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OVERVIEW OF INNOVATIVE TECHNOLOGIES FOR AVIATION FUELS PRODUCTION

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Abstract. The article outlines problems of aviation industry connected with limitation of energy resources for aviation fuels production. Main ecological problems connected with application of conventional jet fuels are determined. Modern trends for transition from conventional aviation fuels to alternative ones are presented. The most popular technologies for alternative fuels production are discussed. Advantages of biofuels implementation in aviation are defined.

Keywords: energy resources, jet fuel, alternative aviation fuel, biokerosene, biomass.

1. Introduction

Nowadays aviation is faced to a number of problems. One of them is constant growth of prices for jet fuel. According to [1, 2] prices for turbine aircrafts fuel (which make about 20 % of all exploitation expenses of aviation companies) are rapidly rising and there is no way back. However, the question is not just in prices, but rather in world energy resources. According to statistical data, deposits of oil are estimated for 40 years, natural gas and coal – 70 and 230 years, respectively. So the resources are being exhausted but their demand is growing [3]. During the 10-year period (since 1992 till 2002) the level of turbine fuel consumption has increased by 21 %, while the volume of passenger transporting has risen up to 53 % [2].

Another side of the problem is ecological situation and contribution of aviation industry to its worsening. Air transport has an impact on the environment both at local (atmospheric and noise pollution) and global (global warming, greenhouse gas emissions) levels. In terms of global pollution, air traffic is responsible for direct and indirect emissions of several greenhouse gases: water vapors, carbon dioxide, tropospheric ozone, methane, *etc.* [2].

Traditionally fuels for aircraft engines are produced from crude oil [4, 5]. As it is known, aviation fuel production is one of the prior directions in world oil-gas industry. First of all it is explained by the increasing number of aircrafts all over the world. However, taking into account limited world oil resources, the search for new alternative kinds of fuel, which could replace the traditional ones, becomes more and more topical. There is a tendency to develop progressive technologies for production of synthetic fuels and make their application in aviation more rational and effective. Scientists all over the world are looking for possibilities to use renewable resources for fuel production in order to satisfy not only physical-chemical and exploitation requirements to aviation fuels but also to improve their ecological properties [2, 6, 7].

Today a number of foreign organizations pay much attention to investigation of existing technologies for jet fuel production. According to [4, 5] research efforts are targeted at alternatives to traditional jet fuel derived from conventional oil, which would become available in the next decade, to help reduce problems of commercial aviation industry. Five different groups of fuel are determined according to the raw material used [2]:

1. derived from conventional oil;
2. derived from unconventional oil (oil sands and oil shale);
3. derived synthetically from natural gas, coal, or combinations of coal and biomass *via* the FT-process;
4. derived from renewable oils (biodiesel, biokerosene, hydroprocessed renewable jet – HRJ or hydrotreated vegetable oil – HVO);
5. derived from alcohols (ethanol and buthanol). However, they are suitable for motor transport but not for aviation.

This article offers basic overview of the new alternative technologies for jet fuel production. However, first of all it is necessary to make a short description of the traditional technology for jet fuel production.

2. Basic Material

As it is known, crude oil is the most common raw material for turbine fuel as well as for other fuels and lubricants. Oil consists of hydrocarbons of various structures, some amount of heteroatomic componds, which include sulfur, nitrogen and inorganic admixtures. Based on [6, 7] there are two ways of oil processing into aircraft engine fuel. According to the first one, known as primary oil processing, hydrocarbon cuts with necessary physico-chemical properties are taken out from crude oil and purified from harmful admixtures. The second way implies chemical transformation of hydrocarbons, change of their composition and form in order to achieve some definite properties of fuel. It is known as secondary oil processing. It includes thermal and thermal-catalytic processing of oil and its purification. Today the main volume of aviation fuel is produced by the first way while the second one is used mainly for obtaining certain fuel components. In general, turbine fuel quality depends on the chemical composition of oil used for its production. In order to satisfy modern requirements to fuels, various additives are applied to improve one or several exploitation characteristics of fuel [4].

As it was said, the traditional raw material for aviation fuels production is crude oil. Thus, there is a need to define what fuel is considered to be alternative. According to the law of Ukraine on Alternative Kinds of Fuel [9], fuel is considered to be alternative if:

- it is fully made of unconventional and renewable sources (including biomass);
- it is a mixture of conventional fuel and alternative one in percentage determined by the certain specification;
- it is made of oil, gas, non-industrial oil and gas condensate field, exhausted fields, heavy naphtha, etc and differs from the requirements to traditional kind of fuel.

