

Method and System for Making a Fuel-tank Inert without an Inert Gas

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ABSTRACT

In Chemistry "Inert" implies 'not readily reactive with other elements; forming few or no chemical compounds or something that is not chemically active'. "Inerting" is the process that renders a substance inert. A method for making a fuel-tank inert without the use of an inert gas is described. In this method fuel-air ratio of ullage is reduced until it becomes inert. The method does not discharge fuel vapors as an inert gas inerting system. Two systems employing the method are described explaining their pros and cons. Advantages of the method over Nitrogen Enriched Air (NEA) inerting method with an On-board Inert Gas Generating System (OBIGGS) are discussed. Patent application on the method and system is pending.

INTRODUCTION

Fire requires three components: adequate fuel, oxygen and an ignition source of sufficient energy to start the fire. In the past, Federal Aviation Administration (FAA) certified airplanes with flammable vapors in fuel tanks based on the belief that potential ignition sources could be precluded by design and maintenance. FAA realized that "safer" fuel tanks are necessary after the explosion of Thai International Boeing 737 model airplane on March 3, 2001. It was the third Center Wing Tank (CWT) explosion in 11 years. In 1990 the CWT on a Philippine Airlines Boeing 737 model, and in 1996 the CWT on a Trans World Airways Boeing 747 model exploded. National Transport Safety Board (NTSB) added "Explosive Mixture in Fuel tanks in Transport Category Aircrafts" as number 1 item to its "Most Wanted" Transportation Safety list in 1997. The FAA conducted review of the certification regulations and amended Federal Aviation Regulation 14CFR§25.981 titled, "Fuel Tank Temperature to Fuel Tank Ignition

Prevention" on July 21, 2008, Reference 1. Inerting of fuel tank using an inert gas is the present method.

AVIATION FUEL AND FUEL-TANK

Fuel types approved for use by an airplane are listed in the Airplane Flight Manual (AFM) and the model Type Certificate Data Sheet (TCDS). Each fuel type has its own properties. Small differences occur in different batches of a fuel type due to crude oil source and/or the refining process. Most widely used fuel types are JET-A or JET-A1, per American Society of Testing and Materials ASTM Specification D1655, "Standard Specification for Aviation Turbine Fuels."

The **Flash Point** of a fuel is the lowest temperature at which it can form an ignitable mixture in air and ignite momentarily or "flash" at sea-level. Flash point is fuel's descriptive characteristic and is generally determined using ASTM D56 method. A fuel sample is placed in a closed cup and heated at a constant rate to maintain fuel and ullage in thermal equilibrium. The lowest temperature at which ignition is observed in the cup's ullage on introduction of a small flame is called the flash point. Minimum **required** flash point of Jet A and Jet A-1 fuels is 100°F (38°C). **Theoretically**, at sea-level the ullage of a Jet A fuel tank is inert at temperatures lower than 100°F, and that it **can** be non-inert at temperatures **equal to or greater than** 100°F (38°C).

The weight of fuel vapor to the weight of air in the ullage mixture is termed **Fuel-Air-Ratio (FAR)**. Fuel-air ratio and altitude domain wherein the ullage mixture is non-inert (called the **Flammable Region**) is shown in Figure 1. The data is from FAA Advisory Circular 25.981-2. Fuel air ratio is convenient in defining the flammability limits since its value at the lower flame propagation limit is quite constant over a wide range of

fuels according to Reference 2 FAA report. Literature data indicate that the FAR at the lower limit is about 0.03.

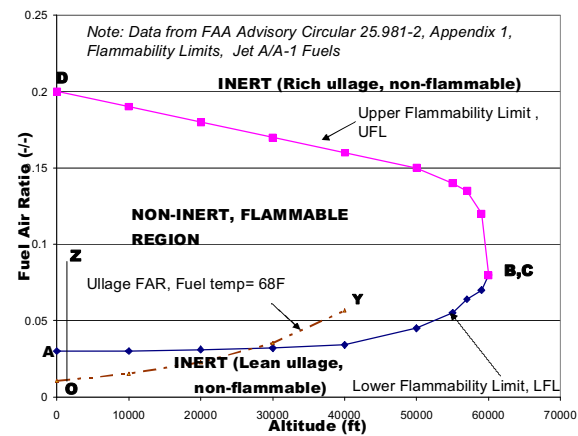


Figure 1: Fuel Air Ratio and Altitude Domain for Inert and Non-Inert Ullage

Figure 2 shows temperature and altitude domain wherein the ullage is non-inert. The data is from FAA Advisory Circular AC25.981-2. Figures 1 and 2 data are for a system in which fuel and ullage are in thermal equilibrium. Figure 2 shows the Flash point as 90°F instead of 100°F. Figure 2 data incorporates a factor of safety. The ullage is non-inert when it is within the region delimited by ABCD. Figures 1 and 2 provide information on flammability of the fuel at conditions other than sea-level.

