Investigation on Recess Variation of a Shear Coax Injector for a Single Element GOX-GCH4 Combustion Chamber

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(Received July 31st, 2015)

In the current study the effects of oxidizer post recess length variation in a shear coaxial injector have been experimentally investigated. Different injector configurations are used to inject oxygen and methane, both in gaseous form, into the combustion chamber at pressure levels between 10 and 20 bar. It has been observed that the GOX post recess enhances the mixing between the propellants when its length is longer than one GOX post exit diameter. The pressure drop across the injector increases with the recessed oxygen tube compared with the flush mounted case. The variation in wall temperature and pressure axial profile, the pressure drop at the injector and the influence of the injector setup on the heat loads to the wall are the focus of the present investigation.

Key Words: Shear Coaxial Injector, Recess, Heat Transfer, Green Propellants

Nomenclature

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
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<tbody>
<tr>
<td>$A$</td>
<td>area</td>
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<tr>
<td>$C_d$</td>
<td>discharge coefficient</td>
</tr>
<tr>
<td>$c$</td>
<td>specific heat capacity</td>
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<tr>
<td>$E$</td>
<td>energy</td>
</tr>
<tr>
<td>$GOX$</td>
<td>gaseous oxygen</td>
</tr>
<tr>
<td>$GCH_4$</td>
<td>gaseous methane</td>
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<tr>
<td>$LOX$</td>
<td>liquid oxygen</td>
</tr>
<tr>
<td>$OF$</td>
<td>mixture ratio</td>
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<tr>
<td>$J$</td>
<td>momentum flux ratio</td>
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<tr>
<td>$m$</td>
<td>mass</td>
</tr>
<tr>
<td>$m_{in}$</td>
<td>mass flow rate</td>
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<tr>
<td>$P$</td>
<td>pressure</td>
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<tr>
<td>$\dot{q}$</td>
<td>heat flux</td>
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<tr>
<td>$R$</td>
<td>recess</td>
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<tr>
<td>$r$</td>
<td>radius</td>
</tr>
<tr>
<td>$T$</td>
<td>temperature</td>
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<tr>
<td>$t$</td>
<td>time</td>
</tr>
<tr>
<td>$u$</td>
<td>velocity</td>
</tr>
<tr>
<td>$VR$</td>
<td>velocity ratio</td>
</tr>
<tr>
<td>$z$</td>
<td>axial coordinate</td>
</tr>
<tr>
<td>$\rho$</td>
<td>density</td>
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</tbody>
</table>

Subscripts

$c$ : combustion chamber
$in$ : inner
$out$ : outer
$hw$ : hot wall

1. Introduction

Hydrocarbon propellants are attractive in the space propulsion field due to their ease in handling and low operational costs. In particular, oxygen/methane is one of the most promising hydrocarbon propellant combination since it features high specific impulse, low coking tendency and good performance.

