Fuels

Introduction

Fuels are chemical substances or their mixtures which release usable energy during their combustion (rapid oxidation). This released energy is contained in the combustion products (flue gas enthalpy) and is also transmitted by radiation to the surrounding bodies. The released energy is used for heating, electricity production, vehicle propulsion and many other purposes. Fuels are composed of combustible material containing mainly compounds of carbon (c), hydrogen (h) as well as other elements and species (e.g. H_2O, N_2, S, Cl, O_2, SiO_2) comprising in most cases undesired ballast. Fuels can be classified using many criteria.

Division by the physical state leads to groups of solid, liquid and gaseous fuels. Another criteria frequently used in the literature are the heating value or calorific value of fuels (low and high calorific fuels), their origin (natural and synthetic fuels) and the ratio of hydrogen and carbon (h/c) in the fuel.

Hard and brown coals, peat, wood and biomass belong to the group of natural solid fuels. Decaying plants were the primary matter from which coals and peat was formed in millions of years lasting transformation. These processes, presented in Fig. 1, were the reason of gradual coalification of the matter.

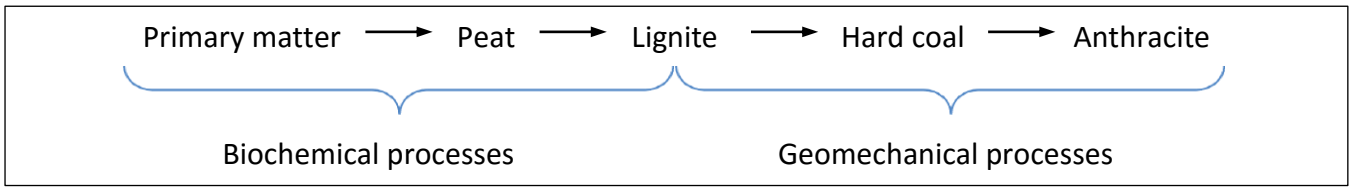

Fig. 1. Solid fossil fuels formation process [2]

Coal (mainly hard coal) has a dominating position in the polish energy balance. Combustion of coals is however a reason of pollution of the natural environment due to emission of noxious substances such as SO_2, NO_x, CO and polycyclic aromatic hydrocarbons (PAH). Chemical composition of fuel (high concentration of sulphur and ash) is not the only reason of these emissions. The other source is the imperfection of combustion technologies. These deficiencies are especially visible in small heating boilers. In order to use the energetic and chemical properties of coal and fulfill the environmental protection restrictions (emission levels) the coals can be chemically and mechanically processed. Mechanical processing includes sorting, enrichment and preliminary sulphur removal directly in the mining works. Main chemical processes include:

- Devolatilization (pyrolysis) – removal of volatiles by thermochemical decomposition of carbonaceous matter from coal in the absence of oxygen. The physical properties and chemical

composition of solid, liquid and gaseous products depends strongly on the temperature. One can distinguish high (above 1000 ^{o}C), medium (600-700 ^{o}C) and low (below 600 ^{o}C) temperature pyrolysis. The final products are: coke, coke oven gas, tar and other hydrocarbons.

- Gasification – process that converts the solid fuel into gas in reaction with oxygen, water vapor or with both of them in oxygen starving conditions. The main final product is a combustible gas called syngas or fuel gas composed of CO, H_2, CH_4, CO_2, H_2O (lower heating value (LHV) in the range 4 to 21 MJ/m^3_n).
- Hydrogenation – is based on removal of sulphur, nitrogen, oxygen, water and mineral matter from coal and de-polymerization of compounds contained within the carbonaceous material. The products are usually liquid materials – oils, gasolines and derivatives.

Biomass is considered as a future fuel whose fraction in world's energy balance constantly increases. There is a vast selection of materials considered as biomass. These include:

- wastes and residues (municipal waste, straw, wood waste)
- growing plants (energy crop) – wood of fast growing plants like poplar, eucalyptus, sugarcane)
- seaweed (kelp)

Biomass can be processed by means of the abovementioned processes, however more often fermentation is used where the final product is ethanol, methanol or methane.

