Boiler Fuels and Emissions

An Online Continuing Education Course for Engineers

Course Number: M-3004

Credit: 3 Hours / 3 PDH / 3 CPD

Boiler Fuels and Emissions

INTRODUCTION

Conversion of water to steam requires sufficient heat to cause the water to boil. Although a variety of energy sources, including nuclear energy and solar radiation, can produce the required amount of heat, combustion of a fuel in the presence of oxygen is the most common source. Combustion is a rapid chemical reaction between oxygen and a solid, liquid, or gaseous fuel. Oxygen required for this reaction is readily available in the air. As air and fuel are mixed at elevated temperatures, the oxygen reacts with carbon, hydrogen, and other elements in the fuel to produce heat. As long as fuel and air are both available, combustion will continue, and heat will be generated.

Heat produced during combustion is useful for a wide variety of applications; however, atmospheric emissions, which are also generated as by-products of the combustion process, must be controlled. Common gaseous emissions include SO_2, NO_x, water vapor, carbon dioxide (CO_2), and CO. The principle solid by-product of combustion is ash, the inorganic residue remaining after ignition of combustible materials.

This course focuses on fuels commonly fired in boilers to generate steam or hot water, atmospheric emissions associated with fuel combustion, and factors that influence how effectively the energy content of the fuel is transferred into usable heat.

FUELS

Many different solid, liquid, and gaseous fuels are fired in boilers. Sometimes, combinations of fuels are used to reduce emissions or improve boiler performance. Fuels commonly fired in boilers include fossil, biomass, and RDFs as well as other types of fuels and fuel combinations.

Coal, petroleum-based oils, and natural gas are fossil fuels commonly fired in ICI boilers. However, other forms of solid, liquid, or gaseous fuel derived from these fossil fuels are sometimes included in this category. One of these fuels, which is referred to as tire-derived fuel (TDF), consists of shredded vehicle tires.

Another boiler fuel is referred to as biomass. Biomass is renewable organic matter. Examples of biomass include fast-growing trees and plants, wood and wood waste, agricultural crops and residue, aquatic plants and algae, animal wastes, and organic municipal and industrial wastes.

RDF is a potentially valuable energy source. It consists of MSW that has been processed using size reduction and material recovery techniques to eliminate materials such as aluminum, steel, glass, plastic, and rock.

Common types of fuels fired in boilers are listed in Table 1 with key properties provided in Table 2. Additional information about some of the more common fuels is presented below.

Coal

Coal is a brown-to-black combustible, sedimentary rocklike material composed primarily of consolidated and chemically altered plant material that grew in prehistoric forests.[1] The chemical composition of coal varies from one location to another, depending on the vegetation from which it was formed and the environmental conditions (such as temperature and pressure) to which the formation was exposed. In addition to its major chemical constituents of carbon, hydrogen, nitrogen, and oxygen, coal also contains some water and impurities of which ash, mercury, and sulfur are major concerns from an emissions viewpoint.

Table 1. Fuels fired in boilers to generate hot water or steam

Fuel	Description
By-product/waste	Any liquid or gaseous substance produced at chemical manufacturing plants or petroleum refineries (except natural gas, distillate oil, or residual oil) and combusted in a steam generating unit for heat recovery or for disposal.[2]
Biomass	Organic matter that is used as fuel is called biomass;[3] biomass is a nonfossil fuel that includes materials such as wood, bagasse, nut hulls, rice hulls, corncobs, coffee grounds, and tobacco stems
Coal	Coal is a brown-to-black combustible sedimentary rocklike material composed principally of consolidated and chemically altered plant material that grew in prehistoric forests;[1] it includes all solid fuel classified as anthracite, bituminous, subbituminous, or lignite coal, coal refuse, or petroleum coke. [2]
Coal refuse	Waste products of coal mining, physical coal cleaning, and coal preparation operations containing coal, matrix material, clay, and other organic and inorganic materials. [4]
Distillate oil	Fuel oils that contain 0.05 wt% nitrogen or less and comply with the specifications for fuel oil Nos. 1 and 2 as defined in ASTM D 396 (Refs. 2 and 5).
Municipal-type solid waste and RDF	Refuse, more than 50% of which is waste containing a mixture of paper, wood, yard waste, food wastes, plastics, leather, rubber, and other noncombustible materials such as metal, glass, and rock, which are usually removed prior to combustion. [2]

Fuel	Description
Natural gas	A naturally occurring mixture of hydrocarbon gases found in geologic formations beneath the earth's surface, of which the principal constituent is methane, or LP gas as defined in ASTM D 1835 (Refs. 2 and 6).
Oil	Crude oil or petroleum or a liquid fuel derived from crude oil or petroleum , including distillate and residual oil. [2]
Propane	Propane is a heavy gaseous fossil fuel processed from crude petroleum and natural gas. [6]
Residual oil	Crude oil and fuel oil Nos. 1 and 2 that have nitrogen content greater than 0.05 wt %, and all fuel oil Nos. 4, 5, and 6 as defined in ASTM D 396 (Refs. 2 and 5).
Solvent-derived fuel	Any solid, liquid, or gaseous fuel derived from solid fuel for the purpose of creating useful heat and includes, but is not limited to, solvent-refined coal, liquefied coal, and gasified coal. [4]
Very low sulfur oil	Oil that contains no more than 0.5 wt % sulfur and that, when combusted without SO_2 emission control, has a SO_2 emissions rate equal to or less than 215 ng/J (0.5 lb/MBtu) heat output.[2]
Wood	Wood, wood residue, bark, or any derivative fuel or residue thereof, in any form, including, but not limited to, sawdust, sanderlust, wood chips, scraps, slabs, millings, shavings, and processed pellets made from wood or other forest products. [2]
Wood residue	Bark, sawdust, slabs, chips, shavings, mill trim, and other wood products derived from wood processing and forest management operations. [7]