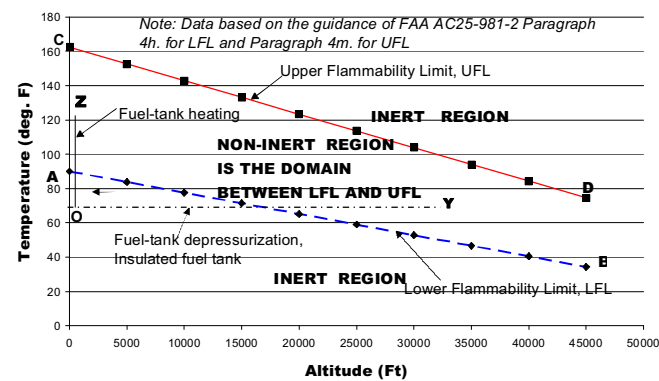


Figure 2: Temperature and Altitude Domain for Inert and Non-Inert Ullage

Fuel-air ratio of “liquid” fuel is infinite; liquid fuel is inert at all temperatures. FAA Airworthiness Directive AD 2002-18-52, Reference 3, requires operators with aircraft outfitted with faulty fuel pumps (suspected of shorting, arcing) to maintain the pumps submerged as arcing in fuel does not produce explosion.

Liquids tend to evaporate to a gaseous form, and vapors tend to condense back into liquid form. The pressure at which the vapor is in dynamic equilibrium with its liquid is called the **Vapor Pressure**. Vapor pressure is a measure of a liquid’s evaporation rate. A liquid of high

vapor pressure is termed **Volatile**. Vapor pressure of a liquid increases non-linearly with temperature, Table 1. **It is independent of pressure.** When the vapor pressure equals ambient pressure the liquid starts to boil.

Table 1: Vapor Pressures

Temperature (°F)	Jet A Fuel (psi)	Water (psi)
32	0.0073	0.0889
68	0.0261	0.3385
104	0.0783	1.0696
140	0.2059	2.8897
176	0.4815	6.8685
212*	1.0300	14.700*

*Boiling temperature of water at sea-level.

Note: water is more volatile than Jet-A fuel.

FUEL-TANK HEATING Inert ullage of a fuel tank can become non-inert when heat is supplied to fuel in the tank. The fuel generates greater amounts of fuel vapors at increased temperature thereby increasing ullage FAR. Line OZ in Figures 1 and 2 shows this phenomenon.

Effects of fuel heating are reversible. The tank can be returned to inert state by either cooling the fuel-tank contents or by removing fuel vapors from the ullage so its FAR remains below LFL. Cooling fuel tank contents is impractical because of the high heat capacitance (approximately 0.5 Btu/lb) for high mass loaded fuel tank. Removal of fuel vapors from the ullage is uncomplicated and efficient as (i) Fuel vapor generation does not depend on fuel mass loading, (ii) Fuel vaporization occurs at fuel surface and consumes heat of vaporization; 140-150 Btu/lb, and (iii) heat inflow to the fuel tank from external equipment is not large and part of the heat inflow is retained by fuel as increased temperature. NTSB conducted an instrumented test on 747 CWT; reference 4, and observed temperature increase from 80°F to approximately 125°F in 2 ½ hours of ground time with residual fuel (critical condition) in the fuel tank. This is equivalent to heat influx of 4500 Btu/hr (1.32 KW/hr) into a 2300 ft³ volume tank. The temperature rise would have been significantly lower at higher fuel mass loading.

DEPRESSURIZATION OF AN INSULATED FUEL-TANK Density of the air in the ullage decreases when a fuel tank depressurizes during airplane climb. Fuel vapor pressure does not change as it is independent of pressure. Reduction of air density (lb/ft³) causes ullage FAR to increase as FAR based on the weight ratio. This can make an initially inert fuel tank non-inert. This

characteristic is represented by Line OY in Figures 1 and 2. The fuel-tank is shown becoming non-inert at approximately 28,000 ft in Figure 1 at approximately 17,000 ft in Figure 2. Figure 2 data uses Flash Point of 90°F instead of 100°F as previously mentioned.

The effects of fuel tank depressurization are reversible. The tank can be returned to the inert state by either pressurizing the fuel tank or by removing fuel vapors from the ullage such that the ullage FAR remains lower than the LFL. Pressurization is impractical for vented fuel tanks. Removal of fuel vapors from the ullage is straightforward and efficient.

