION

When hydrogen and oxygen combine, intense heat and water vapor is formed. When carbon and oxygen combine, intense heat and carbon monoxide or carbon dioxide is formed. When sulfur and oxygen combine, sulfur dioxide and heat are formed. These chemical reactions take place in a furnace during the burning of fuel, provided there is sufficient air (oxygen) to completely burn the fuel. If there is insufficient air or inadequate mixing of fuel and air for complete combustion, the carbon reaction will not be completed, forming carbon monoxide. Carbon particles that cool before they can combine with oxygen to form CO2 or CO form smoke, glowing carbon particles largely causes the yellow color in flames.

All common fuels contain some non combustible materials.
- Residual oils contains up to 5% ash, nitrogen, oxygen, sediment and water.
- Distillate oil contains up to 1% ash, nitrogen, oxygen, sediment and water.
- Natural gas contains up to 6% carbon dioxide, nitrogen and moisture

TYPES OF COMBUSTION

There are three types of combustion
- Perfect Stoichiometric Combustion
- Complete Combustion
- Incomplete Combustion

Perfect Stoichiometric Combustion is achieved when all the fuel is burned using only the theoretical amount of air. Perfect combustion cannot be achieved in a boiler, because mixing of fuel and air in the furnace is imperfect.
Complete Combustion is achieved when all the fuel is burned using the minimal amount of air above the theoretical amount of air needed to burn the fuel. Complete combustion is always the goal. With complete combustion the fuel is burned at highest combustion efficiency with the lowest release of particulates.

Incomplete Combustion occurs when all the fuel is not burned, which results in formation of soot and smoke.

AIR REQUIREMENTS

Oxygen for combustion is obtained from the atmosphere, which is about 21% oxygen by volume or 23% by weight. About 1600 cubic feet of air is required to burn 1 gallon of #2 fuel oil at 15% excess air at sea level. About 11.2 cubic feet of air is required to burn one cubic foot of natural gas at 15% excess air at sea level.

A 100 HP boiler requires 48,000 cubic feet of fresh air per hour for combustion to take place. Most of the 79% of air that is not oxygen is nitrogen, with traces of other elements. Combustion air requirements are based on the composition of the fuel used. Fuels commonly used contain nitrogen, ash, oxygen, sulphur, carbon and hydrogen.

Nitrogen is nearly inert at ordinary flame temperature and forms few compounds as a result of combustion. Nitrogen is an unwanted parasite that must be accepted in order to obtain the oxygen. It contributes nothing to combustion, it increases the volume of combustion products to be vented, it steals heat from the reaction and creates environmental problems as well.

Air required in combustion is classified as:
- Stoichiometric Air
- Excess air
- Primary air
- Secondary and tertiary air

Stoichiometric is a theoretical amount of air required to completely burn the fuel.

Excess air is air supplied to the burner that exceeds the theoretical amount needed to burn the fuel.

Primary air is the air that supplies the base of the burner flame. Simple burners may use only primary air.

Secondary or Tertiary air flows are introduced into an established flame to control combustion characteristics.
Excess air can have a chilling effect on the flame. If too much excess air is present localized temperatures can be too low for combustion and small amounts of fuel can pass up the stack unburned.

Water vapour is a byproduct of burning hydrogen. It too subtracts the heat from the flame and becomes steam at flue gas temperature, passing out of the vent as vapor mixed with the combustion products.

Natural gas contains more hydrogen and less carbon per unit of heat content than oil and consequently its combustion produces more water vapor which carries a great amount of heat up the stack. Therefore gas efficiency is always slightly less than oil efficiency.

Air requirements for combustion are generally expressed in cubic feet of air per gallon of oil or per cubic foot of gas for convenience because fans, ducts and other air moving devices are rated in cubic feet per minute or cubic feet per hour. The Fuel/Air ratio for combustion is actually a weight ratio based on the required weight of oxygen for a given weight of fuel.

