ment of Commerce, are also used to specify fuels and for the most part the *Commercial Standards* and the *ASTM Specifications* are in close agreement.

Oils are classified by their viscosities. Other characteristics of fuel oils which determine their grade classification and their suitability for given uses are the flash point, pour point, water and sediment content, carbon residue, ash, and distillation characteristics.

The flash point of an oil is important with regard to safety in handling and in storage. The distillation characteristics determine whether or not the oil can be completely evaporated in some types of burners, and whether cracking will be likely to occur prior to combustion. A low pour point and low water content are necessary for handling and outdoor storage in cold climates. Sediment should be low to prevent clogging of strainers. Carbon residue is related to the rate of accumulation of unburned material in some types of burners. A low viscosity allows the fuel oil to flow through supply lines readily and to be broken up into small droplets in atomizing type burners. The sulfur content is of importance because undesirable compounds of sulfur may be formed in certain industrial processes. Some of these characteristics of a fuel oil are required to lie within certain limits for each of the grades of fuel oil listed. Some fuel oils do not fall into any of the grade classifications because failure to comply with all of the requirements of one grade does not place the fuel oil in the next lower grade, unless it meets all requirements of the lower grade.

By ultimate analysis the No. 1 and No. 2 fuel oils contain 84 to 86 percent carbon, up to 1.0 percent sulfur, and the remainder predominantly hydrogen. The heavier grades of fuel oil, Nos. 4, 5 and 6, may contain as much as 88 percent carbon, as low as 11 percent hydrogen, and considerably more sulfur than permissible in domestic grades.

Due to variation in the constituents of different fuel oils and the different refining methods used, the API gravities and calorific values of the different grades of fuel oil cover a range in each grade with some overlapping between domestic grades and between commercial and industrial grades. API *gravity*, generally used when referring to specific gravity of oil, is obtained by the following formula in which the term *specific gravity at 60/60 F* indicates the ratio of the weight of a given volume of oil at 60 F to the weight of the same volume of water at 60 F:

$$\text{Degrees API} = \frac{141.5}{\text{specific gravity at 60/60 F}} - 131.5$$

The API gravity of water at 60 F is 10.0. The relation between the API gravity of fuel oils and their calorific value is shown in Table 4. Grades No. 1 and No. 2, which are distillates, are used predominantly in domestic heating equipment whereas grades 5 and 6 are used in commercial and industrial burners. Grade 6 requires preheating to increase its fluidity and to permit atomization. Two grades of No. 5 are available. No. 5 Light may be used in some burners without preheat. No. 5 Heavy requires preheating. Grade 4 fuel oil does not require preheating and can even be burned satisfactorily in a limited number of domestic burners.

Sources and Properties of Residual Fuel Oils

The residues may be classified, in accordance with their previous processing, as straight-run, vacuum-flashed, or cracked residues. Straight-run residues are the materials in crude oil that cannot be distilled at atmospheric pressure without appreciable decomposition and hence are removed as bottom fractions from crude topping units. These materials, often referred to as *topped* or *reduced* crude, are sometimes blended into fuel oil, but more frequently are processed, either by vacuum distillation or by thermal cracking, to produce additional distillates. Residues from vacuum distillation processes are widely used as residual fuel blending stocks. Vacuum-flashed residues from some crudes must be subjected to a mild thermal cracking, known as viscosity-breaking, before they can profitably be blended into fuel oils. Residues produced by thermal cracking of straight-run or vacuum-flashed residues or by thermal reforming of heavy naphthas, also are used in residual fuel oils.

Table 4 .... Typical Gravity and Heating Value of Standard Grades of Fuel Oil

Grade No.	Gravity API	Weight Lb Per Gallon	Heating Value Btu Per Gallon
1	38–45	6.95 –6.675	137,000–132,900
2	30–40	7.296–6.870	141,800–135,800
4	20–28	7.787–7.396	148,100–143,100
5L	17–22	7.94 –7.686	150,000–146,800
5H	14–18	8.08 –7.89	152,000–149,400
6	8–15	8.448–8.053	155,900–151,300

In processing reduced crudes and other stocks that yield residual fuel-blending stocks, the refiner evaluates the severity of treatment against, among other factors, the effect on certain properties of the residues. Perhaps the most significant of these properties is viscosity. Maintenance of fuel viscosity within a certain range by preheating of the oil is necessary to obtain satisfactory combustion efficiency with most burners for heavy oil. In most instances there is a maximum temperature to which the oil should be preheated. Consequently a maximum viscosity is usually placed on the finished product.

