Monitoring the Risks of Microbiological Contamination of Aviation Fuels and Fuel Systems

Iryna Shkilniuk and Nataliia Shevchuk

1 Aviation Fuels as a Factor in Aircraft Flight Safety

Aviation is a factor in the economic success of many countries of the world. Flights have helped develop international trade links and create vital domestic connections that 'stitch' a country together. Accelerating scientific and technological progress, globalization of air transport markets, increased international connectivity and the introduction of the digital economy require continuous monitoring of risks to flight operations and preservation of the infrastructure capacity of air transport to enhance its competitiveness and sustainable development.

The most important part of ensuring the normal operation of aviation is ensuring the safety of ongoing flights.

Aircraft operational safety, together with aviation and environmental safety, is of paramount importance to ensure flight safety. The quality of aviation fuels and lubricants is one aspect of aircraft safety [1]. Generally recognized regulations and requirements have existed and allow for a stable system for maintaining aviation fuel quality and control at every stage of its life cycle.

The reliability and efficiency of aircraft gas turbine engines are highly dependent on the quality of aviation fuels. Operating fluids, including fuels, are complete structural elements of the respective systems from a chemmotologycal point of view. Strict requirements related to reliability, efficiency, and environmental friendliness of aviation transport operations are imposed on aviation fuels used in civil and military aviation.

Low-quality aviation fuels reduce the performance and reliability of aircraft equipment, while higher fuel requirements result in higher fuel prices. Therefore, modern

I. Shkilniuk (✉) · N. Shevchuk
National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Kyiv, Ukraine
e-mail: i_shkilniuk@ukr.net

S. Boichenko et al. (eds.), *Modern Technologies in Energy and Transport*, Studies in Systems, Decision and Control 510, https://doi.org/10.1007/978-3-031-44351-0_12

aviation fuels and lubricants must meet a number of requirements combining the economy, reliability, and durability of aviation vehicles.

The negative effects of fuel properties are mainly due to uncontrolled changes in its composition and properties caused by variable operating conditions.

One of the strategic safety objectives is to identify and monitor existing aviation safety risks and to develop and implement globally effective and appropriate measures to address emerging risks.

2 Purity and Microbiological Contamination of Motor Fuels

The main link in all civil aviation activities is ensuring flight safety. The most important condition is the use of aircraft within the range of expected operating conditions, taking into account operational constraints. One of these is the appropriate quality of aviation fuel.

Flight safety activities are multifaceted and complex. The main, constituent factor in ensuring flight safety is the interaction between the aviation authorities of the state and the air transport process. The quality assurance of aviation safety, including the occurrence of aviation equipment failures, is a worldwide problem today. ICAO, concerned about the prevailing worldwide trend of contaminated aviation fuel reaching airports, has issued Directive 9977 (Guidelines for the Supply of Aviation Fuels to Civil Aviation). IATA has adopted Standard 1530 (Quality Assurance Requirements for Aviation Fuel Production, Storage and Delivery Systems at Airports). The essence of these documents is that at each stage from the production of aviation fuel to the airport, all parties involved have a shared responsibility to ensure quality, purity and control capability at each point in the production and supply chain.

Fuel purity is an issue in the supply of aviation fuels in vehicles, as well as in the inner cavities of the technological equipment of airfield fuel depots, centralized aircraft refueling systems, and fuel tankers [2]. The purity of fuels is determined by the number of impurities in their composition. Contaminants can be of different natures. Inorganic contaminants are particulates and water. Organic contaminants are residues of other petroleum products, fame. Biological contaminants are microorganisms that require hydrocarbons from fuel to function. The most common contaminants are particulates, water, other petroleum products or their residues, and microbial growth [3, 4].

Sources of contamination of jet fuels are materials and substances in contact with the fuel. Such as:

- Mineral impurities introduced into fuel from refined oil;
- Corrosion products on fuel apparatus parts as well as on process surfaces with which fuel comes into contact during transport or storage;

- Contaminants introduced through the tank breathing system and fuel tank drainage system.

