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School of Mechanical and Industrial Engineering

Investigation of a piezoelectric droplet delivery method for fuel injection and physical property evaluation

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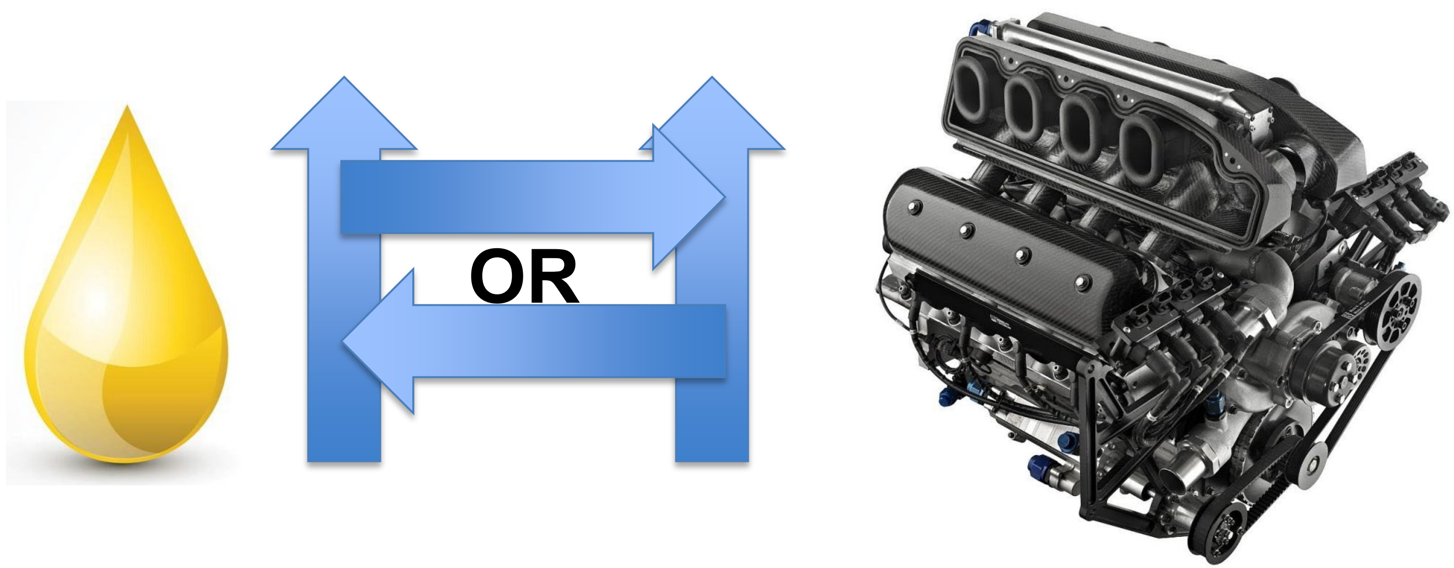
Co-Optimization of
Fuels & Engines

Motivation

- Department of Energy Co-Optima initiative
  - “*Accelerate the introduction of affordable, scalable, and sustainable high performance fuels for use in high-efficiency, low-emission engines*”
    - Do we optimize fuels for advanced engines?
    - Do we optimize engines for emerging fuels?
    - How about we Co-optimize!