**Altitude Differences:**

At sea level or at altitudes up to 2000 feet, the weight of oxygen per cubic foot of air does not vary sufficiently to create major problems. At higher altitudes air density has to be taken into consideration. At 5000 feet above sea level air has approximately 85% of its weight at sea level therefore about 15% more air by volume must be introduced to obtain the required oxygen for combustion. Fuel gas obeys the same physical laws as air- at 5000 feet above sea level 15% greater gas volume is required to obtain sea level weight of combustibles. A gallon of fuel oil has the same weight at any altitude and no fuel input increase is necessary.

**FORCED / NATURAL DRAFT**

When considering air requirements two roles must be considered.
- The correct amount of air must be present for combustion to take place.
- Air pressure is required to move the products of combustion through the boiler.

To accomplish this requires draft, which is simply air movement through the boiler. Since the inner structure of the boiler offers resistance to combustion gas movement (commonly called draft loss). The draft must be strong enough to overcome this resistance.

With forced draft, air is delivered to the combustion zone by the burner blower in sufficient volume to provide the combustion air at sufficient pressure to expel the combustion products from the vent against the draft resistance of the boiler. The combustion zone is consequently under positive pressure - pressure higher than atmospheric.
With natural draft, the draft required to move the combustion products through the boiler is created by a stack or chimney. A stack or chimney creates a draft because the column of the combustion products it encloses is lighter in weight than the surrounding air. That buoyancy creates a negative pressure – pressure less than atmospheric – so the combustion zone is under negative pressure.

If the stack or chimney provides inadequate negative pressure to vent the products of combustion an induced draft fan may be used to compensate for the deficiency of the stack. In that case the burner still operates with negative draft in the combustion zone.

THE COMBUSTION PROCESS

To summarize:

The combustion process occurs when fuel combines with oxygen to produce heat
The goal is to achieve complete combustion – the burning of all the fuel with a minimal amount of excess air.

There are four requirements for complete combustion or **MATT**

- **M** – Proper mixture of air and fuel is required. The air/fuel ratio is controlled for all firing rates. High fire requires more air and fuel proportionally than low fire.
- **A** – Proper atomization of liquid fuel is required. Atomization is the process of breaking up liquid fuel into small droplets to allow rapid vaporization of the liquid (a process called pyrolysis).
- **T** – Proper air, fuel and zone temperatures must be maintained to achieve complete combustion.
- **T** – Proper time must be provided to complete the combustion process before the gases of combustion come in contact with the heating surface.

Note that the heating surface is where there is water on one side and gases of combustion on the other. If the gases of combustion come in contact with the heating surface before combustion is complete, they will cool and cause formation of soot and smoke.

BASIC WATER TREATMENT

We have discussed two thirds of the equation – combustion and heat transfer design - the last important part of the equation is water treatment.
To look at regular tap water you might never guess that treatment is necessary, but the same water that looks clean, cool and clear to eye can be a killer to the equipment necessary for heat transfer.

Untreated or raw water is never pure. Water contains varying amounts gases, solids and pollutants. Water in the form of rain absorbs gases from the air as it falls to ground. As it absorbs into and seeps downward through the ground it picks up even more chemicals and minerals. By the time the water is pumped up from its ground source and delivered to our faucet, it is loaded with salts, dissolved gases and inorganic compounds.

Common impurities that can effect physical plant operations are listed below.

<table>
<thead>
<tr>
<th>Impurity</th>
<th>Source</th>
<th>Effect</th>
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</thead>
<tbody>
<tr>
<td>Algae</td>
<td>Organic growth</td>
<td>Fouling</td>
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<tr>
<td>Calcium</td>
<td>Mineral Deposits</td>
<td>Scale</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>dissolved gases</td>
<td>Corrosion</td>
</tr>
<tr>
<td>Chloride</td>
<td>Mineral deposits</td>
<td>Corrosion</td>
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<tr>
<td>Free Acids</td>
<td>Industrial waste</td>
<td>Corrosion</td>
</tr>
<tr>
<td>Hardness</td>
<td>Mineral deposits</td>
<td>Scale</td>
</tr>
<tr>
<td>Magnesium</td>
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<td>Scale</td>
</tr>
<tr>
<td>Oxygen</td>
<td>Dissolved Gases</td>
<td>Corrosion</td>
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<td>Silica</td>
<td>Mineral Deposits</td>
<td>Scale</td>
</tr>
<tr>
<td>Solids</td>
<td>Undisclosed materials</td>
<td>Fouling</td>
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Regardless of whether the water you buy from your local authority is aerated, chlorinated or fluoridated, its quality still won’t meet the strict operating needs of your equipment. While most suspended solids have been removed, gases and dissolved impurities still remain waiting to be manifested as scale or corrosion.

