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CAUSE-EFFECT ANALYSIS OF THE MODERN STATE IN PRODUCTION OF JET FUELS

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Abstract. The main methods of fuels for gas-turbine engines manufacturing are presented in the given article. Taking into account limitation of the world deposits of oil and other fossil fuels, the perspectives of various kinds of raw materials application for jet fuels production are discussed. Processes of raw materials extraction and processing, further manufacturing and use of jet fuels were analysed and their impact on environment was estimated. Various kinds of natural renewable resources are proposed as an alternative to traditional raw materials for production of fuel for gas-turbine engines.

Keywords: raw materials, gas-turbine engine, environment, renewable resources, exhaust gases, biofuel.

1. Introduction

At modern stage of population development the liquid fuel is obtained mainly as the result of oil refining [1]. Products of oil refining are high-performance fuels, various lubricating materials, bitumen, paraffins, *etc*. Speaking about volumes of oil extraction, thus from the beginning of its industrial production (since the end of 1850) till the middle of 1970 the world oil extraction increased twice approximately each ten years. Then, because of the world oil crisis its rates have decreased. At today's rates of consumption, the amounts of discovered oil will be enough for 40 years approximately, non-discovered – for 10–50 years more. During last 35 years the oil consumption increased from 20 to 30 billion barrels per year [1]. According to data of International Energy Agency (IEA) in 2011 a new historical maximum of daily oil extraction volume was reached and was equal to 89 million barrels per day.

Today there is a great variety of resources for fuel production in the world [2, 3]. This fact is firstly explained by limited world oil resources, causing its disruptive price growth, and secondly – by permanent worsening of ecological situation as a result of oil extracting, refining and usage along with human aspiration for saving environment.

According to United Nations Environment Programme (UNEP) data during last 20 years approximately three fourth of all anthropogenic carbon dioxide emission became a result of extraction and burning of oil, natural gas and coal (Fig. 1) [2]. Today concentration of CO_2 in atmosphere composes approximately 400 ppm (0.04 %). This is twice larger than before the industrial revolution of the XVIII century. Considering today's development rate CO_2 concentration in atmosphere may reach 500 ppm (0.05 %) till 2050.

Modern aviation is one of the important consumers of oil resources in the form of aviation gasoline and jet fuels. The major part of the civil aviation park uses fuel for air-jet engines and it is responsible for about 2 % of world CO_2 emissions. Besides CO_2, exhaust gases of aircrafts contain other components negatively influencing both human health and global climate change on the planet (Fig. 2) [2]. And, according to statements of some experts, till 2050, aviation transport will become a source of 20 % of harmful substances discharged in the world.

Taking into account the increasing scientific-technical progress and sweeping development of technologies in fuels production industry, we see the necessity to classify fuels that are manufactured today in the world in some particular way. However, fuels can be classified according to various properties. The most popular ways used for fuel classification are presented in Table 1 [3, 4, 5].

We consider that the most reasonable and substantial is the attempt to classify fuels according to kinds of raw materials used in their production processes. Fig. 3 shows a schematic classification of primary feedstock, which are used for fuels production.

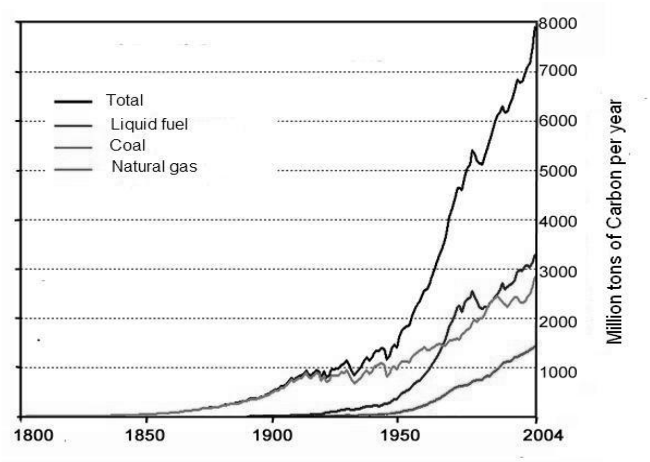

Fig. 1. World's total carbon emissions into the atmosphere [2]

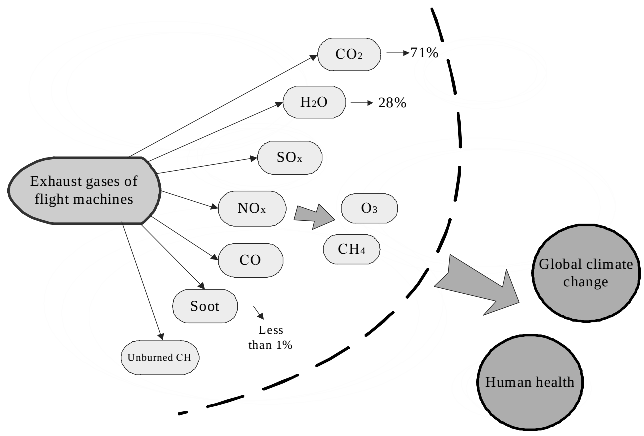

Fig. 2. Composition of exhaust gases of flight machines [2]

Table 1

Classification of fuels

Classification criteria	Kinds of fuels
Aggregate state	Liquid, solid, gaseous
Component composition	Hydrocarbon, hydrocarbonoxygen (alcohols), nitrogen hydrocarbon, fuels with admixtures (water, burning gas, hydrogen, coal powder, *etc.*)
Caloric value	High caloric, average caloric, low caloric
Technological processes of production	Direct distillation, pyrolysis, hydrogenization, gasification, catalytic conversion, electrolysis, esterification, *etc.*
Origin	Natural, industrial (synthetic), on the base of wastes from various manufactures
Sources of raw material	Oil, coal, peat, oil-shales, oil sands, natural gas, biomass, *etc.*

