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LIST OF SYMBOLS

a	Speed of Sound	m/s
A	Pre-exponential Factor for Second Order Reaction	m^3/mole-sec
A_{inj}	Injector Area	m^2
Aij	Wassiljewa Function	-
B	Transfer Number	-
B_M	Mass Transfer Number	-
B_T	Thermal Transfer Number	-
C	Concentration	mol/m^3
C_D	Injector Discharge Coefficient	-
Cex	Coefficient of Thermal Expansion	-
Cp	Specific Heat Capacity at Constant Pressure	J/kg-K
$\bar{C}p$	Molar Specific Heat Capacity at Constant Pressure	J/kg-K
Cv	Specific Heat Capacity at Constant Volume	J/kg-K
$\bar{C}v$	Molar Specific Heat Capacity at Constant Volume	J/kg-K
D	Drop Diameter	micron
$\bar{D}$	Average Drop Diameter	micron
D	Binary Diffusion Coefficient	m^2/s
Dc	Characteristic Diameter	m
D_{inj}	Injector Diameter	m
D_{FL}	Distance Field of View to Lens	m
ΔH	Heat of Reaction	J/mol
ΔP	Pressure Drop	Pa
Δt	Time Increment	s
E	Activation Energy	J/gmol

ε	Force Constant	m^2-K^5/W
f	Focal Length	m
g	Gravitational Constant, = 32.174	lb_m-ft/lb_f-s^2
Isp	Specific Impulse	s
φ	Mass Fraction	-
k	Thermal Conductivity	W/m-K
k'	Reaction Rate Constant for Second Order Reaction	m^3/gmol-s
k_B	Stefan-Boltzmann Constant = 5.6705119E-8	W/m^2-K^4
L	Latent Heat of Vaporization	J/kg
λ	Evaporation Constant	m^2/s
Le	Lewis Number	-
γ	Specific Heat Ratio	-
h	Heat Transfer Coefficient	W/m^2-K
h_F	Horizontal Component of Sensor Size	m
H_F	Horizontal Component of Field of View	m
h_{liq}	Liquid Phase Enthalpy	J/kg
h_{vap}	Vapor Phase Enthalpy	J/kg
$\dot{q}_{gen}$	Heat Generation Rate	W
$\dot{q}_{loss}$	Heat Loss Rate	W
m	Mass	kg
$\dot{m}$	Mass Flow Rate	kg/s
MW	Molecular Weight	g/gmol
μ	Dynamic Viscosity	Pa.s
N	number of moles	moles
$\mathbb{N}$	Molar Flux	mole/m^2-s
Nu	Nusselt Number	-
O/F	Oxidizer to Fuel Ratio	-
Ω_D	Collision Integral	-
P	Pressure	Pa

p	Partial Pressure	Pa
Pr	Prandtl Number	-
θ	Dimensionless Temperature	-
ρ	Density	kg/m^3
r	Radius	m
Re	Reynolds Number	-
σ	Surface Tension	lb_f/ft
σ_x	Hard-sphere Collision Diameter of Species x	Å
SMD	Sauter Mean Diameter	m
t	Time	s
T^*	Dimensionless Temperature	-
τ	Ignition Delay	s
U	Uncertainty	-
U_R	Relative Velocity	m/s
V_{inj}	Injection Velocity	m/s
V	Volume	m^3
v_F	Vertical Component of Sensor Size	m
V_F	Vertical Component of Field of View	m
χ	Mole Fraction	-
Y_F	Fuel Vapor Mass Fraction	-
We	Weber Number	-

Subscripts

gas	Ambient Gas
amb,∞	Ambient Conditions
s	Surface
vap	Vapor
OR	Gas Reference
FR	Fuel Reference
ox	Oxidizer

fuel	Fuel
BN	Normal Boiling Point
R	Reference
CR	Critical
mix	Mixture
tr	Transient
c	combustion, critical

Acronyms

ANOVA	Analysis of Variance
APCL	Advanced Propellants and Combustion Lab
ATO	Assisted Take-Off
EDM	Electric Discharge Machining
FNA	Fuming Nitric Acid
HTP	High Test Peroxide
LSD	Least Significance Difference
MAT	Manganese Acetate Tetrahydrate
MIST	Metered Ignition Sequence Tester
MMH	Monomethyl Hydrazine
MSDS	Material Safety Data Sheet
MSE	Mean Square Error
NAWC-WD	Naval Air Warfare Center Weapons Division
NHMF	Nontoxic Hypergolic Miscible Fuel
NTO	Nitrogen Tetroxide
OMS	Orbital Maneuvering Subsystem
RCS	Reaction Control System
RFNA	Red Fuming Nitric Acid
RGHP	Rocket Grade Hydrogen Peroxide
SCFH	Standard Cubic Feet per Hour
SNA	Strong Nitric Acid

TTL	Transistor-Transistor Logic
UDMH	Unsymmetrical Dimethylhydrazine
UTC	University Technology Center
WFNA	White Fuming Nitric Acid

ABSTRACT

Pourpoint, Timothée Louis, Ph.D., Purdue University, December 2005. Hypergolic Ignition of a Catalytically Promoted Fuel with Rocket Grade Hydrogen Peroxide. Major Professor: William E. Anderson.

The ignition delay for the incipient sustained reaction of hypergolic propellants is of crucial importance. Too short of a delay can lead to injector damage while too long of a delay can lead to very large pressure spikes and engine failure. The coupling of the physical and chemical processes controlling the ignition delays of hypergolic propellants renders the direct analysis of the transient ignition process very difficult. Well defined test conditions must, therefore, be specified to properly study the factors influencing the ignition delays of hypergolic propellants.

Theories regarding the thermal ignition of conventional hypergolic propellants, such as nitrogen tetroxide and hydrazine-based fuels, have been established. The goals of the present research are to investigate the applicability of thermal ignition theories to the ignition processes occurring between a catalytically promoted fuel and hydrogen peroxide and to develop a model of the incipient reactions. The hypergolic fuel considered in the study is a methanol-based mixture containing a soluble metal catalyst.

First, physical and chemical factors influencing an ignition event between liquid hypergolic propellants are discussed. Whenever possible, emphasis is placed on data obtained with fuels that are hypergolic with rocket grade hydrogen peroxide. Following this review, the applicability of traditional vaporization and ignition theories to the ignition of a catalytically promoted fuel with rocket grade hydrogen peroxide are discussed. An experimental program aimed at determining the effects of initial ambient

pressure, initial ambient gas properties, and hydrogen peroxide concentration on ignition delay is presented.

Results show that ignition delay can be reduced by increasing the hydrogen peroxide concentration or the initial ambient pressure. The combined effects of large thermal conductivity and large mass diffusion coefficient of helium rich environments are postulated to be responsible for the significant increase in ignition delay observed with the lowest hydrogen peroxide concentrations. The precise assessment of the relative contribution of heat generation and heat loss due to transport of the ambient gas were difficult to determine in the present experiment. The agreement between the trends and predictions partially substantiate a phenomenological model of hypergolic ignition of a catalytically promoted fuel with rocket grade hydrogen peroxide.

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