The design and optimization of liquid rocket engines using methane require a detailed knowledge and understanding of the dominating physical phenomena of propellant injection, combustion and heat transfer. Although studies have already been performed,1) the current knowledge in oxygen/methane combustion, flame stabilization and injector design criteria is missing a wide-ranging experimental and analytical database. Because the combustor performance (combustion efficiency, combustion stability and heat loads inside the combustor) of liquid rocket engines is strongly influenced by the outlet geometry of the injector, the injector design is very crucial in the rocket engine development. For shear coaxial injectors, which are widely used in liquid rocket engines like SSME and Vulcain 2, the key parameters that characterize the injector geometry are liquid oxygen (LOX) post recess length, taper angle and tube wall thickness at the LOX post exit. For such engines, and other booster engines, the fuel and the oxidizer are injected in the combustion chamber at super-critical and trans-critical state, respectively. Several studies have shown that recessing the LOX post with respect to the injection plane leads to a performance enhancement of the liquid propellant rocket engine. The improvement of atomization and mixing seems to diminish after a certain recess length, values are usually proportional to the inner LOX diameter. In sub-critical LOX/H2 engines an increase of the flame expansion rate and the volume of the flame diameter has been seen for a recess length of $1x_d$ by Kendrick2) and no further improvement has been encountered for recess lengths above $1.5x_d$ by Triphati.3) However, past experiments4) indicate that the impact of LOX post recess are different between sub-critical and super-critical pressure condi-
tions. Indeed, Lux et al. 5) affirm that LOX post recess enlarges the flame expansion shortly after injection, and Woodward et al. 6) observe no improvement in combustion efficiency. Thus, additional investigations need to be done in order to study the effects of recess in the case of supercritical pressure. Recent studies indicate that under these conditions the propellants act like dense gases and the scaling laws for a gas-gas coaxial jet can be applied to super-critical jets. 7) 8) In the context of the national research program Transregio SFB/TRR-40 on “Technological Foundations for the Design of Thermally and Mechanically Highly Loaded Components of Future Space Transportation Systems”, combustion and heat transfer of gaseous oxygen (GOX) and gaseous methane (GCH4) are experimentally and numerically investigated. Before manufacturing and testing of a multi-injector combustion chamber, a single-element combustion chamber was designed and tested in order to characterize the injector, to establish the heat loads to the wall and to validate the numerical tools for the new propellant combination.

In the current study two GOX post recess geometries are investigated. The influence that changes of injector geometry implies, in terms of wall heat flux profile and combustion characteristics, is the focus of the research.

2. Test Specimen and Experimental Configuration

All the experiments have been performed at the Institute for Flight Propulsion’s test facility at the Technical University of Munich (TUM). The movable test bench allows experiments with gaseous methane and gaseous oxygen for designed interface pressures up to 50 bar. In this section a brief description of the single element rocket combustion chamber, the injector geometry, the measurement equipment and data analysis procedures are presented.

2.1. Hardware description

The combustion chamber, depicted in Fig. (1), is a modular heat sink hardware, configured to accomodate changes in chamber length and hardware configurations. With a total length of 305 mm and an inner diameter of 12 mm, the chamber is designed for a testing time up to 4 s at a pressure of 20 bar and mixture ratio of 3.8. The nozzle has a conical shape with a throat diameter of 7.6 mm, leading to a contraction ratio of 2.5. The chamber sections, made of oxygen-free copper (Cu-HCP), are held together by four tie rods having spiral springs to assure constant clamping force during thermal expansion of the chamber.

The injector head of the combustor is designed to allow different injector designs. For the current study, three configurations of a single shear coaxial injector element are used. A flush mounted configuration and two recess lengths, defined as the axial distance R of the end of the inner tube to the injection faceplate, of 3 mm (R3) and 6 mm (R6) are chosen. Those lengths correspond respectively to 0.75x and 1.5x inner GOX post diameter. Recess variation is achieved by exchanging faceplate segments of different lengths. Table 1 shows the main injector characteristic dimensions. To center the injector element in the faceplate, the GOX post is equipped with four equally-spaced fins. For the current test series, the fins are positioned with an angle of 45° to the wall temperature measurement center plane.

To ensure homogeneous injection conditions, in terms of temperature and pressure, two porous plates are placed in the oxidizer and fuel manifolds. A schematic of the injector design for the recessed configuration is shown in Fig. (2).

Table 1. Injector dimensions.

<table>
<thead>
<tr>
<th>GOX inner diameter</th>
<th>d1 [mm]</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>GCH4 outer diameter</td>
<td>d2 [mm]</td>
<td>6</td>
</tr>
<tr>
<td>GOX post wall thickness</td>
<td>t [mm]</td>
<td>0.5</td>
</tr>
<tr>
<td>GOX post length</td>
<td>l [mm]</td>
<td>96</td>
</tr>
<tr>
<td>GOX post recess</td>
<td>R0 [mm]</td>
<td>0</td>
</tr>
<tr>
<td>GOX post recess</td>
<td>R3 [mm]</td>
<td>3</td>
</tr>
<tr>
<td>GOX post recess</td>
<td>R6 [mm]</td>
<td>6</td>
</tr>
<tr>
<td>Taper angle</td>
<td>[°]</td>
<td>0</td>
</tr>
<tr>
<td>Injector area ratio</td>
<td>AGCH4/AGOX [-]</td>
<td>0.7</td>
</tr>
</tbody>
</table>

