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Considerations on Ice Formation in Aircraft Fuel Systems

FOREWORD

Changes in this revision are format/editorial only.

In the past, incidents and accidents occurred in the operation of military and civil aircraft which were attributed to the formation of ice in the engine fuel supply system resulting in intermittent or complete starvation of fuel flow. Considerable effort was devoted by many airframe companies, engine and accessory manufacturers and government agencies to study the problem of ice formation and to evolve corrective measures. By its very nature, the problem of ice formation was difficult to identify and analyze. However, corrective measures were developed which virtually eliminated serious icing problems in aircraft fuel systems. For many years incidents and accidents have not occurred on aircraft equipped with fuel heaters and/or operated with fuel containing anti-icing additive.

This report was initially based on conclusions reached at the combined Air Force-Navy-Industry conference held in 1959 and then updated to contain background information obtained by the SAE Committee AE-5. It represents a summary of opinions available today from experienced fuel system engineering personnel. This AIR is intended for use as a guide in future consideration of ice formation in aircraft fuel systems. It does not cover instructions for conditioning of fuel, such as anti-icing additive mixing, nor does it involve consideration of ice formation in fuel tank vent systems.

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INTRODUCTION

Ice formation in aircraft fuel systems results from the presence of dissolved and undissolved water in the fuel. Dissolved water or water in solution with petroleum fuels constitutes a relatively small part of the total potential water in a particular system; the quantity dissolved being primarily dependent on fuel temperature and the water solubility characteristics of the fuel. One condition of undissolved water is entrained water such as, water particles suspended in the fuel as a result of mechanical agitation of free water or conversion of dissolved water through temperature reduction. Another condition of undissolved water is free water which may be introduced as a result of refueling or the settling of entrained water that collects at the bottom of a fuel tank in easily detectable quantities separated by a continuous interface from the fuel above.

Entrained water will settle out in time under static conditions and may or may not be drained, depending on the rate at which it is converted to free water. In general, it is not likely that all entrained water can ever be separated from fuel under field conditions. The settling rate depends on a series of factors including temperature, quiescence and droplet size. The droplet size will vary depending upon the mechanics of formation. Usually the particles are so small as to be invisible to the naked eye, but in extreme cases can cause slight haziness in the fuel.

Free water can be drained from a fuel tank if sump provisions are adequate. Water in solution cannot be removed except by dehydration or by converting it, through temperature reduction, to entrained, then to free water.

Water strictly in solution is not a serious problem in aircraft fuel so long as it remains in solution. Entrained and free water are potentially the most dangerous because of the possibility of more water available for collection on the surfaces of the system. Further, entrained water will freeze in cold fuel and tend to stay in suspension longer since the specific gravity of ice is approximately the same as that of hydrocarbon fuels.

The elimination or toleration of undissolved water must be examined from the standpoint of two major elements of the fuel supply:

- The bulk storage and ground handling equipment.
- The airframe and engine fuel supply system.

Pertinent considerations of these elements to reduce the icing hazard follow.

1. SCOPE:

This document suggests and summarizes points that should be considered with respect to the formation of ice in aircraft fuel systems. These summaries represent a cross-section of the opinions of fuel system designers and users.

2. REFERENCES:

2.1 U.S. Government Publications:

Available from DODSSP, Subscription Services Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

MIL-E-5007
MIL-F-17874
MIL-F-38363
MIL-I-27686
MIL-I-27686E
MIL-J-5624F
MIL-T-5624H
MIL-T-5624J

3. FUEL CONDITIONING REQUIREMENTS FOR GROUND HANDLING:

3.1 Undissolved Water:

There should be no detectable undissolved water at fuel ambient temperature. The presence of less than 5 parts per million above that to saturate the particular fuel at the fuel ambient temperature is considered to comply with this requirement.

3.2 Solid Contaminant:

Should not exceed 4.0 milligrams per gallon of fuel.

3.3 Control techniques should be used to insure continuous compliance with the requirements of 3.1 and 3.2 above at point of delivery to aircraft. Filtration to control the particulate contamination level of the fuel, and water coalescing-type equipment to separate undissolved water from the fuel should be a part of the fuel supply and/or ground handling equipment for effective fuel conditioning. Refer to Appendix A for reference documents related to fuel cleanliness requirements and water detection instruments.

4. AIRFRAME AND ENGINE FUEL SYSTEM ICING INFLUENCES AND CONSIDERATIONS:

4.1 Aircraft Operational Conditions Tending to Favor Accumulation of Free Water to Retention Within the Aircraft Fuel System:

4.1.1 Descent from high altitude (condensation).

4.1.2 During cold weather operations, maintenance problems can exist below 32 °F (0 °C), without anti-icing additive fuel due to freezing of water; with anti-icing additive fuel the freezing temperature of entrained and free water is lowered.

JP-4 and JP-5 fuels per MIL-T-5624J, dated 30 October 1973, are required by specification to contain anti-icing additive per MIL-I-27686 from .10 to .15% by volume. Starting with MIL-J-5624F, dated 25 September 1962, the military specification required JP-4 to contain anti-icing additive. Then amendment 1 to MIL-T-5624H, dated 30 July 1971, required JP-5 to contain anti-icing additive also. The original anti-icing additive per MIL-I-27686 dated 22 September 1967, contained 87.3% by volume of ethylene glycol monomethyl ether (EGME) and 12.7% by volume of glycerol. From 1962 to 1970 the glycerol content was systematically reduced from 12.7% to zero. Primary reasons for the elimination of glycerol were the adverse effect on filter separators, and the need for glycerol no longer existed as a means of fuel tank top coating protection.

