Principles of Feed Manufacturing: Efficient Boiler Operation

Kansas State University
Agricultural Experiment
Station and cooperative
Extension Service

Feed represents the most significant cost associated with the production of livestock and poultry, ranging between 60 to 70 percent of the total cost. The major portion of this is for the feed ingredients; however, feed processing also constitutes a substantial portion. A large part of the processing cost is connected to energy use for generating steam to condition mash feed before pelleting or grain prior to steam-flaking. Though steam generation can represent a substantial cost, in many cases it is overlooked until major problems arise. The intent of this publication is to review some basic principles of generating steam and to provide guidelines for improving boiler operation efficiency.

Steam Generation

Water can exist in the form of a solid (ice), liquid (water), or vapor (steam). For the purposes of this discussion, only the liquid and vapor phases and the transition of one phase to the other will be considered.

As heat is added to water, its temperature rises until the water can no longer exist as a liquid. From this "saturation" point, any additional heat added to the water will cause the transition of water from the liquid phase to the vapor phase. The total heat (enthalpy) held by the liquid water at the boiling temperature is known as "sensible" heat. The heat that results in water transitioning from a liquid to a vapor is referred to as "latent" heat. The total heat in each pound of steam is the sum of latent heat and sensible heat. If enough heat is added, the 1 pound of water will be converted to 1 pound of steam at atmospheric pressure. If pressure is held constant, adding heat above the saturation temperature will produce superheated steam.

The evaporation of water requires an enormous amount of energy per unit weight of water vaporized. It is on this principle that so called "swamp coolers" are based (i.e., heat in the air is used to evaporate water in the pad thus cooling the air). Similarly, if we surround a relatively cool object (i.e., a particle of corn) with steam, the steam will release its energy to the object and condense as water onto the surface of the object. This release of energy is the basis for steam conditioning mash feed or grain in an atmospheric conditioner.

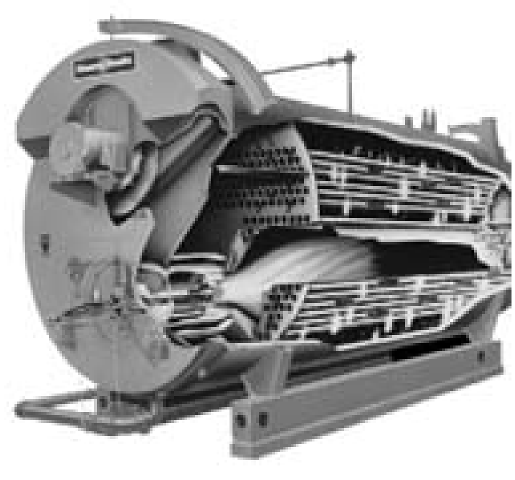

Figure 1. *Illustration of a fire tube boiler (provided by Cleaver Brooks).*

Basics of Design

A boiler is a vessel that contains a series of metal tubes. The tubing conducts the heat from combustion to water. There are two basic types of boilers used, the fire tube boiler and the water tube boiler. In a fire tube boiler, the combusted gases (fire) are within the tubes, which are surrounded by water. In water tube boilers, the water is inside the tubes and tubes are surrounded by fire. The Scotch Marine fire tube boiler is the most common boiler found in the feed industry: therefore, the following discussion will focus on fire tube boilers.

Fire tube boilers may be two-pass design or may contain several (3 to 4) passes, depending on the baffles within the boiler. Generally, the more passes, the more efficient the boiler. The total cross-sectional area of the tubes in each pass must be reduced to help maintain high flue gas velocity. As the gases cool, their specific volume decreases and the area through which the gases pass must be decreased to maintain a high gas velocity, which is needed to maintain good heat transfer rates.

The back-end of the boiler is available either as a *dryback* (refractory) or *wetback* configuration. With a dryback design, there is only one rear tube-sheet, and the back of the boiler (where the gases make the turn from one pass to the next) is refractory lined. Baffles are used to separate the gas path from one pass to the next. Wetback boilers have two tube-sheets; the first is exposed to the highest temperatures and is completely surrounded by water, and the second is exposed to the lower temperatures and has a dryback. The wetback design is thought to be superior because there are fewer thermal stress problems compared to the dryback design. However, with the dryback design, it may be easier to make internal repairs when necessary.

Elements of Combustion

Oil, gas, and coal are among the most common fuels used today to operate boilers. These fuels consist of carbon, hydrogen, and, in some cases, small amounts of sulfur. It is the oxidation of these elements that is involved in combustion. There are three primary chemical reactions that occur during combustion:

Carbon (C) + Oxygen (O) → Carbon Dioxide (CO_2) + Heat

Hydrogen (H) + Oxygen (O) → Water Vapor (H_2O) + Heat

Sulfur (S) + Oxygen (O) → Sulfur Dioxide (SO_2) + Heat

Under perfect conditions, the fuel will be completely converted to carbon dioxide, water vapor, and sulfur dioxide. This is referred to as stoichiometric combustion. However, from a practical standpoint, it is impossible to obtain stoichiometric combustion. Several reasons account for the difficulty in obtaining perfect combustion. The primary reason is imperfect mixing of fuel with air in the combustion chamber. The burner controls the fuel-to-air ratio, and, because the fuel-to-air ratio is so important to boiler operation, the burner is often times referred to as the heart of the boiler. Burners may be equipped with different types of linkages. It is important that these linkages are securely fastened for acceptable burner control.

If the fuel-to-oxygen ratio is too rich, the carbon and hydrogen will not be completely oxidized. This is referred to as sub-stoichiometric combustion or incomplete combustion. During sub-stoichiometric combustion, other combustion products besides carbon dioxide, water, and sulfur dioxide are formed. These products include carbon monoxide, hydrogen gas, hydrocarbon compounds, hydrogen sulfide, and carbon. These compounds escape to the atmosphere in the flue gas and can result in environmental pollution.