2.2. Experimental setup

The hardware is equipped with standard instrumentations required to characterize the operation of the chamber. For a better understanding of the complex heat transport processes, equally spaced pressure transducers on the side wall provide for a well resolved measurement of the wall pressure distribution p(z) along the chamber axis. WIKA A10 pressure transducers are used to record the axial evolution of the static chamber wall pressure. The pressure sensors are individually calibrated...
and operated at a data acquisition rate of 100 Hz. To characterize the injection conditions, thermocouples of type K, with 0.5 mm diameter, and pressure transducers are installed in the chamber manifolds, prior the porous plates. A schematic of the combustion chamber and the associated sensor locations is given in Fig. (1). To determine the temperature field within the chamber material, type T thermocouples of 0.5 mm diameter are mounted with a regular path of 17 mm along the center plane of the combustion chamber with 1 mm distance to the hot wall. Additionally on the first segment, 0.5 mm type T thermocouples are mounted at 3 mm distance to the hot wall at 90° angle and at the same axial positions of the other measurement points. A spring loaded system ensures a continuous contact between the thermocouples tip and the base of the hole, providing a constant force of about 2 N. 9) The thermocouple location pattern is shown in Fig. (3).

![Fig. 3. Schematic of thermocouple positions at 1 mm along the combustion chamber axis.](image)

2.3. Operating conditions

The ignition of the chamber is achieved by a torch igniter using gaseous methane/gaseous oxygen, mounted in the middle of the combustion chamber. The mass flow rates in the combustion chamber (GCH4, GOX, GN2 for purge) are set by sonic orifices in the feed lines to the main injector are manufactured with appropriate diameters and calibrated prior to the test campaign with nitrogen using a Coriolis mass flow meter. In order to increase the accuracy of the calculated mass flow rates, the value of the discharge coefficient \( C_d \) is implemented in the evaluation routine as variable function of upstream temperature and pressure. 10) The test matrix includes testing at nominal pressure levels of 10 and 20 bar for a broad range of mixture ratios that vary from 2.2 to 3.8. For the OF changes, both the GCH4 and GOX mass flow rates are scaled accordingly with pressure. Fig. (4) gives an overview of the performed operating points. Each operating point is run at least two times to ensure the repeatability of the recorded test data for a burning time of 3 s, required to reach stable operation of the combustion chamber needed for a correct thermal load measurements.

Although the nominal mass flow rates of the propellants are set to be the same in all the injector geometry cases, the actual mass flow rate in the 20 bar case for R0 recess was slightly lower. This leads to a lower combustion chamber pressure for these operating points. Despite good agreement and stable conditions are obtained for almost all operating points, the test case with R3 recess has shown unstable behaviour for the 20 bar combustion pressure at mixture ratios of 2.2 and 2.4. It is known from previous experimental investigations that modifications of the injector geometries can lead to injection-coupled instability mechanisms. In some cases an improvement of combustion stability has been seen when using recessed injector elements in subcritical LOX/H2 11) and in LOX/Kerosene investigations. 12) Other studies have shown that the inner mixing layer instability developing inside the recess region of coaxial injectors could influence the combustion stability of the engine. 13) It has been experienced 5) in LOX/GCH4 coaxial injectors that a recessed injector tends earlier to a chugging instability when lowering the pressure drop across the fuel side.

Additional investigations to achieve a better understanding of the role of combustion instability in recess geometry variation need to be carried out and do not represent the focus of this study. Therefore the unstable load points are omitted in the current work.