The second property of oil that is markedly sensitive to refining procedures is specific gravity. Residues may have gravities on either side of API 10, i.e., they may be either lighter or heavier than water. Since residual fuels in many instances are stored and used in the presence of water the densities of the fuel oils must differ sufficiently from water to assure their separation into distinct layers.

The limits imposed by viscosity and specific gravity specifications are met in part by refining practices and in part by blending residues with distillates. These distillates may be straight-run gas oils and distillates produced by thermal or catalytic cracking. Blending of residues and distillates generally entails down-grading of the latter. Consequently efforts are made to reduce to a minimum the quantities of *cutter stock* (the refinery term for distillates used for this purpose) necessary to meet manufacturing specifications. Heavy catalytically- or thermally-cracked distillates are generally used as cutter stock, not only because they are of less value for further processing than straight-run gas oils, but also because they have greater solvency for asphaltic materials in cracked residues.

This discussion of residual fuel oils has been concerned principally with No. 6 fuel oil, the heaviest grade of residual fuel. The other grades of residual fuels, Nos. 4 and 5, have lower viscosities and higher gravities than No. 6 fuel oil. Generally these specifications are met by increasing the ratio of cutter stock to residue, but occasionally these lighter fuels are made by blending No. 6 and No. 2 fuel oils.

Sometimes No. 4 oil will consist entirely of heavy distillates but generally this fuel contains residual stocks. Due to their higher distillate content both No. 4 and No. 5 grades bring higher prices than No. 6 fuel oil, and frequently they are priced in cents-per-gallon rather than dollars-per-barrel.

Oil Burning Indexes

A number of indexes have been used, or proposed, as an indication of the burning qualities of distillate fuel oils. These indexes include single physical properties of the fuel and also combinations of such properties.

API gravity is the simplest of the single-property indexes to determine and has been shown to effectively correlate with smoke-producing characteristics of small pressure burners[4] and of wall-flame burners.[5] Aniline point[6] has shown similar correlations. Diesel index, the mathematical product of API gravity and Aniline point, has been successfully used for correlation purposes.[4,5,7] Also, Burning index has been developed by combining API gravity and 50 percent distillation point.[8] Other combinations have been reported, and some oil refiners use their own special indexes as a method of controlling burning quality. Nevertheless, API gravity remains the most commonly used single index of combustion quality for distillate fuels. For power-type burners of 1 gph or less, a fuel having an API gravity of 30 deg or above will generally prove satisfactory from the standpoint of burning quality.

FUEL GASES

Fuel gases employed for various heating and air conditioning processes throughout the United States fall into three broad classifications: natural, manufactured, and liquefied petroleum. Natural gas is a mixture of several combustible gases and, usually, a small percentage of inert gases obtained from geologic formations. Manufactured gas is made by the distillation or cracking of oil or coal, by the steam-carbon reaction, or by combinations of these processes. Liquefied-petroleum gases (propane and butane) are higher hydrocarbon gases normally obtained as a by-product of oil refineries or by stripping natural gas. These two compounds are generally gaseous under usual atmospheric conditions although they can be liquefied by the application of moderate pressures at normal temperatures.

In American gas practice the heating value of a gas and also appliance efficiencies are based on the gross heating value. This value is the number of Btu liberated by complete combustion, at constant pressure, of one cubic foot of gas saturated with water vapor and measured at 60 F and 30 in. of mercury, with air at the same temperature and pressure. Products of combustion are cooled to the initial temperature of the gas and air and the water formed by combustion of free and combined hydrogen is condensed to the liquid state.