Microorganisms are a specific type of pollution, capable of multiplying and having a complex effect on the habitat, that is the fuel, and the means of using it [5]. More than 150 species of micro-organisms capable of degrading the hydrocarbons that compose aviation fuels have so far been detected and identified [2]. The main representatives of microorganisms are:

1. Anaerobic and aerobic bacteria—Achromobacter, Alcaligenes, Artrobacter, Bacillus, Bacterium, Brevibacterium, Citrobacter, Clostridium, Corynebacterium, Desulfovibrio, Enterobacter, Escherichia, Flavobacterium, Metanobacterium, Micrococcus, Micromonospora, Mycobacterium, Nicrocossus, Pseudomonas, Sarcina, Serratina, Spirillym, Vibrio, Thiobacillus;
2. fungi (or micromycetes)—Alteranga, Aspergillus niger, Aspergillus fumigatus, Hormoconis resinae, Monacus floridanus, Phialophora sp., Cephalosporium, Renicillum;
3. yeasts—Candida, Debaryomyces, Endomycopsis, Hansenula, Rhodotorula, Saccharomyces, Torula, Torulopsis, Trichoderma, Trichosporon.

Numerous researchers confirm that among the microorganisms that develop in aviation fuels, fungi are the most common [6, 7]. Fungi are a heterogeneous group of eukaryotic microorganisms that have a core with a core membrane, a cytoplasm with organelles, a cytoplasmic membrane and a strong cell wall. Fungi consist of long thin filamentous fibers (hyphae) with a thickness of 5 μm, which are woven into mycelium Fungi are specific plant organisms that do not have chlorophyll and do not synthesize organic substances. Fungi need ready-made organic substances for their life activity [8].

Hormoconis resinae is an active destructor more commonly found among microorganisms capable of growing in aviation fuels (Fig. 1) [5, 6]. It is also called the “Kerosene fungus”. In the natural environment, this fungus inhabits the soils of the subtropical and tropical zone [7]. Research by many scientists confirms the presence of this fungus in aviation fuel samples from Australia, Brazil and California, UK, Denmark, India, Syria, Nigeria, Japan, New Zealand, China. Obviously, the development of aviation and flight geography has contributed to the spread of the fungus to other geographical areas. In the scientific literature, it is known by other names: *Hormodendrum resinae*, *Cladosporium resinae*, *Amorphotheca resinae* [10].

Bacteria are prokaryotic cells that have a cytoplasm surrounded by a cytoplasmic membrane, a cell membrane, a capsule, flagella, villi, etc. Bacteria are characterized by a high reproduction rate. The linear size of the bacteria averages 0.15–3 μm [9].

Yeast is a microscopic unicellular fungus that reproduces by division or budding. The size of yeast is: the diameter of the smallest cells is 1.5–2 μm, the diameter of large cells is 8–10 μm, and the length of some species can reach 20–25 μm [7].

Microorganisms are divided into two groups: aerobic, which grow under conditions of air access, and anaerobic, which can grow without air access. Therefore, the

Fig. 1 Hormoconis *resinae* on nutrient media (**a**) and under microscope magnification (**b**)

Fig. 2 Visual representation of microbiological contamination of aviation fuels

reproduction process of microorganisms may occur on the surface of the petroleum product and in the fuel itself [11].

Microbiological contamination of fuels is characterized by the formation of a gelatinous, slimy, amorphous mass ranging from light grey to dark brown (Fig. 2).

The enzyme system of a microorganism for carrying out metabolism can change during the individual development of the microorganism. This property of plastic metabolism is necessary because of the very small size of the microorganism cell and the impossibility of accommodating the entire possible range of enzymes. This explains the existence of potentially active microorganisms acquiring the ability to develop in the hydrocarbon environment of fuels [12].

Microorganisms are highly active organisms that function according to a general biological law: the smaller the organism, the more intensive its metabolism. Microbial enzymes are capable of acting on a large volume of nutrient substrate per unit of time. Microorganisms that do not have the appropriate enzyme systems for the oxidation of an unknown product are capable of producing adaptive enzymes in the process of adapting to a new food source [12, 13].

3 Growth Conditions for Microbiological Contamination in the Fuel and Fuel System

The biological nature of microorganisms determines the conditions for their occurrence and growth in fuels as microbiological contamination [14].

The nutrient medium determines the possibility of microbial growth. Hydrocarbons are a nutrient medium for some microorganisms. Aviation fuels consist mainly of highly sensitive and microbiologically susceptible hydrocarbons. Aviation fuels are middle distillates of petroleum. They contain hydrocarbons of various classes, heteroatomic compounds, and inorganic impurities. The hydrocarbon composition of jet fuels consists of different classes of hydrocarbons. The most common of these are paraffin. All paraffin hydrocarbons are subject to biodegradation, but isooctane (with a branched structure) remains resistant to the action of microorganisms. The physiological characteristics of each species of microorganism determine the direction of degradation of individual hydrocarbons and their mixtures, which have varying degrees of resistance to oxidation. The insolubility of hydrocarbons in water causes difficulties in their uptake by microorganisms. The hydrocarbon-water interface must be as large as possible to activate destructive enzymes. All paraffin hydrocarbons are subject to biodegradation, but isooctane (with a branched structure) remains resistant to microbial attack.