3. Experimental Results and Discussions

In standard cryogenic flames, a jet of low velocity oxidizer is surrounded by an annulus of co-flowing fuel at high velocity. The annulus flow continually shed the liquid core into ligaments and drops, till only the drops field remains. This breakup model indicates that the progress of atomization depends mainly on the momentum flux and/or the velocity ratio between the two propellants. Studies by Kendrick at al. 2) show that the cryogenic propellant flame is attached to the LOX tube lip. When this is recessed inside the fuel tube, the combustion products will both block and add heat to the fuel flow. This will increase the fuel velocity and thus the momentum ratio at the injector exit. The jet break-up will be enhanced and it will lead to an additional pressure loss within the injector. Therefore the velocity ratio \( VR \), in Eq. (1), between the fuel and the oxidizer stream velocity, and the momentum flux ratio \( J \), in Eq. (2), defined as the ratio of the fuel momentum to the oxidizer momentum, are the two non-dimensional numbers employed to characterize the injection conditions.

\[
VR = \frac{\mu_{GCH4}}{\mu_{GOX}} \tag{1}
\]

and

\[
J = \frac{(\rho u^2)_{GCH4}}{(\rho u^2)_{GOX}} \tag{2}
\]

One of the big differences between fluids at sub-critical and super-critical pressures are the thermodynamic properties. At super-critical pressure, surface tension and liquid/gas phase changes diminish. As a result the oxygen in the combustion
chamber no longer experiences liquid atomization, but rather diffuses directly through turbulent mixing similar to a turbulent gas jet.\(^{14}\) Thus, the effects of recess on liquid/gas coaxial jet do not necessarily correspond to those on coaxial jet at supercritical pressures.

For the underlying physical phenomena and due to the gaseous form of the propellants used, no strong variation of the injector pressure drop in the different recess cases is expected. Additionally the values of the velocity ratio and the momentum flux ratio for the flush mounted injector configuration vary with OF in small ranges, from \(V R = 0.7\) to \(V R = 1.2\) and from \(J = 1\) to \(J = 1.8\), respectively. Both ratios are based on propellant temperatures and pressures at injection conditions.

To fully characterize the behavior of the shear coaxial injector, \(C_d\) values have been calculated for all the load points. Because it is not possible to measure the fluid temperatures directly at the entry to the combustion chamber, injection conditions are calculated based on the first pressure sensor in the combustion chamber and the corresponding manifold temperatures. With this approach, heat transfer between the propellants, both at ambient temperature, within the injection element is considered negligible. The \(C_d\) calculations for the GOX use the inner cross section of the oxygen injection tube as reference area, while the ones for methane are based on the effective area of the GCH4 annular gap. Fig. (5) shows as representative the \(C_d\) values of the methane side over the different configurations for the 20 bar case. No strong influence can be observed from the presence of the recess, neither from changes in mixture ratios nor combustion chamber pressure.

![Fig. 5. Discharge coefficient of the methane side.](image)

Nevertheless an increase of approximately 10% of the injector methane pressure drop can be detected when the 6 mm recess is applied, no apparent influence is instead noticed for the 3 mm recess. As can be seen in Fig. (6) the difference in the injector pressure drop, for the recessed case with respect to the flush mounted case, increases with momentum flux ratio, thus approaching lower mixture ratios. Typical values for the pressure drops at the design point (OF=3.4) are for the oxygen tube 25% of \(P_i\) and of around 22% of \(P_i\) for the methane side. The loss in pressure is calculated from the manifold pressure downstream the porous plate to the closest combustion chamber pressure sensor.

To determine the influence of the different recess geometries on the combustion behavior, the pressure and thermal load distributions along the combustion chamber main axis require to be investigated. Additionally, to better understand the effect of the recess in the near injector region, the thermal time response of thermocouples in the aforementioned location is also analyzed.