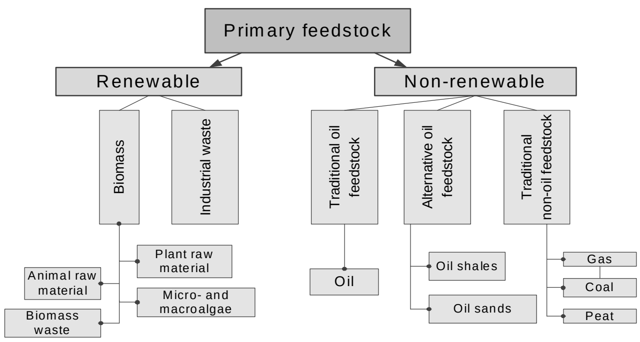

Fig. 3. Classification of primary raw materials [2, 3, 6]

Since the mid of 70's the humanity was in an active search of alternative energy sources with the aim of oil replacement [1]. In Canada and Venezuela, for example, oil sands were developed in an open way (oil sands, in which after the separation of light fractions, heavy oil, bitumen and asphalt still remain). Oil reserves in the oil sands of Canada and Venezuela are about 3400 billion barrels [1]. At the current rate of consumption this amount of oil may be enough for about 110 years. In the USA there are big reserves of oil-shales, which are also used to produce fuels. So, oil-shales totally contain about 2.8–3.2 trillion tons of oil [1]. Besides, natural gas, brown and black coal are widely used as a raw material for production of different fuels [2, 6]. However, the most serious problem, connected with fuel manufacturing from the above mentioned feedstock is their negative impact on the environment [2].

Development of the aviation techniques has a constant trend for increasing speeds and altitudes of aircrafts, improvement of economic efficiency, mass properties, reliability and life span of motor systems of aircraft engines [3]. The most part of the aviation techniques is equipped with gas turbine engines. The reliability and efficiency of the engine work and therefore of the aircraft require high-quality fuel. Modern fuels for civil aviation should meet a number of requirements related to efficiency, reliability and durability of the aviation techniques. Special attention is paid now to the environmental safety of the fuel [4]. Among the general technical requirements for fuels of forgas turbine engines are the following [5]:

- High level of volatility that provides reliable flammability and complete combustion efficiency;
- Good low temperature properties, which provide reliable fuel pumpability at low temperatures;
- Chemical and thermal stability with minimal tendency to form deposits in the fuel system of the aircraft engine;

• Absence of negative impact on metal and non-metal parts of the engine fuel system, equipment for storage and transportation;

• Good lubricating properties that eliminate excessive wearing of fuel assemblies friction parts ;

• The optimal level of electrical conductivity, which excludes fuel electrification and provides safe fuel transfer and filling of fuel tanks;

• Absence of toxic components, impurities and additives, the minimum content of sulphur compounds, which lead to the formation of ecologically harmful products as the result of fuel combustion.

Physicochemical and ecological properties of fuels for gas-turbine engines are primarily determined by the origin and properties of raw materials used for their production, the method of basic fractions obtaining, the methods of their purification and mixing, properties of the additives applied [3].

However, despite the diversity of available natural resources, at the modern stage of development, oil remains the traditional and the most common feedstock for the production of aviation fuels, as well as other types of fuels. The majority of modern fuels for gas-turbine engines are obtained through the direct distillation, destructive methods of oil refining are also applied [4]. At the same time, fuel obtained during processing of the non-oil raw materials, such as coal and oil-shales became widespread in some countries [1, 6]. This is mainly connected with the presence of certain resources on the territory of producing country. Fig. 4 shows a schematic representation of generalized classification of ways for gas-turbine engines fuels production from various kinds of feedstock.

2. Jet Fuel Production

2.1. Jet Fuel Production by Direct Oil Distillation

Oil, extracted from the oil wells contains dissolved gases, mechanical impurities in the form of sand and clay (approximately 1.5 %), water (up to 50 % or more), various salts and other chemical compounds injected to the oil well in order to increase oil recovery from strata [4]. All of these products can partially come into jet fuels, produced by direct distillation, and affect their quality. Due to it, oil passes preparatory processes both in the oil fields and in the manufacturing enterprise. They include stabilization with the purpose of removing the above-mentioned components in order to protect equipment from corrosion and favours high-quality products obtaining [6].

