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Title

Numerical investigation on heat transfer of Rocket Engine Cooling Channel for different LNG Under Trans and Super-Critical Conditions

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Abstract

One of the main challenges of the spacecraft industry is the high cost of accessing outer space, where most of the cost is spent on propellent. There is a notable trend in using Methane as a propellent in space propulsion because it is less expensive and safer plus it has relatively higher specific impulse and smaller storage volume than other propellants. However, Methane in the commercial market is a mixture with other hydrocarbons known as liquefied natural gas (LNG), which have complex thermophysical and transport properties that strongly affect the liquid rocket engine cooling systems' flow evolution and heat transfer capabilities. The main objective of this study is to comprehend the influences of hydrocarbon impurities in LNG flow inside the rocket engines cooling channels on pressure drop and structure temperature.

Pure Methane is considered a reference case, and two different LNG are selected in this study. The lean LNG has a 97.5% methane mole fraction, and the rich LNG has an 88.7 % methane mole fraction. The remaining part is ethane, propane, butane and nitrogen. The GERG-2008 equation of state and extended corresponding states are used to calculate LNG's thermophysical and transport properties, respectively. Turbulent flow and convective heat transfer are numerically investigated using Reynolds averaged Navier–Stokes method with an eddy viscosity turbulence model. A circular, straight cooling channel with uniform heat flux applied on the external walls has been used in this study. The numerical results of wall temperature are compared through experimental data for supercritical pressure for validation.

The results show that the hydrocarbon impurities significantly affect the operating pressure of the cooling channel because they play a vital role in determining the mixture cricondenbar pressure. The pure methane critical pressure is 4.6 MPa. The cricondenbars are 5.1 and 7.5 MPa for lean and rich LNG, respectively. The

operating pressure in the rocket engine cooling channel should be kept above critical pressure for pure Methane and cricondenbar pressure for lean and rich LNG to enhance the heat transfer. The bulk density, dynamic viscosity and thermal conductivity increase, and the bulk isobaric heat capacity decreases along the channel as the percentage of hydrocarbon impurities increases in LNG. The pressure drop of denser LNG is small compared to light LNG at the same mass flow rate because the coolant velocity decreases for denser LNG. The wall temperature in the case of rich LNG is higher than lean LNG and pure Methane, as the bulk isobaric heat capacity of pure Methane is higher than that of lean, rich LNG. Mixture purity is beneficial for cooling capabilities but detrimental to pressure drop. These effects are crucial in the design of modern thrust chambers. Hence, the implementation of real gas dynamics in CFD can significantly benefit the design process of new engines.