The main requirements to the quality of jet fuels are established by International Air Transport Association – IATA, American Society of Test Materials – ASTM, British specification – DERD and so called «Check List». The most widely used jet fuel for civil aviation is Aviation Turbine Fuel – Kerosene Type specified as Jet A-1 [4]. Quality of this aviation turbine fuel is determined by the following standards:

- Def Stan 91-91 Turbine fuel, Kerosene type, Jet A-1;
- ASTM D1655 Standard Specification for Aviation Turbine Fuels;
- ASTM D 7566 Standard Specification for Aviation Fuel Containing Synthesized Hydrocarbons.

Defense Standard 91-91 is the standard for aviation turbine fuel, which the United Kingdom Civil Aviation Authority (CAA) has agreed, is under the technical authority of the Head Defense Fuels Group. This Defense Standard specifies the requirements for one grade of kerosene type aviation turbine fuel intended for use in aircraft gas turbine engines. Jet fuel, specified in the Def Stan 91-91 specification, shall consist predominantly of refined hydrocarbons derived from conventional sources including crude oil, natural gas liquid condensates, heavy oil, shale oil, and oil sands. Previously this Standard has only permitted those fuels solely derived from petroleum sources. However, today this Standard has to encompass and control the use of fuels containing hydrocarbons synthesized from several non-petroleum sources. Synthetic Paraffinic Kerosene according to the Standard may be used, either individually or in combination, as blending components in Aviation Turbine Fuels meeting the requirements of this standard at up to a total combined 50 % synthetic component by volume. It should be mentioned that Def Stan 91-91 does not cover the process jet fuel blends of fully synthetic jet fuel is produced. It just determines technical characteristics these kinds of jet fuel should meet [10].

ASTM D1655 specification similarly to Def Stan 91-91 defines specific types of aviation turbine fuel for civil use in the operation and certification of aircraft and describes fuels found satisfactory for the operation of aircraft and engines. The specification can be used as a standard in describing the quality of aviation turbine fuels from the refinery to the aircraft. Two types of aviation turbine fuels are provided according to this Standard: Jet A and Jet A-1–relatively high flash point distillates of the kerosene type. Jet A and Jet A-1 represent two grades of kerosene fuel that differ in freezing point. Aviation turbine fuel, the same as under Def Stan 91-91, shall consist predominantly of refined hydrocarbons derived from conventional sources including crude oil, natural gas liquid condensates, heavy oil, shale oil, and oil sands. The use of synthesized hydrocarbons from new sources requires specific guidance that is currently outside the scope of Specification D1655. This guidance is found in Specification D7566. ASTM D1655 Standard describes also such issue as application of various additives to aviation turbine fuels (fuel system icing inhibitor, corrosion inhibitor, lubricity improvers, biocidal additives, antioxidants, and others) [11].

This specification ASTM D7566 covers the manufacture of aviation turbine fuel that consists of conventional and synthetic blending components. It defines specific types of aviation turbine fuel that contains synthesized hydrocarbons for civil use in the operation and certification of aircraft and describes fuels found satisfactory for the operation of aircraft and engines. The specification is intended to be used as a standard in describing the quality of aviation turbine fuels and synthetic blending components at the place of manufacture but can be used to describe the quality of aviation turbine fuels for contractual transfer at all points in the distribution system. Two grades of aviation turbine fuels are provided by this Standard: Jet A and Jet A-1– relatively high flash point distillates of the kerosene type. According to this Standard aviation turbine fuel, shall consist of the following blends of components or fuels: conventional blending components of Jet A or Jet A-1 fuel certified to specification D1655; with up to 50 % by volume of the synthetic blending component defined by this specification. ASTM D7566 comprises only two kinds of technologies for blending component production:

1. Hydroprocessed synthesized paraffinic kerosene wholly derived from synthesis gas via the Fischer-Tropsch (FT) process using Iron or Cobalt catalyst. Subsequent processing of the product shall include hydrotreating, hydrocracking, or hydroisomerization and is expected to include, but not be limited to, a combination of other conventional refinery processes such as polymerization, isomerization, and fractionation.

