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MEMBRANE-BASED GAS TRAPS FOR AMMONIA, FREON-21, AND WATER SYSTEMS TO SIMPLIFY GROUND PROCESSING

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Introduction

Gas traps are critical for the smooth operation of coolant loops because gas bubbles can cause loss of centrifugal pump prime, interference with sensor readings, inhibition of heat transfer, and blockage of passages to remote systems. Coolant loops are ubiquitous in space flight hardware, and thus there is a great need for this technology. Conventional gas traps will not function in micro-gravity due to the absence of buoyancy forces. Therefore, clever designs that make use of adhesion and momentum are required for adequate separation, preferable in a single pass.

The gas traps currently used in water coolant loops on the International Space Station are composed of membrane tube sets in a shell. Each tube set is composed of a hydrophilic membrane (used for water transport and capture of bubbles) and a hydrophobic membrane (used for venting of air bubbles). For the hydrophilic membrane, there are two critical pressures, the pressure drop and the bubble pressure. The pressure drop is the decrease in system pressure across the gas trap. The bubble pressure is the pressure required for air bubbles to pass across the water filled membrane. A significant difference between these pressures is needed to ensure complete capture of air bubbles in a single pass. Bubbles trapped by the device adsorb on the hydrophobic membrane in the interior of the hydrophilic membrane tube. After adsorption, the air is vented due to a pressure drop of approximately 1 atmosphere across the membrane. For water systems, the air is vented to the ambient (cabin). Because water vapor can also transport across the hydrophobic membrane, it is critical that a minimum surface area is used to avoid excessive water loss (would like to have a closed loop for the coolant).

The currently used gas traps only provide a difference in pressure drop and bubble pressure of 3-4 psid. This makes the gas traps susceptible to failure at high bubble loading and if gas venting is impaired. One mechanism for the latter is when particles adhere to the hydrophobic membrane, promoting formation of a water layer about it that can blind the membrane for gas transport (Figure 1). This mechanism is the most probable cause for observed failures with the existing design. The objective of this project was to devise a strategy for choosing new membrane materials (database development and procedure), redesign of the gas trap to mitigate blinding effects, and to develop a design that can be used in ammonia and Freon-21 coolant loops.

Material Selection Rational and Database

Material selection is critical for the success of these gas traps. For example, if the membrane is more hydrophilic then a smaller pore size membrane may be used with the same pressure drop. However, the corresponding bubble pressure will be much higher. The currently used hydrophilic membrane is composed of nylon-11. The permeability (pressure normalized flux) of this membrane is such that a 3.6 μm pore size is required to obtain a design pressure drop of 2 psid. This pore size results in a bubble pressure of 6-7 psid. Therefore, a small increase in pressure drop of only 4-5 psid will result in failure of the gas trap.

The new material chosen for the hydrophilic membrane is polyethersulfone (PES). Its Hansen solubility parameter is 25.3 $MPa^{1/2}$ (vs. ~ 22 $MPa^{1/2}$ for nylon-11). A higher solubility parameter is indicative of more polarity and hydrogen bonding capability, both of which are hydrophilic characteristics. For this membrane, a pore size of 0.22 μm will permit a pressure drop of 5 psid and a bubble pressure of 50 psid. Clearly this results in a much higher tolerance for pressure increases. Since the system pressure is 27 psia, 100% capture of bubbles using this material will be possible in a single pass gas trap.

Additional aspects of the materials database that lead to the choice of PES for the hydrophilic membrane include extensive empirical data from manufacturer compatibility tables, surface tension and contact angle data, predictive correlations for flux (Hagen-Poiseuille) and bubble pressure, and industrial availability. This last aspect is the most critical, since spares for the existing design have failed due to oxidation during storage. A reliable industrial supplier should have other customers so that a consistent product is available should replacements be needed in the future. The current membranes were custom-made and have not been reproducible.

<u>Predictive Correlations for Design</u>

A few simple correlations for design variables are given below. For each, these should be approached as guides only, with at least some pilot testing for variation in membrane properties. The first correlation is the Hagen-Poiseuille Equation. This relationship is effective for the membranes used here due to their open structure and relative large pores (convective flow under pressure gradient). In this equation,

$$J = \frac{\varepsilon d_p^2 \Delta P}{32 z \mu} \tag{1}$$

J is the volumetric flux (liters/m^2 hr), ε is the porosity (unitless), d_p is the pore diameter (μm), ΔP is the pressure drop (psid), z is the membrane thickness (μm), and μ is the coolant viscosity (cP). Because J, ε, z, and μ are fixed, this equation serves as an excellent predictive tool for the relationship between pore size and pressure drop. Another useful predictive equation is for the bubble pressure,

$$P = \frac{4k\cos\theta}{d}\sigma \tag{2}$$

where P is the bubble pressure (psid), k is a shape factor (unitless), θ is the contact angle (degrees), d is the pore diameter (μm), and σ is the liquid surface tension (mN/m). Once again, the true value of this equation is the relationship between P and d, since the other parameters are constant. Finally, the pressure normalized flux, or permeability, is defined as,

$$Permeability = \frac{(volume)}{(time)(area)(pressure)} \tag{3}$$

The volumetric flow rate is set and the permeability is a constant based on the membrane and the fluid. When the gas trap captures air bubbles, they will tend to collect at the end away from the entrance. If bubbles are not vented rapidly, they will coalesce and begin to fill out the volume inside the trap. Since this effectively decreases the hydrophilic membrane area for water transport, the pressure drop in the gas trap must increase. Therefore, it should be possible to predict what volume of air (not rapidly vented) will cause failure of the gas trap.

