# Synthesis and Performance Characterization of a Non-Toxic Rocket-Grade Oxidizer

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## Abstract

The focus of this research was to examine the impact of water content in a nitric acid oxidizer reacting with hydrocarbon fuels. Synthesis of varying concentrations of nitric acid is warranted since the supply of 99% white fuming nitric acid (WFNA) is no longer available. Even 90% WFNA has limited supply and is currently being examined in the laboratory-scale droplet and rocket experiments. Experiments with the 90% WFNA showed a longer ignition delay and a greater mass of propellants was required for the same performance as the 99%. Therefore, it was both cost- and time-effective to produce the oxidizer needed for the hypergolic rocket engine rather than to procure it from a supplier. An experimental setup and procedure had to be created to distill >99% white fuming nitric acid. Once the white fuming nitric acid was produced, density calculations and titration results were compared to determine the concentration of the oxidizer produced. Droplet testing was utilized to screen and compare the previous data to the performance of the distilled oxidizer before hot-fire testing in the hypergolic engine.

## Introduction

***Background***

- An experimental, hypergolic, pressure-fed liquid rocket engine is utilized to perform hot-fire tests with the WFNA oxidizer and Tetramethyl-ethylenediamine (TMEDA) fuel.

***Motivations for Studying***

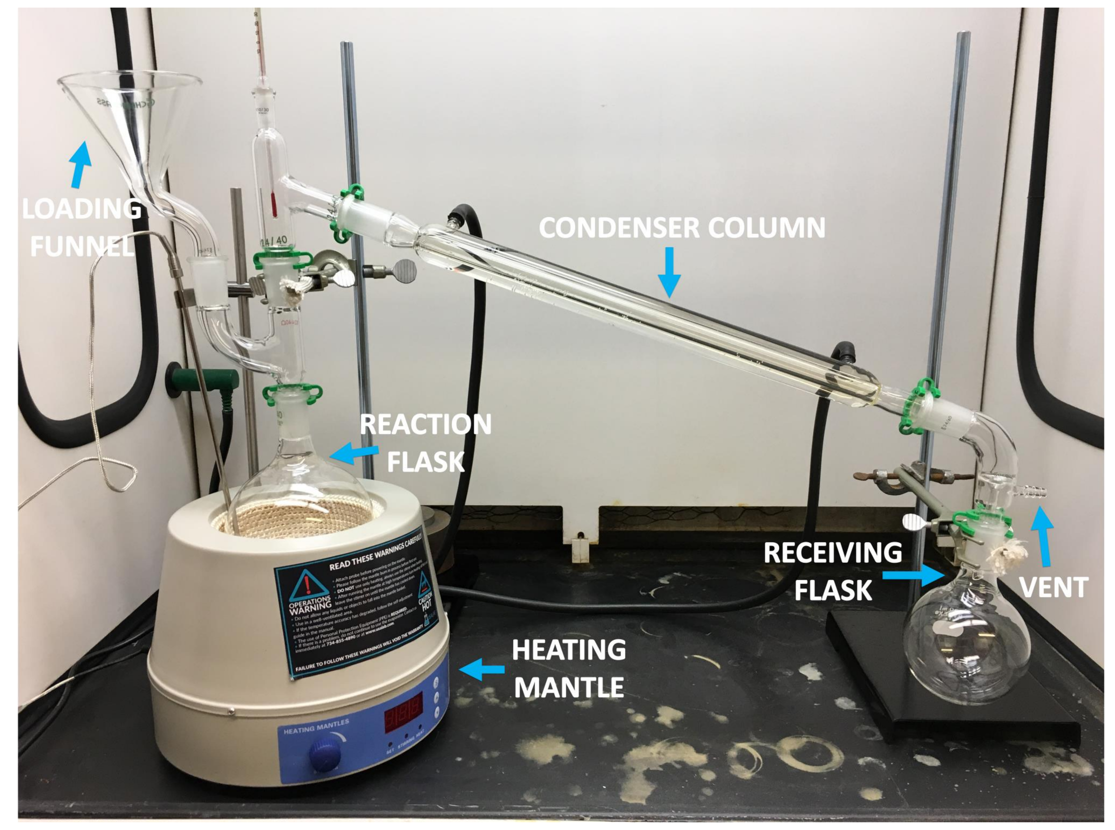
- As space travel increases in frequency it is critical to develop fuels and oxidizers that are safer for humans to handle and our environment/atmosphere.
- This research brings us closer to utilizing energetic reactants that are safe alternatives to toxic propellants such as Hydrazine while reducing production and handling costs.