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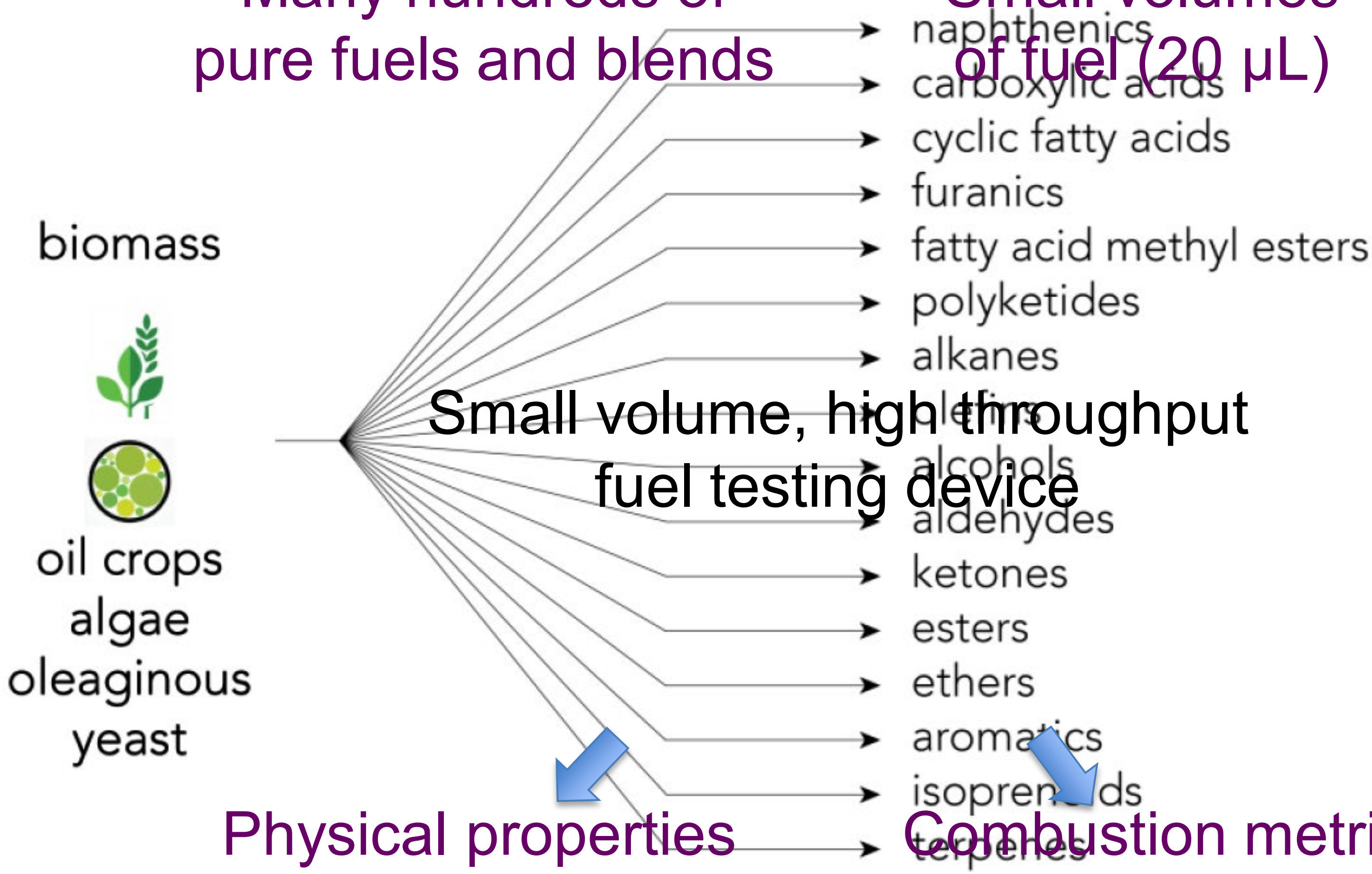
Co-Optimization of
Fuels & Engines

Fuel research at LSU

- Optima program is investigating a large number of novel biofuels

Many hundreds of
pure fuels and blends

Small volumes
of fuel (20 μL)