THE PURPOSE OF WATER TREATMENT

To provide the physical plant with properly treated water in sufficient quantities to meet plant needs.

All Systems require water treatment, however open systems require constant water treatment to deal with constant need for treated water to make up for system water losses of up to 100%. Closed systems also require water treatment, but due to minimal system losses that treatment commonly occurs only at the system fill source.
The majority of the material below deals primarily with problems encountered with open steam systems; however the same chemical systems applied to closed water systems. Open steam systems and closed water systems have differing equipment requirements which will be addressed later.

The five major problems associated with water quality and equipment problems are:
- Scale formation
- Corrosion
- Fouling
- Foaming
- Embrittlement

**Scale** is an extremely hard substance created when mineral salts come out of solution as their solubility drops with a rise in water temperature. Scale forming salts adhere directly to heating surfaces forming layers of insulation on the metal substantially decreasing its heat transfer efficiency.

While 1/16th Inch thickness of scale in a boiler can increase fuel consumption by 12.5%, any accumulation is a problem. Scales results in overheating, energy waste, high maintenance costs and unnecessary safety risks caused by metal fatigue failure.

**Corrosion** occurs when metals (by acid or electrolytic action) attack metals. The metal is eaten away similar to common rust seen on steel. Corrosion increases maintenance costs, results in premature replacement of equipment and causes unnecessary safety risks.

Corrosion occurs where levels of oxygen or carbon dioxide are high, where pH values are low, where contact occurs between dissimilar metals and in damp environments or corrosive atmospheres.

**Fouling** occurs when restriction develops in piping and equipment passages, creating inefficient water flow. The major consequences of fouling to boiler room equipment are energy waste and increased operating/maintenance costs.

When fouling is allowed to continue and proliferate in a system, cooling towers, heat exchangers, and other critical devices could give rise to the emergence of health related issues such as legionnaire’s disease.

**Foaming** is a condition in which concentrations of soluble salts (aggravated by grease, suspended solids or organic materials) create frothy bubbles in the steam space of the boiler.
Foaming may cause priming – in which the bubbles break and create a liquid that combines to form slugs of water that are carried over into steam system. Pressure from the steam can create velocities as high as 80-100 miles per hour for slugs of water discharge into steam lines. These slugs can wreck havoc with turbine blades, actuating devices and piping downstream of the boiler.

**Caustic Embrittlement** occur when hairline cracks appear in highly stressed areas due to high concentrations of alkaline salts that liberate hydrogen which is then absorbed by iron in steel, effectively changing its physical properties. This condition is caused largely by boiler water with pH values 11+ and manifests itself in high temperature areas of the boiler.

Unless embrittlement problems are constantly monitored and controlled, they will take their toll in higher fuel costs, increased safety risks, unnecessary downtime and equipment replacement.

**HOT WATER SYSTEM SUPPORT EQUIPMENT**

Hot water systems are closed systems and are often the systems which will be replacing old low pressure steam systems for heating in new constructions. When dealing with a new system it is important to be aware that there are many harmful substances which remain in the boiler and piping after construction. It is common to find oil, grease, weld slags and other contaminates within the system. It is important that a good initial cleaning or boil out of the entire system be conducted before filling. It is recommended that chemical treatment be provided for initial fill of the system. Generally, chemicals will be required to prevent scale formation, promote elimination of dissolved gases and control pH.

While it is commonly believed that closed systems will require little or no attention to water treatment experience has shown that few systems can be actually considered completely closed. Especially in old hot water systems, you will encounter losses from pump packing, glands, air venting devices and threaded or flanged pipe connections. Makeup is generally provided by an automatic fill device.

Makeup water provided by the fill device ought to have some means attached to provide chemical treatment to the raw water prior to being introduced to the system. This is generally accomplished through a shot type chemical feeder. These devices are used for batch feeding of chemicals in closed loops or low makeup water systems manually without the aid of the pumps. It is also recommended that a water meter be installed to monitor the makeup water required by the system to.