2. Hydroprocessed synthesized paraffinic kerosene wholly derived from hydrogenation and deoxygenation of fatty acid esters and free fatty acids. Subsequent processing of the product shall include hydrocracking, or hydroisomerization, or isomerization, or fractionation, or a combination thereof, and may include other conventional refinery processes [12].

For today, the alternative kinds of raw material comparing to oil are pit, brown coal, oil-shales and natural gas [6, 13, 14]. These materials are also related to fossil fuels. Technologies for jet fuel production using coal and gas are already known for a long time, quit well studied and have been already implemented into production scales [13, 14]. Fig. 1 gives basic representation of existing technologies for jet fuel production according to involved feedstock [13-15].

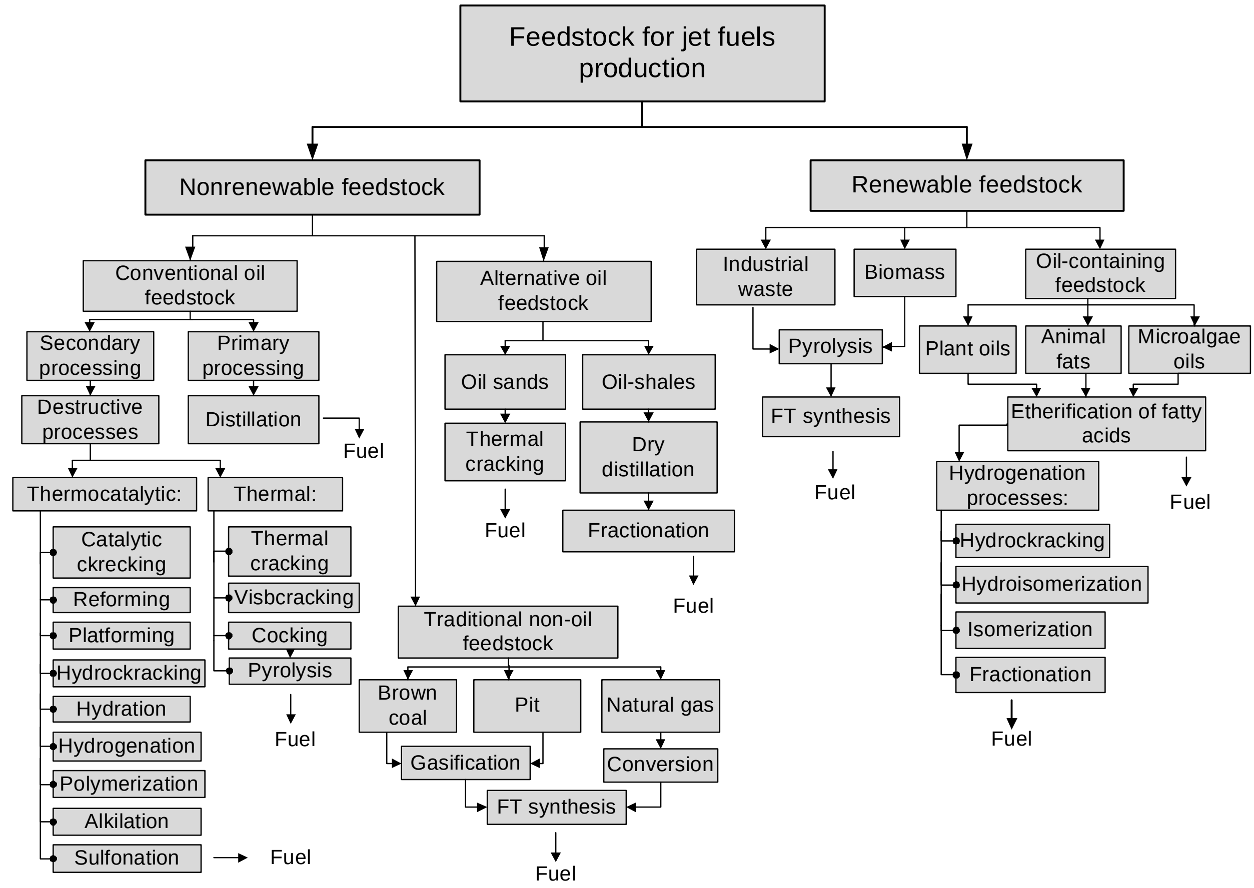

Fig. 1. Classification of technologies for jet fuel production according to the feedstock used [13-15]