Water/moisture is essential for the functioning and evolution of any biological organism. Water is a critical factor in the growth and metabolic activity of microorganisms in aviation fuels. The life activity of microorganisms depends on water, as water constitutes 75–90% of the vegetative cell mass [12].

Jet fuels are hygroscopic. The hygroscopicity of fuels is reversible. Under certain external conditions, the fuel can absorb moisture, which can transfer from the fuel to the environment or form an emulsion of water in the fuel [4]. Over time, droplets of emulsified water will settle and form sludge water as a result of their coalescence by gravity. The water solubility of fuel is governed by Henry's law and is determined by many factors, the main ones being:

- temperature,
- pressure,
- relative humidity of the air in contact with fuel,
- hydrocarbon composition of the fuel.

Individual hydrocarbon molecules in jet fuels are non-polar compounds and are larger in volume than water molecules and are not capable of forming hydrogen bonds with water molecules. The hygroscopic nature of fuels increases with magnification in their content of aromatic hydrocarbons, which are specifically added to aviation fuels and are part of the fuels for air-jet engines. Water solubility in hydrocarbons is very low (not more than 0.01%), but for aromatic hydrocarbons, it is approximately 2–3 times higher. Water in the external environment can be available or inaccessible. The degree to which water is accessible to microorganisms is determined by the activity index of water, which describes the degree to which its molecules are bound.

This index is equal to one for pure free water. The activity index of water is less than one for water in a given interaction with other substances. Microorganisms can grow in media with a water availability coefficient of 0.6–0.9 [15].

The flight of any aircraft can be conventionally characterized by three components—takeoff, horizontal flight, and descent. Each of these flight components is constantly connected with changes in external conditions (temperature, pressure, and humidity air). During altitude climb, there is a decrease in air pressure and temperature and a decrease in the relative humidity of the surrounding air. In horizontal flight, minor changes in air pressure and temperature are possible. The descent section is characterized by an increase in pressure and temperature and an increase in relative air humidity. All these changes outside the aircraft affect the physical and chemical properties of the fuel (density, viscosity, etc.), which in turn leads to changes in its water content and condition. The effect of changes in atmospheric conditions in flight is different for different types and groups of aircraft fuel system tanks.

The evolution of microbiological damage in fuel systems begins in places of water accumulation. Thus, the bottom of aboveground and underground tanks and fuel pipelines are areas of increased risk of microbiological contamination.

Under the influence of external factors, fuel is capable of absorbing moisture, which can transfer from the fuel to the environment or form an emulsion of water in the fuel. Over time, the emulsion water droplets will drain away under the influence of gravitational forces and form settling water. The solubility of water in fuel is determined by many factors, the main ones being temperature, pressure, relative humidity of the air the fuel meets and the hydrocarbon composition of the fuel.

The accumulation of water in fuel during storage in aircraft tanks (reservoirs) can only occur through the ingress of moist air through the drainage system into their above-fuel space. Depending on the changing conditions, the moist air may condense on the cold non-wetted tank (reservoir) walls, on the cold fuel surface, or dissolve directly into the fuel.

The total content of water in jet fuels reaches 0.008–0.012% by weight, including dissolved 0.002–0.007% by weight, during the operation of aviation equipment. The amount of water in the fuel after refueling must not exceed 0.003% by weight. The presence of water has a negative effect on a number of fuel quality parameters.

Air humidity contributes to the watering of the fuel. Accordingly, the water content of jet fuels in storage depends on the period of the year, climate, and geographical location.

Therefore, water is one of the common contaminants of aviation fuels, the occurrence of which is facilitated by a number of environmental factors. Water is a basic requirement for the metabolic activity of microorganisms and is a factor in the formation and development of microbiological contamination.

Some microorganisms are able to survive for months or even years *in dehydrated fuel (e.g. Hormoconis resinae)* [15]. The persistence of *Hormoconis resinae* spores in fuel in the absence of water poses a threat of uncontrolled growth if there is moisture in the fuel and a suitable temperature.