In most cases, to avoid sub-stoichiometric combustion, the fuel-to-air ratio is such that excess oxygen is present during combustion. Oxygen for combustion usually comes from atmospheric air in the boiler room. Atmospheric air consists of approximately 21 percent oxygen and 79 percent nitrogen. Nitrogen is of little importance in the production of heat because only a small percentage takes part in the chemical reactions of combustion. However, it can have a significant effect on boiler efficiency because some of the heat released by the combustion reaction must heat the nitrogen to the same temperature as the combustion products.

Water Management

Having an effective boiler feed water treatment program is paramount to maximizing the lifespan of a boiler and the efficiency in which the boiler operates. All boiler feed water contains impurities. Groundwater will have relatively high levels of dissolved solids and lower levels of dissolved gases; whereas surface water will have higher levels of dissolved oxygen and suspended solids such as sand and silt.

The primary consequences of improper water treatment are scale, corrosion, and carryover. Scale is precipitates in the water that result from physical and chemical changes. Scale will accumulate on the surface of the tubes and act as an insulator on the tubing, which hinders the transfer of heat into the water and results in boiler tube overheating, loss of boiler efficiency, and, eventually boiler tube rupture.

If the water has corrosive properties, the water will return metal in the steam system to its native state as oxides and other compounds causing corrosion. Corrosion destroys boiler equipment, steam processing equipment, and condensate return lines.

Carryover occurs when water in the boiler is incorporated with the steam and leaves the boiler. Carryover results in loss of steam quality and potential steam equipment damage from deposits. To avoid or reduce the incidence of scale, corrosion, and carryover, boiler feed water is treated to control suspended solids, total dissolved solids, dissolved gases, and water pH.

Suspended Solids

If suspended solids (i.e., mud, silt, etc.) are not removed, they can cause foaming and carryover. Additionally, suspended solids can "bake" onto the surface of high heat areas and result in scale accumulation. Suspended solids can also accumulate in low flow rate areas and potentially create blockages. Therefore, a filter or strainer in the inlet line normally removes these impurities.

Total Dissolve Solids (TDS)

Most water sources contain calcium and magnesium salts. If these ions are not removed from the water, calcium carbonate, calcium sulfate, and magnesium carbonate can form resulting in scale build-up. Additionally, TDS can lead to foaming and carryover. As water is converted to vapor and exits the boiler, the concentration of TDS increases in the boiler. Typically, an ion exchanger resin bed type water softener is used to remove these impurities. The TDS concentration in the boiler must be controlled by periodically blowing down the boiler.

Dissolved Gases

Gases dissolved in the water, particularly oxygen and carbon dioxide, can result in corrosion and pitting on the boiler tubes and in the steam system. Oxygen is reactive with iron and other metals. When steam condenses in the steam system, carbon dioxide can form carbonic acid and result in serious corrosion problems in the condensate return system. These gases are removed in two ways. First, the water can be chemically treated in a hotwell with a sulfite or other oxygen scavenger, or second, the water can be preheated and atomized using a deaerator.

pH

Water pH is a measure of hydrogen ion concentration. A pH less than 6 is considered acidic, and a pH greater than 8 is considered alkaline. Either extremely acidic water or extremely alkaline water can be highly corrosive. Generally though, high alkaline water will be most corrosive because the high temperature and pressure in the boiler will break down bicarbonate into carbon dioxide and carbonate. The carbon dioxide reacts with condensate returning to the boiler and forms carbonic acid, which corrodes the metal in the system.

Steam System

In a typical steam system, steam exits the boiler into a steam header and is piped through a series of strainers and steam traps to a pressure regulator and steam separator. Combinations of steam separators, traps, and pressure regulators are commercially available and also work effectively. In any case, the objective is to provide the highest quality steam to the point of use. Poor steam quality indicates that enough heat has been lost from the system to condense the steam vapor back to a liquid phase. This heat loss represents not only a significant loss in energy costs but can also result in pelleting problems if the balance between mash moisture and the conditioning temperature is incorrect.

Failing to properly maintain a steam system will inevitably result in huge economic losses. This not only includes feed water treatment and boiler maintenance, but also checking and replacing faulty steam traps. As a case in point, a ½-inch steam leak in a system at 100 psig translates into approximately 835,000 pounds of wasted steam each month. Assuming a steam cost of $5 per 1,000 pounds, this steam leak would cost more than $50,000 in a year's time. Additionally, more often than not, feed mills will have either completely or partially bare steam lines running from the boiler to the pellet mill conditioner, which can represent a significant cost. Insulation is inexpensive and it is simply counter-productive to invest in converting water into vapor at the boiler only to allow it to condense in the steam lines prior to the conditioner.

Another effective strategy to reduce heat loss in a steam system is to install heat exchangers. Energy from blowdown water, for example, can be captured and used to heat make-up water before it enters the deaerator. This also serves to cool down the blowdown water before it enters the sewage system. Economizers can be installed to capture BTUs exiting the boiler stack that would otherwise be lost to the atmosphere. This heat can be used for space heating inside the feed mill, or, in cold climates, it can be used to heat air entering the pellet cooler.

Conclusion

In many cases, a large part of the processing costs associated with manufacturing feed is the energy used for generating steam. As such, it is essential that feed mill managers pay close attention to boiler water treatment, burner operation, and steam trap failures in order to maximize boiler efficiency and reduce overall feed manufacturing costs.

Leland J. McKinney
Department of Grain Science and Industry
Kansas State University

Keith C. Behnke
Department of Grain Science and Industry
Kansas State University

Kansas State University Agricultural Experiment Station and Cooperative Extension Service

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