Transfer of an analytical transpiration cooling model to the cooling analysis of rocket combustion chambers made of ceramic matrix composites

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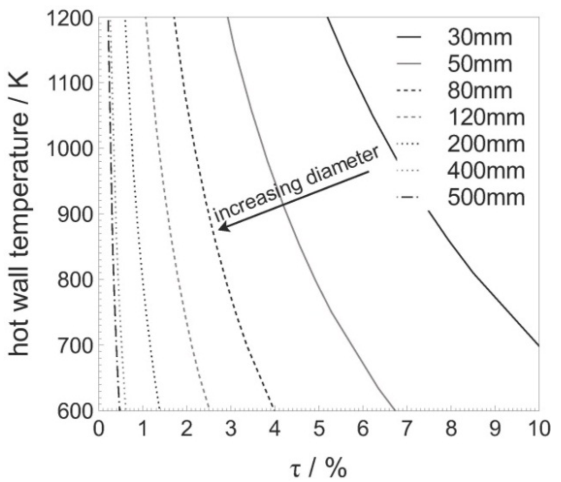
Transpiration cooling with porous high-temperature fiber ceramics promises many advantages over regenerative cooled combustion chambers. Longer durability due to low thermal expansion coefficients, straightforward manufacturing processes promising decreased manufacturing costs and possible weight reductions are examples for these benefits while performance similar to those of regenerative cooled combustion chambers can be achieved. In the SFB/TRR 40 sub-project A5, the investigation of transpiration cooling is the set goal. Experiments under lighter loads than found in combustion chambers (i.e. total temperatures up to 520 K and pressures in the range of 1 bar) have been conducted. Analytical models which describe these experiments quite well have been developed and verified.

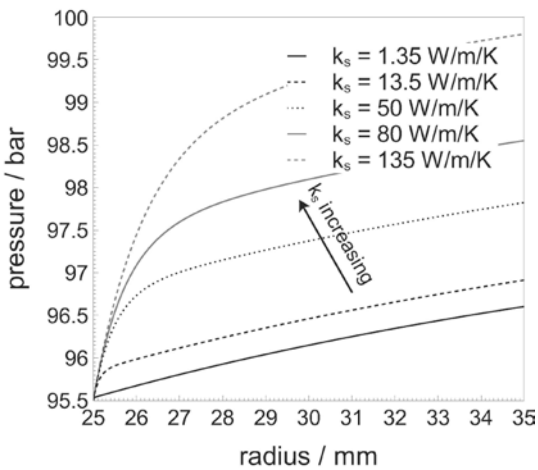
This paper discusses the adaptation of these models to combustion chamber conditions, with the goal of developing an analytical tool, that enables a quick and easy preliminary design of a transpiration cooled combustion chamber. In doing so, the paper assesses the assumptions made in the models and their transfer to combustion chamber conditions. The most important of these assumptions concern the volumetric heat transfer coefficient between coolant and permeable material as well as the heat transfer correlation describing the heat exchange between combustion gas and chamber wall. The most important parameters in a preliminary design are the maximum wall temperature and the pressure loss of the coolant while flowing through the wall. Both are governed by the coolant mass flow ratio

$$\tau = \frac{\dot{m}_{coolant}}{\dot{m}_{total}},$$

which is a mean to describe the efficiency of transpiration cooled combustion chambers.
The models are used to analyze the dependency of these quantities on parameters like chamber diameter and thermal conductivity of the permeable material and the results are compared to available measurements from firing tests of transpiration cooled combustion chambers.



Maximum combustion chamber wall temperature over coolant mass flow ratio for different chamber diameters



Pressure drop of coolant over chamber wall depending on thermal conductivity of permeable material