The effect of deleting the glycerol was considered by the Air Force to have negligible effect on the freeze point of water in aircraft tanks containing fuel with additive per MIL-I-27686E. Figure 1 provides test data showing the effect on freeze point of water by varying concentrations of EGME and glycerol in the water phase. Examination of this data indicates there is very little difference in the freeze point depressant capability of the glycerol or EGME component. This data can be used to predict the freeze point of water in aircraft tanks containing fuel with MIL-I-27686E additive if the concentration of EGME in the water phase is known. Because the additive is water soluble and entrained water tends to settle to the bottom of fuel tanks, the amount of additive in the fuel is diminsed by settling of the water and sump drainage. Therefore, over-dosing and replenishing of additive in the fuel supply system may be necessary for assurance of protection against water freeze.

4.1.3 Increase in fuel temperature tends to increase amount of dissolved water in the fuel. Decrease in fuel temperature tends to release water from solution. Conditions which are conducive to water release are:

- Servicing aircraft with relatively warm fuel with subsequent cooling.
- Prolonged flight as altitude.
- Temperature cycling of fueled aircraft.

4.1.4 High ambient humidity (during flight and on ground).

4.1.5 Temperature cycling of fueled aircraft on ground.

4.1.6 Prolonged exposure to above conditions.

4.1.7 Improper aircraft water drainage procedures.

4.2 Design Features Which Tend to Minimize Icing Problem Within the Airframe and/or Engine Fuel Systems:

4.2.1 Water Drainage Provisions:

4.2.1.1 Provisions and instructions for maximum water drainage in "at rest" attitude by adequate design and proper drainage procedures.

4.2.1.2 Provisions for adequate accessibility for ground maintenance.

4.2.1.3 Provisions for ease of operation for ground maintenance.

4.2.1.4 Prominent and clearly defined markings for ground maintenance.

4.2.2 Component and System Design:

4.2.2.1 Selection of appropriate non-ice adhering materials where possible.

4.2.2.2 Development of non-critical fuel servos and fuel control devices.

4.2.2.3 Elimination of unnecessary screens and filters from the aircraft and engine fuel systems consistent with all other safety of flight criteria.

4.2.2.4 Mandatory use of by-pass around a screen or filter that clogging could result in engine flameout or other safety of flight hazard. Generally, No. 8 mesh screen or coarser is not subject to critical icing; however, this would depend on and should be demonstrated for the critical operation conditions, such as mission profile, fuel, water content and environment.

4.2.2.4.1 Reliable design of by-pass element.

4.2.2.4.2 By-pass element located to prevent backwashing of sediment.

4.2.2.4.3 Multiple by-pass elements in principal filter. (Safety of flight consideration).

4.2.2.5 Impending by-pass or by-pass warning device on principal filter or screen for ground warning and/or, if practical, inflight warning.

4.2.2.6 Use of ice collecting protective devices.

4.2.2.7 Insulation provisions where practical.

4.2.2.8 Adequate access to interior of fuel tanks for inspection and cleaning.

4.2.2.9 Incorporation of adequate water sump capacity with drainage provisions.

4.2.2.10 Ejector pumps to scavenge water from trapped areas in fuel tanks and disperse water to sump areas for subsequent drainage operation on ground. Ejector pump usage to scavenge water and disperse to fuel pumps for subsequent inter-tank fuel transfer or engine fuel feed is acceptable with appropriate design for adequate maxing with fuel to prevent slugs of free water from entering the engine feed system. (Currently large transport aircraft use this method of water scavenge.)

4.2.2.11 Single fuel tank or group of interconnected tanks with more than one vent opening to the atmosphere should be evaluated relative to any adverse effects of inter-vent air circulation through the tank(s). With pressure difference between two vent openings, warm moist air could circulate through the tank(s) and cause considerable quantities of water to be collected during low altitude hold with cold fuel in the tank(s).

4.2.3 Icing Prevention or Control Measures to be Considered:

4.2.3.1 Anti-icing.

4.2.3.2 De-icing (fuel heater installed in engine; no serious icing problems have been reported for aircraft containing fuel deicing systems).

4.2.3.3 Additives (icing problems have been greatly reduced after incorporation of anti-icing additive in fuel).

4.2.3.4 Optimum use of available heat.

4.2.3.5 Environmental location of components.

4.3 Contamination and Water - Design Operational Conditions:

4.3.1 Contamination (since the size and capacity of the fuel filter is an important consideration in the icing problem, this information is included here for reference).

4.3.1.1 Contaminate: per specification MIL-E-5007.

4.3.1.2 Maintenance inspections: per aircraft and engine maintenance manuals.

4.3.1.3 Qualification test:

Aircraft: per specification MIL-F-17874 (Navy) or MIL-F-38363 (Air Force).
Engine: per MIL-E-5007

4.3.2 Water:

4.3.2.1 Amount: for aircraft and engine, use fuel conditioning procedure per MIL-F-17874 or MIL-F-38363 as guide.

4.3.2.2 Qualification test: for system and components use fuel conditioned per MIL-F-17874 or MIL-F-38363 as basis for negotiated test contingent on mission time, environment, etc. applicable to model in question. For aircraft that operate normally with fuels containing anti-icing additive but are allowed to operate with alternate or emergency fuels without additive with no appropriate operating temperature restrictions, qualification testing should be conducted for the worst case i.e. with fuels not containing anti-icing additive. NOTE: Difficulty in reproducing test results has been experienced when handling large quantities of conditioned fuel. One solution to this problem could be not to recirculate the the fuel back to the test tank and to have better control of conditioning fuel with water.

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SAE COMMITTEE AE-5, AEROSPACE FUEL, OIL & OXIDIZER SYSTEMS