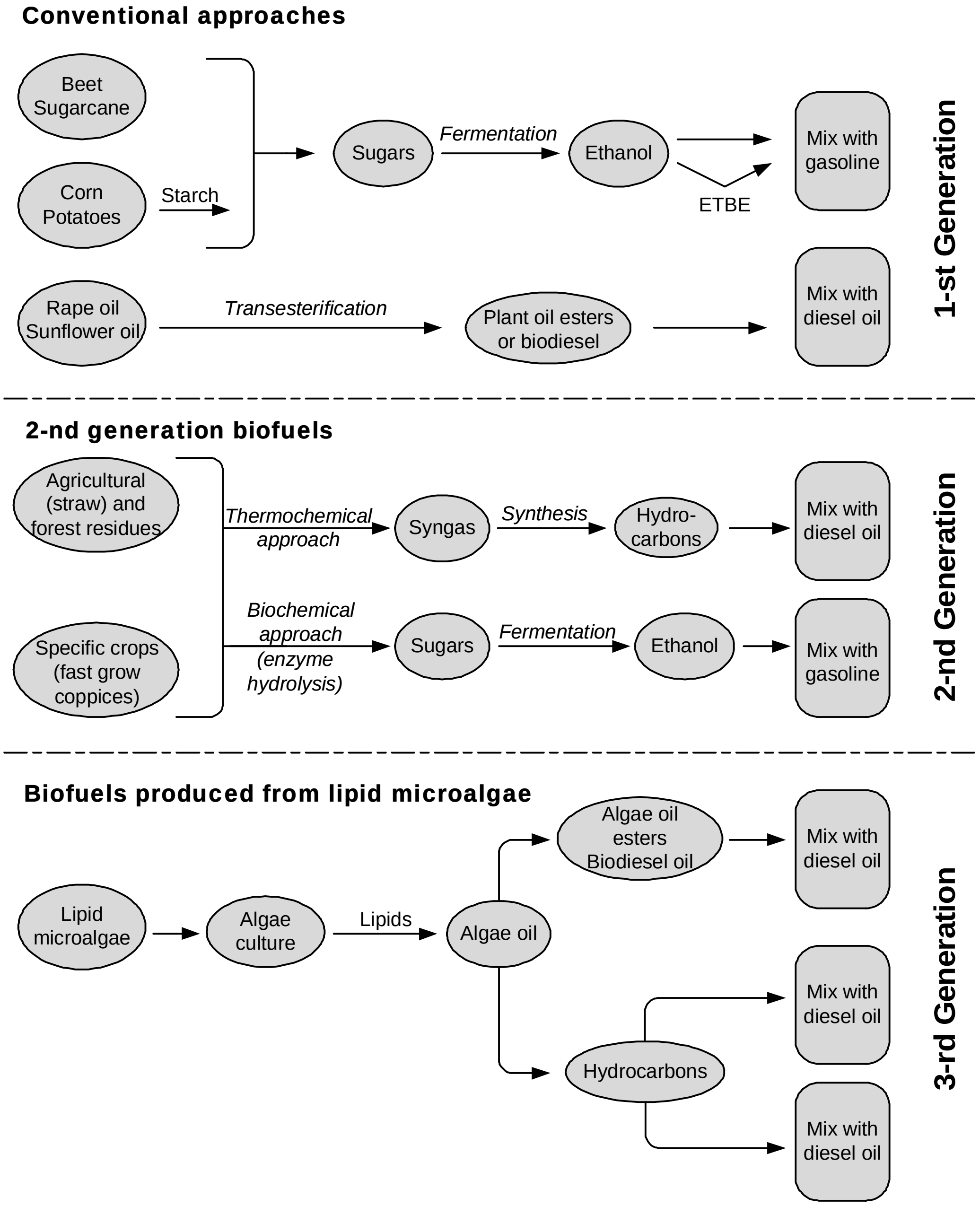

Fig. 2. Development of technologies for biofuels production [2, 15]

As it is seen from the scheme, the bigger part of existed technologies is still directed on the processing of various fossil fuels, such as oil, coal, natural gas, oil-shales, and some others [13, 14, 16]. However, during several decades various renewable resources are being investigated to be processed into jet fuel. The main advantages of renewable energy is that it is of natural origin, can be quickly renewed, does not form extra CO_2 in the atmosphere, poses less negative impact on environment and can be easily decomposed in nature [2, 7]. In general, application of biomass as a feedstock for fuels production is intended onto two global missions: to overcome climate change resulting from CO_2 emissions and to reduce dependence on oil resources (mainly transport sector). However, various kinds of feedstock differ from each other [15]. The distinction is made by their chemical nature: lignocellulosic biomass, biomass with high oil content (plant oils, animal fats), biomass with high sugar and starch content (sugarcane, corn, potatoes, *etc*.). For today there is a great variety of technologies for biomass processing: some of them are already widely used and some are just at the stage of development. According to complexity and the level of maturity, technologies are classified by generations (Fig. 2) [15].