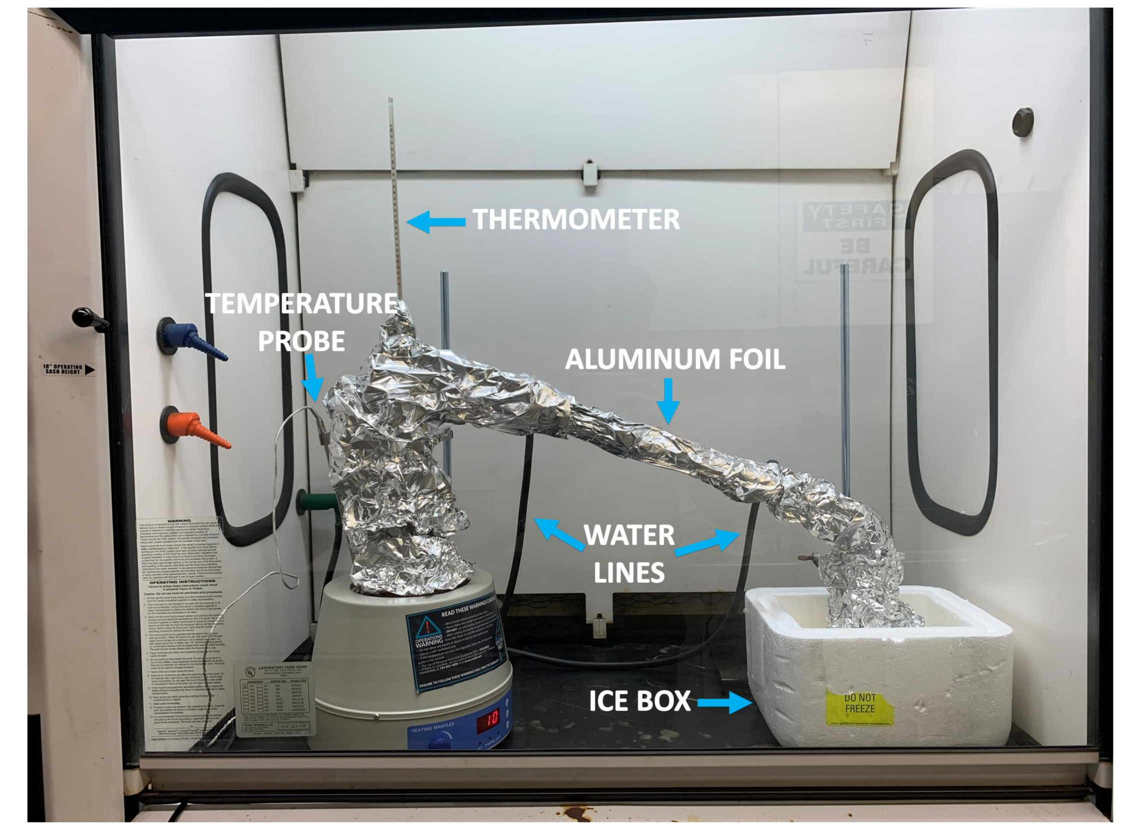
***Project Objectives***

- Produce quantities of WFNA at various concentrations for testing.
- Perform drop tests to measure ignition delay and verify the consistency of the WFNA produced.
- Collect rocket engine data to calculate the combustion performance of the TMEDA/WFNA mixture.

