Paraffin-based and metal-loaded HTPB fuel regression-rates study in a lab-scale hybrid rocket fed with N2O

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Hybrid rocket engines show some features provided by both conventional solid and liquid propellant rockets offering, on the one hand, some interesting advantages such as reliability, throttle-ability and re-ignition but, on the other, hybrids using classical polymeric fuels suffer from slow regression rate and, in general, relatively poor combustion efficiency.

The low fuel regression rate is a consequence of the heat and mass transfer mechanisms involved from the flame to the fuel surface. Combustion occurs in the boundary layer developing on the fuel wall, where oxidizer and gasified fuel react. The diffusive flame develops relatively far from the fuel surface and it is fed, from the outer side, by the oxidizer stream and, from the inner side, by the products of fuel pyrolysis, which is sustained by the flame itself. Heat transfer to the fuel surface is further reduced by the blocking effect, which is induced by the gas blowing from the fuel surface.

In the last years much effort has been expended to study fuel formulations to improve regression rate, and, with this purpose, an extensive experimental activity is required, due to the lack of reliable theoretical models able to predict the complex series of phenomena involved in the hybrid combustion process.

Among the effective means of increasing the regression rate, the addition of metal powders to the conventional fuel grains has been often employed.

Indeed, in comparison with the pure fuel, one may expect that the regression rate increases with the mass fraction of metallic particles; the latter reduce both the effective heat of gasification of the bulk fuel and the blocking effect of mass blowing. In addition, also the flame temperature is increased contributing to the regression rate enhancement on a lower extent. This technique has been investigated in the framework of the *Operative Research Project on Hybrid Engine in Europe* (ORPHEE) financially supported by the European Commission's Seventh Framework Program [1], [2].

Anyway, the ORPHEE program has demonstrated that powder addition does not significantly increase the fuel regression rate.

More recently the use of paraffin-wax fuel has been widely investigated [3]. Results recovered from literature [4] show that the SP1a, a paraffin-based fuel, burns with a regression rate three times higher than that of conventional hybrid fuels like pure HTPB. The main characteristic of the paraffin-based fuels is their non-diffusive-limited combustion mechanism relying on the onset of an unstable, low-viscosity liquid layer on the fuel surface exposed to burning, from which fuel droplets lift-off toward the main gas stream. The droplet entrainment in the flame zone increases the fuel mass transfer rate overcoming the diffusion-limited combustion of classical polymers burnt in hybrid rockets. Nevertheless, pure paraffin fuels cannot be successfully employed because of their very poor mechanical properties; for this reason a more efficient formulation of grain composition is mandatory.

The main purpose of this work is the tradeoff between novel paraffin-based fuel formulations and pure HTPB loaded with metal powders, both burnt with nitrous oxide (N2O). This oxidizer has been selected because, as it is well known, even though it is less performing than oxygen, it offers attractive advantages, such as storability at room temperature, no toxicity and relatively easy handling. N2O can decompose releasing oxygen and a significant amount of heat by a proper catalyst. The exothermic decomposition occurs with a high adiabatic temperature and the decomposed oxygen can be burnt with a variety of fuels.

Focus is on the regression rate obtained through an experimental campaign on a lab-scale hybrid engine burning N2O with two fuels: paraffinic materials (supplied by the SPLab of Politecnico of Milan in the framework of PRIN 2009) and pure HTPB loaded with metal powders (produced by AVIO in the framework of THESEUS program). Regression rate and combustion efficiency outcomes are shown and discussed. Single bore cylindrical grains with different initial port diameters have been burnt by injecting the oxidizer with a shower-head injector.

References

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