HAMMONDS FUEL ADDITIVES, INC.

Considerations for Long-term Storage of Jet Fuel in Aircraft White Paper

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Introduction

Questions continue to be raised concerning the long-term storage limitations of jet fuel in aircraft being parked due to the COVID-19 emergency. The industry demands safe and reliable fuel. How long is too long and what are the main issues to consider with long-term storage in aircraft? Fuel compositions vary depending on refining process and source of crude. There are many variables that determine the stability of fuel in long-term storage. While long-term storage in aircraft is not the norm, the military and fuel industry do store large stockpiles for lengthy periods of time with great success. Assuming fuel was uploaded into the aircraft, dry and free of contaminated solids, what are the main factors that negatively affect fuel stored in aircraft? What can be done to minimize problems associated with long-term storage? Is there a time limit to long-term storage?

Problems

Main factors negatively affecting the long-term storage of fuel in aircraft:

1. Fuel aging and oxidation
2. Water
3. Temperature, temperature vacillations and humidity
4. Additives
5. Microbial contamination

1. Fuel Aging and Oxidation

One fact is likely to never change, fuel ages. As it ages, it degrades. One aspect in the aging process is oxidation. Studies on fuel storage recognize uncontrollable oxidation and attempt to analyze it's affect in stored fuels. (Bessee, Wilson, & O'Brien, 2012) Referred to as autoxidation, the process occurs in well-maintained, stable storage environments. (Czarnocka, Matuszewska, & Odziemkowska, 2015) Although, oxidation does not necessarily require oxygen. Autoxidation is spontaneous and generally occurs in the presence of oxygen, ambient air. There are numerous unknowns involving the degradation of fuel and the aging process. Fuel composition and environmental factors play a part, especially autoxidation. Hydrocarbon molecules react with oxygen in storage systems. The exposure to atmospheric oxygen, the presence of catalyzing compounds (compounds that cause accelerated reactions) and environmental conditions within storage contribute to uncontrollable autoxidation, leading to the formation of resins, gums, particulate and acid formation. (Mick, 1998) There is little that can be done to stop the process. However, there may be ways to slow it down and minimize its effect during long-term storage. Further discussion follows on how water, temperature and microbial contamination contribute to fuel aging.

2. Water

Water is always a factor in fuel degradation. The control and regular removal of water is imperative. For this reason, long-term storage of fuel depends on good housekeeping and maintenance methods. Aircraft are regularly exposed to water contamination. Three main ways water enters into a parked aircraft are through condensation, deteriorated cap seals in the fuel system and intrusion through fuel vent ports. Condensation is the most common form of water contamination. (Passman, 2013) As the tank breathes, condensation forms and water coalesces along the tank walls and roof, eventually settling to the bottom. Even though aircraft are constructed with drain sumps at low points, water can still become trapped resulting in improper drainage limiting its removal. Common places water settles as a result of restricted drainage include welds, rivets, tank baffles and low areas. Trapped water accelerates fuel degradation. Poorly maintained cap seals commonly result in water intrusion. Vents are also subject to intrusion. (Behbahani-Pour & Radice, 2017) During aircraft washing, rain or snow events, water can enter vents and capped areas. Inspections of seals, caps and vents during long-term storage helps minimize water issues. Reducing water minimizes the effects of fuel aging, oxidation and microbial contamination.

3. *Temperature, temperature vacillations and humidity*

Temperature and vacillations of temperature are factors to consider with long-term storage. As temperatures rise, water solubility of fuel increases. Condensation coalescing on the walls of a tank are more readily absorbed into the fuel. The opposite is also true. As temperatures decrease, suspended water coalesces and settles. Other contributing factors such as surfactant additives or biosurfactant microbes cause water emulsifications at any temperature. However, higher temperatures are generally more favorable to higher levels of water solubility. Higher temperatures also increase the reproductivity of microorganisms.