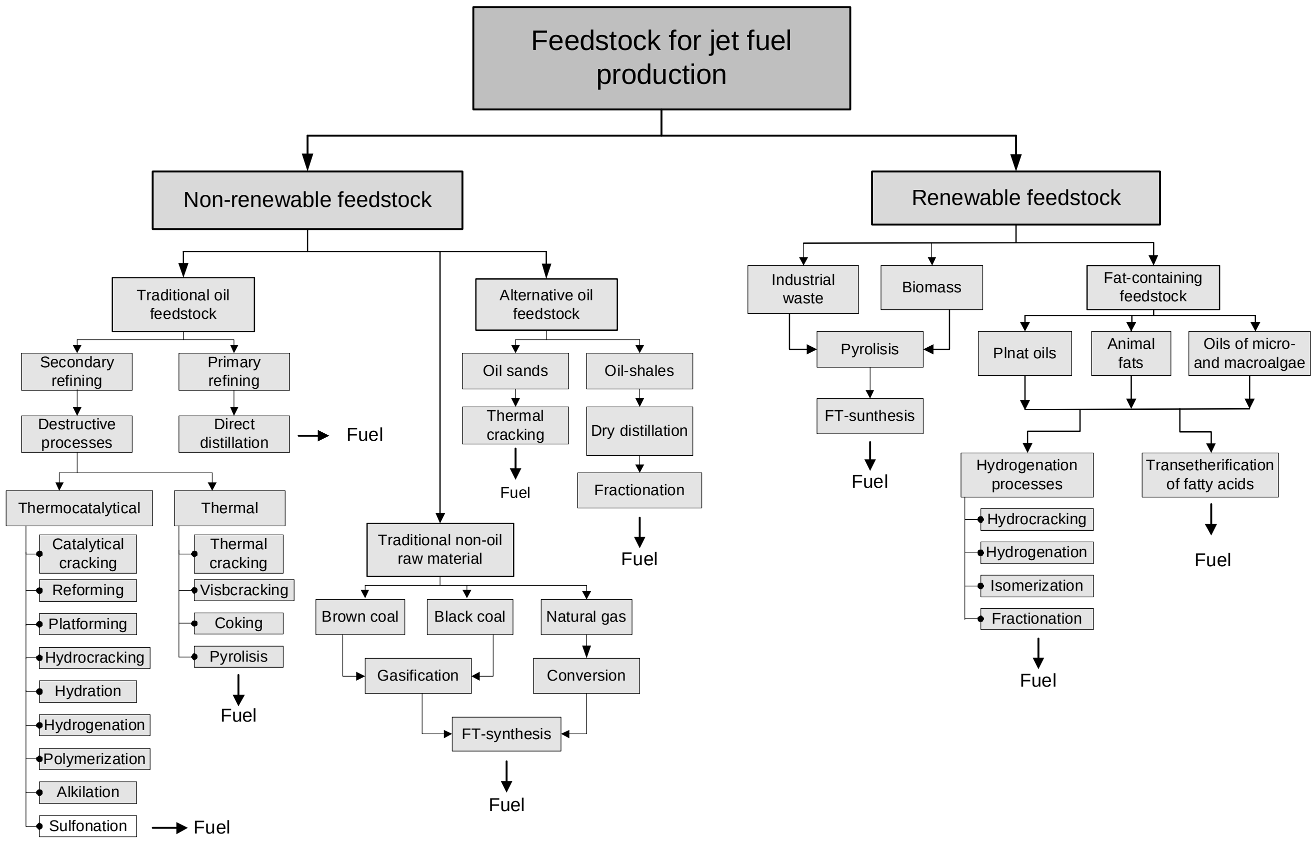

Fig. 4. Classification of ways for jet fuel production from various kinds of feedstock

Then oil is divided into fractions. Jet fuels are represented by middle distillation oil fractions with the boiling range that partially overlaps with the diesel one. They contain different classes of hydrocarbons, heteroatom compounds and inorganic impurities [5]. Fractions of jet fuel are obtained at the atmospheric columns. Oil is divided into a large number of fractions, including gasoline, diesel, kerosene, ligroin, and others. As a result of the considerable diversity of the processed oil and its quality, facilities for oil processing also vary greatly. Depending on the composition of crude oil, enterprise equipment and the required amounts of final products (gasoline, jet and diesel fuels), boiling range of fractions and number of factions involved in jet fuel are not the same. For example, to increase the fire safety of fuel, kerosene fraction is taken out with a higher initial boiling point, and to enlarge the resources the final boiling temperature of the kerosene fraction is increased or mixed with gasoline fraction, extracted from the top of the main distillation column [4, 5].

Crude oil fractions of the direct distillation are purified from the compounds worsening the quality of jet fuels. In order to remove some of these compounds, fractions are treated with a solution of sodium hydroxide and washed with water [6, 7]. It allows removal of naphtenic acids, phenols, as well as hydrogen sulphide and mercaptanes. Alkaline salts of petroleum acids and sodium phenolates, formed during purification, show a tendency to hydrolysis, so they are not completely removed. Sodium hydroxide reacts with hydrogen sulphide forming sulphides and sulphates when there is a lack of alkali. Mercaptans react forming sodium mercaptides. Mercaptides, especially macromolecular, are easily hydrolyzed, preventing their retrieval during kerosene fractions cleaning. Therefore, for removal of mercaptans out of jet fuel alkaline cleaning is almost never used. Further step is washing of kerosene fraction after treatment with sodium hydroxide. As it was said, as the result of alkaline treatment naphtenic acids are removed from jet fuel, then it leads to deterioration of anti-wearing properties. Mercaptans are the most undesirable compounds in the gasoline and kerosene fractions that are used for jet fuel. For removal of mercaptans the following processes are applied: plumbating cleaning, purification with copper chloride and “Merox” process [7].

Effective method for the removal of heteroatomic compounds from fuel is hydrotreatment. It means catalytic purification in the presence of hydrogen and catalyst [6]. In those cases, where it is sufficient to remove only mercaptans out of fuel, the treatment is carried out under “soft” regime; if it is necessary to reduce the total amount of sulphur compounds (hydrodesulfurization), fuel is purified under “hard” regime [7]. But in this case, a lower yield of liquid products and a greater consumption of hydrogen are observed. During hydrotreatment the compounds that play a role of natural oxidation inhibitors, and surface-active substances improving the anti-wearing properties of fuels are also removed along with undesirable substances. Therefore hydrotreated fuels are injected with antioxidant and anti-wear additives or hydrotreated component (up to 70 %) is mixed with the factions of direct distillation [6]. The further increasing of hydrotreating regime hardness leads to partial hydrogenation of aromatic hydrocarbons (hydrodearomatization process) [7]. Reactions of condensation and coke formation during hydrodearomatization are almost not observed. Liquid products yield during hydrodearomatization is about 94–95 %. However, nowadays this process is almost not used, because it became possible in some cases to increase the permissible content of aromatic hydrocarbons in fuel [6].

2.2. Jet Fuel Production by Destructive Oil Refining

In order to increase the yield of high-quality light oil from crude oil the secondary oil refining processes are used [6]. It involves oil processing with cracking (destruction) of heavy hydrocarbons into lighter ones. Such processes are known as destructive ones [6]. They include thermal processes, based on the cability of organic compounds to break down and chemically change under the influence of high temperatures (thermal cracking, visbcracking, coking, and pyrolysis). Thermal-catalytic processes are also used; they are based on the application of different catalysts to accelerate the chemical reactions (catalytic cracking, reforming, platforming, hydrocracking, hydration, hydrogenation, polymerization, alkylation, sulfonation, *etc*.). Let us consider some of them in details.

