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7. BIOLOGICAL RISKS OF AVIATION FUEL SUPPLY

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The work is focuses on microbial contamination in refined petroleum products and product handling systems. Uncontrolled microbial contamination in aviation fuels and fuel systems remains a largely unrecognized but costly problem at all stages of the petroleum industry from production through fleet operations and consumer use. A limited amount of oil resource, the introduction of ICAO and IATA standards, satisfaction of safety and operational safety requirements, economic indicators, financial profitability require a risk-based approach in aviation fuel supply. The risks and consequences of microbiological pollution of aviation fuels have been identified, evaluated and systematized.

INTRODUCTION

Aviation fuel supply exists as much as aviation - more than a hundred years. Fuel is the blood of an aircraft. The mass of fueled jet fuel is up to 70% of the maximum take-off weight of modern aircraft. The main link in all civil aviation activities is flight safety. The most important condition for ensuring the safety of flights is the use of aircraft in the range of expected operating conditions, taking into account operational limitations established in the norms of airworthiness.

Now ICAO is disturbed formed by the world tendency of entering of contaminated aviation fuel in airport. Many documents ICAO, IATA and Joint Inspection Group focuses on pollution fuels. ICAO issued a directive DOC 9977 "Guide to the supply of aviation fuel in civil aviation" and IATA issued EI/JIG STANDARD 1530 "Quality assurance requirements for the manufacture, storage and distribution of aviation fuels to airports". The essence of these documents is that all parties involved are jointly responsible for ensuring the quality, purity and possibility of quality control at every stage of production, supply and operation of aviation fuel.

Fuel and air machinery loss during operation are major aircraft losses for modern aircraft. The main factors and parameters that determine the indicated losses in operation are flight path, speed and altitude; equipment reliability; fuel conditioning.

The study of theoretical and practical aspects of risk, its analysis and assessment is becoming increasingly relevant, because the risk in today's economic environment has a significant impact on the results of enterprises.

LITERATURE OVERVIEW

Analysis of shows that the active study on microbial growth in the composition of petroleum fuels began in the USA during the creation of jet aircraft. Focused research in biological stability fuels operating conditions is practically not carried out.

The modern world legislation raises the level of requirements for quality aviation fuels. In 2012, the International Civil Aviation Organization has developed directive 9977/AN 489 'Guidelines for the supply of aviation fuel for civil aviation', which focused on the clean air fuels, including microbiological contamination.

MAIN MATERIAL

Air transport is a major consumer of high-quality fuels and lubricants. For large scale high oil consumption issue efficiency of aviation technology, economy and management of aviation fuel has an important public and economic value. The efficiency and reliability of the fuel system software greatly depends on the quality of aviation fuel. The largest number of failures and malfunctions elements of the fuel system, engine and aircraft related to fuel quality and purity.

A limited amount of oil resource, the introduction of ICAO and IATA standards, satisfaction of safety and operational safety requirements, economic indicators, financial profitability require a risk-based approach in aviation fuel supply.

The risk indicator is introduced for the quantitative characteristics of the safety of objects. Risk is a measure of danger. The analysis of the threats to sustainable aviation fuel supply is to identify all sources of threat and assess their impact on flight safety.

The process of performing risk analysis has traditionally consisted of the following consecutive procedures [1]:

- planning and organization of work;
- identification of risks;
- risk assessment;
- development of risk management recommendations.

The key stages in the risk analysis process are the identification of risks and their classification. At the risk identification stage, the risks that exist at different stages of the jet fuel cycle life were analyzed.

Stages of the fuel life cycle:

- 1) oil recovery stage,
- 2) oil refining stage,
- 3) stage of production of commodity jet fuel,
- 4) stage of jet fuel transportation,
- 5) jet fuel storage stage,
- 6) fuel use stage.

Specific aspects can be distinguished from the point of view of the chemotological reliability. One of them is the purity of fuel, the presence or absence of mechanical impurities, water, microorganisms and other contaminants that should not be present in the fuel when shipped from production sites, but which can accumulate during transportation, storage, pumping and other operations.

