# Modeling and Simulation of Combustion of Metal-Liquid Oxidizer Propellants

A Dissertation Presented to the Faculty of the

Indian Institute of Technology Gandhinagar

By,

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In partial fulfillment of requirements for the degree of

Doctor of Philosophy, 2025

# Declaration

I, Prasanna P Kulkarni, hereby declare that the research reported in this thesis titled "**Modeling and Simulation of Combustion of Metal-Liquid Oxidizer Propellants**" was carried out by me in the Department of Mechanical Engineering, Indian Institute of Technology Gandhinagar, under the supervision of Prof. Dilip Srinivas Sundaram. I also declare that this work has not been submitted elsewhere for a degree.

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# Certificate

It is certified that the work reported in this thesis titled “**Modeling and Simulation of Combustion of Metal-Liquid Oxidizer Propellants**” has been carried out by Prasanna P Kulkarni (17210069), at Indian Institute of Technology Gandhinagar under my supervision, and this work has not been submitted elsewhere for a degree.

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*Dedication*

# Abstract

Add abstract

# Acknowledgements

Add Acknowledgements

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# Nomenclature

| Symbol | Meaning |
|---|---|
| Al | Aluminum |
| $C_D$ | Drag coefficient |
| $C_p$ | Specific heat |
| $d_p$ | Particle diameter |
| $D_d$ | Departure diameter |
| $D_{AB}$ | Binary diffusion coefficient |
| $E_a$ | Activation energy |
| $f$ | Drag factor |
| $f_d$ | Departure frequency |
| $f_i$ | Momentum source for $i^{th}$ phase |
| $F$ | Force |
| $F_{net}$ | Net force |
| $h$ | Enthalpy per unit mass |
| $h_m$ | Mass transfer coefficient |
| $h_{fg}$ | Enthalpy of vaporization |
| $H$ | Enthalpy per unit mole |
| $J$ | Nucleation rate |
| $k_{eff}$ | Effective/mixture thermal conductivity |
| $k$ | Thermal conductivity |
| $\dot{m}''$ | Mass flux |
| $\dot{m}'''$ | Mass source/sink term per unit volume |
| Mg | Magnesium |
| $MW$ | Molecular weight |
| $M_p^o$ | Initial particle mass |

| | |
|---|---|
| **N** | Number density |
| $P, p$ | Pressure |
| $Q_r$ | Heat release per kg of metal consumed |
| $R$ | Bubble radius |
| $Re_r$ | Relative reynolds number |
| $Ru$ | Universal gas constant |
| $r_b$ | Linear burning rate |
| $S$ | Geometrical factor |
| $Sh$ | Sherwood number |
| $Sc$ | Schmidt number |
| $T$ | Temperature |
| $T'$ | Temperature gradient |
| $u$ | Velocity |
| **u** | Velocity vector |
| $V$ | Bubble volume |
| $W$ | Work done |
| $X$ | Mole fraction |
| $X_{eff}$ | Effective mole fraction |
| $Y$ | Mass fraction |

**Greek letters**

| Symbol | Meaning |
|---|---|
| $\alpha$ | Volume fraction |
| $\alpha^d$ | Thermal diffusivity |
| $\mu_g$ | Gas phase dynamic viscosity |
| $\omega$ | Collision integral |
| $\phi$ | Volume fraction |
| $\rho$ | Density |
| $\sigma$ | Surface tension |
| $\sigma_{Ab}$ | Average hard-sphere collision diameter |
| $\sigma_e$ | Evaporation coefficient |
| $\theta$ | Contact angle |
| $\tau_b$ | Particle burning time |
| $\tau$ | Shear stress tensor |
| $\theta$ | Granular temperature |

**Subscripts**

| Symbol | Meaning |
|---|---|
| $a$ | Ambient temperature and pressure |
| Ar | Argon |
| $cr$ | Critical bubble size |
| $D$ | Drag |
| $eq$ | Equilibrium |
| $f$ | Fluid phase |
| $g$ | Gas pahse |
| $lw$ | Liquid water |
| $M$ | Metal |
| $MO$ | Metal oxide |
| $mp$ | Moving particles |
| $p$ | Particle phase |
| $PC$ | Phase change |
| $sp$ | Stationary particles |
| $sat$ | Saturation |
| $vo$ | Void phase |
| $wv$ | Water vapor |

# Chapter 1

# Introduction

Add Introduction

# Chapter 2

# A Comprehensive Examination of Combustion of Metal-Liquid Oxidizer Mixtures

Module 1

# Chapter 3

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Module 2

# Chapter 4

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Module 3

# Chapter 5

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Module 4

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# Conclusion and Future Scope

Add conclusion

# Appendix I

# Calculation of Heat Release $(Q_r)$:

Appendix one

# Appendix II

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