High temperatures are also attributed to accelerated fuel aging, oxidation and accelerated microbial growth. (Graef, 2003) Reactions that result in oxidation occur more rapidly in higher temperature environments. Low temperatures result in ice crystal formation if deicer is not used. Ice formation is never a good thing for aircraft maintenance or safety. Temperature vacillations are a major cause of water in the form of condensation. In geographic regions where daily temperature vacillations are wide, water droplets form more readily within the fuel system. The greater and more frequent the vacillations, the more potential for water. As thermal changes take place, fuel chemistry changes adding to the challenge of maintaining fuel quality over the long-term. (West, 2011)

Humidity plays a role in water accumulation often combining with temperature and temperature vacillations to create unwanted environmental concerns within fuel systems. Aircraft parked in tropical regions are statistically more prone to water and as a result microbial contamination. (IATA, 2009) Admittedly, there is more recordable rainfall in the region as well. Temperature and humidity play a significant role in predetermining potential water issues. However, they are not the sole determining factors in fuel aging or biodeterioration (the detrimental change to materials due to bioorganic activity).

4. *Additives*

Some jet fuel additives may have adverse effects on the long-term storage of fuel in aircraft. Any additive that lowers the surface tension of the fuel acting as a surface-active agent – a surfactant – is a potential problem. (Johnson, 2018) A surfactant reduces the surface tension between the fuel and water present. (Hostetler & Powers, 1963) When surface tension is reduced, fuel becomes more water soluble making it more difficult to settle out and drain off. If enough water is absorbed over time an additive with surfactant qualities becomes water laden and heavy enough to settle out with water. (Johnson, 2018) DiEGME has been associated with this problem, identified by the US Military as “apple jelly.” (Waynick & Dipoma, 2002) They concluded that the combination of water and DiEGME in stored jet fuel resulted in a complex mixture settling to the bottom of tanks. The additive proved to be unstable, settling out of solution. The caveat, any additive that bonds to water or is highly water soluble might

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have similar results. Long-term storage will test the solubility and proper distribution of any additive blended in jet fuel. Using stable additives reduces the possibility of additional fuel quality issues and safety concerns.

5. *Microbial Contamination*

Microbial contamination left unchecked accelerates fuel degradation and leads to serious fuel system problems. Loss of product quality, emulsification, system corrosion and sludge formation are just a few of the more serious issues associated with microbial contamination. Microorganisms play a damaging role in fuel and fuel systems. The following summary is meant to be an overview. This is not an attempt to cover every aspect of microbial contamination, only highlight potential issues in long-term storage.

There are two microorganisms commonly found in fuel: bacteria and fungi. Yeast and molds are the most common fungi found. Fungi often observed in the water-fuel interfaces on the bottom of tanks form thick membranes or films most evident in bottom samples. Bacteria are single-cell microorganisms found everywhere. As the tank breaths, microbes are a part of ambient air flowing in and out of the fuel system. (Onuorah, Obika, Orji, & Odibo, 2016) If allowed to grow and multiply, biomass forms often supporting bioemulsifiers and biosurfactants – microbes capable of creating emulsifications and lowering the surface tension of the fuel similar to a surfactant additive. Both are capable of pulling water into fuel resulting in biodeterioration.

Three types are relevant: aerobes, anaerobes and facultative anaerobes. Aerobic bacteria require oxygen to survive. Some remain dormant in the lack of oxygen. Oxygen found commonly in water-fuel interfaces and condensation provide a ready source. Anaerobic bacteria cannot tolerate oxygen and will likely die or remain dormant. Biomass and enzymatic byproducts created by microbes often provide anoxic environments (oxygen free). (Little & Lee, 2007) The most damaging anaerobe found in fuel systems is Sulphate Reducing Bacteria (SRB) associated with accelerated, damaging corrosion. They produce hydrogen sulfide that corrode metal, plastic and rubber. While microbial influenced corrosion is a potential with most microbes, SRB corrosion is thought to be the worst. (Gaylarde, Bento, & Kelley, 1999) Facultative anaerobes survive in both oxygen and anoxic environments. Bacteria are highly adaptive and given time will create their own environments.