One of the destructive oil refining processes is hydrocracking [5, 6]. The given process is used to produce jet fuels from high-boiling vacuum oil distillates. Hydrocracking catalysts contain metals of platinum group, as hydrogenation components, such as nickel, molybdenum, tungsten, cobalt placed on amorphous and crystalline aluminosilicates. Due to such catalysts the increased amounts of *iso*-alkanes are produced during hydrocracking, which makes it possible to get jet and diesel fuels from heavy distillates without deparafinization process. As the result gasoline, or predominantly (not less than 70 %) jet or diesel fuels are produced from the same raw material. This peculiarity of the process is especially important, because it allows to vary the volume of produced fuel taking into account the necessity, including the seasonal one. Jet fuels after hydrocracking have freezing point below 213 K and contain some aromatic hydrocarbons (≈ 10 %). Similarly to hydrotreated fuels, they virtually have no heteroatomic compounds. To reduce the tendency of fuels to oxidation and improve their anti-weaing properties it is better to introduce the appropriate additives [5].

During the deep hydrogenation process the jet fuel is obtained from kerosene-gasoil distillates of straight run distillation of selected oils or products of catalytic cracking, containing more than 60 % of aromatic hydrocarbons. During the process, aromatic hydrocarbons are converted into naphthenes. Appropriate selection of raw material allows receiving a fuel that contains mainly naphthenes of high density (840 kg/m^3 at 293 K), low sulphur content (< 0.01 %), alkenes (iodine value < 0.2 g I_2/100 g) and existent gums (< 3 mg/100 ml). There is an assumption [6] that almost all heteroatomic compounds and alkenes undergo hydrogenation. Due to the low content of natural antioxidants in the products of hydrogenation, there is a necessity to introduce additives into the fuel. Despite the absence of surfactants, the product possesses satisfactory anti-wearing properties due to its relatively high viscosity.

Currently on the territory of Ukraine three types of jet fuel are adopted for the air jet engines: RT, TS-1 and Jet A-1 [5]. All of them are produced *via* the primary and secondary oil refining processes.

TS-1 fuel. This kind of fuel is usually used in subsonic and supersonic aircrafts with a limited duration of supersonic flight. It is produced both as a straight-run and mixed fuel with hydrotreated component. In the latter case, hydrotreated component is added to the oil straight-run fraction [3]. Technical characteristics of the given fuel are defined by the industrial standard of Ukraine. Technological scheme of TS-1 fuel production is schematically shown in Fig. [3, 6].

RT fuel. RT fuel is usually hydrotreated. It meets the requirements for the fuel TS-1, and can replace it. Additionally, it is more thermally stable and allows heating in the fuel system of aircraft to higher temperatures, and thus can be applied in more heat-stressed engines of aircraft with the increased length of supersonic flight [3]. Requirements to RT fuel are determined by the industry standard of Ukraine. Technological scheme of RT fuel production is schematically shown in Fig. 6 [3, 6].