EVAPORATION AND CONDENSATION In the evaporation process, liquid molecules located near the surface, moving in the proper direction, and having sufficient kinetic energy to overcome liquid-phase intermolecular forces spontaneously become gaseous without the liquid reaching the boiling point temperature. However, since the kinetic energy of a molecule is proportional to its temperature, evaporation proceeds more quickly at higher temperature. As the faster-moving molecules escape, the remaining molecules have lower average kinetic energy, therefore the temperature of the liquid decreases. Evaporation consumes heat energy. Jet A fuel consumes 149 Btu/lb at a temperature of 104°F to evaporate. This phenomenon is known as evaporative cooling. If evaporation takes place in a closed vessel, the escaping molecules accumulate as a vapor above the liquid. In due course, many of the molecules return back to the liquid phase. When the process of escape and return reaches equilibrium the vapor is said to be "saturated."

In condensation process, vapor changes into liquid when the temperature of the vapor is reduced below the saturation temperature corresponding to the pressure of the vapor. Sustaining condensation on a cold surface requires cooling of the surface by external means as heat, equivalent to the heat of evaporation, releases during condensation. Condensation of vapor on a cold surface is termed film wise. If vapor temperature falls below its saturation temperature, condensation occurs in the bulk vapor. This phenomenon is called homogeneous condensation (formation of fog).

INERTING METHOD

The fuel tank is rendered inert by reducing ullage FAR to levels that are inert. This is accomplished by condensing fuel vapors out of the ullage at a rate faster than they are generated by fuel. The operating principle is shown in Figure 3, where Q is the heat input (positive, zero or negative) to the fuel tank. X lb/min of fuel evaporates from the fuel surface and enters the ullage at fuel temperature T_{fuel} . The evaporation rate depends on fuel vapor pressure that depends on T_{fuel} . Conditions change with time and thus Q and X are shown as functions of time (t).

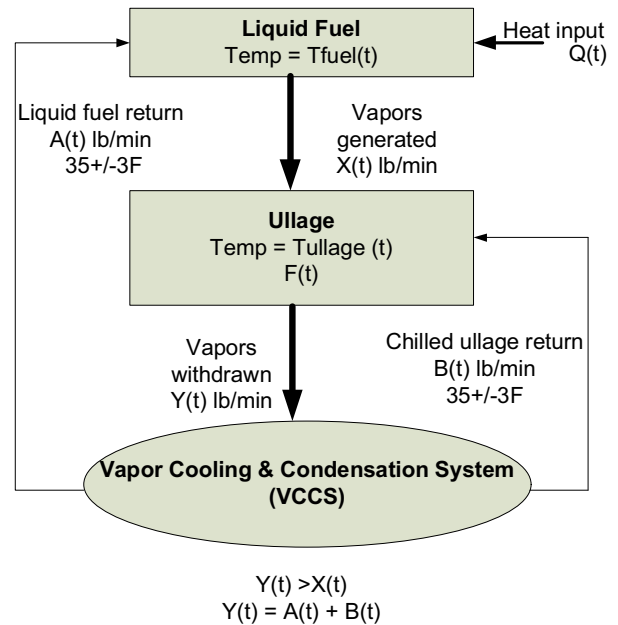


Figure 3: The Method

Y lb/min of fuel vapors of fuel-air ratio F are withdrawn from the ullage by the vapor cooling and condensation system (VCCS). The system is designed to withdraw ullage mixture from the ullage such that Y is greater than X. Both X and Y is function of time (t).

Vapor cooling and condensation system (VCCS) cools the ullage to low temperatures; suggested $35 \pm 3^\circ\text{F}$. During cooling A lb/min of fuel vapors condense to liquid fuel and B lb/min remain in vapor form. Air in the ullage mixture also cools to low temperature. Ullage mixture returns to the ullage and fuel returns to the tank both at $35 \pm 3^\circ\text{F}$. A and B are functions of time (t).

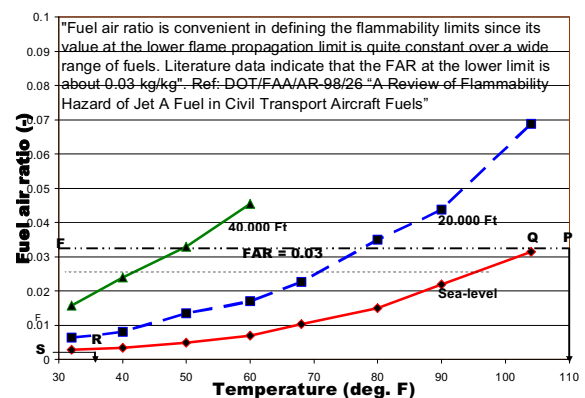


Figure 4: Cooling and Condensation Process

The cooling process, at sea-level, is shown in Figure 4. P represents the initial state of ullage mixture (temperature 110°F, unsaturated and at fuel air ratio F) withdrawn by VCCS from the fuel-tank. PQ shows cooling at constant fuel-air ratio to the saturation fuel-air ratio F (temperature 105°F). At Q the mixture is