Crude oil and its derivatives belong to the natural liquid fuels. Explanations of crude oil origins are frequently explained by the so called organic theory. Crude oil deposits, as well as of natural gas, are placed mainly in sedimentary rock formed from sea water salt and decayed remains of living organisms (plants and animals). Crude oil is composed of a mixture of about 3000 hydrocarbons. The main ingredients are paraffins (alkanes), olefins (alkenes), cycloalkanes and aromatic hydrocarbons. In order to separate the various fractions of crude oil the phenomenon of different boiling temperatures of these fractions is used. This fractionation process is called crude oil distillation and is run in tower like columns at various pressures – the atmospheric process at 0.1 MPa and vacuum process at 8-9 kPa. Crude oil fractionation products are presented in Table 1.

Table 1. Main products of crude oil distillation process [1,2]

Product	**Main compounds**	**Boiling temperature (^{o}C) at 0.1 MPa**
Dry and liquid gas	$C_1 – C_4$	< 20
Light gasoline	$C_5 – C_9$	40 – 150
Heavy gasoline	$C_9 – C_{12}$	150 – 190
Naphtha	$C_{19} – C_{16}$	190 – 240
Diesel, heating oil	$C_{15} – C_{22}$	240 – 350
Heavy gas oils (mazut)	> C_{20}	350 – 500
Vacuum distillates (petroleum tar, etc.)	> C_{20}	220 – 380*

* at 8÷9 kPa

The dry $C_1 – C_2$ and liquid $C_3 – C_4$ are usually used directly in the petrochemical works or comprise a product for further processing. Applications of selected fuels obtained from crude oil distillation are presented in Fig. 2.

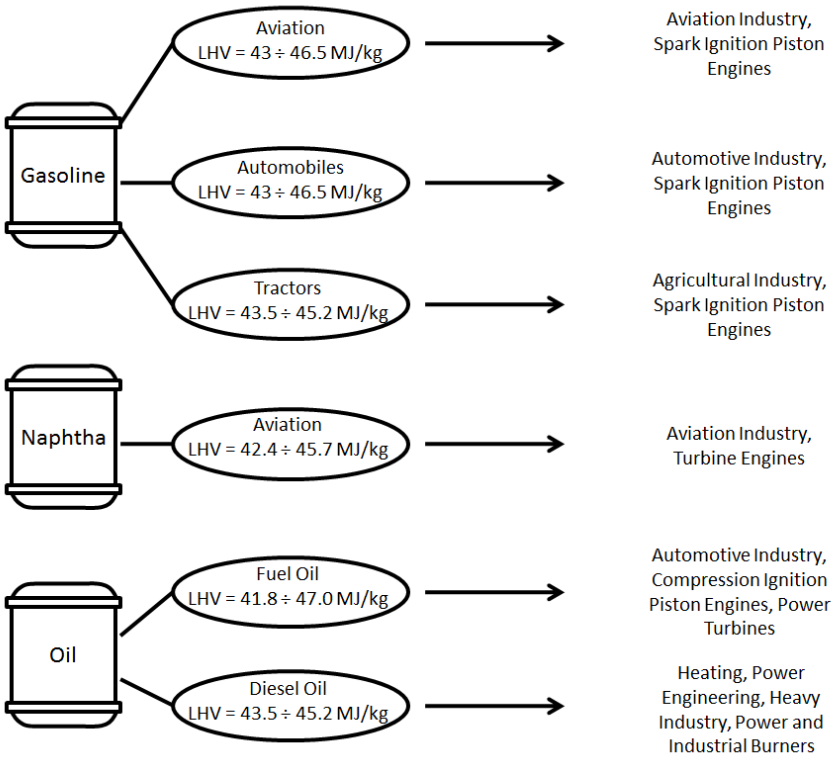

Fig. 2. Applications of selected fuels obtained from crude oil distillation

In order to further refine the liquid fuels and obtain desired products, other processes like reforming, catalytic cracking or gasification are used. Pathways of further possible crude oil processing are presented in Fig. 3.

The main fuels belonging to the synthetic liquid fuels alcohols (ethanol, methanol), oils originating from coal tars and vegetable oils (colza, sunflower). Application of these fuels is attractive due to lower emission factors of SO2 and NOx, however is limited due to relatively low production and maladjustment of combustion technology devices.

Natural gas as a fossil fuel resides frequently in the same deposits as crude oil. Utilization of natural gas is ecologically clean (highest h/s ratio, no SO2 and low NOx emissions). Furthermore it possesses many other advantages like high heating value and easy of combustion process automation. Natural gas is transported in pipelines and does not require storage at the end-user site. The disadvantages of natural gas are low density and easy of formation of combustible mixture which can lead to uncontrolled explosions. Natural gas is extracted from the deposit through holes. Besides the natural gas there are many synthetic gases used in industry, which come from coal and crude oil processing or biomass fermentation.

