

Ares I Reaction Control System Propellant Feedline Decontamination Modeling

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The objective of the work presented here is to quantify the effects of purge gas temperature, pressure, and mass flow rate on Hydrazine (Hz) decontamination rates of the Ares I Roll Control System and Reaction Control System. A survey of experts in this field revealed the absence of any decontamination rate prediction models. Three basic decontamination methods were identified for analysis and modeling. These include low pressure eduction, high flow rate purge, and pulse purge. For each method, an approach to predict the Hz mass transfer rate, as a function of system pressure, temperature, and purge gas mass flow rate, is developed based on the applicable physics. The models show that low pressure eduction is two orders of magnitude more effective than the high velocity purge, which in turn is two orders of magnitude more effective than the pure diffusion component of pulse purging of dead-heads.

Eduction subjects the system to low pressure conditions that promote the extraction of Hz vapors. At 120 °F, Hz is saturated at approximately 1 psia. At lower pressures and 120 °F, Hz will boil, which is an extremely efficient means to remove liquid Hz. The Hz boiling rate is predicted by equating the rate at which energy is added to the saturated liquid Hz through heaters at the tube outer wall with the energy removed from the liquid through evaporation.

Boil-off fluxes were predicted by iterating through the range of local pressures with limits set by the minimum allowed pressure of 0.2 psia and maximum allowed wall temperature of 120 °F established by the heaters, which gives a saturation pressure of approximately 1.0 psia. Figure 1 shows the resulting boil-off fluxes as a function of local eduction pressure. As depicted in figure 1, the flux is a strong inverse function of eduction pressure, and that minimizing the eduction pressure maximizes the boil-off flux. Also, higher outer wall temperatures lead to higher boil-off fluxes and allow for boil-off over a greater range of eduction pressures.

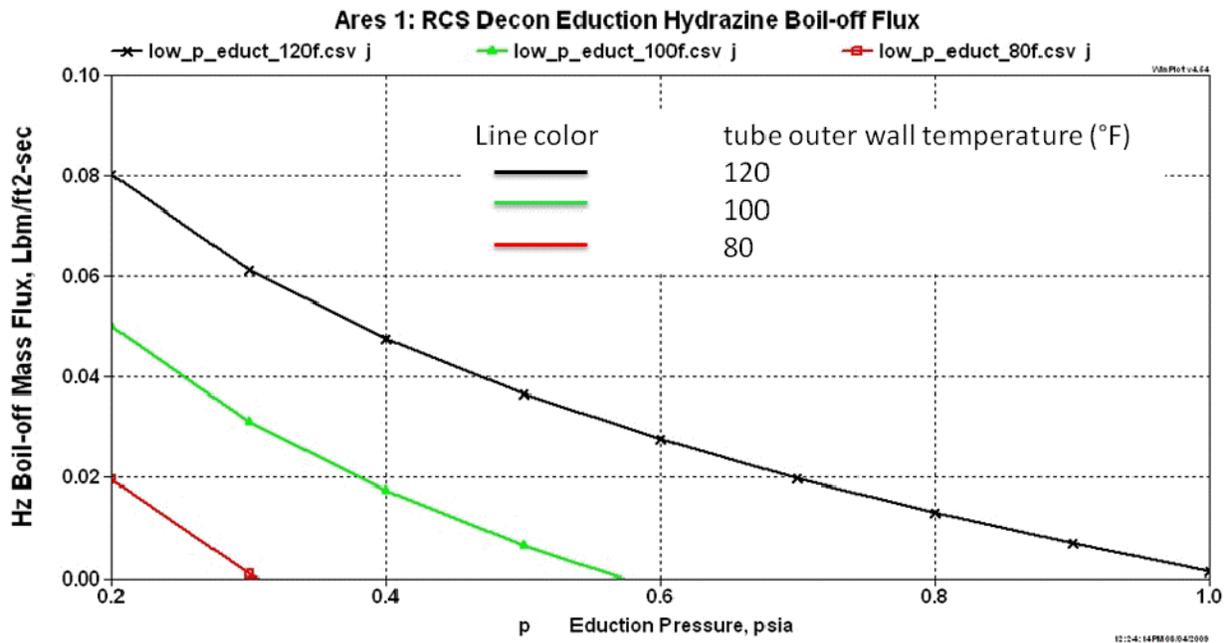


Figure 1. Hz boil-off flux as a function of eduction pressure for three tube outer wall temperatures.

After eduction at low pressure has removed the liquid Hz, a relatively thin film of Hz will remain. A high flow rate of GN2 is used to remove a portion of this remaining Hz. The Hz removal mechanism in this scenario is forced convection evaporation, and is modeled analogously to heat transfer between a tube wall and internal forced convective fluid. The evaporating mass flux is related to the product of an experimentally determined mass transfer coefficient and a driving potential, which is the difference in diffusing gas concentrations at opposite ends of the diffusion path. This is analogous to the relationship between heat flux and the product of the heat transfer coefficient and a temperature difference. The Nusselt number is replaced with the Sherwood number. For a turbulently flowing purge gas, the Sherwood number is modeled as a function of the Reynolds number and the Schmidt number. Data for the diffusion coefficient of Hz into GN2 were absent from the literature reviewed. Therefore, it became necessary to develop a theoretical prediction for this parameter.