The first generation of biofuels is already available for wide use at gas stations, mixed with gasoline and diesel oil in various proportions up to 100 %. It includes two principal kinds of biofuels: biodiesel intended for diesel engines and produced from oil-containing plants (rape, soya, sunflower, palm, *etc*.) and ethanol, which is alcohol, produced by fermentation of sugar or starch contained in plant biomass and used for gasoline engines [2, 15].

The second generation of biofuels is produced by processing the whole plant – particularly its lignocelluloses, the main component of plant cell walls. The resource is available in large quantities in a variety of forms: wood, straw, hay, forestry waste, plants residues, *etc*. The second generation processes do not compete with food uses. The objective is to produce fuels that can be used either directly or in blends with gasoline, diesel fuel or kerosene. Two processes are being studied: biochemical conversion and thermochemical conversion [15].

The third generation of biofuels can be produced using either autotrophic (operating *via* photosynthesis) algal biomass or heterotrophic process (operating *via* the supply of an external carbon, such as sugar). Some microalgae can accumulate CO_2 produced by photosynthesis as lipids, present in concentrations of up to 80 % of the dry substance. However, today a number of obstacles still limit the economic and environmental viability of biofuel production from microalgae (production cost, energy consumption, yield, harvesting procedures, *etc*.) [15].

3. Research of Innovative Technologies

3.1. Jet Fuel Production by Fisher-Tropsh Synthesis

One of the most widely known technologies for synthetic fuel production is Fisher-Tropsch (FT) synthesis [2]. It is known since 1920's and was widely used before World War II. The basis of this technology is catalytic process of carbon monoxide hydration with further formation of various liquid hydrocarbons. The process has four main steps. The first step is creation of synthetic gas, which is a mixture of hydrogen and carbon monoxide. When natural gas is the feedstock, this step can be accomplished by one of two methods: partial oxidation or stem reforming. When coal or biomass is the feedstock, this step is accomplished by gasification, during which the feedstock is reacted with steam at high temperatures and moderate pressure.

The synthetic gas leaving the coal gasifier contains large amounts of CO_2, as well as small amounts of gaseous compounds derived from impurities, such as sulfur, that are present in the feedstock. Both CO_2 and impurities have a detrimental effect on FT synthesis. The second main step in the FT process removes these undesirable compounds from the synthesis-gas stream. When coal or biomass is the feedstock, the result of this second step is the release of the concentrated CO_2 stream to the atmosphere. When natural gas is the feedstock, depending on the process applied, synthesis-gas preparation either consumes or causes negligible emissions of CO_2 [2, 16].

The third step is the FT synthesis. During this step, the synthesis gas is passed over an iron- or cobalt-based catalyst under specific process to form a broad mixture of hydrocarbons ranging from gases (such as ethane) to waxes (longer hydrocarbons). By altering the reaction conditions (catalyst, temperature, pressure and time) the distribution of carbon length of the resulting hydrocarbons can be shifted to maximize, for example middle kerosene distillates [13, 14].

After leaving the FT section of the facility, the hydrocarbon product is upgraded to liquid aviation fuels using well-established methods commonly used in petroleum refineries. The outputs of the process can be narrowed to middle distillates and naphtha, both of which have a near-zero sulfur content. The middle distillates can be separated into a mix of automotive diesel and jet fuel.

Today, the most widely-used raw material for synthesis gas production is pit and brown coal. The technology of aviation kerosene production from coal is known as the CtL (coal to liquid) technology. The technology, similar to CtL, but when instead of coal natural gas is used, is called GtL (gas to liquid) technology [2, 16]. These technologies are defined to be quite effective and efficient. However, amounts of CO_2 emissions into the atmospheric air during CtL technology application are even higher than during production of traditional kerosene from oil [2].

