RHEOLOGICAL, OPTICAL AND BALLISTIC INVESTIGATIONS OF PARAFFIN-BASED FUELS FOR HYBRID ROCKET PROPULSION USING A 2D SLAB-BURNER

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This paper describes combined rheological and ballistic experimental analyses performed on paraffin-based mixtures that can be used as high regression rate solid fuels in hybrid rocket engines. Mixtures of different kinds of pure waxes doped with stearic acid and graphite were considered. In particular different kinds of macro, intermediate and micro crystalline waxes were tested. Following a rheological analysis of different kinds of paraffin-based mixtures, a ballistic analysis was performed in terms of regression rate.

$$\dot{m}_{ent} \propto \frac{p_{dyn}^{\alpha} h^{\beta}}{\mu_l^{\gamma} \sigma^{\pi}} \tag{1.1}$$

According to the relationship in Eq. (1.1) given by Karabeyoglu et al [3] the entrainment mass transfer of paraffin-based fuels is related with the viscosity of the liquid melt layer h. The melt layer thickness h, dynamic pressure p and surface tension are the other parameters, which are expected to influence the entrainment mass transfer in Eq. (1.1). Some of the exponents are reported in literature for film cooling experiments [2, 5]. For paraffin-based fuels no fundamental relation is reported. Only very little data has been published which links rheological behavior and regression rate of paraffin-based fuels [1, 4]. This implies the need for detailed rheological analyses to obtain viscosity measurements at different temperatures. These rheological tests have been done both at Politecnico di Milano in Italy and at DLR Institute of Space Propulsion in Germany.

One of the investigated paraffin samples is type 0907 from Sasol. This is a micro-crystalline type with a congealing point of 83-94 °C. A rotational rheometer with a plate-plate or plate-cone geometry was used to measure the viscosity and other parameters of the fuels. Tests have been done with pure 0907 and also with additives. Two additives have been chosen to compare their

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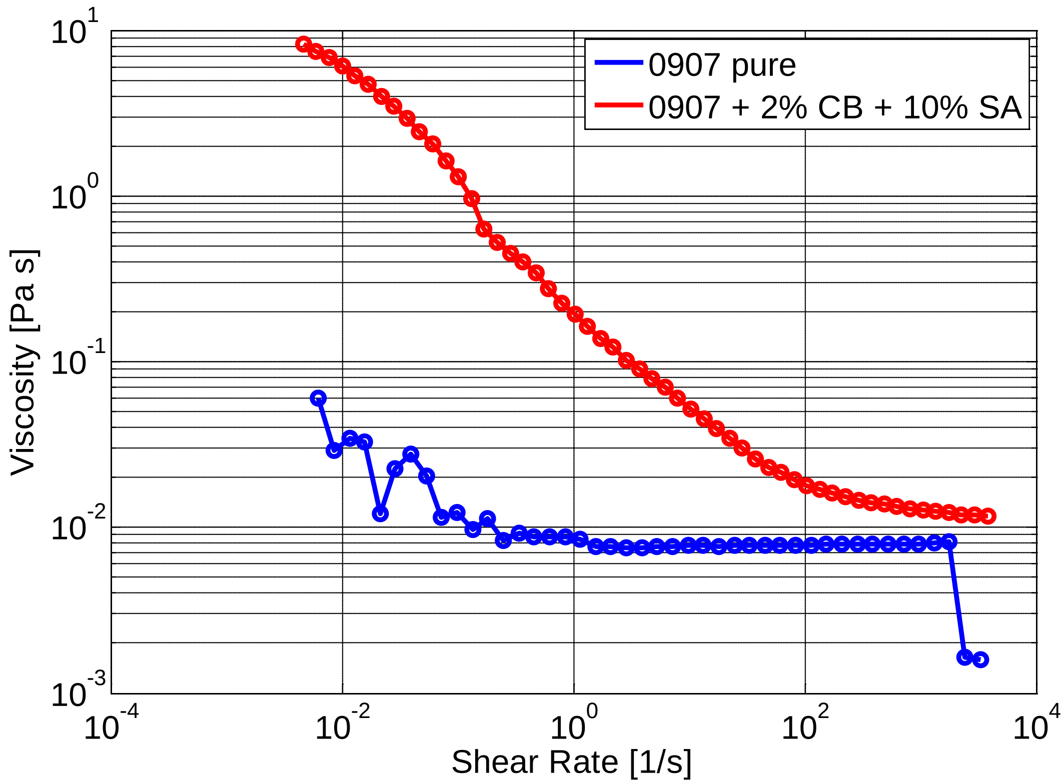