Small volume, high throughput
fuel testing device

Physical properties

Combustion metrics

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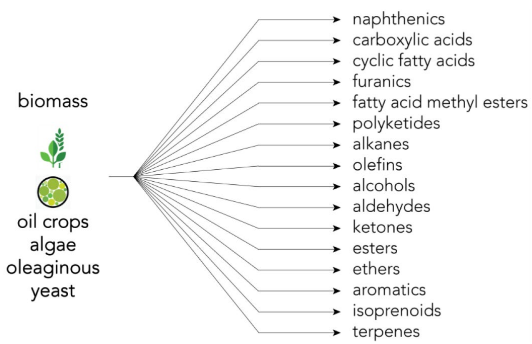
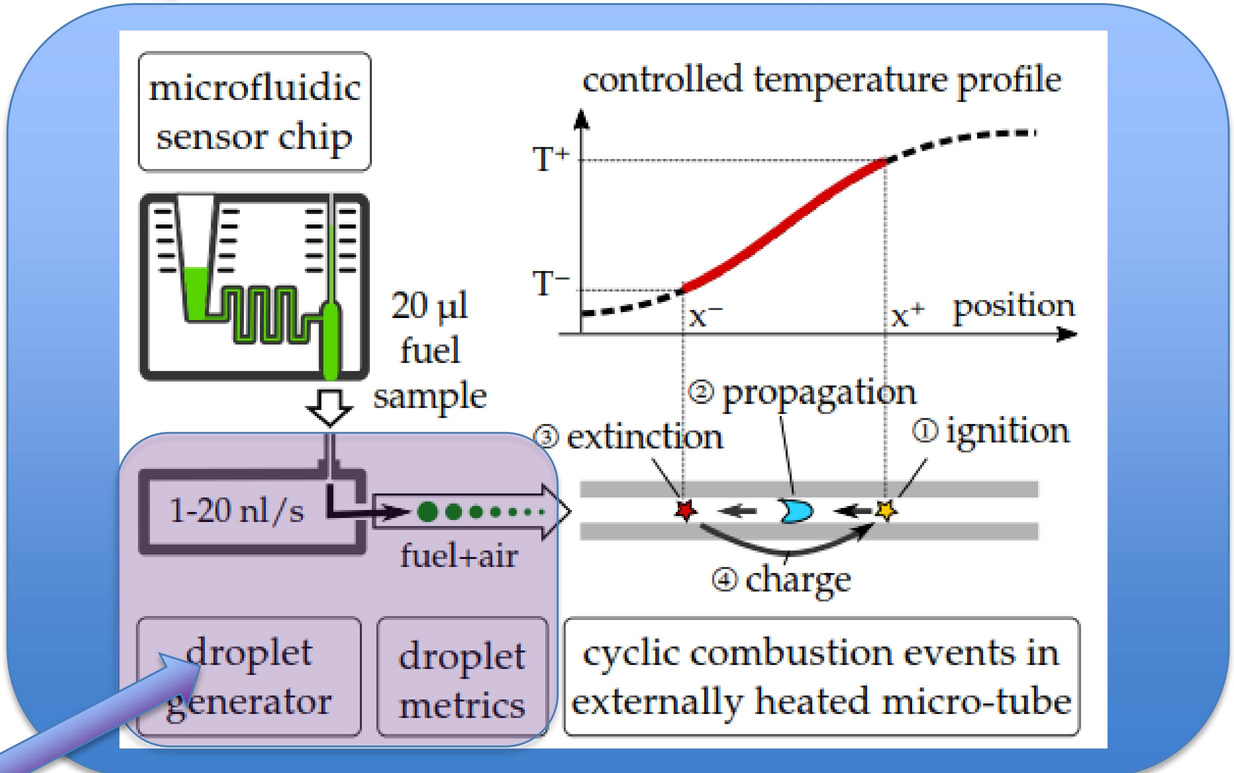
Co-Optimization of
Fuels & Engines

µL-Fuel Ignition Tester ⇔ Micro-FIT

Small volumes of fuel

Many hundreds of pure fuels and blends





Focus of this presentation!