Taking into account modern trends for alternative fuels manufacturing, scientists actively investigate and develop possibilities to use renewable feedstock for jet fuel production. The new BTL (biomass to liquid) technology is also used to get synthesis gas for jet fuel production by FT-synthesis [2, 7, 15]. According to this technology the raw material is biomass (wood waste, straw, plant residues, which are used for production of other kinds of biofuel). First biomass comes through the process of pyrolysis and then the obtained liquid mass is used for production of synthesis gas for further FT process. The kerosene fraction obtained using the BtL technology is of very good quality, free from sulfur and other impurities. However, according to the reports [2] the technology is still unmature and needs further investigation so it can be used on industrial scale. Fig. 3 presents technological scheme of jet fuel production by FT synthesis using different feedstock [2, 16].

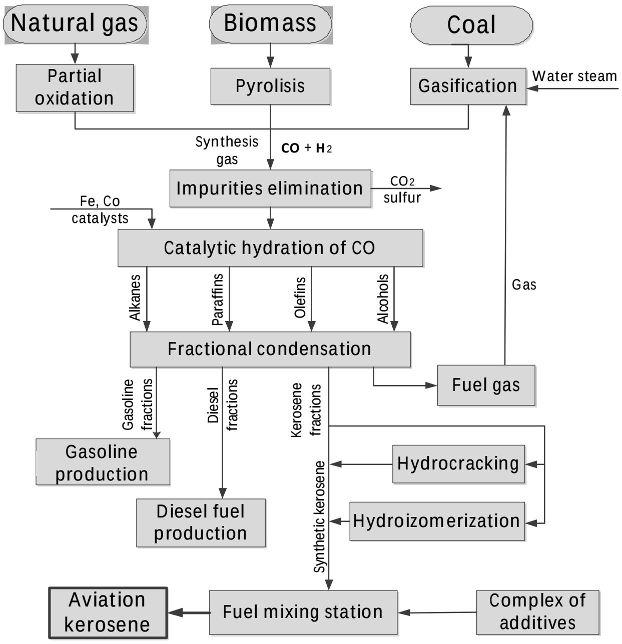

Fig. 3. Technological scheme of jet fuel production by FT synthesis using different feedstock [2, 16]

3.2. Jet Fuel Production by the MtSynfuels Process

The main and the largest by volume product of GtL technology is methane. It may be used for further synthesis of gasoline and other oxygen containing compounds, for example, esters that are used as fuel additives. A new technology of fuel production from methanol during the MtSynfuels (Methanol to Synthetic fuels) process is developed in Germany [16]. It includes the following processes: Megamethanol – process of synthetic gas and methanol simultaneous production, MtP (Methanol to Propylene) or MtO (Methanol to Olefins) – synthesis of propylene or olefins, oligomerization of the obtained olefins with their further hydration and obtaining of synthetic fuels. Fig. 4 presents technological scheme of jet fuel production by MtSynfuels process [16].

The MtSynfuels process is an alternative to FT-synthesis and possesses higher outcome of required products and lower initial expenses [7]. BTL (biomass to liquid) technology is also used to get synthetic gas for aviation fuel production by MtSynfuels process as well as by FT-synthesis [7, 16].