Figure 1: Viscosity vs. shear rate diagram of pure and doped 0907.

effects on viscosity. Both stearic acid (SA) with 10% and carbon black (CB) with 2% by weight have been added to the paraffin. The first tests investigate the viscosity vs. shear rate of the samples, as shown in Figure 1. It can be seen that pure 0907 shows no dependence of the viscosity on the shear rate between 20-1000 1/s. In contrast 0907 doped with 2% CB and 10% SA shows a non-newtonian behavior over the complete measurement range. Figure 2 shows the behavior of the two samples at different temperatures. It can be seen, that the doped paraffin has about 40% higher viscosity than the pure one. This difference is also expected to result in different regression rate during burning tests.

The burning rate tests of wax-based fuel formulations were evaluated in terms of regression rate values. Experimental investigation was carried out at Space Propulsion Laboratory (SPLab) of Politecnico di Milano, using a 2D-radial micro-burner with centrally perforated cylindrical strands. Experimental activities for regression rate evaluation in a 2D slab configuration were performed at the DLR Institute of Space Propulsion in Germany.

This paper describes in detail the experiments performed at DLR and compares them with the results at SPLab. Additionally the flame behavior of the fuels is analyzed through windows at the side of the chamber.

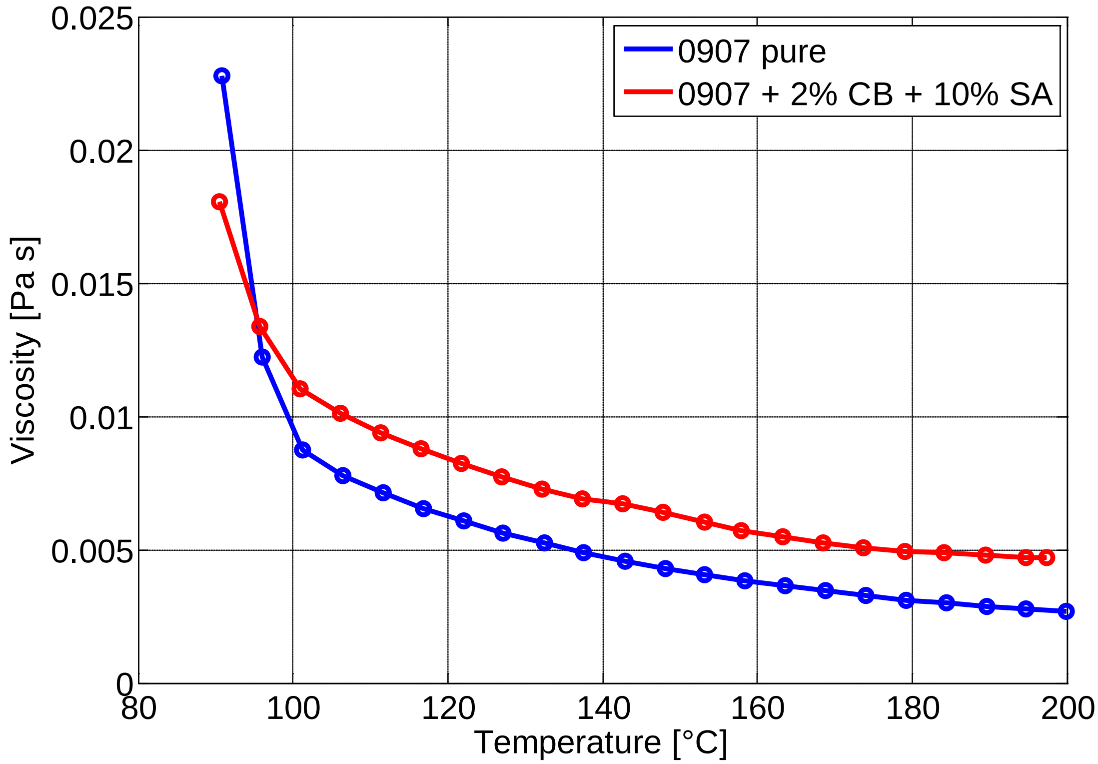

Figure 2: Viscosity vs. temperature diagram of pure and doped 0907.

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