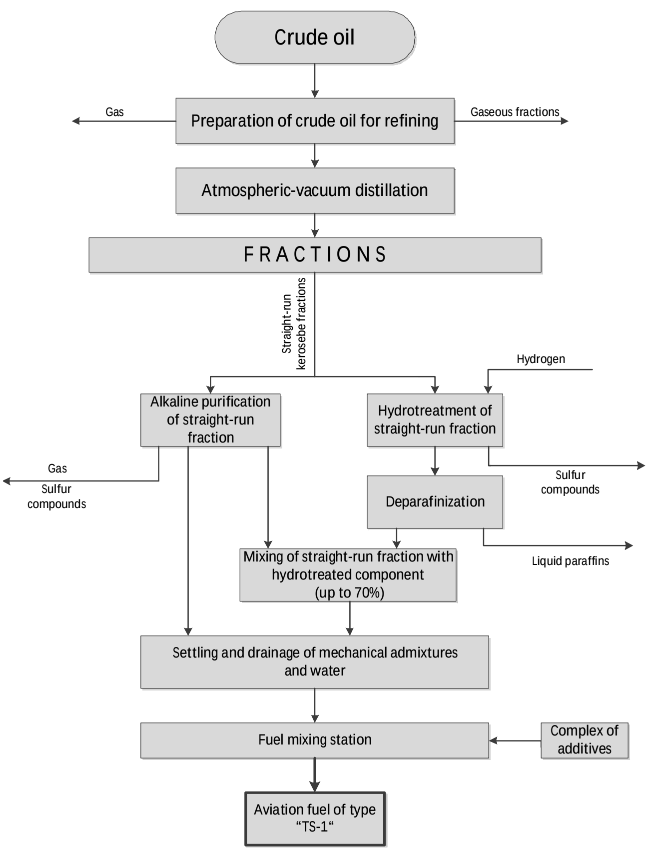

Fig. 5. Technological scheme of TS-1 fuel production

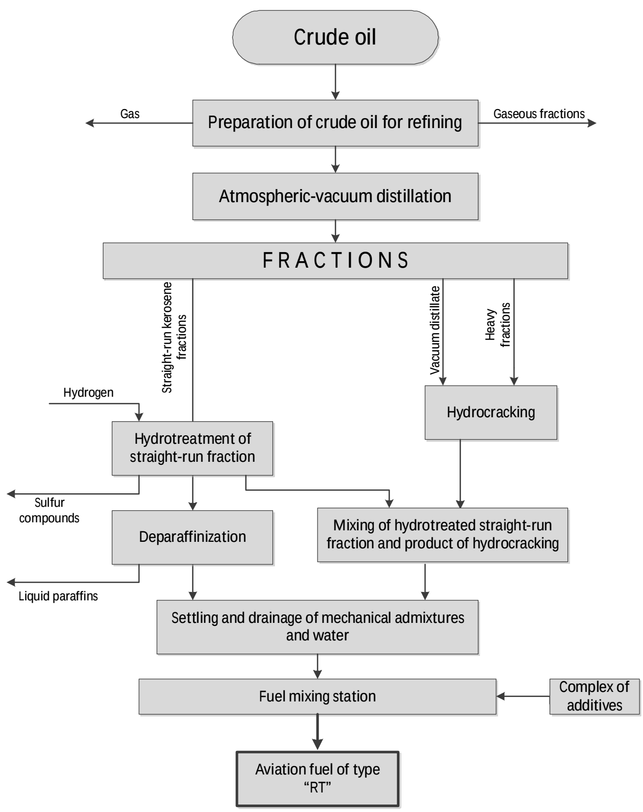

Fig. 6. Technological scheme of RT-fuel production

Jet A-1 fuel. Aviation fuel Jet A-1 is a kerosene oil-derived fuel and used for the majority of gas-turbine engines. It is characterized by a little bit higher flash point temperature and self-ignition temperature comparing with fuels TS-1 and RT. This type of fuel is used throughout the world and meets the requirements of ASTM, DEF STAN, IATA Guidance Material (Kerosene Type), NATO Code F-35 [5]. In Ukraine, the quality of the fuel Jet A-1 is defined by the standard of Ukraine. Technological scheme of Jet fuel A-1 production is schematically shown in Fig. 7 [3, 5, 6].

Having analyzed the technological schemes of fuels for jet engines production, we made a conclusion that the simplest technology is production of TS-1 fuel. It is obtained by the direct distillation and only in some cases can be mixed with hydrotreated components. In their turn, fuel brands JF and Jet A-1 are the mixing ones. During the production process a number of secondary oil refining processes are applied in order to increase the quantity and quality of the manufactured products. However, such technologies are more power-consuming and require significant investments.

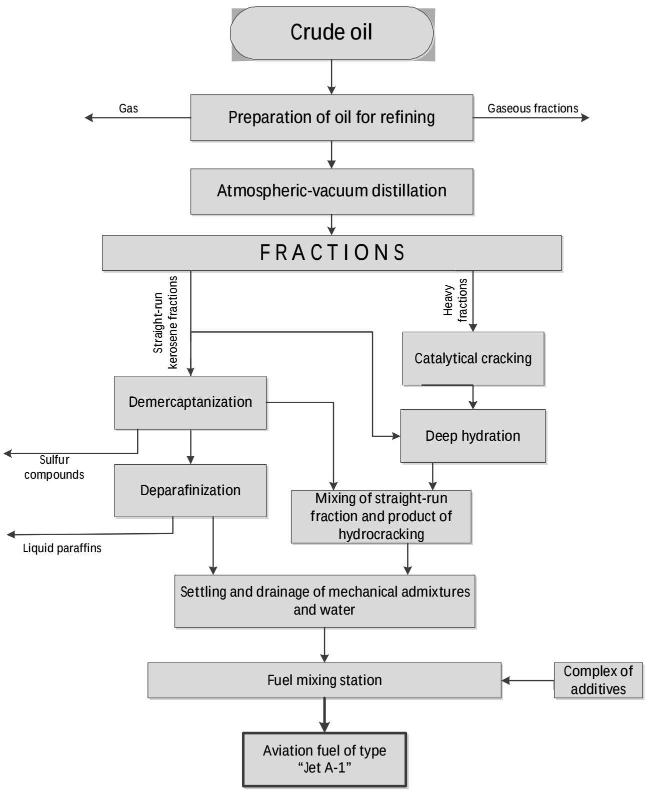

Fig. 7. Technological scheme of Jet A-1fuel production

As it was stated earlier, the aircraft exhaust gases contain a number of substances that are harmful to the environment, both at the global and local levels. Carbon dioxide, sulphur oxides, methane, carbon monoxide, soot, nitrogen oxides, unburned hydrocarbons and others should be referred to such substances. Ecological characteristics of modern oil-derived fuels for jet engines are determined primarily by their content of heteroatom compounds, such as sulphur. Sulphur compounds affect the content of sulphur oxides in the exhaust gases of the aircraft and therefore their toxicity. Thus, in order to reduce the negative impact on the environment, the sulphur content in oil-derived fuels should be reduced. For this purpose a number of technological processes described earlier are used. In addition, exhaust gases contain soot. The presence of soot is caused by the quality of oil used for fuel production, namely its component composition – the amount of aromatic hydrocarbons.

It should be also said about the impact of production processes and use of traditional oil-derived fuels for gas turbine engines on greenhouse gas emissions. The main product of aviation fuel combustion is CO_2. There is a certain amount of carbon dioxide on the planet that is in a state of dynamic balance. Production of fuels for air jet engines is associated with extraction of oil from the Earth, which inevitably leads to imbalance and increase of CO_2 amount in the atmosphere. As a result, the strengthening of global greenhouse effect on the planet is observed.

2.3. Jet Fuel Production by Oil-Shale Refining

Technology of jet fuel production from oil-shales is well-known and established one. Oil-shales are solid sedimentary rocks composed mainly of carbonate and silicate minerals. There are 50–80 % of inorganic substances and 20–35 % of kerogen (sometimes up to 50 %) in the dry matter of oil-shales [2]. Kerogen contains aromatic, acyclic, and also organic oxygen-and sulphur-containing compounds, practically insoluble in organic solvents. The base part of the oil-shales refining process is dry distillation in a retort (Fig. 8), where oil-shale itself is subjected to the pyrolysis at temperature of about 753–813 K. Shale kerogen decomposes with formation of gasoline gas, pyrogenetic water, flammable gases and vapours of shale tar. In the following processes, shale tar can be distilled like the traditional oil.

