

OBIGGS for Fuel System Water Management - Proof of Concept

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ABSTRACT

Fuel on-board dehydration during flight technologies have been modeled and experimentally studied on a laboratory testing setup in normal specific gas flow rates range of 0.0002-0.0010 sec⁻¹. Natural air evolution, ullage blowing and fuel sparging with dry inert gas have been studied. It has been shown that natural air evolution during aircraft climb provides a significant, substantial, but insufficient dehydration of fuel up to 20% relative. Ullage blowing during cruise leads to a constant, but a slow dehydration of fuel with sufficient column height concentration gradient. Dry inert gas sparging held after the end of the natural air evolution or simultaneously with natural air evolution provides rapid fuel dehydration to the maximum possible values. It potentially may eliminate water release and deposition in fuel to -50°C. It has been found that for proper dehydration, necessary and sufficient volume of dry inert gas to volume of fuel ratio is about 1.

INTRODUCTION

Water can affect fuel system component reliability and lead to operational delays and increased maintenance activities. Water is always present in jet fuel, usually in a mixture of forms - dissolved and free [1]. Dissolved water poses little problem to fuel systems reliability and function so long as it

remains dissolved in fuel. Free water may be suspended in the fuel as fine droplets, settled as pools at the bottom of aircraft fuel tanks or settled at low points as slugs in pipe networks. Since the solubility of water in fuel decreases with decreasing temperature [1], during cruise, water from dissolution (rejection of dissolved water from fuel) can form droplets of the order of microns suspended within the fuel [7]. In addition, natural convection currents bring the saturated fuel into contact with cold tank surfaces where water from dissolution causes condensation on cold surfaces [7]. On subcooled surfaces, frost like deposition has been observed [7]. The frost grows at the expense of water droplets known as the Bergeron process [7]. The frost is melted when the tank surface is warmed above the melting point. The melt water runs down the walls of the fuel tank and collects as free water pools in the bottom of the tank [12]. At sufficiently cold temperatures the free water can freeze to form ice crystals capable of plugging pump strainers [8], which may have operational implications.

The Airbus Water & Ice Systems Design Optimisation & Management (WISDOM) research project is concerned with developing new technologies and capabilities to remove the aircraft maintenance burden associated with water and ice contamination within fuel tanks. The introduction of Fuel Tank Inerting Systems (FTIS) on aircraft brings an additional opportunity for water management.

Since the TWA accident (17th July 1996), there is a significant effort to reduce fuel tank flammability. The atmosphere in the ullage contains combustible components such as oxygen and fuel vapor, which in conjunction of an ignition source could cause an explosion. *Inerting* looks to reduce the oxygen and fuel vapour by replacing them with an inert gas. Inert gas, i.e. argon, nitrogen and carbon dioxide, could be injected into the ullage for inerting. Typically, an On-Board Inert Gas Generation System (OBIGGS) is used to generate Nitrogen Enriched Air (NEA) from engine bleed air for inerting. Conditioned bleed air is passed through hollow fiber membrane in an Air Separation Module (ASM). The process removes oxygen, water vapor and other gases (i.e. carbon dioxide) in the bleed air. It has been proposed to take further benefit from the system by using NEA to dehydrating the fuel onboard [9].

Figure 1 shows a schematic of the proposed arrangement. Dry NEA is injected in the fuel and the ullage for optimized water management in the tank. NEA injected in the fuel rises through the fuel. It dehydrates the fuel as it rises to the fuel surface. The NEA becomes laden with water vapour. When released from the fuel at the fuel surface, the wet NEA helps to maintain a low oxygen level in the ullage by displacing the ullage atmosphere. Since water vapour is an inert gas, water vapour has no effect on the inerting property of the NEA. The dry NEA injected directly in the ullage is used to ensure an effective distribution of NEA and mixing with the ullage atmosphere. It is also used to control the humidity in the ullage atmosphere. A preliminary study of a dual-use OBIGGS that could reduce the risk of both fuel contamination with water and fuel tank flammability has been conducted [6].