In purge flow, the three trade parameters of system pressure and temperature, and GN2 mass flow rate were evaluated for their effects on Hz evaporation flux. Figure 2 presents the results of these trades for parameter ranges deemed reasonable for the study. The trade for pressure is the black curve, for temperature is the green curve, and for mass flow rate is the red curve. The results show that the rate of Hz removal with a purge flow varies directly with purge gas temperature and mass flow rate, and inversely with pressure. In these scenarios, nominal values were 10 psia, 0.005 Lbm/sec, and 550 °R. Hence, all three curves intersect at these values. The temperature and pressure effects are a direct result of their respective influence on the diffusion coefficient. The mass flux effect occurs because of its influence on Reynolds number, and hence, the Sherwood number.

Removal of Hz from regions of the propellant flow line that are removed from the direct purge flow path, called dead-headed volumes, is typically accomplished through pulse purging, in which the propellant lines are filled with purge gas to a high pressure, then the pressure is relieved. During pressure relief, the propellant that has diffused from the surfaces in the dead-head region is swept out into the main flow path by the flow of the combined purge gas and propellant vapor mixture. Repeating this process many times decontaminates dead-headed regions.

It was determined that too many uncertainties existed in the events of decontaminating dead-head regions through pulse purging to warrant developing a predictive model. However, functional dependencies of the separate physical events involved are reviewed to determine options to optimize decontamination efficiency.

It is reasonable to say that a higher flow rate of gas from dead-heads will better sweep away the propellant vapor. Flow rate from dead-head regions is maximized by maximizing the purge gas density in the dead-heads prior to depressurization. Density varies directly with pressure, and inversely with temperature. As figure 2 shows, though,

the propellant diffusion rate varies oppositely with pressure and temperature than does density. Diffusion rate varies directly with temperature to the 1.75 power, and inversely with pressure.

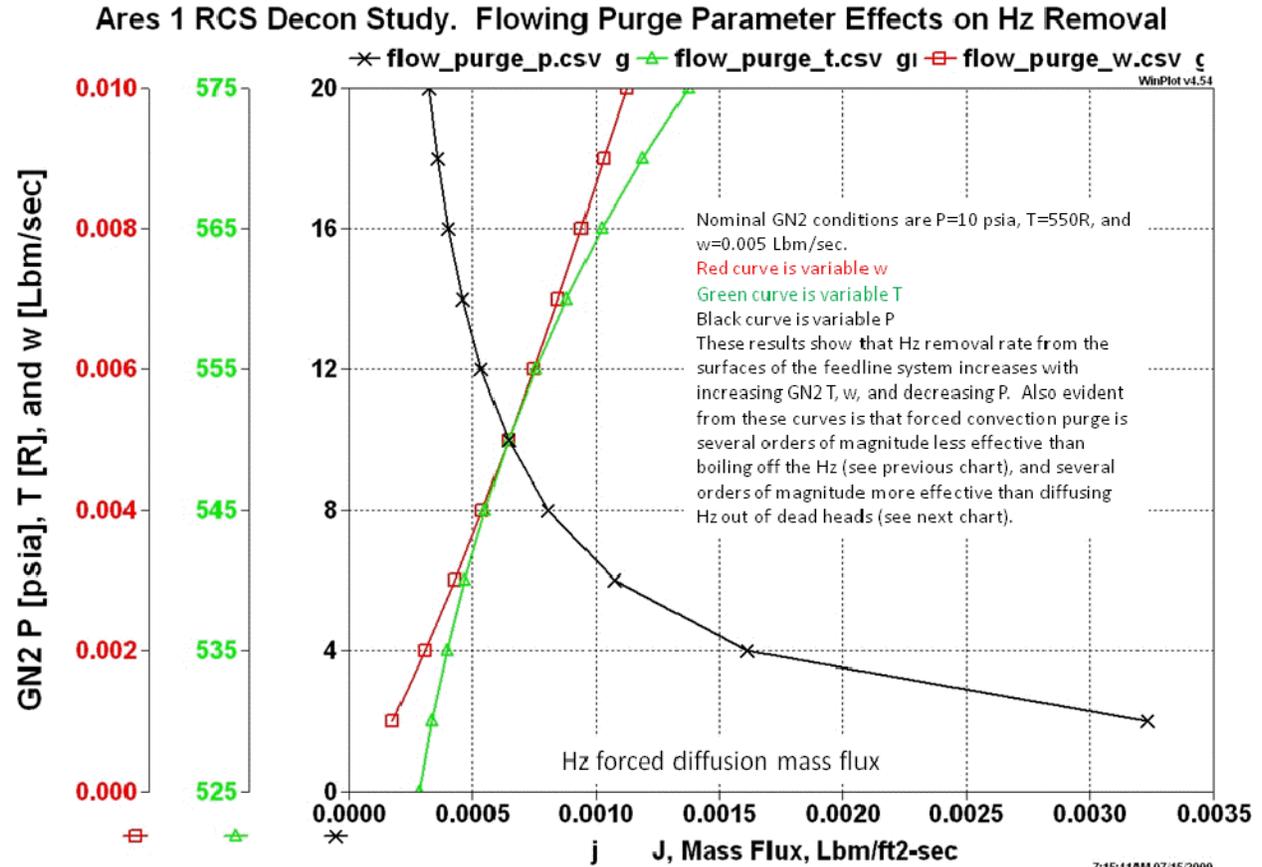


Figure 2. Flowing purge trade study of effects of purge gas flow rate, temperature, and pressure.