Processes of oil-shale dry distillation can be divided into two types – with direct and indirect heating [9]. The process, where the resulting gas is burned, is a typical process with direct heating. Retort for dry distillation of oil-shales is a vertical veneered in the middle part refractory brick chamber, where crushed shale is constantly moved down and heated to a temperature of dry distillation with hot gases, rising up and contacting with the solids. At the same time kerogen is thermally decomposed, releasing vapours of shale tar and exhaust gases which are cooled by new oil-shale during their moving up. Fresh oil-shale is fed from the top. Then gases are removed from the retort and sent to the cooling system and the separation. Shale tar is separated by passing of cooling vapours and gases through a special refrigerator, from which part of the fuel gas returns to the retort of dry distillation [10].

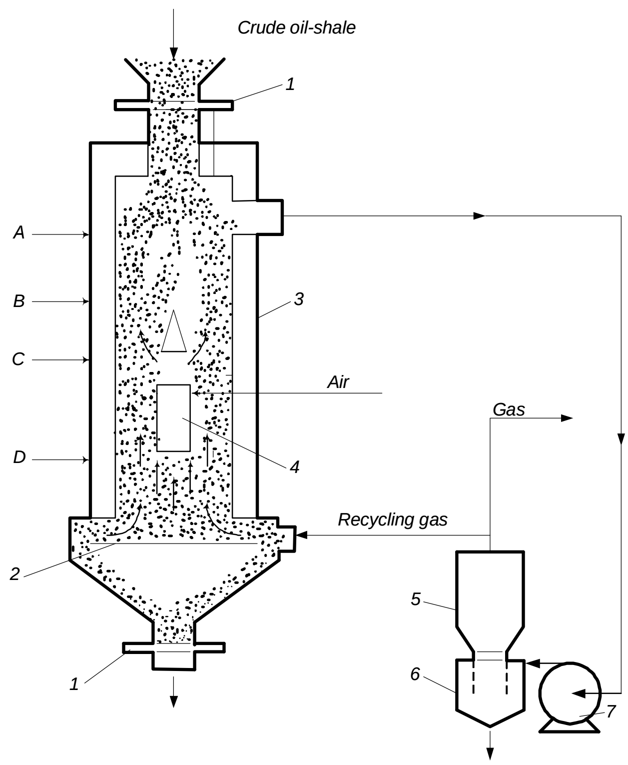

Fig. 8. The scheme of installation for dry distillation of oil-shales [9]: gas firming (1); disc feeder (2); retort (3); mixing camera (4); electrostatic mixer (5); centrifugal separator (6) and air blower (7). Zones: cooling of kerogen decomposition products (A); dry distillation (B); gas burning (C) and heat exchange (D)

Shales dry distillation can be performed both after their extraction on the surface, and directly in the places of layers natural occurrence. In the latter case underground oil-shales are heated to the temperature of dry distillation of 723–813 K by burning some part of the shale or introduction of exhaust gases, such as natural gas, or overheated water steam. Then the product is pumped to the surface [9]. The main advantage of underground oil-shales processing is absence of need for its extraction, transportation to the dry distillation plant and removal of the ash, remaining in the form of wastes.

Shale tar is applicable for mid-distillate fuels production like diesel and kerosene. However it has a high density, medium sulphur, nitrogen and unsaturated hydrocarbons content. Density and freezing point of shale tar are higher than those of many oil fractions with the same viscosity. Production of jet fuels from oil-shales by the method of high-temperature dry distillation requires hydrotreating to reduce the content of mentioned organic compounds and to improve its quality. For this purpose, such additional processes as visbreaking, catalytic hydrotreating and hydrocracking that should be implemented at the facility or in the vicinity of the installation for oil-shales dry distillation. In general, production of jet fuel from oil-shales of appropriate quality is connected with deeper processing and higher expenses than the production of fuels from crude oil [9]. Today, there is an already developed and approved oil-shale processing technology that includes fractionation, prolonged coking and hydrocracking. This technology is schematically presented in Fig. 9 [9].

Fuel for gas turbine engines, obtained by processing of oil-shales has the average content of aromatic hydrocarbons (10–25 %) and does not cause problems associated with lubricating qualities. Moreover, it shows a high level of stability during long-term storage [2, 9]. Jet fuels produced as a result of oil-shales processing are now approved for use in both civil and military aviation.

Volumes of greenhouse gases emitted as a result of oil-shales refining depend mostly on applied processing technology. Totally, processes of oil-shales refining and fuel manufacturing require considerably larger energy inputs than during crude oil refining, and consequently emissions of greenhouse gases are also more significant. Moreover, formation of greenhouse gases is influenced by such factors as construction of installation for oil-shales refining, use of electric power for installation heating, way of energy obtaining, value and quality of by-products, availability of device for CO_2 and other gases recovery [2].

As it was already mentioned, production processes of jet fuels from oil-shales include stages of deep hydrotreatment. Finally, we obtain the product with low content of sulphur and in some cases (depending on applied purification method) the product with low content of aromatic hydrocarbons. Thus, implementation of aviation fuels produced from oil-shales, provides considerably low content of sulphur oxides and solid particles in exhaust gases of aircrafts [2, 10].

