THE UNIVERSITY
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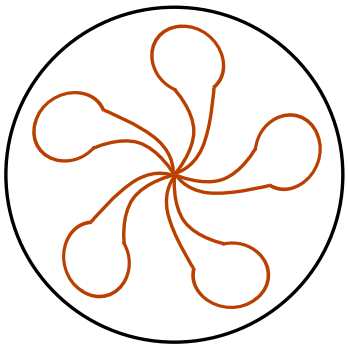
Faculty of Engineering, Computer and Mathematical Sciences
School of Mechanical Engineering

The Emissions and Chemical Autoignition Delay of Biodiesel Fuel



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Abstract

Biodiesel is an alternative to diesel fuel that can reduce life–cycle greenhouse emissions. It is made from plant oils or waste animal fat. Changing an engine's fuel from #2 diesel to biodiesel does not require modifications to the engine, and has typically reduced emissions of particulate matter (PM) but increased nitrogen oxides (NO_x). However, government regulations tightly limit exhaust pollutants, hence the increase is problematic.

In order to investigate the relationship between biodiesel fuel, ignition delay and emissions, experiments with a compression ignition, direct injection (CIDI) engine were performed. The emissions, ignition delays and apparent heat release rates from four locally produced biodiesel fuels and #2 diesel were measured. Emissions of NO_x were greater on average from the biodiesel fuels than the #2 diesel. Emissions of PM were not consistent, and measurements of ignition delay were the opposite of expectations. It was postulated that the fuel was undergoing atypical combustion, but this could not be confirmed with the limited data available from this investigation technique.

The engine experiments exemplified the need for alternative investigation techniques and numerical simulation of CIDI combustion was the leading choice. This technique was already well developed, however chemical ignition delay models for #2 diesel had received little validation and no data existed to generate a biodiesel chemical ignition delay model.

The novel drop method was conceived to measure the chemical ignition delay of heavy fuels at CIDI combustion relevant conditions and a shock tube was designed and built to use this method. It combusted fuel in a heterogeneous environment and minimised pre–experiment reactions. It was validated with *n*–dodecane, which indicated an assumed equivalence ratio at the ignition point was required. It then produced the first measurements of the chemical ignition delay of methyl oleate (a biodiesel surrogate) and #2 diesel at CIDI relevant conditions without pre–experimental reactions. Methyl oleate generated shorter chemical ignition delays than diesel and displayed NTC behaviour. The drop method shows strong potential for future measurements of the chemical ignition delay of many different heavy fuels.

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I used to believe that people can do anything they put their minds to. Now I realise what limits us is endurance, and without the support of every one of the following people I would have reached my limit a long time ago and never finished this thesis.

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Ian and all the crew at Bar 9, my favourite coffee store. Not only did they introduce me to many great coffees, but the store was the perfect place to work, doubling my productivity. Near a third of this thesis was written there.

Declaration of Originality

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution to Marcus Boyd and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

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Signed

Marcus Boyd

Nomenclature

Acronyms

AHRR	—	Apparent heat release rate, see Appendix B, page 221 for a definition
ARF	—	Australian Renewable Fuels
ATDC	—	After top dead centre
B30	—	A fuel comprised of 70% #2 diesel and 30% biodiesel
BP	—	British Petroleum
CI	—	Compression ignition
CIDI	—	Compression ignition, direct injection
CFD	—	Computational fluid dynamics
CN	—	Cetane number, see Sec. 2.2.3.1, page 23 for a definition
DI	—	Direct injection
EGR	—	Exhaust gas recirculation
FAME	—	Fatty acid methyl ester, see Sec. 2.1, page 7 for a definition
F–T diesel	—	Fischer–Tropsch diesel
GC/MS	—	Gas chromatography and mass spectrometry
GRI	—	Gas Research Institute
HCCI	—	Homogeneous charge compression ignition
HRR	—	Heat release rate
IDI	—	Indirect injection
JSR	—	Jet stirred reactor
KH/RT model	—	Kelvin–Helmholtz/Rayleigh–Taylor hybrid droplet breakup model
LHV	—	Lower heating value, see Sec. 2.1, page 10 for a definition
LLNL	—	Lawrence Livermore National Laboratory
NASA	—	National Aeronautics and Space Administration
NO_x	—	Nitrogen oxides (NO & NO_2)
NTC	—	Negative temperature coefficient
PAH	—	Poly–aromatic hydrocarbons
PM	—	Particulate matter
PRF	—	Primary reference fuel, a mixture of *iso*–octane and *n*–cetane
RCM	—	Rapid compression machine
RME	—	Rapeseed oil methyl ester, a biodiesel fuel