However, the presence of purge gas does not promote propellant diffusion. Therefore, the benefits of high temperature and low pressure diffusion of propellant vapors can occur in the absence of the purge gas. After a certain period, the purge gas pressurization process takes place at high gas pressure and low temperature. The duration of the pressurized period can remain short, followed by the depressurizing sweep, since the majority of Hz vapor and purge gas mixing occurs as the purge gas flows turbulently into the dead-head volume.

Lacking a complete pulse purge predictive model, a model for dead-head diffusion was developed to predict diffusion mass flux prior to the depressurization sweep of pulse purging. Figure 3 presents the predicted diffusion rates as a function of system pressure (black curve) and local temperature (green curve) of the surface with Hz. Again, 10 psia and 550 °R are the nominal values for this trade analysis. It is evident that lower pressure and higher temperature promote higher diffusion rates. The mass flux rates are approximately two orders of magnitude less than for high velocity purging, making pure diffusion by far the most inefficient of the three methods modeled.

Ares 1 RCS Decon Study. P,T Effects on Dead head Hz Removal

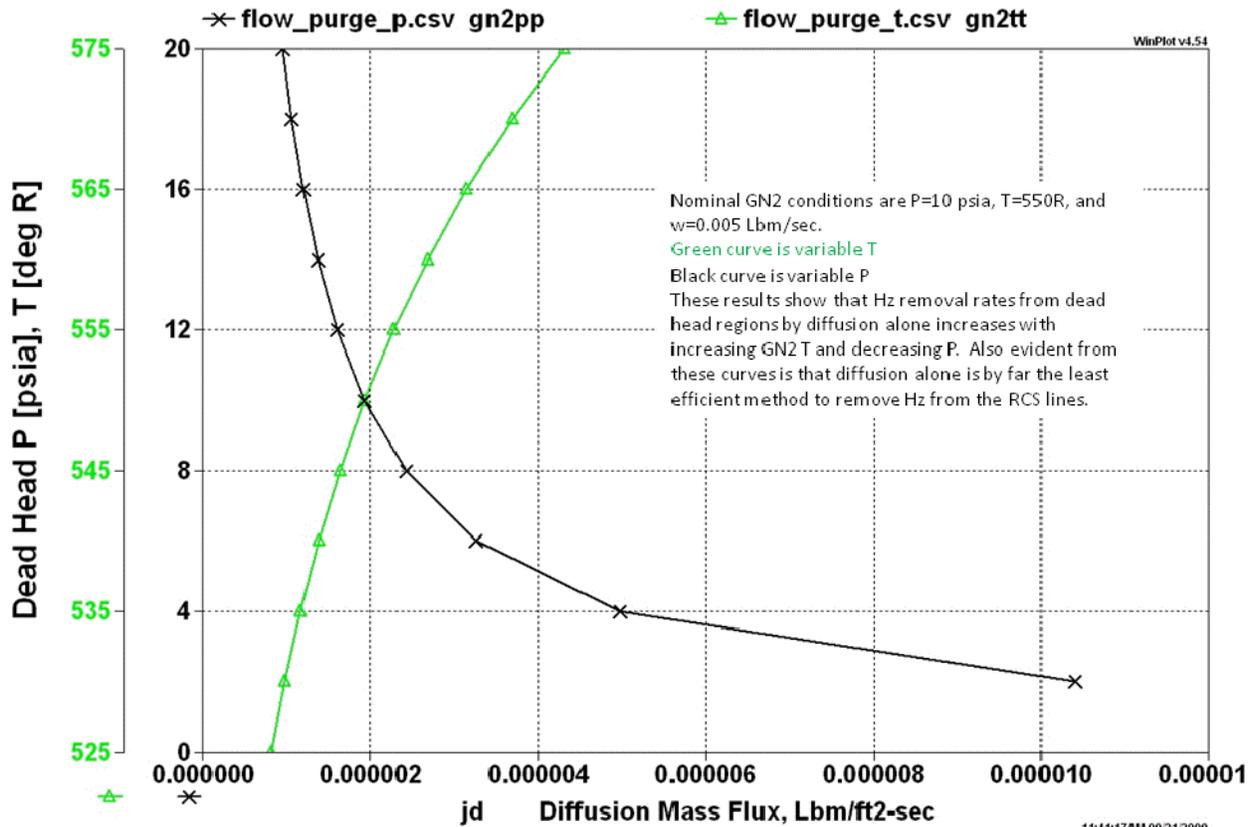


Figure 3. Diffusion mass flux as a function of local pressure and temperature.