### 3.1. Pressure distribution

Due to the transient behavior of the hardware, for the evaluation of the test data three time intervals are defined, see Fig. (7): a time \(t_0\) for initial conditions, a time \(t_1\), named evaluation time, characteristic for the hot run and a time \(t_2\) for shutdown conditions. To minimize the influence of the transient start up and shut-down phase and allow good comparability of the evaluated data points, the evaluation time \(t_1\) is taken at 2/3 of the hot run, where the temperature signals show an almost constant gradient. Accordingly, the performance parameters as well as the temperature, pressure and the heat flux distribution along the combustion chamber axis are calculated as mean values over a 0.5 s time interval at the evaluation time. A different approach is instead followed for the evaluation of the combustion chamber pressure distribution. To reduce possible deviations coming from signal noise, a piecewise linear fit is applied on the pressure signal, before determining the value at the evaluation point. Moreover, a mean value of a test and its repetition is presented. The deviation between the two tests is displayed by an error bar in Figs. (8), (9) and (10).

![Fig. 7. Temperature and pressure build-up.](image)

The design of the combustion chamber allows for the implementation of a high number of pressure sensors equally spaced with a distance twice the spacing for the thermocouple measurements. Due to combustion processes the mixture injected will accelerate from injection velocity up to hot gas velocity. Consequently, the wall pressure is expected to decrease along the chamber axis, according to Bernoulli’s equation. An indicator
of completeness of the combustion process is the flattening of the pressure gradient. Fig. (8) shows the wall pressure distribution for the 20 bar case at the different mixture ratios tested, normalized with the last pressure sensor in the chamber, mounted shortly upstream the throat at \(z=272\text{ mm}\). As already seen in previous studies using H2/LOX propellant combination, \(^{15}\) a strong pressure gradient of up to the 4% of the combustion chamber pressure is visible along the chamber axis. In the region close to the faceplate a drop in wall pressure, linked to the presence of a recirculation zone, is observable. The combustion process seems to be accomplished shortly before the nozzle section for all the mixture ratios and pressures tested. As an example of the test results obtained for the different injector configurations, the 20 bar, OF=2.6 test case is presented in Fig. (9).

For the \(R6\) recess geometry the flattening of the pressure profile at \(z=200\text{ mm}\), indicates an earlier achievement of the end of combustion process. Moreover the lower pressure decay level \((\Delta p/\Delta z)\) along the combustion chamber axis, encountered for the recess case, is an indicator for a better mixing between the methane and the oxygen flows. Indeed, lower pressure decay corresponds to lower axial acceleration of the combusted gas in the chamber. In fact the gases, already accelerated in the recess region, would be injected with a higher velocity into chamber and the required acceleration to accomplish the combustion process will diminish. Although the difference in the axial pressure profile is highlighted for this mixture ratio case, all profiles tend to be similar increasing the mixture ratio for the configuration \(R6\). The configuration \(R3\) instead, does not show a clear behavior and not a real trend could be extrapolated from these test results. An example of this attitude is given in Fig. (10) for OF=3.0.

3.2. Temperature distribution

During the firing, the temperatures rise steadily due to the heat sink nature of the chamber design. Fig. (11) shows the axial temperature readings of the thermocouples in the first segment installed at 1 mm distance from the hot gas side during the hot run for the \(R0\) injector configuration. The numbering of the thermocouples increases with the axial distance from the faceplate. Two main gradients can be recognized: a steeper increase in the first second after ignition, as the thermal wave travels through the chamber wall, and a smoother temperature increase during the remaining run time. Furthermore it can be noticed that the slope of the wall temperature versus time profiles decreases with time into the firing. The same trend could be identified for each temperature signal for the tests analyzed.

The temperature readings of the thermocouple placed at \(z=17.5\text{ mm}\), close to the faceplate, for the different injector configurations is given in Fig. (12). The signals, zoomed into the hot firing part, display a substantial increase in slope when the 6 mm recess is installed. Instead only a slight increase is visible.
for the configuration \(R3\). Since the hardware is having a transient behavior, the energy absorbed by the combustion chamber wall is proportional to the energy released by the combustion processes. Hence for a given time interval, higher heat release would lead to higher temperature gradients in the structure. This kind of behavior suggests an enhancement of the mixing between the coaxial jets for the injector configuration \(R6\) in the near injector region.

