N95- 70891

# Metallized Gelled Propellants: Oxygen/RP-1/Aluminum Combustion Experiments

Bryan Palaszewski
NASA Lewis Research Center
Mail Stop SPTD-2
21000 Brookpark Road
Cleveland, OH 44135

## SUMMARY

A series of combustion experiments using metallized gelled liquid propellants were conducted. These experiments used a small 30- to 40-$lb_f$ thrust engine composed of a modular injector, igniter, chamber and nozzle. The fuels used were traditional liquid RP-1 and gelled RP-1 with 0-wt %, 5-wt%, and 55-wt% loadings of aluminum and gaseous oxygen was the oxidizer. Ten different injectors were used during the testing: 6 were for the baseline $O_2$/RP-1 tests and 4 for the gelled fuels. Relatively high C-star efficiencies were obtained with gelled RP-1 (0-wt% RP-1/Al) and metallized 5-wt% RP-1/Al over the O/F range tested: 90-98%. A peak of 98% efficiency was reached with ungelled $O_2$/RP-1 and up to 95% efficiency was obtained with gelled RP-1/Al (55-wt% Al). Injector erosion was evident with the 55-wt% testing, while there was little or no erosion seen with the gelled RP-1 with 0 and 5-wt% Al. A protective layer of gelled fuel formed in the firings that minimized the damage to the rocket injector face. This effect may provide a useful technique for engine cooling.

## Introduction

Metallized gelled propellants have been studied analytically and experimentally for over 60 years[1]. The historical work has focused on the benefits of high specific impulse, high density, and safety[2, 3, 4, 5, 6]. Current non-NASA uses for these propellants may lie in tactical and strategic missiles and aircraft ejection seats[3, 4, 5, 6]. Extensive work has been conducted with metallized-gelled Earth-storable propellants, such as hydrazine ($N_2H_4$), Inhibited Red Fuming Nitric Acid (IRFNA), and monomethyl hydrazine (MMH). However, these propellants are not planned for use in future NASA launch vehicles. To explore the potential of metallized-gelled fuels, NASA chose to pursue the propellant combinations that were more suitable to its future plans in the Metallized Propellant Program[7-14]. This program, at the NASA Lewis Research Center, has been conducting both experimental, analytical, and mission studies since 1987. This program's concentrated on

$O_2$/RP-1 and $O_2/H_2$ propellant combinations and the issues related to using these gelled propellants with metal particle additives. Several mission studies have indicated that $O_2$/RP-1/Al can have significant benefits by increasing propellant density. Testing was therefore conducted with $O_2$/RP-1/Al propellants using gelled RP-1 with aluminum particles. Some of the results of that testing are summarized in this paper.

## Purpose of Experiments

Rocket performance and heat transfer measurements were desired in this test program. During the combustion of metal particles, the two-phase flow creates a mismatch in the combustion time scale of the liquid droplets and the solid particles. The heat transfer measurements were envisioned so that some estimate might be made of the delay in ignition for the aluminum. Both baseline non-metallized propellants and various metal loadings with gelled RP-1 were used to compare the combustion temperature heat flux profiles of the different combustion environments.

## Experimental Setup

All of the experiments were conducted in the Rocket Laboratories of NASA Lewis. The combustion testing was conducted in Cell 21 and Cell 14 was used for propellant mixing. Cell 21 is a test facility with a very flexible capability and many diverse propellants can be tested. Oxygen /hydrogen igniters flows, $O_2$/CO, $O_2$/Al and gelled-metallized propellants are some of the combinations that have been tested. Except for the RP-1 and RP-1/Al, all of the propellants in the cell are provided in gaseous form. The gases are $O_2$, $H_2$, and $N_2$. Nitrogen is used as a purge gas to protect the igniter and engine after engine shutdown. Both the $O_2$ and $H_2$ are provided from high-pressure trailers. The liquid RP-1 propellants are delivered to the engine using a pressurized tank attached to the cell. Gelled propellants are pressurized and fed using a piston-cylinder tank. Micro-Motion flow meters are used to determine the liquid flow rates while a series of orifices are used to control the gas flow rates. A TRADAR data acquisition system with up to 100 data channels is used.

## Engine Hardware

Both heat sink and calorimeter experiments were conducted. The heat-sink combustion chamber has a 2.6-inch inside diameter and it is 6 inches long and the nozzle has a 0.6-inch diameter throat. A 22-channel cooling passage calorimeter chamber was used. The associated calorimeter nozzle has 9 cooling channels. Numerous thermocouples are located in the cooling passages of the calorimeter combustion chamber. The injectors use a oxidizer manifold within the injector body and have a fuel dome set atop it. The injector elements are an O-F-O design and both four and eight element patterns were tested. During the testing, a wide range of oxidizer-fuel ratios (O/F) were investigated. The injectors were designed for an O/F range of 1.2-4.2 for $O_2$/RP-1 and 1.4-3.7 for $O_2$/RP-1/Al.

Fuel Preparation

Several types of gelled-metallized fuels with different metal loadings were investigated. All of the propellant mixing was conducted in Cell 14 of the Rocket Laboratories. When mixing, it is important to add the "dry" elements first: adding metal, then gellant, then fuel. A small amount of liquid surfactant, Tween 85, is also added to the high metal loading fuels. The gelled RP-1 was prepared with a 6.5 wt% gellant concentration. This gellant wt% was selected based on a series of gelling experiments in which a range of 1-10 wt% was used. With the 5 wt% RP-1/Al fuel, 5 wt% gellant was added and with the 55 wt% RP-1/Al, the gellant fraction was 3.5 wt%.