Physical properties

Combustion metrics

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Objectives

1. **Fuel Delivery**: Low vapor pressure liquid fuels with flowrates ~ 1 μl/min, 1-10 atm pressure

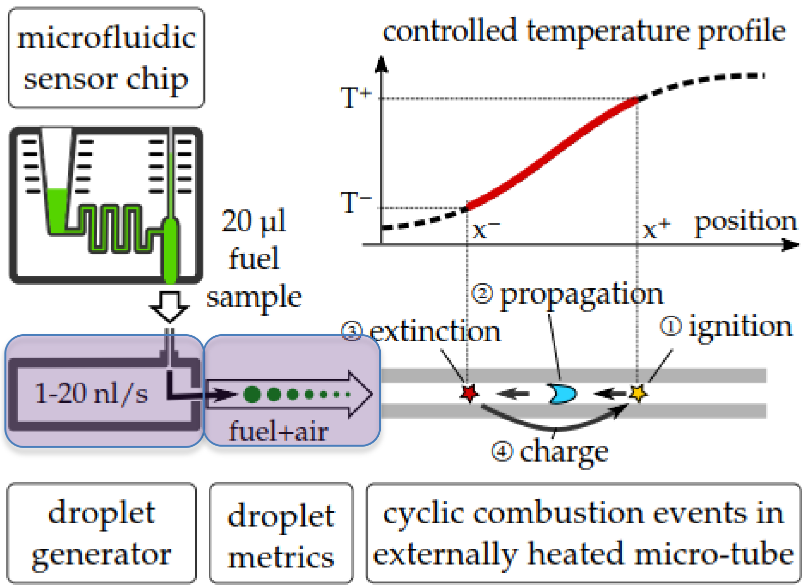
2. **Fuel Property Measurement:**
   Surface tension, viscosity, …

$$D_{drop}, V_{drop} = f\left(V, PZT_{properties}, Fuel_{properties}\right)$$

3. **Mixture Preparation**: Mix with air to produce mixture of desired stoichiometry

4. **Fuel Vaporization Observation:**
   Distillation curve, boiling point, …

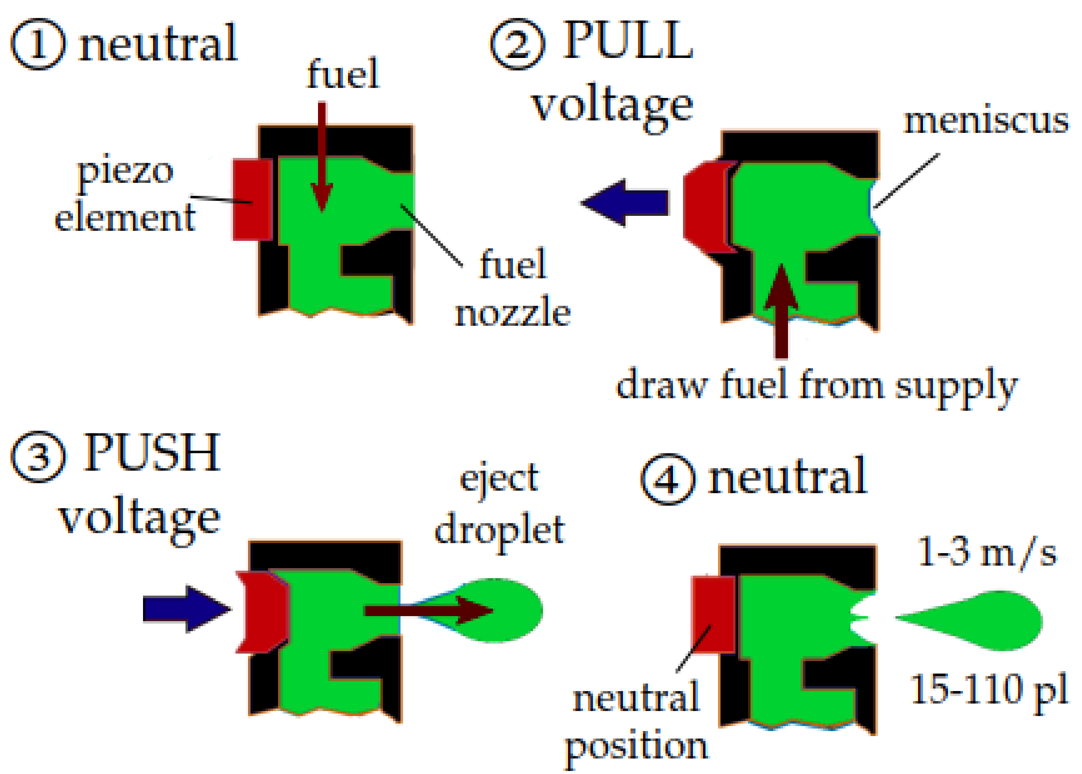
$$D_{drop} = f\left(Fuel_{properties}, Air_{properties}\right)$$