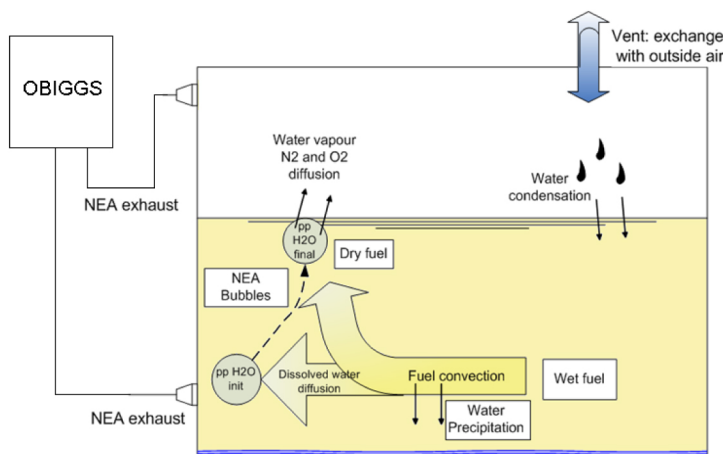


Figure 1. Schematic of the proposed dehydration system for dehydrating fuel within the fuel tanks.

NEA injected into the fuel forms bubbles, which rise through the fuel, and diffusion of water from the fuel into the gas occurs until equilibrium is reached. By reducing the

concentration of dissolved water in the fuel, there is a reduction in the amount of water that can precipitate out of the fuel due to, e.g. a decrease in fuel temperature. NEA is also injected into the ullage to prevent the ullage atmosphere becoming over saturated with water vapor. By limiting the water vapor saturation in the ullage atmosphere, there is a reduction in the amount of water that can precipitate out of the atmosphere due to condensation.

DRYING

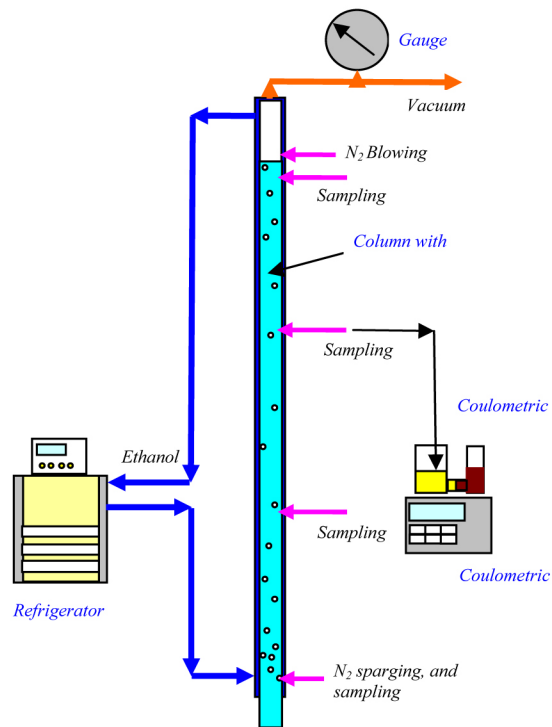
The capability of OBIGGS to supply dry and warm NEA may be utilized to reduce water precipitation from water dissolution from fuel and water condensation from ingress humid air during the different flight phases. The NEA has three primary effects on fuel system dehydration [6]. They are: -

- **Sparging** - Dry NEA injected into the fuel forms bubbles, which rise through the fuel, and diffusion of water from the fuel into the gas occurs until equilibrium is reached. The process dehydrates the fuel by reducing the concentration of dissolved water in the fuel. When the fuel is dehydrated, there is a reduction in the amount of water that can precipitate out of the fuel due to decrease in solubility with decreasing fuel temperature. The rate of diffusion is dependent on several factors, including temperature and the interfacial area between the fuel and the gas.
- **Ullage blowing** - Injection of a flow of dry NEA directly into the ullage may be used simultaneously with the injection of dry NEA into the fuel so as to prevent the relative humidity in the ullage atmosphere from becoming saturated. By limiting the water vapor saturation in the ullage atmosphere, there is a reduction in the amount of water that can precipitate out of the atmosphere due to condensation.