There are many risks in the production of fuels, including the risk of microbiological contamination. The hydrocarbon component is the most dangerous raw material from this

point of view. On the one hand, this is the basis of fuels, on the other is the source of potential infection of microbiological oil destructors.

The biological risk factor can be defined as biological matter capable of self-replication and which can have a destruction effect on the fuel.

Microbes may be introduced into fuels as products cool in refinery tanks. Bacteria and fungi are carried along with dust particles and water droplets through tank vents. In seawater ballasted tanks, microbes are transported with the ballast. Vessel compartments ballasted with fresh, brackish, or seawater, all of which may contain substantial numbers of microbes, may easily become contaminated with the microbes transported with the ballast water [3].

Today it is known 200 species of microorganisms, including 30 families that can use hydrocarbons as sole source of carbon and energy. These include bacteria, yeast and fungi. Active development of the fuel and the fuel systems of microscopic fungi (*Hormoconis resinae*, his types. *Penicillium*, *Aspergillus fumigatus*, *Paecilomyces variotii*, etc.) recognized the most dangerous. Fungi form a dense mycelium, the accumulation of which not only clog pipelines and fuel filters, but also create numerous localized areas of corrosion on the surfaces of fuel systems. A most active destructor of aviation fuel until recently was recognized *Cladosporium resinae* (modern name *Hormoconis resinae* or *Amorphoteca resinae*) of microscopic fungi. This so-called "kerosene" fungi. Today this group classified as fungi *Monascus floridanus*, which is inherent in the ability to develop rapidly in the aviation fuel [4].

After arriving in fuel tanks, microorganisms may either stick to overhead surfaces or settle through the product. Some microbes will adhere to tank walls, whereas others will settle to the fuel/water interface (fig. 1). Most growth and activity takes place where fuel and water meet. The tank bottom fuel/water interface is the most obvious fuel/water boundary. However, there is also a considerable area of fuel/water interface on the interior surface of tank-shells. Microorganisms require water for growth. Although bacteria and fungi can be present in the fuel phase, their growth and activity is restricted to the water phase of fuel systems. The water phase includes volumes ranging from trace (several μL) to bulk ($>1 \text{ m}^3$) accumulations and water entrained within deposits that accumulate on system surfaces. Typically, fuel and system deterioration is caused by the net activity of complex microbial communities living within slimy layers called biofilms. Biofilms may be found on tank roofs, shells, at the fuel/water interface, and within bottom sludge/sediment [3, 4].

The high temperature characteristic of distillation and other refinery processes sterilize refinery stocks used in fuel blending. However, conditions in refinery tankage, transport systems, terminal tankage, and users' system tankage may lead to microbial contamination and possible biodeterioration.

In refinery tankage, water can condense and coalesce as product cools. Tank vents draw moisture from the outside atmosphere and may allow precipitation to enter the tank.

Moreover, product withdrawal creates a partial vacuum that pulls pollen, dust, and other microbe-carrying particulates through tank vents. Consequently, refinery products tanks are the first stage of petroleum handling where significant microbial contamination can occur.

In transport by means of tanker or pipeline, additional water may be introduced by condensation. In contrast to pipelines, condensate is not the major source of additional

water. Rather, inadequate cargo compartment stripping, use of water as false bottoms to facilitate complete cargo discharge, and other incidental, intentional water use provide substantial water to fuel tanks. Biofilms can form on tanker or pipeline surfaces where they entrain water, inorganic particles, and nutrients to support growth. Such growth can slough off and be carried to terminal and end user tankage. In terminal tanks, turnover rates may be a week or longer, allowing particulates (including biofilm flocs) to settle into the sludge and sediment zone before product is drawn from the tank. As turnover rates increase, the likelihood of drawing biomass with fuel also increases, due to reduced settling times. Population densities of less than two million cells/mL will have no effect on fuel clarity. Consequently, contaminated fuel is rarely detected visually at the terminal rack.

