Experimental investigations on liquid film cooling in a GOX/ kerosene rocket combustion chamber

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The understanding of the mechanisms of heat transfer and advanced cooling techniques is a key for mastering the design of reliable and efficient rocket combustion chambers. The effects determining film cooling efficiency as well as influences on the combustion process itself under conditions, which are typical for rocket combustion chambers, are still not fully understood.

Within the national research program Transregio SFB/TR-40 on “Technological Foundations for the Design of Thermally and Mechanically Highly Loaded Components of Future Space Transportation Systems” film cooling is investigated at TUM-LFA. A single-element rocket combustion chamber is operated with kerosene and gaseous oxygen (GOX) at hot gas temperatures exceeding 3500 K and application-relevant combustion chamber pressures of up to 10 MPa, which allows sub- and supercritical propellant injection. In the tests performed, the film coolant is injected sufficiently downstream of the injector in order to minimize the effect of the injection and combustion processes on the film. Different cooling fluids and methods of film injection are applied. Special attention is paid to the effects caused by possible reactions of the cooling film with the core stream and the decrease in surface tension when combustion pressure is increased, as well as implications on heat transfer and cooling film behaviour due to soot deposition.

The film applicator being used for the film cooling experiments is shown in Figure 1. The configuration with the film applicator installed after the second water-cooled chamber segment (i.e. in the middle of the combustor, designated position 3) and a dedicated measuring segment used in the latest test campaigns is shown in Figure 2.

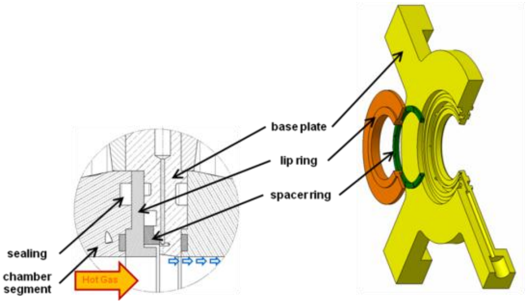

Figure 1: Film Applicator Cross-Section

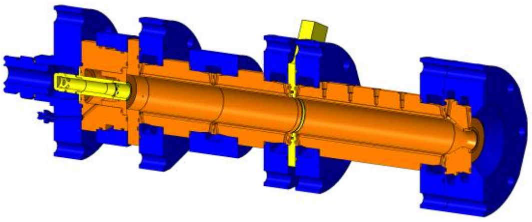

Figure 2: Chamber Setup with Film Applicator

The determination of the cooling efficiency is a challenging problem. While the direct measurement of the hot wall temperature led to unreliable results in former test campaigns, the heat flux determined by the coolant heat pick-up has a limited spatial resolution [1][2]. Temperature measurements within the cooling channels showed a characteristic footprint of the instrumentation in the heat flux profiles. However, comparative evaluation of the film cooling effectiveness is possible and gives useful and plausible results.

At first, film cooling tests have been performed with kerosene as coolant at combustion chamber pressure levels of 4, 6 and 8 MPa and cooling mass flow rates varying from 7 g/s to 53 g/s, which equals a film to total fuel mass flow ratio varying from 5% at 4 MPa up to 20% at 8 MPa [3]. While above mentioned experiments have been performed in a transcritical flow regime, the additional tests have been conducted with sub-critical kerosene, argon, methane and nitrogen at a combustion pressure level of 2 MPa [4]. The most recent experiments, which will be focused on the full paper, employ the injection of film fluids water and liquid (sub-critical) kerosene at different film applicator positions.

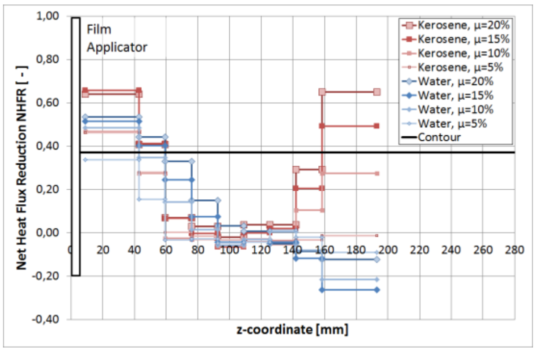

Figure 3: NHFR, position 2;
p_c=2.0 MPa, $(O/F)_{throat}$=2.72

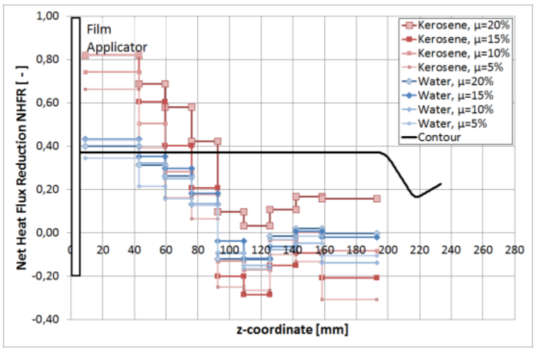

Figure 4: NHFR, position 3;
p_c=2.0 MPa, $(O/F)_{throat}$=2.72

Preliminary results of the net heat flux reduction (NHFR) downstream of the film injection are given for the film fluids water and kerosene for the position 2 (film injection 114 mm downstream of face plate) in Figure 3 and position 3 of the film applicator (film injection 209 mm downstream of face plate) in Figure 4. The initial film cooling effectiveness is higher for the farther downstream film injection when kerosene is used, while it is slightly higher for the more upstream film applicator position in the case of water as film coolant. In general, the film cooling effectiveness is mostly lower for water than for kerosene. This is an unexpected result since water has both heat capacity and heat of evaporation higher than kerosene, but this might be an indication for formation of a thermally isolating soot layer in case of the kerosene film. The recovery of cooling effectiveness especially for the kerosene film at position 2 might also be traced back to soot. These effects are still under investigation and a comprehensive analysis shall be presented in the full paper.

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Nomenclature

$$NHFR = 1 - {}^{\dot{q}_{Film}}\!/_{\dot{q}_{ref}} \cdot \left({}^{p_{c,ref}}\!/_{p_{c,Film}}\right)^{0.8}$$

$$\mu = \frac{\dot{m}_{Film}}{\dot{m}_{Film} + \dot{m}_{Fuel,Injector}}$$

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