## Significance to Field & Society

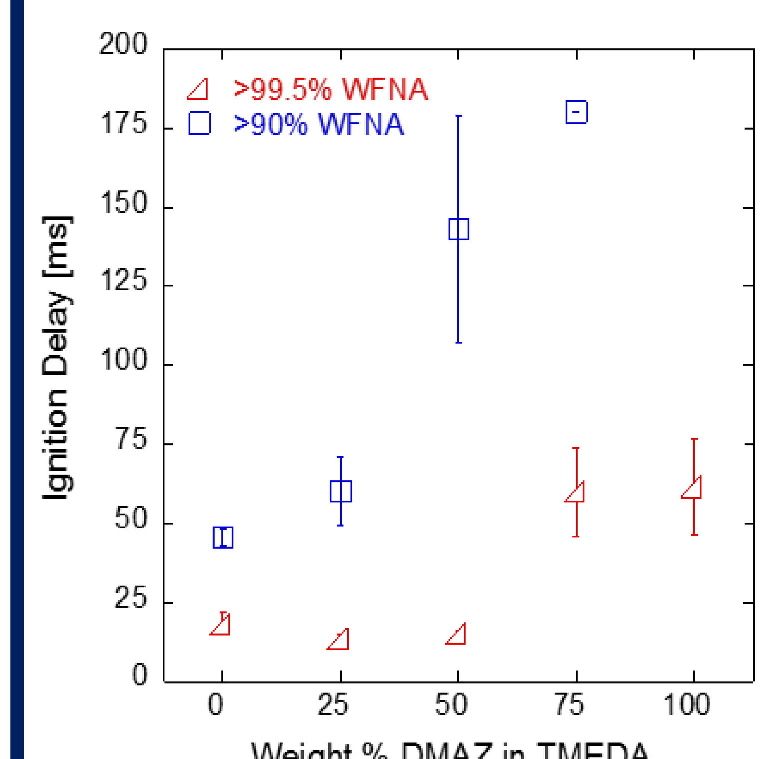
- The development of non-toxic fuels and oxidizers will allow space travel to become more sustainable, environmentally-friendly, and reduce launch costs by as much as $100k per launch.
- "Green" reactants may be implemented into our world to increase safety and reduce handling costs of energetic substances.




Sulfuric acid and sodium nitrate were loaded into the reaction flask. The funnel was replaced with a stopper, the heating mantle was turned on, and the setup was covered in aluminum foil since nitric acid degrades when exposed to light. The reaction produced nitric acid vapors which condensed into liquid and collected in the receiving flask. The temperature was maintained around 32 degrees Celsius for approximately 2 hours.

To calculate density, the mass of the WFNA had to be measured. This was done under a fume hood while wearing personal protection equipment including butyl gloves, eye protection, and a lab coat.




The graph compares ignition delays from droplet testing of >99.5% WFNA and >90% WFNA with a mixture of TMEDA and DMAZ fuel. Identical testing will be done on the distilled WFNA to verify it reacts similarly to the previously-purchased oxidizer as well as hot-fire experiments, seen using TMEDA/WFNA > 99%.

TMEDA is dropped into a pool of the distilled WFNA as a preliminary drop test to determine ignition capability. The images above are three consecutive frames, where it can be seen after impact, a luminous flame was observed. Average ignition delay time, or time from droplet impact until first light, was measured as < 33 ms.

## Density Calculations

- The first run yielded 33mL of fuming nitric acid at a mass of 51.572 g, giving a density of 1.513 g/mL.

$$\rho = \frac{m}{V} = \frac{51.572g}{33mL} = 1.513g/mL$$

- This density correlates to a concentration of >99%.

## Cost Analysis

- A yield of 33mL of fuming nitric acid cost $11.94 in chemicals to produce, giving a price of $0.36/mL at a concentration greater than 99%.
- A supplier of 98% fuming nitric acid offers 400mL for $552, giving a price of $1.38/mL.
- $33.66 was saved in this first run from distilling rather than buying.
- The cost/mL will decrease further as the procedure is refined and perfected.

## Conclusions

- Rocket-grade fuming nitric acid was successfully distilled at a concentration greater than 99%.
- Distilling WFNA is more cost-effective than purchasing it from a distributor due of the lack of supply.
- It is time-effective to distill the oxidizer in the laboratory since the procedure does not require constant supervision.
- A variety of concentrations can be produced from distillation and the process can easily be repeated.
- The fuming nitric acid instantly combusted upon contact with the TMEDA fuel.

## Future Work

- Perform titration analysis on the fuming nitric acid to compare with the density calculations.
- Perform drop tests at various concentrations to compare ignition delay with previous data.
- Conduct hot-fire testing using the distilled WFNA to continue researching non-toxic rocket propellants.
- Repeat distillation process using potassium nitrate instead of sodium nitrate to compare cost per yield.
- Run oxygen through the FNA to produce WFNA.

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