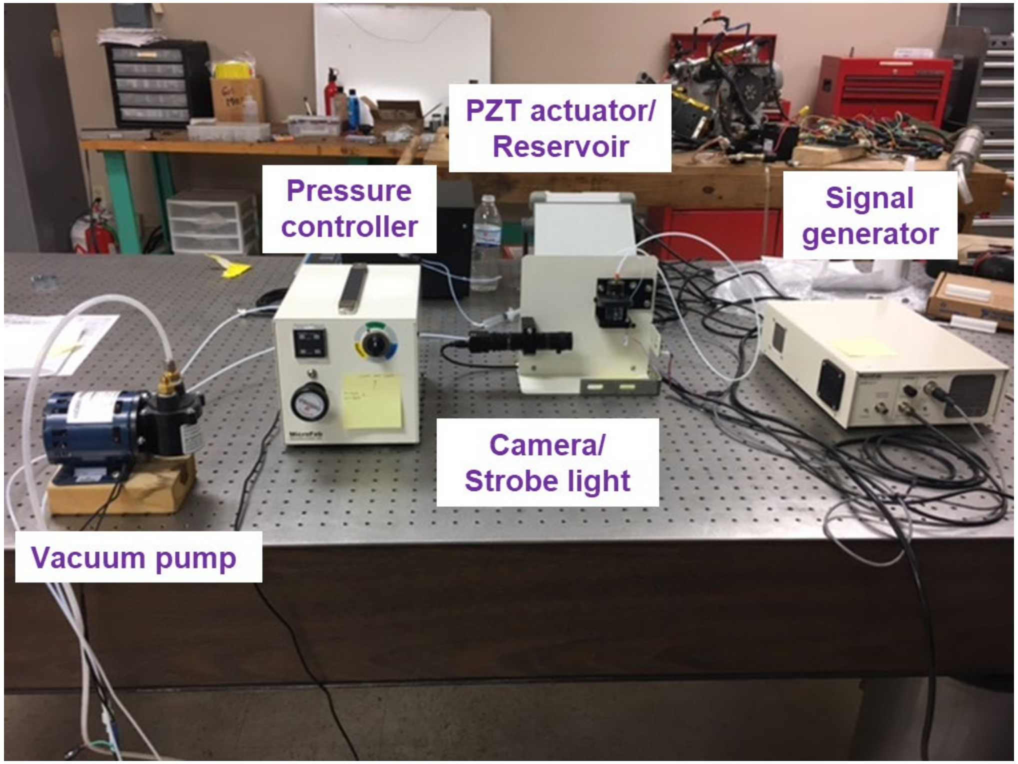
Micro-FIT

Approach – Fuel Delivery

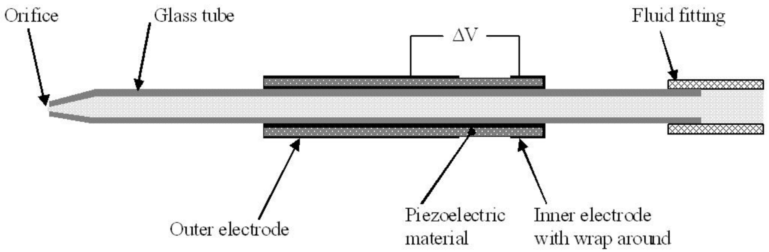
- **Piezo-electric droplet generator** for fuel delivery
  - Can achieve required flow rates
  - Produces droplets → can use to measure fuel metrics



