Chapter 6

Steel Plant Fuels and Water Requirements

A. Lehrman, Development Engineer, LTV Steel Co.
C. D. Blumenschein, Senior Vice President, Chester Engineers
D. J. Doran, Manager of Market Development, Metals, Nalco Chemical Co.
S. E. Stewart, District Account Manager, Nalco Chemical Co.

6.1 Fuels, Combustion and Heat Flow

Any substance capable of producing heat by combustion may be termed a fuel. However, it is customary to rank as fuels only those which include carbon and hydrogen and their compounds. Wood was the earliest fuel used by man. Coal was known to exist in the fourth century B.C., and petroleum was used by the Persians in the days of Alexander. Prehistoric records of China and Japan are said to contain references to the use of natural gas for lighting and heating.

Heat generated by the combustion of fuel is utilized in industry directly as heat or is converted into mechanical or electrical energy. Fuel has become the major source of energy for manufacturing enterprises.

Fuel enters significantly into manufacturing costs, and in some industries represents one of the largest items of expense. The steel industry is one of the major consumers of metallurgical coal and also consumes large quantities of electricity, natural gas and petroleum.

Energy conservation efforts and technological improvements have combined to decrease domestic steel industry energy consumption from 34.40 gigajoules per net tonne (29.58 million Btu/ton) of shipments in 1980 to 24.44 gigajoules per net tonne (21.02 million Btu/ton) of shipments in 1995 per AISI survey data. The actual total steel industry average has dropped to an even lower value because most of the non-surveyed companies are electric arc furnace based, which inherently consume fewer gigajoules per net tonne (Btu/ton).

6.1.1 Classification of Fuels

There are four general classes of fuels; namely, fossil, byproduct, chemical and nuclear. Of these classes, the first three listed achieve energy release by combustion of carbon and/or hydrogen with an oxidant, usually oxygen; the process involves electron exchange to form products of a lower energy state and results in an energy release in an exothermic reaction. The fourth class liberates energy by fission of the nucleus of the atom and converting mass into energy.

Fossil fuels are hydrocarbon or polynuclear aromatic compounds composed principally of carbon and hydrogen and are derived from fossil remains of plant and animal life. These fossil remains have been transformed by biochemical and geological metamorphoses into such fuels as coal, natural gas, petroleum, etc.

Byproduct and waste fuels are derived from a main product and are of a secondary nature. Examples of these fuels are coke breeze, coke-oven gas, blast-furnace gas, wood wastes, etc.

Chemical fuels are primarily of an exotic nature and normally are not used in conventional processes. Examples of these fuels are ammonium nitrate and fluorine.

Nuclear fuels are obtained from fissionable materials. The three basic fissionable materials are uranium–235, uranium–233 and plutonium–239.

Fossil and byproduct fuels currently used in the steel industry are classified further into three general divisions; namely, solid, liquid and gaseous fuels. Fuels in each general division can be classified further as natural, manufactured or byproduct. Fuels found in nature sometimes are called primary fuels; those manufactured for a specific purpose or market, together with those that are the unavoidable byproduct of some regular manufacturing process, are called secondary fuels. The primary fuels serve as the principal raw materials for the secondary fuels. Table 6.1 gives a classified list of the important fossil fuels. It also lists some interesting byproduct fuels, many of which have been utilized by industry to conserve primary fuel.

6.1.1.1 Importance of Each Class

Coal is the major fuel of public utilities for the generation of power and is essential to the steel industry for the manufacture of coke.

Coal has been supplanted almost entirely by liquid fuels for the generation of motive power by railroads in North America. However, coal continues as a major raw material for many chemical plants as a source of carbon, hydrogen, and their compounds.

The growth of petroleum consumption has resumed after the price shocks of the past two decades due to the increasing demand for its distillation products. Gasoline, the most important product, is used as a motor fuel. Diesel engine fuel is a distillate of crude oil. Distillate and residual fuel oils, and some crude petroleums of too low commercial value for distillation are used for industrial and domestic heating. Crude and refined petroleum of various grades are used for lubrication of all types of machinery and prime movers. Petroleum and natural gas are raw materials for the petrochemical industry.

Natural gas has replaced coal to a considerable extent for domestic and industrial heating due to the installation of very large pipelines from producing to consuming centers, the relative level in the price of natural gas over the intervening time, and its convenience, cleanliness, controllability and versatility as a fuel. The byproduct gaseous fuels—coke-oven gas and blast furnace gas—are major integrated steel industry fuels.

The nuclear energy industry has fallen on hard times. The development of a practical method for fission of the atom and the release of nuclear energy in controlled chain reactions had given rise to a different type of power generation system. Many large reactors were built throughout the country and are still in operation. However, no new units are under construction or are being designed. Nuclear power will contribute an ever decreasing share of power to the electric grid as units are taken out of service unless some major breakthrough in design and operation occurs.