• **Fuel and tank warming** - For optimum operation, the ASMs in the OBIGGS are operated between 40 to 95°C [10]. The NEA is conditioned to a lower but still a warm temperature before injecting into the fuel and ullage. The warm NEA heats up the tank walls and the fuel. An increase in fuel temperature would reduce precipitation of dissolved water, since water solubility within the fuel increases with fuel temperature. An increased in surface temperature reduces the amount of condensation from ingress air.

NEA flow reduces the volume of air ingress into the ullage and therefore the water that it brings in. In addition to the effects from the NEA mentioned above, fuel degassing at high altitude, or low pressure, supplement the drying in fuel systems. Amongst other factors, the solubility of air in fuel is a function of pressure [1]. During climb and at early stage of the cruise, fuel becomes over saturated with dissolved air due to reduced solubility as a result of reduced pressure. Air degasses from fuel to attain a new equilibrium. The degassing

(a)



(b)



Figure 2. Experimental setup. (a) Schematic of the laboratory rig. (b) Laboratory rig.

generates air bubbles. Water transfers from fuel to the air bubbles in the same way as that for the NEA bubbles.

EXPERIMENT SETUP

A laboratory rig has been designed and constructed for characteristic proof of concept. The schematic of the rig and a photo of the rig are shown in [Figure 2](#). The rig consists of a glass condenser column, of Liebig type, of height 120.0 cm and diameter 3.4 cm. It consists of a large outer glass tube containing a smaller inner glass tube running its entire length. The inner tube is filled with fuel to a depth of 96.0 cm and leaving an ullage of 24.0 cm high at ambient conditions. The fuel depth and the ullage height are representative of that found in a typical aircraft fuel tank. Aviation jet fuel grade TS-1 (RF specification GOST 10227) was used in the experiments.

The annular between the inner tube and the outer tube is filled with liquid coolant, ethanol. It provides a cooling jacket around the inner tube to control the fuel and the ullage temperature. In this setup, the coolant flows from bottom to top and is circulated through a Julabo refrigerated circulator. The fuel cooling rate is controlled between 5 to 10 °C/hr and the fuel is operated between 20 to -20 °C. A slow cooling simulates the effect of fuel and tank warming by NEA in the real application. The pressure in the ullage is controlled by a water jet vacuum pump. A slow ascend from sea level (1.0

bar) to a high cruise level of 38.6 kft (0.2 bar) in 30 minutes is simulated. The pressure is then held at 0.2 bar simulating a constant cruise level. After reaching the cruise altitude, two technologies of possible dehydration were studied separately: ullage blowing and sparging.

To simulate the sparging of NEA, nitrogen gas from a gas bottle was used. The nitrogen gas was bubbled in the fuel at the bottom of the fuel column via a single nozzle in a hollow needle with a flow rate of 0.2-1.0 Ncm³/sec or a normal specific flow rate of 0.0002- 0.001 sec⁻¹. The fuel level was raised by 1.5-2% without significant foaming. A separate gas line supplied the nitrogen to the ullage. It injected the gas near the fuel free surface at a rate of 1.0 Ncm³/sec.

Fuel samples were taken from four points positioned along the height of the column. The points are separated from the adjacent one by 30.0 cm. The first point was co-located with the nitrogen sparging point. Samples were taken with a syringe. Fuel was forced into the syringe by helium gas at a pressure of 1 bar. Helium was used because it has small solubility in fuel. The gas pressure prevented degassing from the fuel. Total water content, both dissolved and suspended water, in fuel was analyzed by Karl Fischer's reagent coulometric titration method ([Fig. 3](#)).