- Monitor system loss
- Identity system loss

Triad Boiler Systems, Inc. 1099 Atlantic Drive, Unit 2, West Chicago, IL 60185, Ph: 630-562-700. www.triadboiler.com
Correct system loss

In some cases, depending upon the preference of the customer, no automatic means of makeup water is provided. Instead a low water alarm is used to alert the operator of the loss in the system water and a need for system make up. The operator can then diagnose the system loss and treat the makeup water properly.

Rule of Thumb: Any closed system that requires make-up in excess of .5% of its circulation rate requires the same water treatment as an open system.

BOILER SELECTION

There are five points of concern that should be applied when selecting the appropriate boiler design for a specific installation:

- System type: Steam or Hot Water
- System Load
- Performance Considerations
- Codes and Standards

The two system types encountered are Steam and Hot Water systems. Steam and Hot Water boilers for these systems are defined according to the design pressure and operating pressure.

Design Pressure is the maximum pressure used in the design of the boiler for purposes of calculating the minimal permissible thickness or physical characteristics of the pressure vessel part of the boiler. Typically, the safety relief valves are set slightly below design pressure.

Operating Pressure is the pressure of the boiler at which it normally operates. The operating pressure is set at a suitable level below the setting of the pressure relieving valves to prevent their frequent opening during the normal operation.

Steam Boilers are designed for low pressure or high pressure application. Low pressure boilers are limited to 15 psig design and are typically used for heating applications only. High pressure boilers have operating pressures typically from 75 psig to 300 psig and are typically used for process loads and or heating requirements.

Hot Water Boilers are commonly used for heating applications with the boiler supplying water to the system at 180F to 220F. Typical operating pressures for these systems are from 30 psig to
125 psig. If a system requires hot water of more than 240F, a high temperature water boiler should be used.

System Load is measured in either BTU or pounds of steam (at a specific pressure and temperature). To determine system load, you will need to know the following information.

- Heating Load
- Process Load
- Combination Load

**Heating load** is typically low pressure steam or hot water and is relatively easy to define. The heating load will include large seasonal variations but no large instantaneous demand changes.

The heating capacity of the boiler room should be sized to worst probable weather conditions, which means that true capacity will rarely be reached. Once a heating load is computed, the number can be easily transferred into equipment size requirements.

**Process Load** is usually a high pressure steam application pertaining to manufacturing processes where heat from either steam or hot water is used in the process. A process load can be further defined as continuous or batch load.

**Continuous Load** is defined as a load that is fairly constant, very much like a heating load. Batch loads are loads characterized by short term demands or the M.I.D. (Maximums Instantaneous Demand) factor. Because very large instantaneous demand can be several times larger than the rating of the boiler, very careful boiler selection should take place in such process load situations.

Many facilities have combination loads with a mixture of different types of processes and heating, so the information above should be considered in an additive manner.

Loads vary so a boiler must be capable of handling the minimum load, the maximum load, and all the load variations in between. These variations fall in three basic types.

- Seasonal Variations
- Daily Variations
- M.I.D Variations

To accurately determine the load of any system, load tracking is recommended. The ability of the boiler to answer variable load demands on the boiler type, feed water valve control and
combustion controls. If the analysis of the load show a highly variable situation a more complex controlled package may be required.

Selection of the correct number of boilers should be considered:

- Need for back up boilers?
- Load type?
- Downtime?

When selecting boilers consideration also should be given to future expansion, emergency repairs and maintenance situations.

Often, especially in a heating process mixed load situation, a section of a large winter boiler and a smaller summer boiler will provide the best and most cost effective solution for your customer when measured on a lowest yearly operating costs benefits.

Two other performance considerations when selecting a boiler for an application are:

- Fuel Choice
- Efficiency desired

Normally your fuel choices will be gas or light oil. Increasingly stringent regulations have greatly reduced the use of heavy oil and solid fuels such as coal and wood. Of the fossil fuels, gas is the cleanest requiring minimum maintenance. In certain areas of the country, most gas boilers are backed up by oil as secondary fuel. Waste fuels such as methane reduce fuel costs in specific situations but require back up with a standard fuel to insure safe operation and operating flexibility.