Microbes work in consortia (communities working together). Biodeterioration results from microbes working together. It is not uncommon to find aerobic, anaerobic and facultative communities working in concert to create environments beneficial to growth. They require a food source, most of which is found in the hydrocarbon molecule. There are ways to reduce the development of fuel eating bacteria and fungi in aircraft.

Solutions

The negative effects of fuel aging, oxidation, temperature related issues, water problems, microbial contamination and additive issues are a challenge. A few well-planned steps limit their effect and allow for successful long-term storage in aircraft.

1. Maintain good housekeeping
2. Sample and test for microbial contamination
3. Inspect items susceptible to water intrusion
4. Add inspections as needed following post-water events
5. Administer biocide – Biobor®JF

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1. Maintain good housekeeping

Water is the enemy. First and foremost, remove free water. This is where regular, good housekeeping efforts pay off. High temperature geographies or those with temperature vacillation may require more attention. Optimally, drain water weekly. This helps minimize free water collection and the problems that go with it. Keeping fuel as dry as possible reduces the proliferation of microbial contamination. It does not guarantee a microbial free system, but it does create a more favorable environment.

2. Sample and test for microbial contamination

Sample and test fuel to determine any changes in fuel quality before it becomes a serious problem. Sample and visually inspect fuel during weekly water draining. If fuel shows signs of contamination or discoloration, test for microbial contamination. Test monthly for microbiological growth even in the absence of water. The absence of discernible water often presupposes the absence of microbial growth. It is possible to have bacteria without water or to have microbial colonies in one section of the tank and not another. Fuel samples are only representative of the small area the sample is retrieved from. They only provide a glimpse of a portion of the fuel system environment. It is virtually impossible to obtain a representative sample of any storage tank. If contamination is detected, a visual borescope inspection helps identify the level of contamination and the steps to remediation, following OEM recommended practices.

3. Inspect items susceptible to water intrusion

Successful long-term storage depends on proper maintenance and inspection schedules. Pre-storage inspections of aircraft fuel system access points and seals is recommended. Specifically inspect for deficiencies in seals, caps and vents. The smallest defect or damage is a potent for bigger problems during long-term storage. Replace or repair deficiencies, thus limiting water intrusion events. If during storage, unusual volumes of water are found in the fuel system, reinspect component parts to verify the system is properly sealed. Make repairs as necessary.

4. Add inspections as needed following post-water events

Rain and snow storms, especially those with driving winds, present additional water intrusion concerns. Additionally, aircraft washing is a known source of water intrusion. A post-water inspection helps eliminate problems during long-term storage. Effective water management strategies, including additional inspections, reduce microbial contamination by finding water before it becomes a problem.

5. Administer biocide – Biobor®JF

The prior steps only help reduce contamination and limit fuel degradation. No matter how good the process, microbial contamination is probable. In order for fuel to be effectively preserved during long-term storage, a biocide is essential. (Hill E. H., 2001) What are the requirements for such a biocide? Biobor®JF, was developed specifically for aviation use to eliminate the problems associated with microbial contamination in aircraft. Its solubility, potency, compatibility and stability demonstrate its effectiveness as a fuel preservative and solution to the challenges existing during long-term storage.

Biobor®JF is soluble in both fuel and water phase. It was designed to adequately partition between both phases in a fuel system. As stated, fuel systems contain small amounts of water. Bacteria and fungi make their home in the water-fuel interface layer and therefore it is imperative to have a biocide that effectively partitions and distributes between the two immiscible phases to provide sterilization in both layers.

One significant difference between Biobor®JF and other biocides is its effective penetration of films, slimes and biomass often associated with microbial contamination. Microbial enzymatic biolayers make it difficult for biocides to penetrate and kill bacteria or fungi. Testing shows Biobor®JF effective at penetrating the layers. Studies also show the effective long-term sterilization of fuel systems containing water contamination. Biobor®JF is proven through efficacy studies to be a potent and effective sterilizer. A shock dose is most effective, sterilizing fuel and providing aircraft protection.