Recommended Materials and New Design

Since the current design is still working on the Space Station, it was determined that particles are not fatal to the performance of the hydrophobic membrane. Therefore, no material change was made on the hydrophobic membrane (Celguard, Inc.). The hydrophilic membrane will be composed of PES instead of nylon-11. PES tubular or capillary membranes are widely available in industry. Some potential sources are Membrana, Hydranautics, and PCI Membrane Systems among others. In addition, a smaller pore size material may be used with comparable pressure drop, but much greater bubble pressure.

Because air bubbles collect at one end of the gas trap, the new design will incorporate a bundle of five (5) hydrophobic membranes for gas venting. To prevent excessive water loss, 80% of the fiber length (near the entrance) will be coated with an impermeable layer. This will permit the same previous design area for gas venting, but all of the area will be located where the bubbles collect. Previous experience shows that gravity is sufficient to drain water from the surface of a particle fouled hydrophobic membrane, and thus it should be a reasonable assumption that a coalesced air bubble will have the same effect, and that all of this area will be available for gas venting. A diagram of the proposed design is given in Figure 2.

Designs for Ammonia and Freon-21

Ammonia and Freon-21 have vapor pressures 1000 and 100 times greater than water, respectively. Therefore, any continuous venting system will probably result in an unacceptable loss of coolant. Therefore, besides the exterior tube membrane made of perfluoroethylene (PTFE), the interior venting membranes will be replaced by a solenoid valve and accumulator at the end of the gas trap away from the fluid entrance. Since captured gas bubbles cause an increase in pressure drop, this can be monitored to trigger the solenoid valve after a significant amount of air is captured in the gas trap. Use of an evacuated accumulator will provide sufficient driving force to displace the air from the trap before closure of the valve.

Conclusions and Future Directions

A sound diagnosis of previous gas traps failures has resulted in a rational approach for future material selection. The new design should permit minimal resistance to coolant flow with 100% capture of NCG. Gas venting will be performed continuously for water systems and periodically for ammonia and Freon-21 systems due to differences in vapor pressures. A Center Director's Discretionary Fund proposal has been put forth as a result of the work herein, with collaboration between various groups in the Flight Projects Directorate and the Engineering Directorate.

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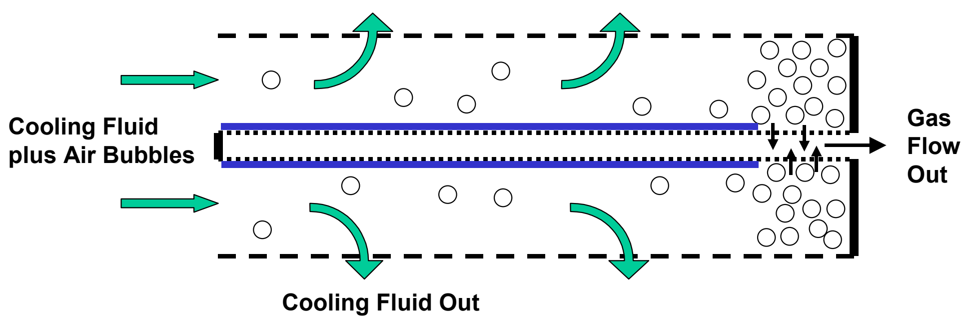

Figure 1: Failure mechanism for current water coolant loop gas trap.

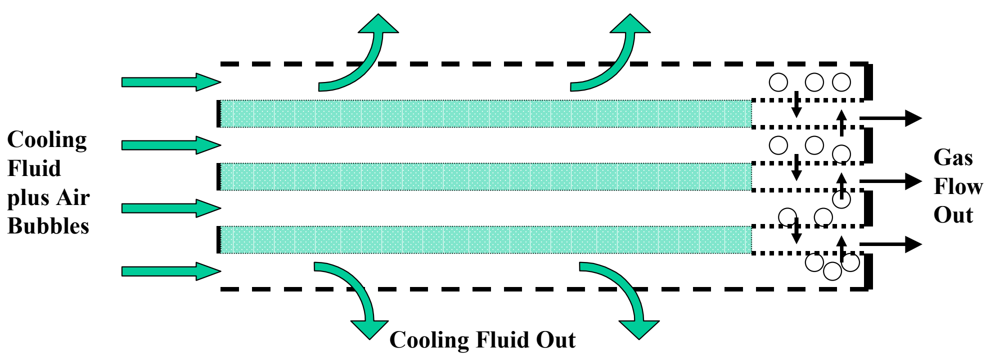

Figure 2: Proposed design for water coolant loop gas trap.