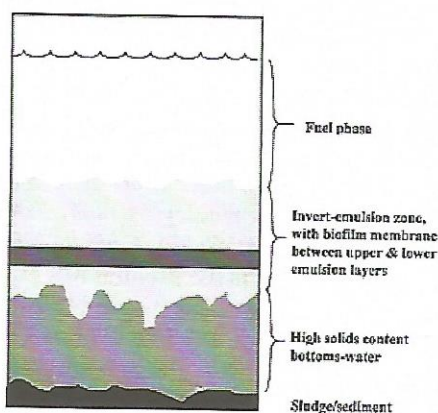


Fig. 1. Schematic of Fuel Tank Bottom Sample with Significant Microbial Contamination and Biodeterioration

The places of microbiological colonies development of on the fuel life cycle are established during the analysis of biological risk of aviation fuel supply. The places of microbiological colonies are presented in fig. 2 [3].

Microbes require water as well as nutrients. Consequently, they concentrate at sites within fuel systems where water accumulates.

Water is essential for microorganisms growth and proliferation. Even negligible traces of water are sufficient to support microbial populations.

Nutrients are divided into macro-nutrients and micronutrients. Carbon, hydrogen, oxygen, nitrogen, sulfur, and phosphorus (CHONSP) comprise the macro-nutrients, and most of these are readily available in fuels. Only phosphorous is likely to be growth limiting in most fuel systems. A variety of elements, including calcium, sodium, potassium, iron, magnesium, manganese, copper, cobalt, nickel, and other metals, are required in trace quantities. None of these elements is limiting in fuel systems. Fuel systems that provide both the requisite water and nutrients will support microbial growth and proliferation [3].

The rate of microbial growth increases with increasing temperature within the physiological range (temperature range within which growth occurs) of a given microorganism. Microbes are generally classified into three groups, based on their temperature preferences/requirements. Some microbes require low temperatures (<20°C).

Others thrive in superheated environments ($>100^{\circ}\text{C}$). However, the physiological range of the microbes most commonly recovered from fuel tanks is 0°C to 35°C , with growth optimal between 25°C and 35°C [4-6].

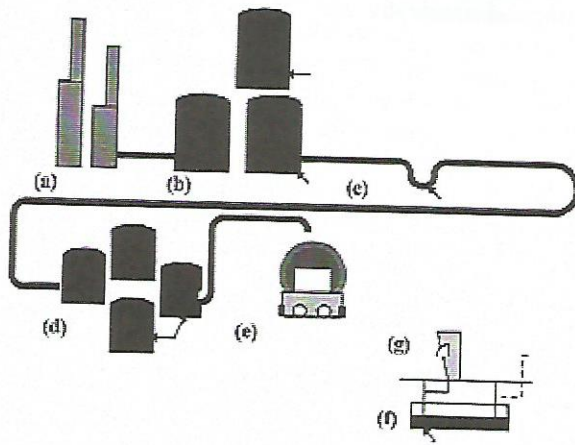


Fig. 2. Fuel supply scheme (arrows indicate sites where water and biologicals tend to accumulate): (a) refinery distillation towers, (b) refinery product tanks, (c) fuel transportation pipeline (low points in pipeline trap water), (d) distribution terminal tanks, (e) commercial dispensing rack and tank truck, (f) retail/fleet underground storage tank, (g) retail/fleet dispensing system

The risk of uncontrolled microbial contamination is generally greatest in tropical regions. However, in the absence of adequate housekeeping practices, microbial contamination problems can also occur in fuel systems located in cold climates.

Water pH is generally not a controlling factor in fuel systems. Most contaminant microbes can tolerate pH's ranging from 5.5 to 8.0. As with temperature, there are microbes that prefer acidic environments (some grow in the equivalent of 2N sulfuric acid) and others that grow in alkaline systems with $\text{pH} > 11$. Fuel tank bottom-water pH is usually between 6 and 9.

