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HEAT TRANSFER AND PYROLYSIS CHARACTERISTICS OF METHANE IN ROCKET NOZZLE COOLING CHANNELS

Abstract

A propulsion system using hydrocarbons, liquid or hybrid, continues to be a challenge for today's rocket and space propulsion systems. Methane has emerged as one of the most interesting propellants for future first and second stage rocket engines, primarily due to its potential to support high system efficiency. This follows from the high energy density and storage temperature, as well as its non-toxicity, which simplify storage and handling compared to hydrogen. Moreover, methane has higher specific impulse than kerosene and supports increased re-usability of engine components. Finally, there may be possibilities to produce methane straight forward from water and carbon dioxide which could facilitate extraterrestrial space exploration through in-situ resource utilization. It is of strategic importance that the industry and academia develop necessary knowledge of the heat transfer characteristics and material degradation at relevant operating conditions. Here the focus is on methane in super-critical state as a coolant for rocket nozzle walls of sandwich structure.

Before combustion the fuel is lead through cooling channels in the rocket nozzle. Methane undergoes thermal decomposition at high temperatures which leads to coking in cooling channels. This is aggravated by the nickel content found in the high-temperature alloys used for rocket nozzles, as nickel is a known catalyst used to promote thermal cracking e.g. in petrochemical industry. This investigation focuses on nickel-alloy steels and typical cooling geometries used in the rocket nozzle.

A combination of numerical conjugate heat transfer and pyrolysis calculations and experiments in a dedicated test rig at KTH – Royal Institute of Technology, Sweden, are undertaken in order to characterize the impact of methane on the nozzle cooling characteristics in terms of heat transfer and pressure loss. In the test rig, the methane can be pre-heated from 273 - 673 K at pressure levels between 10 - 200 bar and enters a final heater that simulates the single-sided heat load from the flame using electric cartridges in a well-insulated copper block. The heat flux is between 1 - 7 MW/m^2 for cooling channels representative of rocket engine concepts such as Prometheus, the ETID nozzle and similar systems. This paper focuses on the validation of the CFD models used within the project, based on experimental results using methane of 99.95% purity. Moreover, as data on pyrolysis of methane under these conditions is not available in open literature, initial work is undertaken to provide a basis for future pyrolysis modelling work.