2.4. Jet Fuel Production by Coal Processing

Fisher-Tropsh method or process (FT-process) is a widely known technology of fuel production since the World War II [11]. The main feedstock, used for this technology is black and brown coal. Moreover, natural gas and biomass are also successfully used today [12]. FT-process includes four main stages. The first one is obtaining of synthetic gas which is a mixture of hydrogen and carbon monoxide ($CO+H_2$). Syngas is obtained as a result of coal gasification, *i.e.* its treatment with saturated water vapour at high temperatures and average pressure. Syngas, coming from coal gasifier contains the considerable amount of carbon dioxide and certain percentage of gaseous substances, formed by additives present in the raw material, for example, sulphur. Both CO_2 and other compounds negatively influence FT-process proceeding. That is why the next important stage is elemination of harmful substances from synthetic gas flow. This process is connected with the considerable emissions of CO_2 into the atmosphere. The next stage is the catalytic process of carbon monoxide hydration with application of iron and cobalt catalysts with further formation of liquid hydrocarbons mixtures: alkanes, olefins, paraffins, alcohols, *etc*.

Changing the reaction conditions it is possible to vary ratios of obtained fractions. After finishing the FT-process, synthesized fractions of hydrocarbons are treated in the way similar to the processes of fuel production from crude oil (Fig. 10) [2]

Obtained fractions are characterized by almost zero content of sulphur heteroatom compounds. The major part of obtained products is used for production of jet and diesel fuels. Fuels, obtained by FT-process, contain paraffin hydrocarbons, comparing with conventional kerosene, aromatic hydrocarbons are practically absent [2]. As a result, their tendency to soot formation is considerably lower, and they are more thermally stable. In addition, jet fuel obtained during coal processing possesses a higher combustion value, so its consumption during flight is less. However, the results of experiments indicate [12-14] that such fuel has worse lubricating properties and this fact requires application of additives.

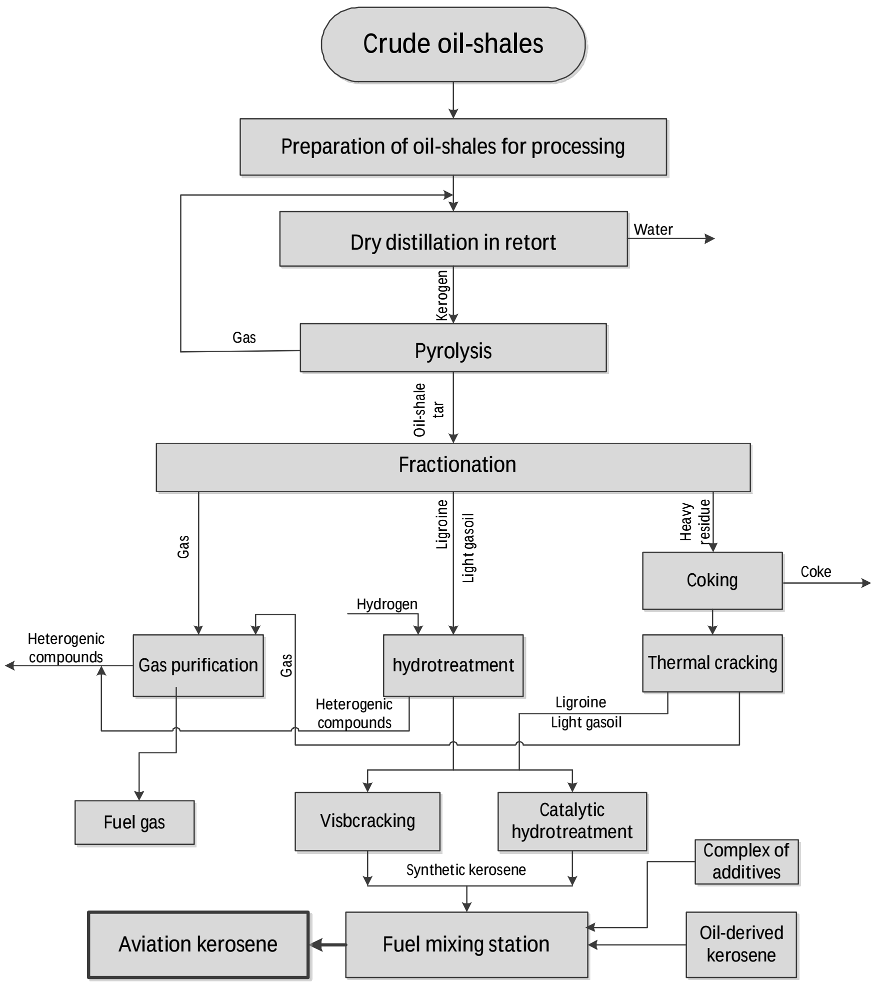

Fig. 9. Production of jet fuels from oil-shales by processing [9]

