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THERMAL MANAGEMENT OF CRYOGENIC STORAGE VESSELS TO PREVENT BOIL OFF

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ABSTRACT

In the recent years, cryogenic storage techniques for liquid hydrogen as well as other liquefied gases are of widely increasing interest. Liquid storage of hydrogen has very significant advantage over gaseous or chemical storage because of much lower storage volume and ease of regeneration of the fuel with its demand. Because of its very low normal boiling point and high latent heat of vaporization, hydrogen's most challenging aspect in cryogenic storage is the losses due to boil-off under the effect of the heat leak through the insulation layers of the tank from the surrounding environment. Conventional cryogenic storage tanks suffer loss of hydrogen due to boil-off of the cryogen induced by heat leak. In order to control the tank pressure within its structural limits, the stored fluid needs to be bled off periodically. The Zero Boil Off (ZBO) concept has evolved as an innovative means of storage tank pressure control by a synergistic application of passive insulation, active heat removal, and forced mixing within the tank. A cryocooler (with a power supply, radiator, and controls) is integrated into a traditional cryogenic storage subsystem to reject the storage system heat leak. Therefore, the fuel can be stored for a very long time without any loss. This paper presents both steady-state analysis of an active heat dissipation system and the transient analysis of a passive heat dissipation system. The active system includes a tank with cylindrical wall and oblate spheroidal top and bottom and a cold-spray nozzle head whose face is set perpendicular to the axis of the tank. The nozzle head has many nozzles on its down face. The cold fluid from the cryocooler enters the inlet opening at the top of the tank, follows an axial supply tube to the nozzle head and injects into the heated fluid inside the tank through the nozzles. The displaced fluid exits the tank through an annular outlet opening (also at the top of the tank and co-axial to the inlet opening) then goes back to the cryocooler. The passive system includes a tank with cylindrical wall and oblate spheroidal top and bottom, a heat pipe located along the axis of the tank, and an active circulator, which is a pump-nozzle unit including a pump body, a suction tube, and a spray nozzle facing the evaporator section of the heat pipe. The evaporator section removes heat from liquid hydrogen inside the tank and transports it to the external condenser section of the heat pipe that dissipates heat to the ambient via a cryocooler and radiator. The entire system has been modeled numerically by solving equations for the conservation of mass, momentum, and energy. Simulations with different on/off periods for the operation of the pump and different normal speeds of fluid discharged at the nozzle face are run for a parametric analysis. Typical distributions of velocity and temperature are presented. Average speed and maximum temperature are evaluated for assessing mixing and boiling effects, respectively. The effectiveness of the combination of operating parameters is estimated for the optimization of the tank design. The results provide valuable guidelines for the design of ZBO cryogenic storage systems.

Keywords: Cryogenic Storage, Liquid Hydrogen, Active Storage System.