Environmental temperature is the second most important physical factor for microbial growth in fuels. The temperature of the fuel determines the metabolic activity of the microorganisms and the rate of degradation of the hydrocarbons in the fuel. Most of the microorganisms that can grow in fuel belong to the group that develops actively at temperatures of 20–45 °C, i.e. mesophiles. The metabolic potential of microorganisms increases with increasing temperature within the optimum range. Microbial growth slows down at temperatures below the optimum range. If the temperature exceeds the optimum range, microbial cells may die or retard their growth for some time. Studies [16] confirm that *Hormoconis resinae* and *Phialophora sp.* strains are resistant at –57 °C. *Hormoconis resinae* spores are viable for a maximum of 3 days at 60 °C and die at 70 °C. *Phialophora sp.* spores are viable at 55 °C for no more than 24 h and die at 60 °C. Strains of Aspergillus fumigatus isolated from supersonic jet fuel survive at temperatures as low as minus 32 °C and 80 °C.

The area of microbial growth is the accumulation of water in tanks and fuel lines. Water is characterized by its pH value. A neutral pH allows the growth of most microorganisms capable of degrading hydrocarbons in fuels [24]. Fungi grow at pH 4–6; SRB bacteria grow best at pH 7.5. The pH of the tank bottom water is a safe environment for microbial growth as its pH range is 6–9 [15]. The effect of pH on the microbial cell can be direct or indirect. In the case of an indirect effect, the pH affects the nutrient components of the external environment, which in turn affects the penetration of these components into the microbial cell [12]. The pH value can have an effect on the development of different types of microorganisms in the sub-bottom water. Scientists [15] have studied the types of microorganisms which grow in fuel tanks on ships where seawater is used in the ballast system of the ships and accumulates on the bottom of the fuel tanks. The pH of the seawater is 8. The results showed that *Hormoconis resinae* grows in the tanks in the presence of the yeast *Candida sp. Candida sp.* produces acidic metabolites that lower the pH. This ability of the yeast creates conditions for the growth of *Hormoconis resinae*, which reproduces poorly at alkaline pH. Low pH suppresses the development of bacteria that grow on fuel hydrocarbons. High pH suppresses fungal growth. For example, some microorganisms are able to lower the pH by producing organic acids, thereby allowing other oil-degrading microorganisms to proliferate. The pH can influence the development of different types of microorganisms in the sub-bottom water.

The hydrocarbon composition of the fuel, the presence of water, and the ambient temperature determine the occurrence of microbiological contamination. These are interdependent factors in the growth of microorganisms in fuel systems.

Microorganisms grow actively at the fuel-water interface. This is due to the assimilation of fuel hydrocarbons and the ability to carry out biochemical reactions to convert these hydrocarbons into an energy source when water molecules are available. The greatest accumulation of microorganisms and the products of their living activities accumulates in vessels located at the water-hydrocarbon interface (Fig. 2).

There are other factors contributing to microbiological contamination in fuels. These do not directly affect the life activity of the microbial cell. The Ishikawa diagram shows other factors that contribute indirectly to the formation and development of microorganisms in fuels (Fig. 3). One of the tools used to analyze

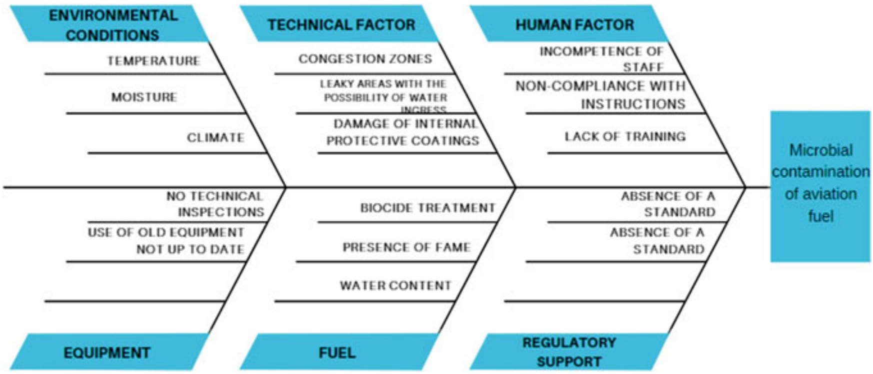

Fig. 3 Ishikawa diagram of the factors that are related to the problem of microbiological contamination of aviation fuels

and visualize the relationship between sources and factors causing microbiological contamination in aviation fuel is Ishikawa diagram. This involves establishing relationships between factors that influence the formation process of a particular adverse phenomenon. The Ishikawa diagram is created after carefully detailing and examining all factors and grouping them into categories.