Efficiency is used in the measure of economic performance. Because the measure of boiler efficiency is often highly subjective in its methods and implementations this area is often subject to marketing rather than scientific analysis.

Realized equipment efficiencies are very different measure from the theoretical equipment efficiencies. Codes and Standards are the varying local, industry, insurance, utility, state and federal regulations that apply in individual territories. These include ever changing emissions standards.
BOILER HEAT BALANCE

Fuel fed to a burner is converted to heat. The heat is absorbed by the water in the boiler, but not all the heat released from the fuel is used to heat the water. Some of the heat is wasted in the water. The heat balance of the boiler consists of accounting for all the heat units in the fuel used or wasted. It is a balance because it is a sum of all the heat consumed. Heat balance of the boiler is found by using the following equation.

A = heat available in the fuel
B = heat absorbed by the water in the boiler
C = heat losses
A = B + C,
Therefore, efficiency of the unit = B divided by A

For example, BTU losses that occur in a boiler could result from:
- Heat in gases of combustion to atmosphere (about 6% natural gas, 8% #2 oil)
- Radiation losses from the boiler shell (about 1%)
- Water vapour produced from the burning of hydrogen (about 11% natural gas, 7% #2 oil)
- Incomplete combustion (much less than 1%)
- Moisture in fuel (less than 1%)
- Moisture in air used in combustion (less than 1%)

Total heat losses (BTU Losses) in this example equal about 18-19% natural gas, 16-17% #2 oil

Some of these losses can be prevented by the way the boiler is operated, such as:

- Heat carried away in dry chimney gases caused by too much excess air or dirty heat transfer surfaces.
- Incomplete combustion of the fuel caused by inadequate nozzle maintenance or improper adjustments.
- Unburned combustibles.

Much of the resulting efficiency of the boiler is the direct result of its basic heat transfer design. Boiler designs that use all possible heat transfer surfaces to their fullest advantage consistently produce the most efficient source of steam or hot water with lowest total lifetime costs.
RATINGS

Commercial boiler ratings may be stated in several ways, but are always directly related to the amount of heat that will be produced when the boiler is fired at a specified fuel input under specified conditions. The basic factor governing boiler output is the rate of heat release that can be maintained in the furnace as determined by the type of firing equipment used:

**The heat release rate of a boiler output is the rate at which combustion of the fuel liberates heat energy based on the fuel input in BTU’s per hour.**

Heat release rate may be defined as either BTU per hour per cubic foot of furnace volume or as BTU per hour per square foot of radiant heating surface.

**Gross output rating** is the total amount of heat available at the boiler outlet for a specific fuel input. Gross output is usually expressed in:

- Thousands of BTU per hour (MBH)
- Boiler Horsepower (BHP)
- Pounds of steam per hour

One Boiler Horsepower is defined as the evaporation of 34.5 pounds of water at 212°F into steam at 212°F in one hour. At 0 gauge pressure, or 212°F, heat of vaporization of steam is 970.3 BTU per pound:

Therefore, One Boiler Horsepower is equal to 33475 BTU/hr

In order to avoid confusion the gross output for any steam pressure is always shown at the standard condition “from and at 212°F.” Although more heat input per pound of steam is actually required as steam pressure increases, the work equivalent per pound of steam also increases as the steam pressure increases. So the ratings stated at “standard” condition are valid regardless of the pressure at which the boiler is operated.

HEATING SURFACE

Regardless of how a boiler is constructed, its only purpose is to transfer the heat produced by the burning fuel into the water. Transfer of heat will occur through all of the metal surfaces if they are exposed to heat on one side and water on the other side. These surfaces are those that makeup boiler heating surface calculations.
Heating surface is expressed in a square feet is defined as:

- **Radiant Heating Surfaces** (also called direct or primary) Including all those water backed surfaces that are directly exposed to the radiant heat of the combustion flame.
- **Convected Heating Surfaces** (also called indirect or secondary) Including all those water backed surfaces exposed only to hot combustion gases.
- **Extended Heating surfaces** referring to the surface of economizers and super heaters used in certain types of watertube boilers.