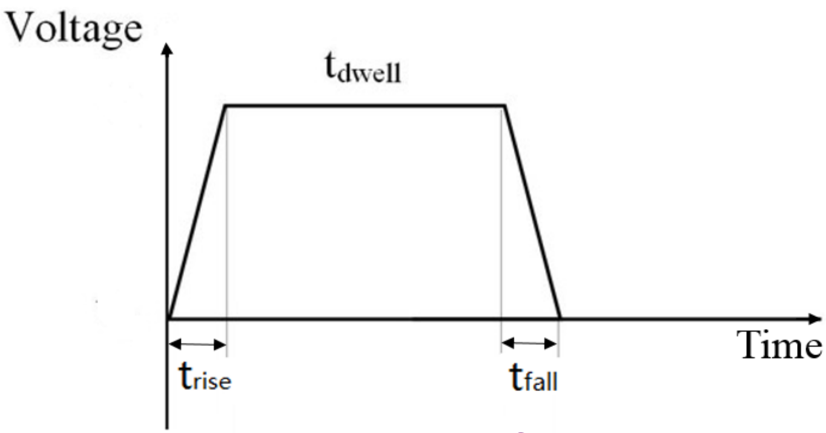
Approach – Fuel Delivery



Piezo-electric droplet generator



PZT actuator

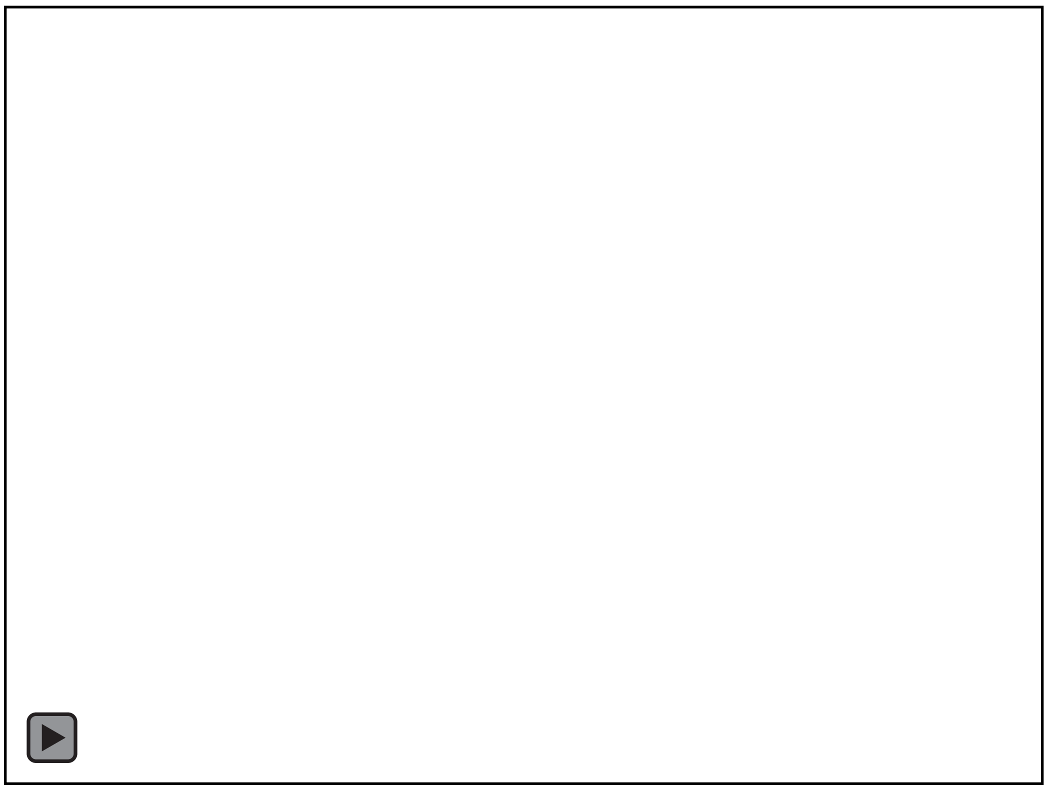


Applied waveform

http://www.microfab.com/assemblies

Results – Fuel Delivery

- Droplet generation at 1 atm pressure
  - Water; Iso-propanol; Iso-octane
  - Droplet size & velocity calculated using ImageJ software