This diagram shows how to identify and systematize potential factors and relationships for a thorough analysis and selection of methods to prevent or solve the problem of microbial fuel contamination. The results presented in this material can be used by organizations or companies involved in the storage and supply of aviation fuels.

4 Effects of Microbiological Contamination on the Quality of Fuels, Operating Materials, Fuel Systems and Vehicle Operability

Fuel cleanliness is the permissible level of impurities of various origins in the fuel at which the operation of the fuel control and fuel handling equipment is uninterrupted. There are several factors that influence the level of fuel purity. The first is size. Individual microbial cells are very small and do not present a danger to filtration. However, groups of microorganisms (colonies, biofilms) in fuel can be as large as even the human eye can see. Secondly, surfactants are substances released as a result of microorganism metabolism, known as biosurfactants, which have a positive effect on the coagulation of mechanical contaminants in the presence of moisture. Thirdly, the slime-like and sticky properties of microbial colonies or biofilms, adhere to the filter material and disrupt the operation of fuel-regulating equipment [5].

Changes in the group composition of fuels are a result of the microbiological degradation of hydrocarbons. The consumption of a particular type of hydrocarbon is determined by microbial activity and the availability of hydrocarbons for consumption in the fuel environment. The ability to biodegrade hydrocarbon groups depends on the physiological characteristics of the microorganism, in particular the adaptability of its enzymatic apparatus to environmental conditions. Changes in the paraffinic composition of aviation fuels affect the energy properties of the fuel since alkanes have the highest calorific value. In turn, the calorific value affects the efficiency of an air jet engine.

A change in the chemical composition of fuels due to a reduction in alkanes affects physico-chemical parameters such as density, fractional composition, vaporability, flash point. The rate and completeness of combustion of fuel depend on paraffinic hydrocarbons, as they have a lower flash point. These, in turn, affect flight and technical and economic performance [5]. Density is an important physical property and performance indicator for calculating and accounting for fuel. Vaporability is a property of fuel that determines the rate at which a combustible mixture of fuel and air is created, which in turn affects the completeness of fuel combustion and the ease of engine starting. Fractional composition is an indicator related to vaporability and characterizes the vaporability and startability of fuel as well as the safe operation of the aircraft fuel system [2, 5].

The results show a significant increase in the acidity of the samples tested, with the exception of aviation gasoline. Acidity is an indicator of the content of organic acids in fuels and is measured by the amount of alkalinity required to neutralize them [5]. Organic acids improve the anti-wear and protective properties of fuels, but have a negative effect on the corrosive properties of fuels, particularly compatibility with consumables. Therefore, the value of acidity in jet fuels is limited. The increase in acidity in contaminated fuel is explained by the appearance of intermediate products of the metabolism (Krebs cycle) of microorganisms [12].

The presence of microflora in fuels, as determined by fuel surveys, is indicated by:

- presence of biomass clumps in the form of lumps of sticky slime, felt-like formations in the water sediment;
- presence of lumps of sticky slime on internal tank walls;
- swelling of the sealant and corrosion of the surface of the fuel tank;
- clogginsg of filters and pump nets installed in tanks with sticky mass;
- malfunction of fuel metering equipment;
- unpleasant odour.

In the case of the same level of contamination in the fuel (up to 0.005% by weight), the pressure drop across the filter increases more rapidly in the case of microbiological contamination of the fuel than in the case of normal mechanical particles [15]. The differential pressure across the filter increases more rapidly with bacterial contamination than with fungal contamination. Measuring the mass of deposits on the filter when the maximum differential is reached, the mass is 9 g for normal contamination, 8 g for fungal contamination, and 5 g for bacterial contamination. It can be concluded that biological contamination is more dangerous for fuel pumping and filter life than normal contamination. The physiological ability of microorganisms to produce biosurfactants is the reason for this. Biological surfactants promote adhesion to fuel system components and storage material, including the surface of the filter material. Consequently, an easily observed symptom of microbiological heavy fuel contamination is the increased pressure drop and impaired fuel flow. The microbiological effect is one of the most important manifestations of the corrosive and aggressive effects of the environment on metal products and structural elements of aircraft and fuel-supplying equipment in contact with fuel [2]. Corrosion phenomena in fuel tanks begin at the sites of microbial growth on the bottom of fuel tanks at the fuel-water interface.