Classification of Gases

Natural gas contains from 55 to 98 percent methane with various percentages of higher hydrocarbons, chiefly ethane and non-combustive gases. Typical compositions include methane, CH_4 (70–96 percent); ethane, C_2H_6 (1–4 percent); propane, C_3H_8 (0–4 percent); butane, C_4H_{10} (0–2 percent); pentane, C_5H_{12} (0–0.5 percent); hexane, C_6H_{14} (0–0.2 percent); carbon dioxide, CO_2 (0–2 percent); oxygen, O_2 (0–1.2 percent); nitrogen, N_2 (0. 4–17 percent). Percentages of the different components vary with the area from which natural gas is withdrawn, but these variations are inconsequential insofar as the utilization of the gas is concerned. Heating values of natural gases vary from 900 to 1400 Btu per cu ft but the usual range for use is from 1000 to 1050 Btu (gross) per cu ft.

Manufactured gases such as coke oven and carburetted water gas, which were distributed with a heating value of 500 to 600 Btu per cu ft (gross), are no longer common in large communities due to the widespread availability of natural gas.

Mixed gases are a result of increased distribution of natural gas, through transcontinental transmission lines, into areas having existing manufactured gas facilities. In such instances some gas companies supply a 600 to 800 Btu mixture.

Liquefied petroleum gases, such as propane and butane or mixtures thereof have calorific values ranging from 2500 to 3200 Btu per cu ft. Propane is generally available by the bottle or cylinder, or in bulk in tank truck, truck transport or tank car lots. Butane is generally not available in cylinders. In such cases the liquid evaporates when pressure is relieved, the heat necessary for vaporization being obtained from the surrounding air or ground. As butane boils at 32 F some provision is necessary for maintaining the gas above this temperature or for lowering the partial pressure by dilution if the gas is utilized in colder climates. Propane, with a boiling point of −40 F, may be served in localities where temperatures substantially below freezing are encountered. When employed for heating purposes, these gases are usually delivered by tank truck into bulk storage pressure vessels of sufficient size to give the customer an adequate supply of fuel. Both gases, mixed with air, or in undiluted form, are also extensively employed by gas companies to augment their base load supplies during peak load periods. In some smaller communities, where gas manufacturing plants are not economically feasible and natural gas is unavailable, liquefied petroleum gases or liquefied petroleum gas-air mixtures are supplied through mains in much the same manner as manufactured or natural gas.

FUNDAMENTAL PRINCIPLES OF COMBUSTION

Regardless of the type of fuel under consideration, its combustion results in the production of gaseous products. Many kinds of solid fuels contain minerals which cannot be burned and are therefore left as a residue commonly called ash. Moreover, unless sufficiently high temperatures are employed and an ample supply of oxygen properly distributed is present, the combustible constituents of solid, liquid, and even gaseous fuels cannot be completely burned. Incomplete or partial combustion of all fuels produces toxic gases, such as carbon monoxide, with smaller quantities of aldehydes, ketones, and other hydroxylated hydrocarbon compounds. While combustion processes involving common types of fuel may be regulated by experienced operators to produce the most efficient results, normal combustion processes can create hazards unless both design and operation are planned with a knowledge of the fundamental principles of combustion.

Combustion may be defined as the chemical combination of a substance with oxygen resulting in the evolution of heat, and usually some light. The rate of combustion depends upon the rate of reaction of the substance with oxygen, upon the rate at which oxygen is supplied, and upon the temperature obtained due to surrounding conditions. This is combustion in its simplest form. All solid, as well as liquid and even gaseous fuels generally contain several combustible elements in combination with others which, depending on their nature, affect oxygen requirements and thus govern the combustion process. For a continuous reaction, as in heating processes, it is necessary to establish an effective balance between rates of removing heat and of supplying fuel and air or oxygen to keep the reaction going. In establishing such a balance, consideration must be given to the removal or venting of products of combustion, so that the entire process is one of flow wherein draft conditions in the combustion space are important.

Complete combustion is obtained when all combustible elements in a fuel are oxidized by all of the oxygen with which they will combine. All oxygen or air supplied is generally not utilized, and this excess portion is commonly called *excess oxygen* or *excess air* and expressed as a percentage of the air required for perfect combustion.