Table 2. Key properties for selected fuels

Fuel	High heating value	Carbon (%)	Hydrogen (%)	Ultimate CO_2 (%)
Anthracite coal	12,680 Btu/lb	80.6	2.4	19.9
Bagasse	8,200 Btu/lb	45.0	6.4	20.3
Bark				
15% moisture	8,500 Btu/lb	52.0	5.5	20.0
30% moisture	8,500 Btu/lb	52.0	5.5	20.0
45% moisture	8,500 Btu/lb	52.0	5.5	20.0
60% moisture	8,500 Btu/lb	52.0	5.5	20.0
Bituminous coal	14,030 Btu/lb	80.1	5.0	18.5
Distillate No. 1	19,423 Btu/lb 131,890 Btu/gal	86.6	13.3	15.4
Fuel oil No. 2	18,993 Btu/lb 137,080 Btu/gal	87.3	12.5	15.7
Fuel oil No. 5	18,909 Btu/lb 149,960 Btu/gal	88.7	10.7	16.3
Fuel oil No. 6	18,126 Btu/lb 153,120 Btu/gal	88.5	9.3	16.7
Kerosene	19,942 Btu/lb 137,000 Btu/gal	86.5	13.2	15.1
Natural gas	21,830 Btu/lb	69.4	22.5	11.7
Propane	21,573 Btu/lb	81.6	18.4	13.8
Wood				
10% moisture	8,800 Btu/lb	50.0	6.5	20.0
20% moisture	8,800 Btu/lb	50.0	6.5	20.0
30% moisture	8,800 Btu/lb	50.0	6.5	20.0
40% moisture	8,800 Btu/lb	50.0	6.5	20.0

Source: Ref. 8.

A number of physical and chemical properties influence the coal selection process. These properties are determined by laboratory analysis of representative coal samples using test methods established by the American Society for Testing and Materials (ASTM). Important coal properties include[9]

- moisture;
- proximate analysis (fixed carbon, volatile matter, ash);
- ultimate analysis (carbon, hydrogen, nitrogen, oxygen, sulfur, and chlorine);
- gross caloric value (as received and on a dry basis);
- mineral matter in coal (ash, major and minor elements, fusibility of ash, trace elements, mercury, fluorine, arsenic, selenium, and sulfur in ash);
- petrographic analysis;
- grindability;
- free-swelling index;

- CO_2;
- forms of sulfur (pyritic, sulfate, organic); and
- ash abrasiveness.

The chemical composition of coal is also determined in a laboratory by chemical analysis. Results of these analyses are used for heat-balance calculations and the determination of theoretical air requirements.

Moisture represents an impurity that adds to the weight of coal but not to its heating value. The moisture may be a constituent of the coal, or it may be present on the surface of the coal because of precipitation or coal cleaning operations. Moisture content, which is expressed as a percentage, is defined as the difference between the weight of a coal sample before and after the sample is maintained in an oven at 220°F for 1 h. When moisture in [illegible]l is heated, some of the heat generated by the combustion process must be [illegible]ater to steam. Normally it is more economical to burn coa[illegible] coal is burned on certain grates, there are[illegible]ll amounts of moisture present. Moisture tends [illegible]el bed even, and promote uniform burnin[illegible]ommended for use in chain-grate and travelin[illegible] to enhance the combustion process is re[illegible]

When coal is heated, the [illegible]tter." This matter, which consists mostly of [illegible] above the fuel. Coal with a relatively high perc[illegible] coal with a relatively low percentage [illegible] is burned in a pulverized form, the volati[illegible]akes soft coal relatively easy to burn bec[illegible]n is achieved with minimum flame travel. Co[illegible]latile matter, is more difficult to accomplis[illegible]ulverize hard coals with low volatility to [illegible] more intense firing methods.

Inert solid matter that remai[illegible] called ash. It includes mineral or inorganic material, such as silica, that was introduced as the coal was being formed. Clay, silt, sand, shale, slate, and pyrite particles are other ash-forming materials commonly found in the stratified layers of coal seams. Because ash is inert, coal with a high ash content may have a lower heating value. Although ash is usually considered a waste product that must be transported for disposal, it can have value as a construction material. For example, fly ash has been used as a base for roadways, structural fill, waste stabilization, soil modification, and backfill. Fly ash that is produced in some coal-fired boilers may be suitable for use as a mineral admixture in concrete if it satisfies chemical and physical specification requirements established by the ASTM.[11] Ash from certain coal combustion processes is also used in the manufacture of concrete masonry units. Sulfur is an impurity in coal that occurs in three forms: (1) organic sulfur, which is part of the plant's molecular structure; (2) pyritic sulfur, which occurs as iron sulfide and is better known as the mineral pyrite; and (3) sulfate sulfur, which is primarily from iron sulfate.[10] The highest sulfur source is from sulfates found in some freshwater and seawater. Bituminous coals that are found