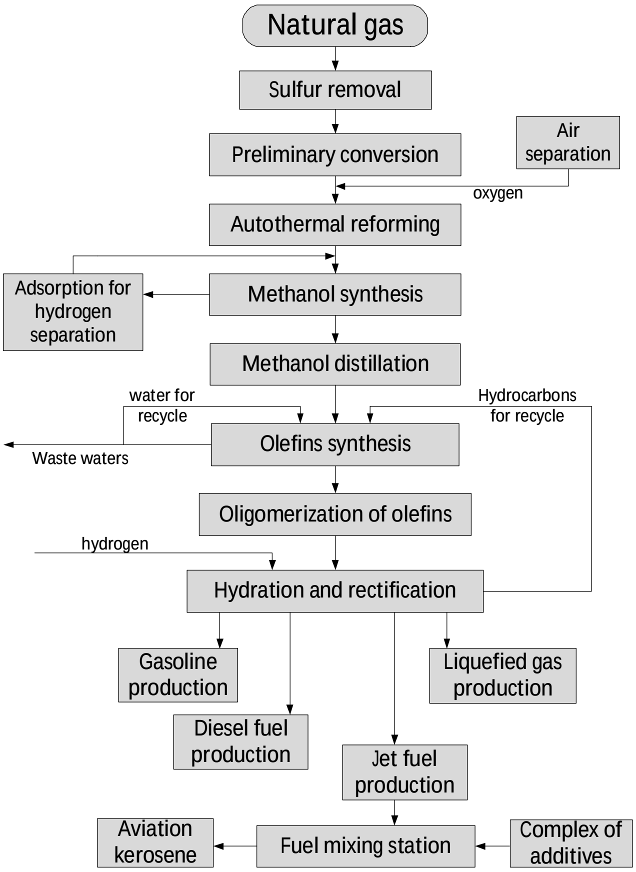

Fig. 4. Technological scheme of jet fuel production by MtSynfuels process

3.3. Technology of Biokerosene Production

There is a direction in development of alternative aviation fuels, which are produced from vegetable oils and animal fats [18]. This kind of alternative jet fuel is known as biokerosene. It is a mixture of traditional oil-derived kerosene and biocomponent in certain concentrations. The content of biokerosene may reach up to 50 %. The technology of biokerosene production was being developed in Brazil during 1980–1985 and it belongs to the first generation of biofuels [15, 17]. Biocomponent is obtained during the process of transetherification of plant oils or animal fats at the presence of methanol or ethanol and some basic catalyst. Chemically, biocomponent is fatty acids of methyl or ethyl esters of vegetable oils (FAME/FAEE) [18, 19].

The technology of biokerosene manufacturing is similar to the technology of biodiesel production [2, 18]. First, seeds of oily plants are pressed in order to extract the oil. Then oil comes to reactor, where the process of transetherification takes place. The reaction proceeds with alcohol (methanol or ethanol) with the presence of catalyst

(KOH or NaOH) at the temperature 343–363 K for 1–2 h. In the result two products are obtained: biocomponent (used for biokerosene production) and glycerine (used for further industrial application). The process of biocomponent production is presented schematically in Fig. 5 [18, 19].

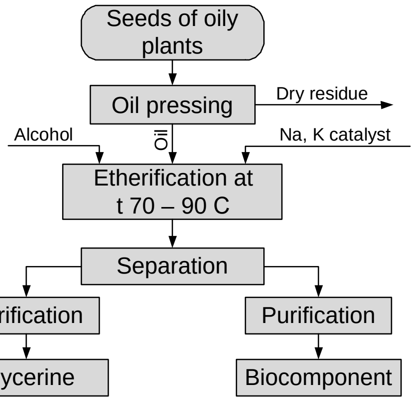

Fig. 5. Technological scheme of biocomponent production

Various oily plants can be used as a raw material for biokerosene production. Depending on the regional and climatic conditions of the territory, the following plants can be grown: rape, sunflower, jatropha, palm, soy, camelina, and a number of other plants. Except plant material, different animal fats, such as waste from food industry, can be used as well. During last years a new kind of raw material for biokerosene production is investigated. Scientists [15] claim that microalgae are dozens of times richer in oil content comparing to plants and they do not need large territories for their cultivation. However, it was already mentioned that the use of microalgae as a feedstock belongs to the third generation of biofuels. Anyway, one of the advantages of such kind of biofuel is that countries, which do not possess oil, gas or coal deposits may easily solve the problem for fuel production [15, 18].

For today, some countries have already conducted successful trial flights, using biokerosene in at least one of the aircrafts engines [17]. Application of this biofuel has shown good antiwearing properties. Biokerosene mixtures possess extra low sulfur content providing better quality of aircrafts exhaust gases. It may also reduce CO_2 emissions significantly and improve global carbon oxide balance. Despite this positive experience application of biokerosene in aviation needs further detailed investigation and optimization of its production technology [2, 15].

3.4. Technology of Hydrotreated Vegetable Oils Production

Another technology developed for alternative jet fuel production is transformation of vegetable oils and animal fats, high in triglycerides and/or fatty acids, into paraffin kerosene cuts as an alternative to fossil kerosene [2]. The process involves processing of oils or fats in the presence of hydrogen in order to remove oxygen they contain (Fig. 6). The product resulting after such processing is called HVO (Hydrotreated Vegetable Oil). Hydrotreating of vegetable oils or animal fats is an alternative process to esterification for producing biobased diesel or jet fuels [2, 13, 14]. Hydrotreated products are also called renewable diesel or jet fuels.

