

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 or limit 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 frequently 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. Two other grades of residual fuels, Nos. 4 and 5, are produced and marketed. These fuels 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 grade of 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 on a different basis, *i.e.* in cents-per-gallon rather than dollars-per-barrel.

The specifications of the three grades of residual fuels and of the two grades used on the Pacific Coast were presented in Table 4.

Analysis of Fuel Oils

Crude oil in its natural state contains primarily paraffin hydrocarbons (chemical formula C_nH_{2n+2}), naphthene hydrocarbons (formula C_nH_{2n}), and aromatic hydrocarbons (formula C_nH_{2n-6}) where n is a whole number. Fuel oils produced by pure distillation, that is the straight-run fuel oils contain essentially these same hydrocarbons. Those produced by cracking processes may contain generally all the hydrocarbon series from C_nH_{2n+2} to C_nH_{2n-14} , and especially do they contain appreciable percentages of the olefin hydrocarbons which are relatively less stable than the paraffin, naphthene, and aromatic hydrocarbons. The paraffin hydrocarbons are hydrogen-saturated, are among the most stable, and have the highest hydrogen-carbon ratio of any of the hydrocarbon series. The straight-run fuel oils have the highest paraffin content, the highest hydrogen-carbon ratio and are the most stable of the fuel oils. The thermally-cracked fuel oils have the lowest paraffin content while the catalytically-cracked fuel oils are intermediate in paraffin content and stability. The hydrogen-carbon ratio of straight-run fuel oils ranges from 0.155 to 0.170, and in catalytically-cracked fuel oils ranges from 0.133 to 0.156, while it is some-

what lower for thermally-cracked fuels. The blending of straight-run oils with cracked oils is common practice to improve the paraffin content, stability, and ignition characteristics of fuel oils. A high paraffin content and a high hydrogen-carbon ratio are generally desirable characteristics for domestic fuel oils and consequently, the straight-run distillates are better suited to this use than the fuel oils produced by the various cracking processes. On the other hand, thermally-cracked fuel oils often have a lower pour point and a lower viscosity than comparable straight-run fuel oils.

COMBUSTION OF FUEL OILS

Many theories have been advanced during the past century to explain the mechanism of combustion of hydrocarbons in oil burners and other devices used for producing heat or light. These theories have been modified from time to time to agree with new experimental evidence. Much still remains unknown about the process of decomposition and combustion of hydrocarbons.

Only three theories will be discussed here: (1) the carbonic combustion theory, (2) the aldehydeous combustion theory, and (3) the chain reaction theory.

The carbonic combustion theory postulates that thermal destruction of hydrocarbon molecules is likely to occur if (1) the oil is suddenly exposed to intense heat without allowing time for previous evaporation, (2) the oil and air are not adequately mixed, and (3) there is no preheating of the air or mixture. According to this theory the hydrocarbons would be thermally decomposed into hydrocarbons of lower molecular weight along with some free carbon atoms released under the conditions just described. The free carbon atoms may produce smoky combustion while those carbon atoms that are oxidized to carbon dioxide will produce a yellow luminous flame.

The aldehydeous combustion theory is based on the evidence that aldehydes, alcohols, and possibly peroxides are formed as intermediate products when hydrocarbons are decomposed and oxidized to the final products of combustion. The formation of formaldehyde is certain since it can be identified in the flue gases from blue flame oil burners when insufficient combustion air is provided. Alcohols have been identified by certain investigators during the oxidation of methane and ethane. Aldehydeous combustion is illustrated by the blue flame oil burner and the conditions conducive to this type of hydrocarbon decomposition consist of (1) allowing the oil time and opportunity to evaporate completely prior to combustion, (2) mixing the air and oil vapor thoroughly before combustion, and (3) preheating the air or the mixture.

Blue and yellow flame combustion can be demonstrated by the apparatus illustrated in Fig. 3. If methane is burned in an atmosphere of air, as in burner A, a yellow flame will result, whereas the introduction of the air for combustion in the center of a stream of methane, as in burner B, will result in blue flame combustion. As the center of the flame in burner A is exposed to intense radiation the methane is thermally decomposed and liberates carbon particles which emit a yellow luminous flame during oxidation. In burner B the center of the flame cone is filled with air which cannot decompose under heat, the methane gas at the zone of contact with the air is only moderately heated because of outward radiation, and the air is preheated in the center as it approaches the flame; each of these conditions tend to produce aldehydeous combustion.

It is probable that the chain reaction theory is an extension of the alde-