Microbial corrosion is a complex process of interaction between microorganisms and metal that occurs in a biofilm. The composition and properties of the biofilm influence the development of corrosion processes through metabolic activity and electrochemical reactions. Microorganisms do not only directly "corrode" the metal itself, but often influence chemical, electrochemical and mechanical factors to enhance or mitigate any type of damage. Therefore, despite its widespread occurrence, biochemical corrosion is not always easy to recognize [5].

Thus, microbiological corrosion of metals is part of the complex problem of microbiological contamination of fuels. It occurs under the influence of the products of life activity of microorganisms present in the affected fuel, in the process of cell adhesion to the metal and implementation of electrochemical reactions.

The physiology and developmental characteristics of microorganisms determine their impact on the environment. Microorganisms can affect the environment through their physical presence, nutrient requirements, metabolic products, and biocorrosion capacity. Deterioration of fuel quality, clogging of filters and failure of fuel control devices, and corrosion of metal and rubber surfaces are related to aspects of the physiology of microorganisms that contaminate aviation fuel (Fig. 4).

The interconnectedness of micro-organisms and the negative effects of their development on fuel and means of operation, transportation, and storage demonstrates the complex impact and importance of controlling microbiological contamination of aviation fuel at every stage of its life cycle.

5 Monitoring of Aviation Fuels, Fuel Systems and Fueling Complexes for Risk Assessment of Microbiological Contamination

Aviation fuel supply is complex. Aviation stakeholders face a range of risks that can affect not only the business operations of organizations, but also the lives and health of the people who use their services. Increased demand for air transport, complex designs, new composite materials, and technologies are leading to more costly aircraft grounding incidents.

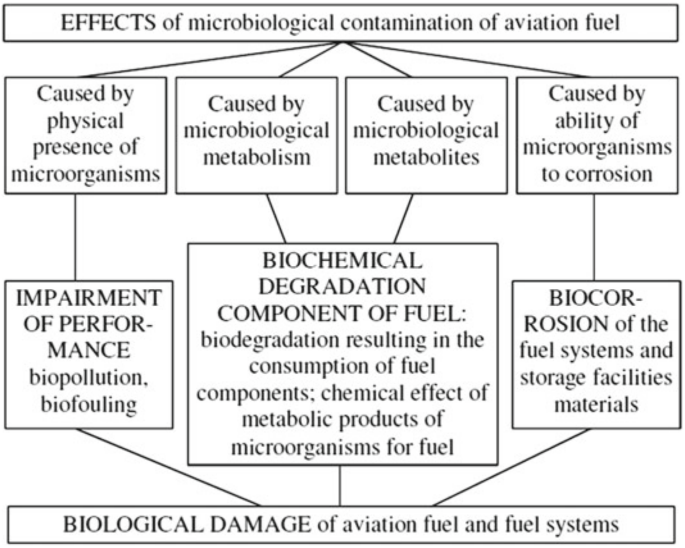

Fig. 4 The risks and consequences of microbial contamination of aviation fuels

The ICAO coordinated risk-based approach to improving aviation safety [159] is the application of logical and systematic methods to identify, analyze, evaluate and manage the risk associated with an aspect of aviation activity in order to reduce the risk or the likelihood of its recurrence. Risk management is a way of anticipating a problem or threat in advance. A risk-based approach makes preventive action part of strategic and operational planning and ensures that risks are considered and assessed.

Scientist Passman [17] developed criteria for evaluating the risk of microbiological contamination of oil products based on average annual precipitation: low risk (average annual precipitation of 64 cm), medium risk (average annual precipitation between 64 and 190 cm), high risk (average annual precipitation over 190 cm) and number of days when it occurs (low risk—less than 100 days per year, medium risk—100 to 200 days per year, high risk—over 200 days per year).

Aviation fuel is one of the elements affecting the flight safety of air transport. A system analysis of existing risk management methods [160–164], in particular in the aviation industry [159, 164–165], helped to implement risk theory approaches to the problem of microbiological contamination of aviation fuels and develop a Monitoring the Risks of Microbiological Contamination of Aviation Fuels and Fuel Systems presented in the form of a scheme (Fig. 5).