6.1.2 Principles of Combustion

Fossil and byproduct fuels consist essentially of one, or a mixture of two or more, or of four combustible constituents: (1) solid carbon, (2) hydrocarbons, (3) carbon monoxide, and (4) hydrogen. In addition to these combustible constituents, nearly all commercial fuels contain inert material, such as ash, nitrogen, carbon dioxide, and water. Bituminous coal is an example of a fuel which contains all four of the combustible constituents named above, and coke is an example of a fuel containing only one (solid carbon). The constituents which make up liquid fuels and many coals are quite complex, but because these complex constituents decompose or volatilize into the four

Table 6.1 Classification of Fuels [(a)]

	Primary Fuels	Secondary Fuels	
	Natural	**Manufactured**	**Byproduct**
Solid	Anthracite coal Bituminous coal Lignite Peat Wood	Semi-coke (low-temperature carbonization residue) Coke Charcoal Briquettes: Coal slack and culm, Lignite, Peat, Sawdust, Petroleum-refining residue Pulverized coal	Charcoal—low-temperature distillation of wood Wood refuse—chips, shavings, trimmings, tan bark, sawdust, etc. Bagasse—refuse sugar cane Anthracite culm—silt refuse of anthracite screening Coke breeze: Byproduct coke—screenings, Petroleum coke—petroleum-refining residue Waste materials from grain: Corn, Barley, Wheat, Buckwheat, Sorghum
Liquid	Petroleum	Gasoline Kerosene Alcohol Colloidal fuels Fuel oil: Residual oils, Distillate oils, Crude petroleum Naphtha Vegetable oils: Palm, Cottonseed	Coal distillates: Tar, Napthalene, Pitch, Benzol—coke manufacture Acid sludge—petroleum-defining residue Pulp-mill waste
Gaseous	Natural gas	Producer gas Water gas Carburetted water gas Coal gas Oil gas Reformed natural gas Butane[(b)] Propane[(b)] Acetylene Hydrogen	Blast-furnace gas—pig-iron manufacture Coke-oven gas[(c)]—coke manufacture Oil-refinery gas Sewage gas—sewage sludge Basic oxygen furnace gas—steel manufacture

(a) Excluding chemical and nuclear fuels.
(b) Liquefiable heavier constituents of natural gas.
(c) Considered byproduct of coke manufacture in steel industry but a manufactured fuel in the gas industry.

simpler constituents named above before actual combustion takes place, a knowledge of the combustion characteristics of these constituents is sufficient for nearly all practical applications. All of these four constituents of fuels except carbon are gases at the temperatures where combustion occurs. Combustion takes place by combining oxygen, a gas present in air, with the combustible constituents of a fuel. The complete combustion of all fuels generates gases. It is apparent, therefore, that a review of the properties, thermal values and chemical reactions of gases is necessary for an understanding of any class of fuel.

Because fuels are used to develop heat, a knowledge of heat terms and the principles of heat flow are also essential for the efficient utilization of this heat. The combustion of fuels involves, besides combustion reactions, the factors and principles which influence speed of combustion, ignition temperature, flame luminosity, flame development, flame temperature and limits of flammability. The ensuing divisions of this section deal generally with these subjects. Sections 6.2, 6.3 and 6.4, respectively, deal specifically with the combustion of solid, liquid and gaseous fuels.

6.1.2.1 Units for Measuring Heat

Heat is a form of energy and is measured in absolute joules in SI units.

In the centimetre-gram-second (cgs) the unit for measuring heat was the calorie (abbreviated cal), defined as the amount of heat required to raise the temperature of one gram of pure, air-free water 1°C in the temperature interval of 3.5° to 4.5°C at normal atmospheric pressure: this unit was the gram-calorie or small calorie, identified in the Table 6.2 as $cal_{4°C}$. The temperature interval chosen for this definition was selected because the density and, therefore, the heat capacity of water varies slightly with temperature and the temperature of maximum density of water is very nearly 4°C. A larger heat unit in the cgs system was the kilocalorie (kilogram-calorie or large calorie), equal to 1000 gram-calories and abbreviated kcal.

Other values for the calorie were obtained by selecting other temperature intervals, resulting, for example, in the $cal_{15°C}$ and the $cal_{20°C}$ listed in Table 6.2. Yet another variation was the mean calorie (abbreviated cal_{mean}), defined as 1/100 of the amount of heat required to raise the temperature of one gram of water from 0°C (the ice point) to 100°C (the boiling point).

None of the foregoing definitions of the calorie were completely satisfactory because of the variation of the heat capacity of water with temperature. Consequently, on the recommendation of the Ninth International Conference of Weights and Measures (Paris, 1948), the calorie came to be defined in energy units in ways that made its value independent of temperature. The thermochemical calorie (abbreviated $cal_{thermochem}$) was defined first in international electrical-energy units and later (1948) in terms of mechanical-energy units. The calorie used in the present International Tables, identified as cal_{IT} was adopted in 1956 at the International Conference on Properties of Steam in Paris, and is expressed in mechanical-energy units.

As stated above, the SI unit used to define the calorie in terms of mechanical-energy units is the absolute joule: the word "absolute" differentiates the SI joule based on mechanical-energy units from the international joule formerly used which was based on international electrical units.

The presently accepted values in absolute joules of the various calories discussed above are presented in Table 6.2 here.

Table 6.2 cgs/SI Equivalent Values for Measuring Heat

1 $cal_{4°C}$	=	4.2045 joules
1 $cal_{15°C}$	=	4.18190 joules
1 cal_{mean}	=	4.19002 joules
1 cal_{IT}	=	4.1868 joules (exactly)
1 $cal_{thermochem}$	=	4.184 joules (exactly)