When taking into consideration that the \(R6\) configuration was running at lower mean combustion chamber pressure compared to the other cases, see Fig. (4), this even underlines the aforementioned enhancement. A better overview of the influence of the combustion chamber pressure to the heat flux is given in paragraph 3.3.

Due to steady combustion, the temperature increases continuously along the chamber axis till the accomplishment of the reaction processes. The temperature distribution along the chamber axis (\(\Delta T(z)\)) for the complete set of thermocouples positioned at 1 mm distance from the hot gas is shown in Fig. (13) for the \(R0\), 20 bar case. In a heat sink hardware, higher initial temperature of the test hardware would lead, for the same test duration to higher level of temperature. For this reason only the temperature difference between the signal at the evaluation time (\(t2\)) and at the initial time (\(t1\)) is taken into consideration. All the curves present a constant rise along the chamber axis until \(z=240\ mm\) and a short plateau is identified in the last section, close to the nozzle, as indication of completeness of the reaction process. No change of trend is visible for mixture ratio variations or injector configurations. In Fig. (14) the temperature difference for the 20 bar, \(\text{OF}=2.6\) case is taken as example to describe the temperature trend. Although an increase in temperature is detectable in the region close to the faceplate when the \(R6\) recess is used, proceeding towards the end of the combustion, all temperature profiles tend to flatten reaching the same level. The higher temperature level, observed in the faceplate region, confirms the hypothesis of higher heat release with this injector configuration, compared to the \(R3\) and \(R0\) cases. The hypothesis accords also with the comparison of the heat up curves (Fig. (12)) and the characteristic of the pressure distribution as described in section 3.1.

### 3.3. Experimental heat flux distribution and performance parameter

The characteristic of an injector element is mainly defined by the heat loads to the hot wall. The mixing mechanisms in the near injector region determine the flow conditions and influence the flame behavior. Hence a better mixing produced by variation of the injector characteristics would lead to variation in the heat flux distribution along the chamber axis.

Due to the capacitive design of the hardware, heat fluxes can only be calculated from wall temperature measurements. At the evaluation time \(t1\), the temperature distribution is fully established. Therefore, with the assumption of a constant heat flux, the temperature may be considered to equally change along the radius. This allows to define the heat transfer problem only by the heat capacity. The observation of the temperature traces over time implies a constant slope \(dT/dt\) at time \(t1\). The energy balance, including the energy storage term, is defined by Eq. (3)

\[
E_{in} - E_{out} = E_{stor}
\]  

That is possible to write in terms of heat flux as Eq. (4)

\[
\dot{q}_{in} - \dot{q}_{out} = \frac{mc\Delta T}{A_{wall} \Delta T}
\]  

The temperature variation over time (\(\Delta T/\Delta t\)) is calculated from the measured temperature signals during the time interval \(t1\). The Eq. (4) is applied at each thermocouple position, since independent from the temperature level. The heat flux dispersed outside the chamber by natural convection, can be considered...
negligible and the properties, density, heat capacity and conductivity of the copper, are assumed constant.

It is concluded that the rate of heat release to the inner walls by combustion is equal to the rate of heat absorbed by the chamber as stated in Eq. (5).

\[
\dot{q}_{in} = \rho c \cdot \frac{r^2 - r_m^2}{2r} \cdot \frac{[T(t_i) - T(t_{i-1})]}{\Delta t}
\]  

(5)

Fig. (15) shows the heat flux distribution along the chamber axis for the R0 configuration of the 20 bar case for different mixture ratios. The heat flux increases with axial position, to its highest between 240 mm till the end of the combustion chamber. The peak heat flux value is approximately 5.6 MW/m² for the 20 bar, OF=2.6 test, and approximately 2.9 MW/m² for the 10 bar pressure level. Also in this case, as already described in the temperature trend, the signal presents a plateau, however, longer than seen in pressure profile (Fig. (9)). The brass adapter ring between the nozzle segment and the holding frame (visible in Fig. (3)) behaves as an additional heat sink due to its non negligible mass and heat conductivity. This can cause the observed flattening of the heat flux curves towards the end of the chamber. A slight increase in the heat flux can be noticed with the increasing mixture ratio. The same trend has been shown by all the injector configurations tested and no significant influence could be observed on the maximum heat flux level when the recesses are mounted.