Chemically hydrotreated vegetable oils (HVOs) are mixtures of paraffinic hydrocarbons and are free of sulfur and aromatics. Cold properties of HVO can be adjusted to meet the local requirements by adjusting the severity of the process or by additional catalytic processing. HVO fuel is of very high quality and its properties are very similar to the GTL and BTL jet fuels produced by FT-synthesis [13-15].

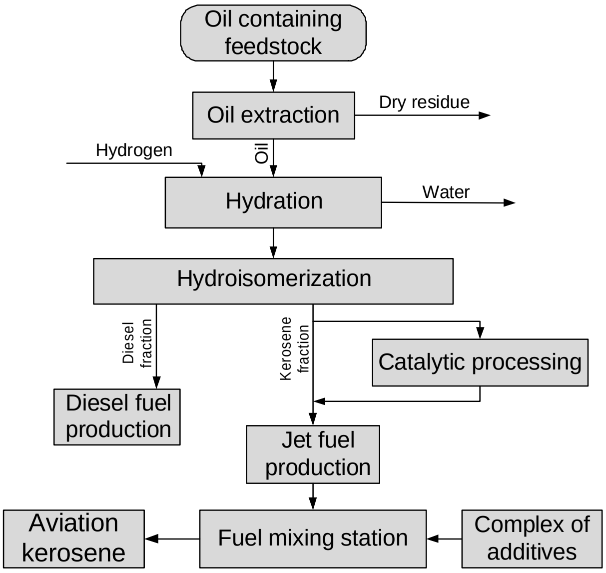

Fig. 6. Technological scheme of HVO kerosene production

The quality of FAME/FAEE is known to depend on the properties of the feedstock used and this limits the use of feedstock in cold climates. On the contrary, HVOs can be produced from various vegetable oils without compromising fuel quality. Existing agricultural feedstock such as rapeseed, sunflower, and soybean oil can be used, as well as other non-food plant oils such as jatropha and algae oil. Waste animal fats can also be used as a feedstock for HVO process.

In the HVO production process, hydrogen is used to remove the oxygen from the triglyceride (vegetable oil). A second hydroisomerization stage can be applied to get the required standardized low-temperature properties. The process is very flexible, allowing production of either kerosene cut, which can be blended in any portion with fossil kerosene, or a product that fits within the distillation range of gas oil. Additional chemicals like alcohol for FAME-production, are not needed. HVO production process does not produce any glycerine as a side product. The main challenge faced by the HVO process is having sufficient resources to satisfy the needs of aviation industry. Commercial airlines have already conducted successful test flights using a HVO biokerosene blend on at least one of the engines [2].

4. Conclusions

Analyzing modern situation in oil processing industry and constant worsening of the world's ecological situation, transition to alternative aviation fuels seems to be inevitable. As it was discussed, the great variety of technologies and raw materials for synthetic and biofuels production are available. For today some of them have already got the legislative base for production and use in civil aviation. However, each of these alternative aviation fuels should possess the following characteristics:

- worldwide distribution to meet the needs of intercontinental flights; this implies introduction of common standards of alternative fuel production at the international scale;
- great life span of aircraft (over 30 years on average) requires the compatibility of alternative fuels and existing fuels without any need to make significant changes to the engine or aircraft construction;
- alternative fuel must undergo stringent certification procedures with a view to demonstrating its full compatibility with all engine parts and materials in contact with the fuel (from logistics and distribution to combustion);
- alternative fuels must provide an incredibly restrictive operating mode, since fuel is consumed by aircraft in a wide range of conditions such as varying temperatures and varying pressures.

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ОГЛЯД ІННОВАЦІЙНИХ ТЕХНОЛОГІЙ ВИРОБНИЦТВА АВІАЦІЙНИХ ПАЛИВ

Анотація. *У статті висвітлено проблемні питання авіаційної промисловості, пов'язані з обмеженістю енергетичних ресурсів для виробництва авіаційних палив. Розглянуто основні екологічні проблеми, пов'язані з використанням традиційних палив для повітряно-реактивних двигунів. Представлено сучасні тенденції переходу від традиційних авіаційних палив до альтернативних. Розглянуто найбільш розповсюджені технології виробництва альтернативних палив та означено переваги використання біопалив.*

Ключові слова: *енергетичні ресурси, паливо для повітряно-реактивних двигунів, альтернативне авіаційне паливо, біогаз, біомаса.*