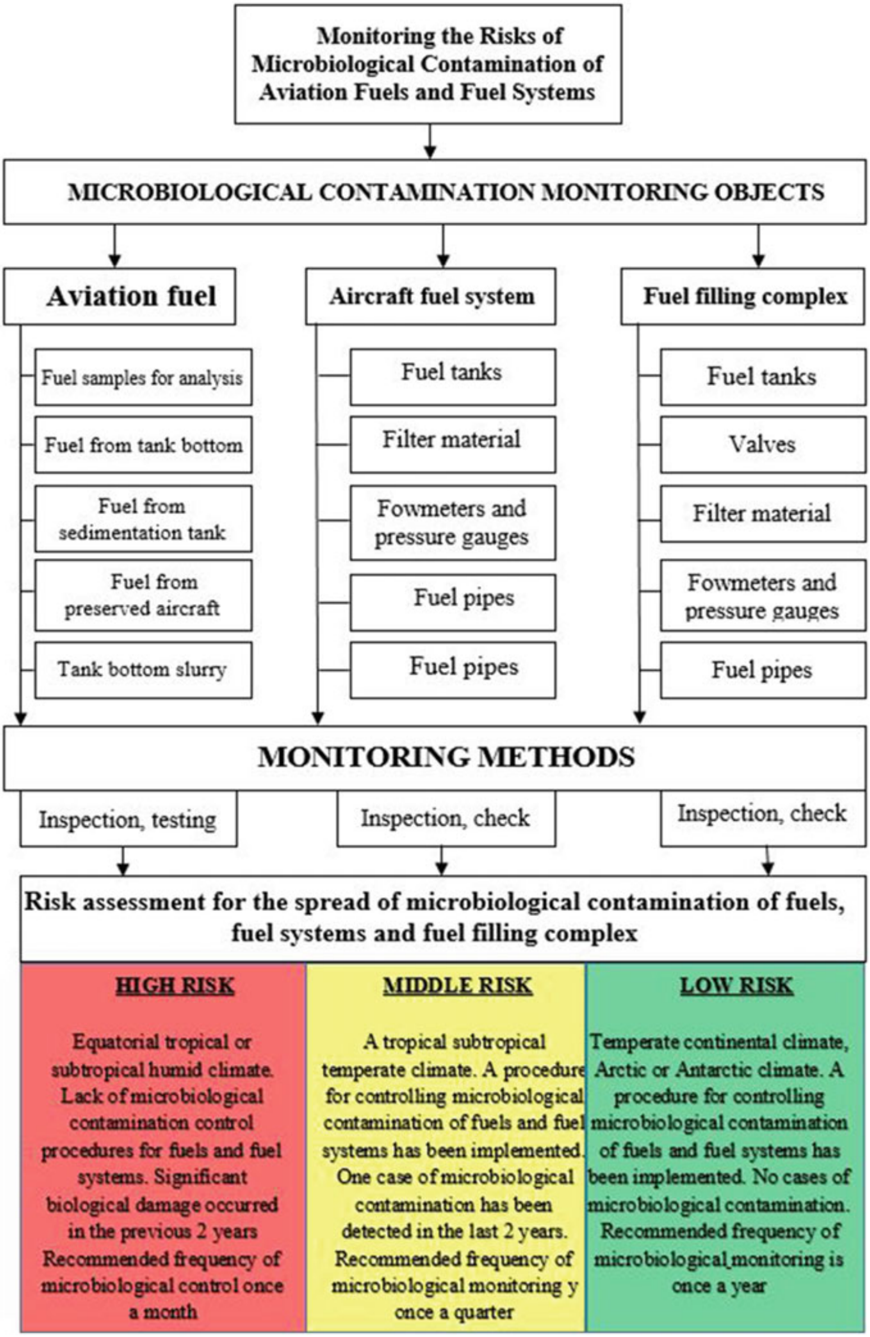

Fig. 5 Monitoring the risks of microbiological contamination of aviation fuels and fuel systems

The proposed system is a generalized algorithm for deciding on the frequency of monitoring objects (aviation fuel, elements of fuel systems, and fueling complexes) and the selection of prevention methods based on a qualitative risk assessment. The algorithm consists of the definition of the monitoring object, the selection of monitoring methods (inspection, testing or verification, depending on the monitoring object), the analysis of monitoring results, and the assessment of the risk of microbiological contamination spreading in fuels and fuel systems, and the selection of methods to prevent or control the development of microbiological phases.

The factors identified in the preliminary analysis and the construction of an Ishikawa cause-effect diagram helped to formulate attributes for each risk level. The first of these is climate (characterized by humidity and temperature). Temperature is an intensifying risk factor.

The principle of risk classification is based on aspects of the physiology of the micro-organisms that can grow in the fuel environment. These are the dependence of the micro-organisms on the nutrient medium and the presence of water. The risk of water in the fuel depends on the humidity of the environment.