The ideal biocide should have no adverse effect on fuel specifications or approved fuel additives. Biobor®JF was extensively tested and used for over five decades with no known deleterious effects. It is compatible with other fuel additives. Both short-term and long-term additive compatibility studies were completed with common aviation fuel additives. Rigorous testing performed and continued use over more than 55 years confirm its compatibility.

Biobor®JF does not affect fuel water separating tendencies. It contains no surfactant qualities. In testing, it was blended in fuel for evaluation using the CRC water separator test and the ASTM water tolerance test. It had no adverse effects, including fuel filterability. (Scovill & Gron, 1964) Tests were conducted using full scale filtration equipment to show that Biobor®JF does not alter the water separating or fuel filtering effectiveness of filtration equipment.

Biobor®JF is compatible with common aircraft materials and performed well in testing. A battery of tests on common materials used in engines, fuel systems and aircraft equipment concluded broad compatibility. Soak tests at elevated temperature were performed on metals, sealants, coatings and gaskets. Critical parameters were measured during testing with positive results. Fuel biocides are known to be corrosive. According to NACE Standard TM-01-69, Biobor®JF is classified a non-corrosive material, one additional point of differentiation. (Truesdail Laboratories, Inc., 1974)

Numerous engine hours were accumulated on fuel containing Biobor®JF up to 1000ppm showing no adverse effect on engine components. No harmful effects on jet engine performance were noted during testing or in field. It should also be noted that Biobor®JF adds lubricity, reducing wear scar tendency and improving engine performance.

Biocides can be dangerous and difficult to handle. (Burnett & et al, 2010) Common fuel biocides contain potentially dangerous chemical mixtures including thiocyanate or isothiazoline. (Hosteing & Etal, 2014) (Hughes & et al, 2011) They are toxic, acidic, corrosive making them difficult to handle. (Silva & et al, 2020) In contrast, Biobor®JF is a non-corrosive, low-toxic biocide requiring normal handling precautions. As a boron product, it has low-toxicity to mammals and is beneficial to plant growth. Recent studies indicate boron is a beneficial pharmaceutical, attributed to bone health, having antiviral and antibiotic properties. (U.S. Department of Health and Human Services, 2010) Other biocides have additional handling requirements because of their undesirable characteristics, making them more difficult, costly and riskier to apply.

Fuel blending is another factor to consider. Biobor®JF blends well in fuel and is extremely stable. With any chemical, molecular structure is important. The unique design of Biobor®JF's molecular structure makes it both stable and soluble. (Scovill & Gron, 1964) It is suitable for batch blending, injection and over-wing splash blending, evenly distributing throughout the fuel in the tank. The product is not subject

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to stratification. Long-term studies demonstrate its stability and solubility, remaining in solution, not settling or stratifying even under the less than desirable conditions of long-term storage. Another facet of Biobor®JF's stability is its freeze point. It has a deicing characteristic to its chemistry, which is another advantage over other biocides. It is easier to handle in cold weather and less likely to be affected by extreme temperature changes.

Conclusion

Long-term storage of fuel in aircraft is challenging but not impossible. While oxidation plays a part in fuel aging, the source of most fuel degradation comes from the presence of water. Good housekeeping, sampling, testing and inspections reduce contamination. The potential for microbial contamination remains with or without the evidence of water. (DeGray & Killian, 1961) A majority of airlines indicate minimal volumes, no more that 10% of capacity during long-term storage, leaving 90% unprotected. Dry space in a fuel system represents an area of frequent condensation and is always unprotected. Fuel biocides can only protect what it touches. Biobor®JF provides the necessary assurance for fuel and the wet space during long-term storage. Effective, stable and soluble, it will stay in solution during extended storage. Studies show with proper fuel management, fuel can be stored for extended periods of time. Military organizations regularly store jet fuel for as long as 36 months with no significant changes to fuel quality specification. (Bessee, Wilson, & O'Brien, 2012) While there are many variables and no guarantees, fuel is regularly stored long-term with no depreciable affects. The key is to reduce the variables through regular, well-planned aircraft maintenance, inspections and fuel quality management. In the end, fuel quality testing provides answers to questions about fuel specification and usability if required.

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