As water activity tends to be greatest at interface zones, this is where microbes are most likely to establish communities, or biofilms. Numbers of microbes within biofilms are typically orders or magnitude greater than elsewhere in fuel systems. Biofilms can form on tank overheads, at the bulk-fuel, bottom-water interface, and on all system surfaces.

Using fuel hydrocarbon vapors as their carbon source, microorganisms can colonize tank overheads, where condensation provides the necessary water activity. Biofilms on overheads generally look like slimy stalactites [3].

Whereas a 1-mm thick biofilm on a tank wall may seem negligible, it is 100 times the thickness of most fungi, and 500 to 1000 times the longest dimension of most bacteria. This seemingly thin film provides a large reservoir for microbial activity. Within the biofilm micro-environment, conditions can be dramatically different from those in the bulk product.

Microorganisms consortia (communities) give the biofilm community characteristics that cannot be predicted from analysis of its individual members.

Microorganisms are able to consume hydrocarbons directly excrete waste products that other consortium members use as food. The net effect is a change in pH, oxidation-reduction (or redox) potential, water activity, and nutrient composition that has little resemblance to the environment outside the biofilm [4, 5].

Microbes growing anaerobically produce low molecular weight organic acids (formate, acetate, lactate, pyruvate, and others). These acids accelerate the corrosion process by chemically etching the metal surface. There are data demonstrating that biofilm communities can deplasticize the polymers used in fiberglass synthesis. Such activity can result in catastrophic tank failure and is most likely to occur along the longitudinal centerline (the same place of the greatest frequency of MIC pinholes).

Biosurfactants facilitate water transport into the fuel phase and some fuel additive partitioning into the water phase. Other metabolites may accelerate fuel polymerization. Produced at concentrations that are difficult to detect against the complex chemistry of fuel components, these metabolites can have a significant deleterious effect on fuel stability. Although most of the change occurs within a few centimeters of the biofilm-fuel interface, product mixing can distribute metabolites throughout the fuel system.

The authors of this work identified and systematized the consequences and the risks of microbiological contamination of aviation fuel (fig. 3).

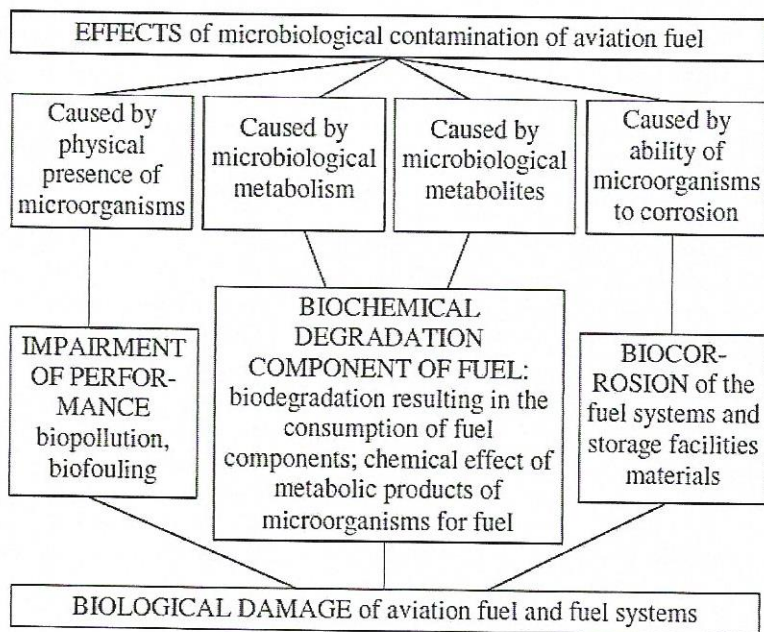


Fig. 3. The risks and consequences of microbial contamination of aviation fuels

More particularly after microbiological contamination of aviation fuels the following effects are observed in the presence of the above-mentioned favorable conditions [4]:

- *change in physical and chemical properties of fuels*, namely increasing of major physical-chemical parameters values as kinematic viscosity, refractive index, pH, content of actual resins and others. Also characteristic features are the formation of sediment, turbidity fuel and peculiar odor;

