A Study of Gelled Propellant Simulants Using Impinging Jet Injectors

J. A. Mallory*, P. E. Sojka
Department of Mechanical Engineering, Purdue University, USA
jamallor@purdue.edu and sojka@purdue.edu

Abstract

The present study experimentally and analytically investigates the effect of liquid rheology on the flowfield resulting from non-Newtonian impinging jets. Sheet instability wavelengths, sheet breakup lengths, ligament diameters, and drop diameters were measured from high-speed video images and compared to predictions from a linear stability theory, which accounted for the Bird-Carreau pseudoplastic rheology, and to semi-empirical theories of sheet breakup length taken from the literature. Analytical results showed an improvement over previous linear stability theories in that they no longer consistently over-predict measurements.

Introduction

The primary objective of this study is to determine how gelled propellant rheology and atomizer geometric parameters control sheet and drop formation. Key issues addressed include: the impingement zone sheet formation and impingement wave evolution, the shedding of ligaments and the subsequent breakup of ligaments into drops, and the effect of rheological behavior on all of these.

Materials

The shear-thinning, inelastic, solid-like gel propellant simulants used in this study were 1 wt.-% Kappa carrageenan and 1 wt.-% Agar. Due to the solid-like nature of the gel propellant simulants, accurate surface tension measurements are difficult to obtain. Therefore, several shear-thinning, inelastic, liquid-like carboxymethylcellulose (CMC) solutions were used to validate the analytical model: 0.5 wt.-% CMC-7HF, 1.4 wt.-% CMC-7MF, 0.8 wt.-% CMC-7MF, and 0.06 wt.-% CMC-7MF 75 wt.-% glycerin.

Bulk rheological properties were determined through the use of rotational and capillary rheometers. Two approaches were used to experimentally measure the surface tension of the solid-like gel propellant simulants.

Results and Discussion

The first linear stability analysis using a nonlinear rheological model for non-Newtonian liquids was applied to predicting the maximum instability wavelength, sheet breakup length, and drop diameter from 0.5 wt.-% CMC-7HF, 1.4 wt.-% CMC-7MF, 0.8 wt.-% CMC-7MF, 0.06 wt.-% CMC-7MF 75 wt.-% glycerin, 1 wt.-% Kappa carrageenan, and 1 wt.-% Agar impinging jet sprays. The developed theory either accurately predicted or bracketed experimental results, with the exception of 1 wt.-% Agar. As a result, it is more precise than previous theories [1], which consistently over-predicted experiment data.

Comparison studies between Kappa carrageenan and Agar gelling agents, which are similar in rheology, lead to the conclusion that molecular structure may have a greater affect on atomization behavior than investigated spray parameters and needs to be considered in predictive models for improved accuracy.

A preliminary demonstration of this concept is the drop diameter equation of Ryan *et al*. [5], which incorporates both sheet and fluid property characteristics. Comparing the three investigated drop diameter expressions, the one of Ryan *et al.* consistently accurately predicted drop diameter more than the others. This shows the importance of incorporating both fluid and sheet characteristics into a predictive analytical model.

An investigation was also conducted comparing measured ligament and drop diameter ratios. It was found non-Newtonian liquids have a ligament to drop diameter ratio of roughly one. As viscosity is increased, this ratio becomes larger. However, the ligament to drop diameter ratio is consistently lower than the Newtonian value of 1.89 regardless of what non-Newtonian liquid was tested.

References

[1] Chojnacki, K., 1997. *Atomization and Mixing of Impinging Non-Newtonian Jets*, Ph.D. Dissertation, The University of Alabama, Huntsville.
[2] Ryan, H., Anderson, W., Pal, S., and Santoro, R. (1995). Atomization Characteristics of Impinging Liquid Jets. *Journal of Propulsion and Power, 11*(1), 135-145.

* Corresponding author: jamallor@purdue.edu