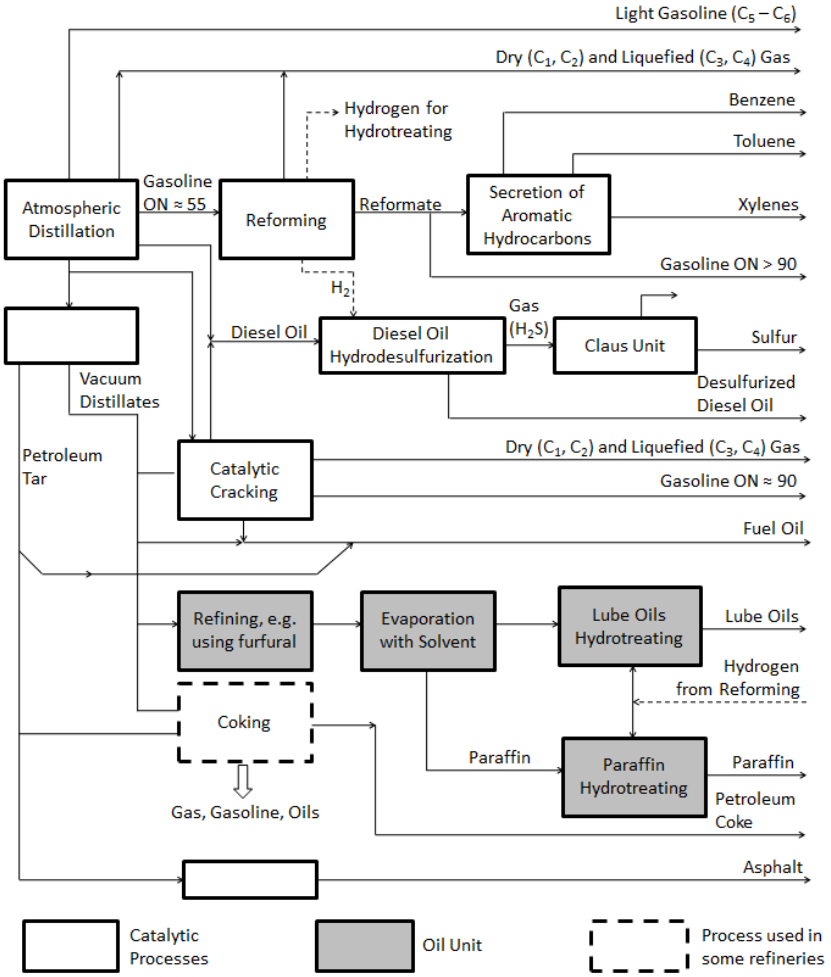

Fig. 3. Pathways of crude oil processing

The aim of the exercise

The aim of this exercise, which comprises the introduction to the combustion laboratory, is to get acquainted with fuels currently used in combustion processes. Observation of ignition and combustion process of the subsequent fuels will help understanding problems related to the underlying energy processes.

Test facility description

The test rig is placed on a laboratory table. The main device used is a gas burner which is a source of an open flame. Additional pieces of equipment are tweezers and a set of loop finished sticks. The sticks are made out of high temperature resistant wire.

Experimental procedure

Revision of the measurement system and verification of its condition is the first task which should be done prior following the steps presented below:

1. open the main gas valve and ignite the gas while increasing gently the gas flow rate by means of the burner valve
2. prepare small samples from fuels indicated by the teacher
3. look at the fuels carefully and note their physical state, color and smell
4. place the prepared samples in the flame by means of the tweezers or sticks
5. write down information regarding the ignition and combustion of the samples. Note the occurrence of soot formation
6. note down your findings about the look of the samples after combustion
7. after finishing the exercise close the burner valve and the main gas valve. Clean the table and facility

Analysis of the results

Write down your observations in a table with accordance with the scheme given in Table 2.

Table 2. The observation results

Name of fuel	Physical properties			Chemical properties				
	Physical state	Color	Smell	Ignition tendency	Self-flame burning ability	Flame description	Presence of soot	Combustion residue

Literature

[1] Technologia podstawowych syntez organicznych, E. Grzywna, J. Molenda, WNT, Warszawa, 1995
[2] Spalanie i paliwa (W. Kordylewski - red.), Oficyna Wydawnicza Pol. Wrocławskiej, Wrocław, 1999