Engine Efficiency

Some preliminary results are presented here based on initial analyses of the test data. All of the results presented here are for the heat sink engine. The testing with the calorimeter engine is not yet completed, therefore no heat transfer data is presented. With the $O_2$/RP-1, the maximum Cstar efficiency occurred near a 3.0 O/F. With the gelled RP-1 (0-wt% RP-1/Al), the O/F for the maximum Cstar efficiency was nearly the same. Both demonstrated very high C-star efficiencies of up to 98%. Using $O_2$/RP-1/Al (5 wt% RP-1/Al) a 90-95 % Cstar efficiency was delivered. The efficiency curve had a very flat response, with no obvious peak in the curve. At a 55 wt% RP-1/Al loading, the Cstar efficiency peak occurred near 1.5-2.0 O/F.

Observations

Self-protection of injectors. During the testing with gelled RP-1 and the -wt% RP-1/Al, some residual propellant was found in the rocket chamber, coating the injector face and chamber walls. Once this thin layer was removed with a soft cloth, the metal surfaces exhibited minimal erosion. This is a marked contrast to the blackening of the $O_2$/RP-1 injector faces and injector-face erosion that occurred with the 55-wt% RP-1/Al. Am improved cooling technique might be derived from this effect.

Metal agglomerations in the nozzle. When testing the 55-wt% RP-1/Al, metal agglomerations occurred in the nozzle. After 15, 2-second firings, the agglomeration had reduced the throat diameter from 0.6 inches to 0.45 inches. Several finger-like filaments extended out if the nozzle along its walls. This agglomeration was a hardened metal buildup that could not be easily removed. After taking the nozzle off the rig, the agglomeration could be chipped off with a chisel and once loosened, came off in large segments.

## Conclusions

High efficiency combustion of gelled metallized propellants was realized with even simple 4- and 8-element triplet injectors. With gelled metallized fuels, C-star efficiencies of over 90 percent were achieved, with the highest efficiency for the 55 wt% RP-1/Al being 95 percent. Though the high metal loading, 55-wt% RP-1/Al, engine runs experienced some agglomeration and erosion difficulties, the 0- and 5-wt% tests ran well, with a high C-star efficiency, and demonstrated a self-protective layer of gelled propellants and combustion products.

## Acknowledgements

I'd like to thank NASA Headquarters, Office of Advanced Concepts and Technology for their support of this work. Also, many thanks to Jim Zakany for his work as operations engineer for the rocket engine testing, Paul Molnar for his mechanical skills, and to J. P. for retiring from NASA.

## REFERENCES

1) Sanger, E., Raketenflugtechnique, Berlin: R. Oldenberg, 1933, pp. 53.

2) Wells, W., "Metallized Liquid Propellants," Space/Aeronautics, Volume 45, June 1966, pp. 76-82.

3) Olson, T. and Setze, P., "Some Combustion Problems of High Energy Fuels for Aircraft," NACA Preprint, 1958, International Symposium on Combustion, pp. 883-893 and 7th International Symposium on Combustion, London and Oxford, Aug 28-Sept. 3, 1958.

4) Allan, B. and Chew, W., "A Review of Thixotropic Gels for Advanced Propulsion Systems," JANNAF Propulsion Meeting, CPIA Publication 602. Volume III, November 1993.

5) Arszman, J. and Chew, W., "TACAWS Propulsion Development Program," JANNAF Propulsion Meeting, CPIA Publication 602. Volume III, November 1993.

6) Trikha, A., Warren, S., and Peters, J., "Advanced Crew Escape Capsule Technologies Program," SAFE Association, Newhall, CA Proceedings, 1987, pp. 196-202.

7) Palaszewski, B. and Rapp, D., "Design Issues for Propulsion Systems Using Metallized Propellants," AIAA 91-3484, September 1991.

8) Rapp, D. and Zurawski, R., "Characterization of RP-1/Aluminum Gel Propellant Properties," AIAA 88-2821, July 1988.

9) Mueller, D. and Turns, S., "Some Aspects of Secondary Atomization of Aluminum/ Hydrocarbon Slurry Propellants," AIAA Journal of Propulsion and Power, Volume 9, Number 3, May-June 1993.

10) Wong, W., Starkovich, J., Adams, S., and Palaszewski, B., "Cryogenic Gellant and Fuel Formulation for Metallized Gelled Propellants: Hydrocarbons and Hydrogen with Aluminum," AIAA 94-3175, June 1994.

11) Palaszewski, B. and Powell, R., "Launch Vehicle Propulsion Using Metallized Propellants," AIAA 91-2050, June 1991.

12) Palaszewski, B., "Advanced Launch Vehicle Upper Stages Using Metallized Propellants," NASA TP-3191, presented at the JANNAF Propulsion Meeting, Anaheim, CA, October 3-5, 1990.

13) Palaszewski, B., "Lunar Missions Using Advanced Chemical Propulsion: System Design Issues," NASA Technical Publication (TP) -3065, AIAA 90-2341, July, 1990, also in AIAA Journal of Spacecraft and Rockets, May-June 1994.

14) Palaszewski, B., "Metallized Propellants for the Human Exploration of Mars ," NASA TP-3062, November 1990. Also, AIAA Journal of Propulsion and Power, Nov.-Dec. 1992.