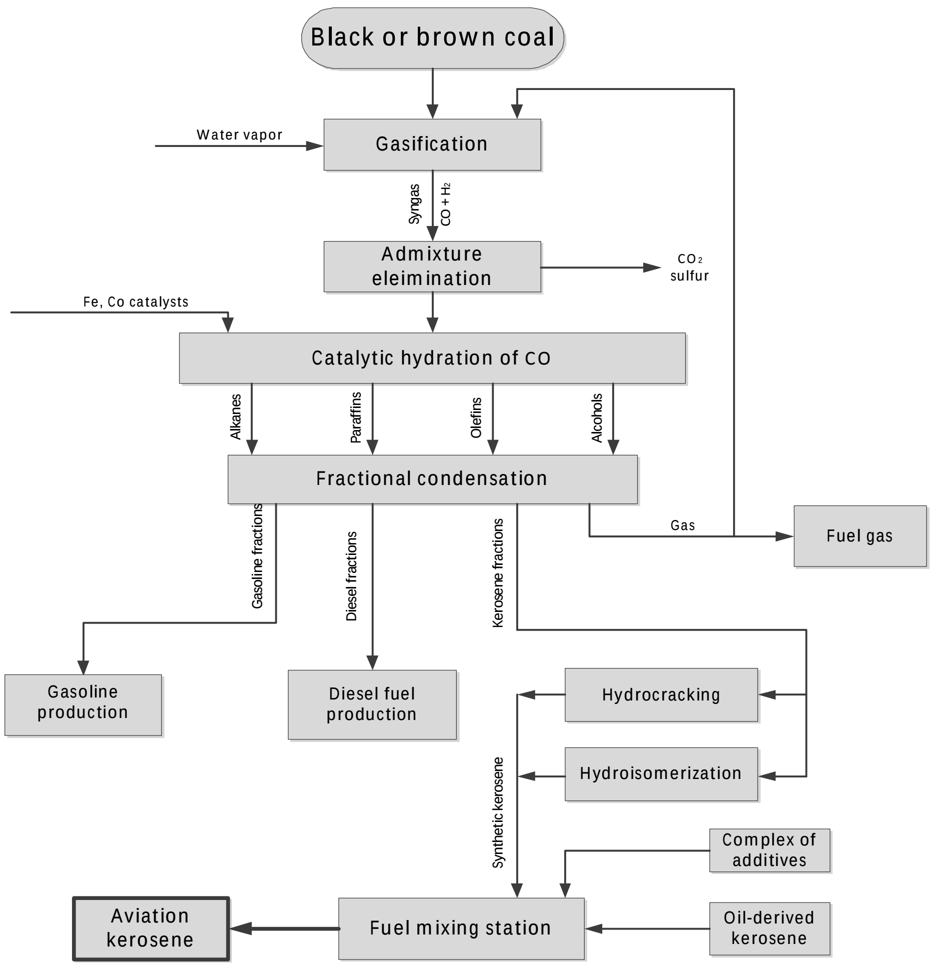

Fig. 10. Scheme of jet fuel production by coal processing [2]

As it was already mentioned, natural gas is widely used along with coal for jet fuel production by FT-process [15]. The main component of natural gas is methane. As a result of FT-process the above mentioned synthetic gas ($CO+H_2$) is obtained, then by the method of catalytic hydration a mixture of various hydrocarbons is formed and used for jet fuel manufacturing. Technological scheme of fuel production for air jet engines from natural gas is similar to the scheme, where coal is used, but the exception is the absence of the first preparatory stage of coal gasification. This technology is described in detailes in scientific works [2, 5, 9, 11].

As it is known [2, 5, 11, 14] implementation of technologies for both natural gas and coal processing leads to considerable emissions of CO_2 and other substances. Thus, according to data [2], during the process of synthetic jet fuel production from gas, the volume of discharged greenhouse gases is by 1.8 times and from coal is by 2–2.4 times higher than those from oil refining. Besides the peculiarities of coal treatment, its chemical composition also plays an important role. For example, the use of bituminous coal as a raw material is accompanied by CH_4 emissions that are also a greenhouse gases. It should be mentioned that during combustion of fuel produced from natural gas, sulphur emissions are absent.

3. Conclusions

In the given article the analysis of traditional technologies, applied for jet fuel production is carried out. Thus, the most popular and wide spread ones are the methods of fuel production by direct oil distillation and secondary (destructive) oil refining. Moreover, there are already known and well developed technologies of aviation fuel production from non-oil feedstock – oil-shales, coal and some other resources. Each of technologies described in the article has its own peculiarities and advantages. However, the discussed technologies are usually more complicated, expensive and require considerable investments comparing with traditional oil refining. Besides, the common thing for these methods of fuel production is the use of fossil raw material, which sources are finally limited. Another aspect of fossil fuel usage for aviation fuel production is connected with emissions of harmful exhaust gases during combustion in aviation engines. Therefore, today scientists are actively engaged in the development of alternative technologies of jet fuel production from renewable sources, being able to substitute the traditional fuel and decrease the negative impact on the environment in the future.

On the basis of carried out analysis, the existing nowadays methods of fuels for gas turbine engines production were classified, depending on the primary raw material, used for the production process. Given classification scheme presents a set of methods for jet fuel production from renewable feedstock. These technologies suppose application of biomass, vegetable oils and animal fats, oils of micro- and macroalgae, various agricultural and wood processing industry waste, *etc*. The most investigated and widely known alternative technologies of jet fuel production are represented by synthetic aviation kerosene, obtained from biomass by FT-process, biokerosene based on ethers of plant oils or animal fats, and also hydrotreated vegetable oils. Peculiarity of given types of fuel is the consumption of natural, renewable, mostly plant raw material. At the same time general carbon dioxide balance in the nature is not disturbed because plants consume carbon dioxide required for their development from the atmosphere. Also it should be mentioned that use of aviation biofuel allows to considerably decrease the toxicity of aircrafts exhaust gases. First of all it is explained by the absence of heterogenic compounds in biofuels, such as sulphur, nitrogen and others that negatively influence the composition of exhaust gases. Thereby, the use of natural plant raw material during jet fuel production processes will help to solve the problem of dependence on non-renewable energy sources and minimize impact on natural environment.

Taking into account all above mentioned factors, we see the necessity for future investigation and development of alternative technologies of fuel for gas turbine engines production from renewable plant feedstock.

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ПРИЧИННО-НАСЛІДКОВИЙ АНАЛІЗ СУЧАСНОГО СТАНУ ВИРОБНИЦТВА ПАЛИВ ДЛЯ ПОВІТРЯНО-РЕАКТИВНИХ ДВИГУНІВ

Анотація. *Приведено основні методи виробництва палив для повітряно-реактивних двигунів (ПРД). Розглянуто перспективи використання різних видів сировини для одержання реактивних палив в контексті обмеженості світових запасів нафти та інших видобувних енергоресурсів. Проведено аналіз впливу процесів добування, перероблення сировини, а також виробництва і використання авіаційних палив на довкілля. Як альтернативу традиційним сировинним ресурсам для виробництва палив для ПРД запропоновано застосування різних видів природної відновлювальної сировини.*

Ключові слова: *сировинні ресурси, повітряно-реактивний двигун, довкілля, відновлювальні види сировини, відпрацьовані гази, біопаливо.*