SAFF	—	Australian Farmers Federation
SOC	—	Start of combustion
SOI	—	Start of injection
TDC	—	Top dead centre
UoAST	—	University of Adelaide Shock Tube

Symbols

A	—	Arrhenius pre–exponential factor
A_{f_4}	—	A key constant in the Shell model, for a definition see Sec. 2.4.2 on page 40
a	—	Speed of sound
B	—	An intermediate species in the Shell model
B_0	—	Breakup constant in the Kelvin–Helmholtz wave breakup theory
C_b	—	Breakup length constant in the Kelvin–Helmholtz wave breakup theory
C_d	—	Venturi meter discharge coefficient
C_v	—	Heat capacity at constant volume
d	—	Venturi meter throat diameter
D_i	—	Area at interface i in L1d
d_a	—	Nozzle diameter in the Kelvin–Helmholtz wave breakup theory
E	—	Energy
E_a	—	Arrhenius activation energy
EI_{NO_x}	—	Nitrogen oxides emission index
ϕ	—	Equivalence ratio, see Sec. 2.2.2, page 15 for a definition
f_i	—	Rate term for reaction i in the Shell model
F_{wall}	—	Shear friction force at the wall in L1d
F_{loss}	—	Body–force due to losses from sudden changes in pipe diameter in L1d
k	—	Rate constant
L_b	—	Breakup length in the Kelvin–Helmholtz wave breakup theory
m	—	Mass
M_s	—	Incident shock Mach number
MW_i	—	Molecular weight of i
n_i	—	Number of moles of i
P	—	Pressure
p_i	—	Pressure in zone i, see Fig. 2.23 on page 59 for a definition of shock tube zones
Q	—	An intermediate species in the Shell model, or the flow rate in the Venturi meter
q	—	Heat transfer

Q_K	—	Energy release in the Shell model
Q_L	—	Heat loss through the boundary walls in the Shell model
R	—	Universal gas constant
$\tilde{R}$	—	Molar gas constant
$\bar{\mathrm{R}}$	—	All radicals in the Shell model
r	—	Radius
r_c	—	Radius of new droplets from the Kelvin–Helmholtz wave breakup theory
RH	—	The fuel in the Shell model
Re	—	Reynolds number
T	—	Temperature
T_i	—	Temperature in zone i, see Fig. 2.23 on page 59 for a definition of shock tube zones
t	—	Time
Ta	—	Taylor number
U_r	—	Relative drop/gas velocity
u	—	Velocity
V	—	Volume
v	—	Rate of reaction
v_i	—	Stoichiometric number of substance i
W_s	—	Incident shock velocity
W_r	—	Reflected shock velocity
We_g	—	Gas Weber number
Z	—	Ohnesorge number
α	—	Cut off ratio, see Sec. 5.3.2, page 126 for a definition
β	—	Venturi meter throat–to–pipe diameter ratio
γ	—	Ratio of specific heats
Δ_{KH}	—	Wavelength of the fastest growing wave in the Kelvin–Helmholtz wave breakup theory
λ	—	Ratio of carbon monoxide to carbon dioxide in the Shell model
η_{th}	—	Thermal efficiency
ρ	—	Density
σ	—	Surface tension
τ_{id}	—	Ignition delay
τ_{KH}	—	Breakup time in the Kelvin–Helmholtz wave breakup theory
Ω_{KH}	—	Growth rate of the fastest growing wave in the Kelvin–Helmholtz wave breakup theory