

COMBUSTION PROCESS AND COMBUSTION PRODUCTS FOR DIFFERENT ORGANIC FUELS. EMISSION PROBLEM

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Summary

This chapter deals with industrial hydrocarbon fuels of organic origin, their composition characteristics and properties, essential features required. It describes the process of fuel combustion, its elements, and the necessary conditions for its effective organization. The composition of combustion products and their properties are shown. Ecological problems accompanying the formation of combustion products are noted. Examples of measures for reduction of contaminating emissions during combustion are given.

1. Industrial Fuel

Up to now, organic fuel has been and specialists predict that for the coming decades it to be the main source for power generation in the world with its growing consumption. Industrial fuel constitutes such matters, which in the course of complicated chemical transformations jointly defining the combustion process, are capable of liberating considerable heat to be later used for useful work. The basic requirements for these matters are as follows:

- a) Availability in nature in quantity.
- b) A possibility of effective use of a substantial part of heat released in their combustion.
- c) Convenient application of combustion products as a working medium for industrial power plants and basic equipment.
- d) Harmlessness of fuels and their combustion products for the Human and the environment.
- e) Sufficient availability and low cost of the oxidizer, air for instance (its oxygen), to be used for combustion (combustible oxidation) of these fuels.
- f) Stable combustion parameters and performances together with a considerable storage life at varying parameters of the outer atmosphere and working conditions.

The given definition and the above-listed general requirements are, to the greatest extent, met with gas, liquid and solid organic matters on carbon and hydrogen basis. These elements together with sulfur, which is rather common in fuels, make up the combustibles. They are naturally found in fuels not in free state but as various carbon compounds with hydrogen, sulfur, oxygen, nitrogen and others. Besides they usually contain incombustibles: moisture, mineral part (ash).

Natural organic fuel directly extracted is, as a rule, subject to one or another kind of processing, without which industrial combustion is impossible, inefficient and economically unattractive.

Fuels of any aggregate state can have three general features in common: composition, heating value and their attitude to heating.

Fuel composition (chemical) should show which compounds the fuel contain and in what amount. Unfortunately, today it is possible with a sufficient exactness and comparative ease to perform chemical analysis only for gas fuels (in volume percent). It is difficult and very often impossible to determine chemical composition even for liquid and especially for solid fuels. It is common practice to make “an elementary analysis” for them which is usually determined by recalculation of the given chemical composition for gaseous combustion products of the given fuel. It implies that the fuel composition is by convention presented as a sum of separate elements in mass percent. For example, the total “working” mass has the index “p”: carbon (C^p), hydrogen (H^p), oxygen (O^p), sulfur (S^p), ash (A^p), moisture (W^p). It is also possible to utilize another data set: dry mass, combustible or organic mass of the fuel.

Heating value Q_1^p (lower heating value) is taken without regard for latent heat of evaporation of moisture in fuel and its combustion products. It is given in kJ per m^3 for gases and in kJ per one kilogram of liquid or solid fuel. The quantity Q_1^p is rather strictly specified only by the data of a chemical analysis or by experimental results obtained in fuel calorimetric study. The quantity can be approximately determined with the use of the elementary analysis data from empirical relations like those introduced by D.I. Mendeleev:

$$Q_1^p = 4.19 [81 \times C^p + 246 \times H^p - 26(O^p - S^p) - 6 \times W^p] \quad (1)$$

The fuel attitude to heating characterizes its thermal stability, i.e. the ability of retaining its composition and properties at high temperatures.

In a number of cases some fuels utilize other characteristics.

Natural gases usually have a lower heating value high enough (about 30-50 MJ m^{-3} and more), whereas the quantity Q_1^p for artificial gases is only up to 5-10 MJ m^{-3} .

Liquid fuel is mainly obtained by specific processing of natural oil from different deposits. The greatest part of its composition always consists of carbon C^p ~85% and hydrogen H^p ~ up to 12-14%, there is also a small amount (up to 1.0-1.5)% oxygen O^p and sometimes – up to (3-5)% sulfur S^p and others. The presence of sulfur in oil is

undesirable because of the corrosive nature of sulfur compounds being as well detrimental to constructional materials.