- *corrosion of storage tanks for aviation fuels.* Corrosion development of bottom part where accumulates water sludge, especially on verge of system distribution "fuel-water", corrosive damage of aircraft tanks, corrosion of aircraft power constructions;
- *clogging and damage of fuel filters, pumps and fuel systems.* Sedimentation of mycelium and bacteria colonies at the inner walls of the fuel systems leads to clogging of pipelines, filters, pumps and fuel systems;
- *threat to the safety of aircrafts flights.* Changing the physical, chemical and exploitation properties of aviation fuels leads to early clogging of filters, pollution of regulating equipment, causing unstable operation of the fuel system, and therefore can cause failure of the engine, and even complete failure of the system, and as a consequences is appearance of accidents and emergency landings [5].

Table 1. Consequences of Microorganisms of Aviations Fuel Systems

Risks	Principal Types of Microorganisms
Blockage of pipes, valves, filters	Fungi; polymer-producing bacteria
Increased water content	All
Sludge formation	All
Surfactant production	Fungi; and aerobic bacteria
Corrosion of storage tanks and lines	Fungi; and anaerobic bacteria
Production of suspended solids in the fuel	All
Breakdown of hydrocarbons	Fungi; and aerobic bacteria
Shortened filter life	All
Fouling injectors	Aerobic bacteria and fungi
Increased sulfur content of fuel	Sulfur-reducing bacteria (SRB)
Shortened life of engine parts	Undetermined
Penetration of protective tank	Fungi
Health problem	Endotoxing-producing bacteria, SRB

A host of problems will likely surface when uncontrolled microbial growth is allowed to develop (table 1). Microbial activity has been shown to cause degradation of fuel hydrocarbons. Flight safety also will likely be compromised, as well as increased maintenance and cost. Not all microorganisms, however, cause the same problems.

Assessment or analysis of risk is a process for identifying hazards, assessing the probability of an event and its consequences. The ratio of risk objects and risky events makes it possible to determine the link between the biological risk in the field of the use of aviation fuel with technogenic and economic risks. Technogenic risk is a complex indicator of reliability of elements of technical means of operation. It expresses the probability of an accident or disaster during the operation of machines and mechanisms, in particular vehicles, and the implementation of technological processes. The source of Technogenic risk is the violation of the rules of operation of technical systems, the untimely conduct of preventive inspections. Economic risk is determined by the ratio of benefits and harm that society receives from a particular activity.

Risk reduction is an action to reduce the likelihood of a negative event or mitigate the consequences of this event if it occurs.

A key factor is a multi-aspect approach to fuel hygiene to eliminate the inconveniences and costs associated with contamination of the fuel system. Each air operator should conduct his own risk assessment in order to determine the optimal regime.

An important component of this regime is the frequent checks of drainage systems, as well as regular testing and monitoring of microbiological contamination in the entire fuel system.

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BIOLOGICZNE ZAGROŻENIA DOSTAWY PALIWA LOTNICZEGO

Streszczenie

Prace koncentrują się na skażeniu mikrobiologicznym produktów rafinacji ropy naftowej i systemów transportu produktów. Niekontrolowane skażenie mikrobiologiczne paliw lotniczych i systemów paliwowych pozostaje w dużej mierze nierozpoznanym, ale kosztownym problemem na wszystkich etapach przemysłu naftowego, od produkcji po operacje flotowe i użytkowanie przez konsumentów. Ograniczona ilość zasobów ropy naftowej, wprowadzenie norm ICAO i IATA, spełnienie wymogów bezpieczeństwa i bezpieczeństwa operacyjnego, wskaźniki ekonomiczne, rentowność finansowa wymagają podejścia opartego na ryzyku w zaopatrzeniu w paliwo lotnicze. Ryzyko i skutki zanieczyszczenia mikrobiologicznego paliw lotniczych zostały zidentyfikowane, ocenione i usystematyzowane.