Machine vision camera with strobed delay

Nozzle diameter = 30 μm

Iso-octane droplets
- ~40—55 μm
- ~1—2 m/s

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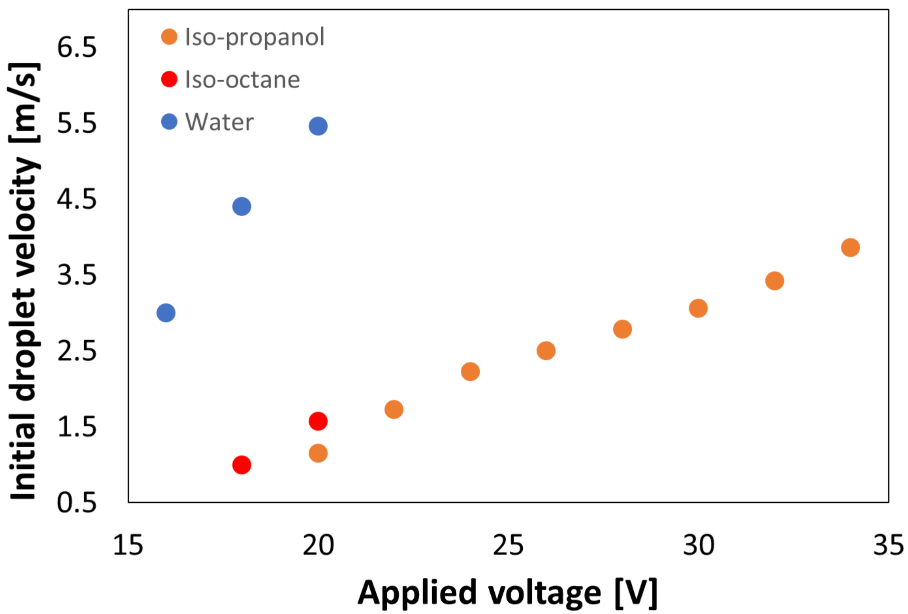
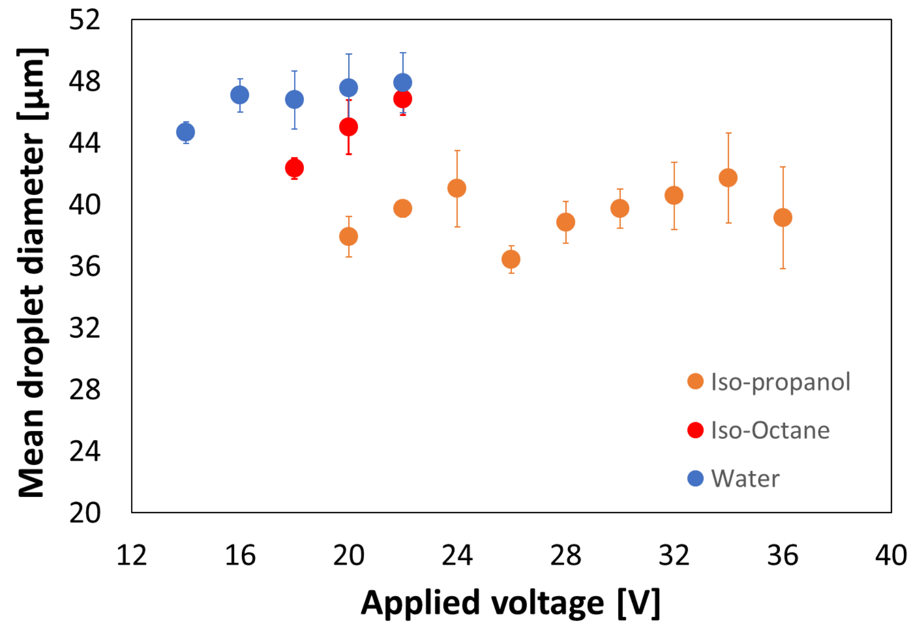
Results – Fuel Delivery