The risk of past events indicator is also used to form a risk level indicator. Past events of microbiological contamination of aviation fuel and fuel systems increase the level of risk and influence the selection of actions and organizational measures to minimize it.

The implementation of this system will make it possible to ensure the biological purity of aviation fuel, prevent the occurrence of microbiological contamination in fuel systems and refueling complexes and, as a consequence, eliminate the impact of microbiological fuel contamination on flight safety.

6 Conclusions

Contamination of fuel by microorganisms is incidental. However, this does not negate the existence of certain patterns. Factors such as oxygen, moisture, temperature, nutrients and pH affect the appearance, growth rate and spread of microorganisms in fuel. Natural and climatic conditions determine the numerical and qualitative composition of microorganisms and their activity in the environment. Normal metabolism, growth, and reproduction are possible only in the presence of moisture.

Problems caused by microbiological contamination of fuel systems can be divided into the following categories: problems caused by the physical presence of microbial colonies; problems caused by the metabolism of microbial petrodestructors; problems caused by metabolites of microbial petrodestructors; problems related to the property of microorganisms to cause corrosion.

Microbiological fuel contamination is an indirect sign of a microbial contamination problem in the fuel system and environment of the aircraft and aviation.

References

1. Iakovlieva, A., Boichenko, S., Vovk, O.: Impact of aviation fuel quality on flight safety and environment. Sci. Innovat. **9**(4), 25–30 (2013)
2. Shkilniuk, I.: Investigation of the microbiological stability of traditional and alternative aviation fuels. Int. J. Sustain. Aviat. **2**(2), 111–118 (2016)
3. Vangsness, M.D.: Best practices for fuel system contamination detection and remediation. Physicist University of Dayton Research Institute, USAF AFMC AFRL/RQTF (2015)
4. Behbahani-Pour, M.J., Radice, G.: Fuel contamination on the large transport airplanes. Aeronaut Aerospace Eng. **6**, 4 (2017)
5. Shkilniuk, I., Boichenko, S.: (2020). Biological Risk of Aviation Fuel Supply. In: Babak, V., Isaienko, V., Zaporozhets, A. (eds) Systems, Decision and Control in Energy I. Studies in Systems, Decision and Control, 298. Springer,
6. Harold, W.G. (2003) An analysis of microbial contamination in military aviation fuel systems. Technical report AFIT/GEE/ENV/03–10. Department of the air force Air university Air forceinstitute of technology, p. 221.
7. Kondratyuk, T., Kharkevich, E., Zaharchenko, V., Nakonechnaya, L., Roy, A., Zhdanova, N., Pashkevich, R.: Biodeterioration of aviation fuel TS-1 by microscopic fungi. Mycol Phytopathol **41**(5), 442–448 (2007)
8. Joseph B. Morton (2021) 6 - Fungi, Principles and Applications of Soil Microbiology, pp. 149–170.
9. Mary Ann Bruns (2021) 5 - Bacteria and archaea. Principles and Applications of Soil Microbiology, pp. 112–148.
10. Rafin, C., Veignie, E. (2018) Hormoconis resinae, the kerosene fungus: Handbook of hydrocarbon and lipid microbiology, Springer International Publishing AG, pp. 16–21.
11. Gaylarde, C.C., Bento, F.M., Kelley, J.: Microbial contamination of stored hydrocarbon fuels and their control. Rev de Microbiol **30**, 1–10 (1999)
12. Pirog, T. (2004) General microbiology: handbook, Kyiv, p. 471.
13. Shkilniuk, I., Boichenko, S.: Methodically organizational principles of biological stability providing of aviation fuel. Trans Inst Aviat Warsaw **4**(237), 6–83 (2014)
14. Nezbrytska, I.M., Shamanskyi, S.I., Boichenko, S.V., Kharchenko, G.V.: Some problems of the use of microalgae for nitrogen and phosphorus removal from wastewater (a review). Hydrobiol. J. **57**(2), 62–78 (2021)
15. Robbins, JA., Levy, R. (2004) A review of the microbiological degradation of fuel. In: Directory of microbicides for the protection of materials. Kluwer Academic Publishers, pp. 177–202.
16. Vasilieva, A.A., Chekunova, L.N., Poliakova, A.V.: Influence of temperature on growth and viability of Hormoconis resinae u Phialophora sp., developing in aviation fuels. Mycology and phytopathology, 43(4), pp. 312–316 (2017)
17. Passman, F.J.: Microbial contamination and its control in fuels and fuel system. Int. Biodeterior. **1**(88), 104 (2013)