A zoom of the heat flux profile in the near injector field for the different recess at both the target pressures and mixture ratio of 2.6 is given in Fig. (16). The dominating phenomenon for the heat release is the combustion itself, as highlighted from the increase in steepness and absolute value of the heat flux profile with increasing pressure in the combustion chamber. Nevertheless the higher injector momentum flux, which promotes the mixing for the R6 recess case, yields higher heat flux in the near injection region. Furthermore for the 20 bar case the characteristic of the heat release seems to be shifted upstream the chamber axis to one previous axial position, from the location z=136 mm for the configuration R0 to the location z=119 mm for the configuration R6.

It has to be also taken into account that the heat flux level, due to the lower mean combustion chamber pressure of the R6 recess test campaign, should have a threshold of around 4.5% higher of the actual value, when considered the proportionality by Bartz, given in Eq. (6)

\[
\dot{q} \propto P^{0.8}
\]  

(6)

Experiments performed with pressure variations from 10 bar to 25 bar have shown a good agreement with the Bartz correlation. The heat flux for the reference case at a mixture ratio of 3.0 normalized with the mean chamber pressure as in Eq. (6) is given in Fig. (17).

The normalized heat flux profile of Fig. (16) for the 20 bar case is given in Fig. (18).
has a positive effect in the mixing and combustion characteristics of the shear coaxial injector. No significant change is visible in the R3 configuration, for which the boundary layer appears less stable, maybe due to high frequencies in the chamber.

Although an improvement of the mixing is clearly detectable for the injector configuration R6 in the near injector region, no strong effect is visible on the combustion efficiency. The combustion efficiency is both calculated with adiabatic wall assumption and with the JANNAF method,\(^{10}\) in which the heat losses to the wall are taken into account. The values for the 20 bar, OF\(_2=2.6\) case, are given in Table 2. As expected the values of the combustion efficiency with adiabatic wall assumption are lower for the recessed configuration, because of higher heat losses. The still lower efficiency for the R6 configuration when using JANNAF method is unexpected. Potential causes, e.g. the lower combustion chamber pressure, are under investigation.

| Table 2. Combustion efficiency at Pe=20 bar, OF=2.6. |
|-----------------|-----------------|-----------------|
|                 | R0              | R3              | R6              |
| Comb. Efficiency (adiabatic) | 0.946           | 0.942           | 0.935           |
| Comb. Efficiency (Jannaf)   | 0.967           | 0.964           | 0.960           |

4. Conclusion

In the context of the national research program Transregio SFB/TRR-40 on “Technological Foundations for the Design of Thermally and Mechanically Highly Loaded Components of Future Space Transportation Systems”, the effects of the GOX post recess in a shear coaxial injector using gaseous oxygen and gaseous methane have been investigated by means of experiments on a wide range of mixture ratios at 10 and 20 bar combustion chamber pressure. By comparing the experimental results in the different recess length cases, it has been verified that the GOX post recess enhances the mixing of the propellants when its length is longer than one GOX post exit diameter. That is additionally confirmed by the axial pressure and temperature profiles, as well as the increase of the injector pressure drop. Furthermore the experiments for the recess of 0.75 x \(d_i\) have shown combustion instabilities for low mixture ratios at 20 bar combustion chamber pressure. Further investigations to achieve a more detailed understanding of the underlying physical phenomena are ongoing. Moreover numerical simulations to calculate and compare the heat flux to the wall with the inhouse tool Thermtest and an Inverse Method approach, based on finite difference methods, are performed and will be presented in further publications.

Acknowledgments

Financial support has been provided by German Research Foundation (Deutsche Forschungsgemeinschaft-DFG) in the framework of the Sonderforschungsbereich Transregio 40. The authors would like to acknowledge Nikolaos Perakis for the support provided during the test campaigns and the post processing.

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