The easiest way to produce various sorts of industrial liquid fuels (gasolines, ligroins, which are products of distillation of crude oil at temperature 470-490K, kerosenes, diesel and motor fuels), i.e. basically artificial light liquid fuels, is sequential heating within certain temperature limits with evaporation of the original oil mass followed by condensation of vapors generated. It is usually possible to obtain by such procedure up to 30-÷35% of the original mass of oil as a sum of light liquid fuels. Fuel oil residue is often exposed to secondary treatment for additional light fuel production, removal or neutralization of some corrosive components to be largely concentrated in the ash (A^P) of heavy liquid fuels, its amount reaching 0.6-0.7% oil original mass.

The use of secondary processing methods of the cracking process type enables the increase of light fuel yield upto 50-60% oil original mass and more. The heating value of different liquid fuels is usually 38÷47 MJ kg⁻¹. A serious circumstance for organizing and carrying out the combustion process is the fact that the ignition point for light fuels is always above their boiling point.

For successful combustion even of light (kerosene) liquid fuels (with the density of about 0.73-0.86 g cm⁻³) it is necessary to pulverize them to increase abruptly the surface of heat transfer and evaporation in particular and of combustion as a whole.

The ash component of heavy liquid fuels often contains vanadium, sodium, sulfur compounds like V₂O₅, Na₂SO₄, NaCl and others. They can induce intensive corrosion in constructional materials, result in solid ash deposits on flow passage parts and also cause erosion of design elements (turbine blades) by solid, sometimes melted ash particles.

To eliminate these harmful matters and their effect, washing of fuel as well as introduction of additives like magnesium, calcium, silicon oxides and others are often utilized. The contents of vanadium-sodium compounds is nevertheless to be restricted to between one thousandth and ten thousandth of a percent.

Solid fuels contain lignites and bituminous coals, combustible shales, peat, wood and others. Bituminous coals, for instance, contain up to 85-÷95% C^P, to 6-7% H^P, to 2-5% O^P, 1-2% N^P, sometimes up to 4-6 S^P, 10-12% and more ash as well as moisture and others. Peat usually contains about 50-60% C^P, 5-6% H^P, up to 20-25% O^P, ash – approximately 3-8% A^P; sometimes - up to 40% moisture and others. Its $Q_1^P \sim 10-12$ MJ kg⁻¹.

For solid fuels and especially for bituminous coals the tar yield and that of various gases, so called “volatiles” (v , %), in their heating up to 1100-1150 K in the air-free atmosphere is of particular importance.

There is residual char that remains finally, and its combustion gives the major part of Q_1^P . Thus ignition of solid fuels is to be characterized by two temperatures (of volatiles and that of char). The mass yield and state (type) of char (caking, non-caking,

conglomerate), its boiling point are very important.

Natural solid fuel is usually subject to physico-mechanical or physicochemical processing. In the first case its chemical structure practically does not change (crushing, drying, briquetting). Among physicochemical methods are, for example, charcoal burning of wood, coking and semi-coking of bituminous coal, and others.

Direct combustion of bituminous coals in fuel-burning devices (combustors of internal combustion engines, gas turbines in particular) requires further cleaning of fuel gases (combustion products) from solid coal and slag particles to avoid the solid deposits, erosion and corrosion of working parts. All particles above $15\div 20\ \mu\text{m}$ in size are to be removed.

There are also other ways of using solid fuels in engines. This may be their prior gasification or burning in devices like air boilers (regenerative type heat exchangers) for air heating. This may be also hydrogenation of coals to produce artificial liquid fuels.

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Biographical Sketch

Yuri M. Pchelkin graduated from the Moscow Bauman State Technical University (1951). He took his Ph.D. degree in 1954 and became D.Sc. (Eng) in 1976. He is the author of more than 130 publications in the field of gas turbine engineering, combustion processes for organic fuels and emission problems. His text book on the combustion chambers for gas turbine engines was the first one (1967) and it was renewed several times. He takes part on the design work on transport and electric power gas turbine engines and on the combustion chambers for the liquid, gas and solid fuels.