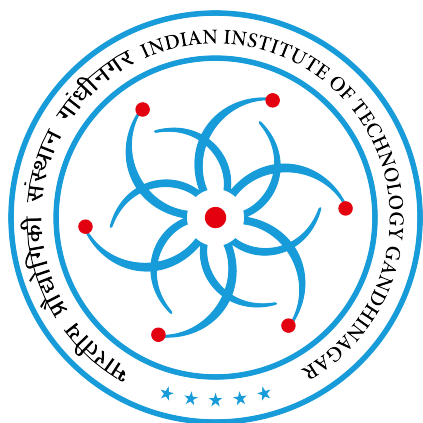


# **Modeling and Simulation of Combustion of Metal-Liquid Oxidizer Propellants**



A Dissertation Presented to the Faculty of the  
Indian Institute of Technology Gandhinagar

By,

Prasanna P Kulkarni,

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.

Prasanna P Kulkarni

(Roll no.: 17210069)

# 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
<b>Al</b>	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
<b>Mg</b>	Magnesium
$MW$	Molecular weight
$M_p^o$	Initial particle mass

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<b>N</b>	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
<b>u</b>	Velocity vector
$V$	Bubble volume
$W$	Work done
$X$	Mole fraction
$X_{eff}$	Effective mole fraction
$Y$	Mass fraction

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### Greek letters

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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

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## Subscripts

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

# **Chapter 1**

## **Introduction**

Add Introduction

## **Chapter 2**

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

Module 1

## **Chapter 3**

# **A Computational Fluid Dynamics Model of Metal Water Combustion in a Strand Burner**

Module 2



## **Chapter 4**

# **Nano-Aluminum and Water Strand Combustion**

Module 3

## **Chapter 5**

# **Effects of Particle Size, Packing Density, and Equivalence Ratio on Burning rates**

Module 4

# **Chapter 6**

## **Conclusion and Future Scope**

Add conclusion

# **Appendix I**

## **Calculation of Heat Release ( $Q_r$ ):**

Appendix one

# **Appendix II**

## **Burning Time Correlation of Mg in Water Vapor:**

Appendix two