- Effect of applied voltage
  - ↑ Voltage -- ↑ Droplet velocity
  - ↑ Voltage -- ↑ Droplet diameter

Downstream distance from nozzle





Strobe delay [µs]

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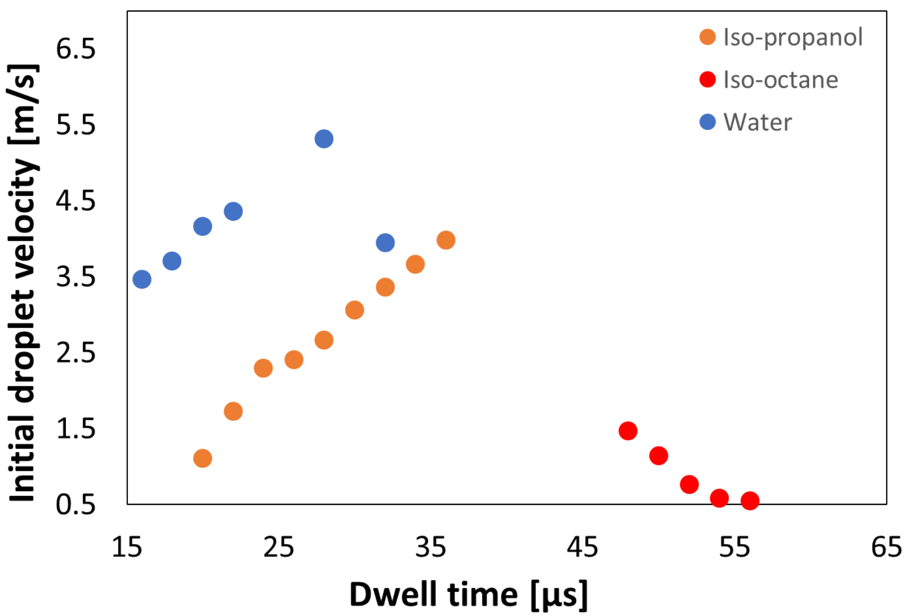
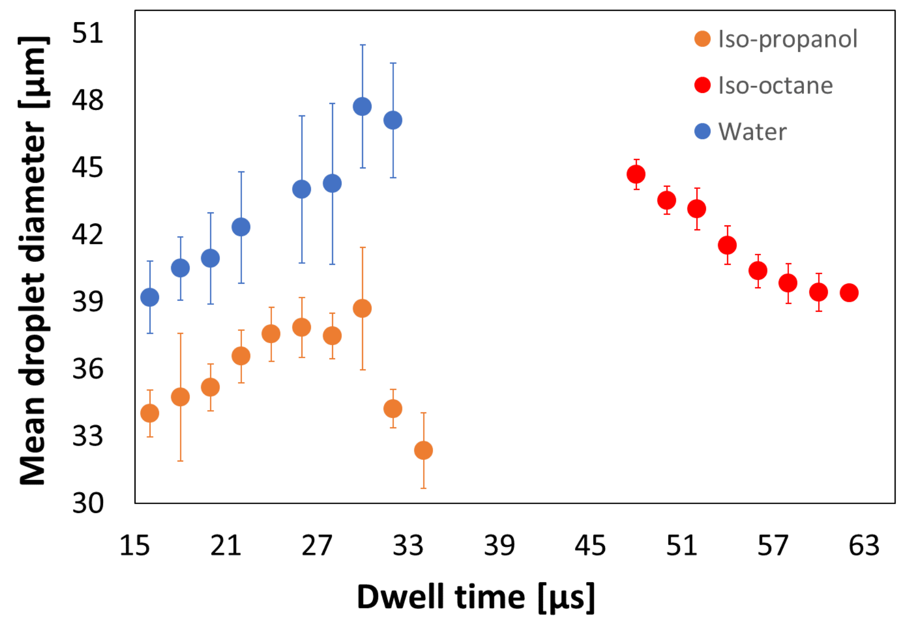
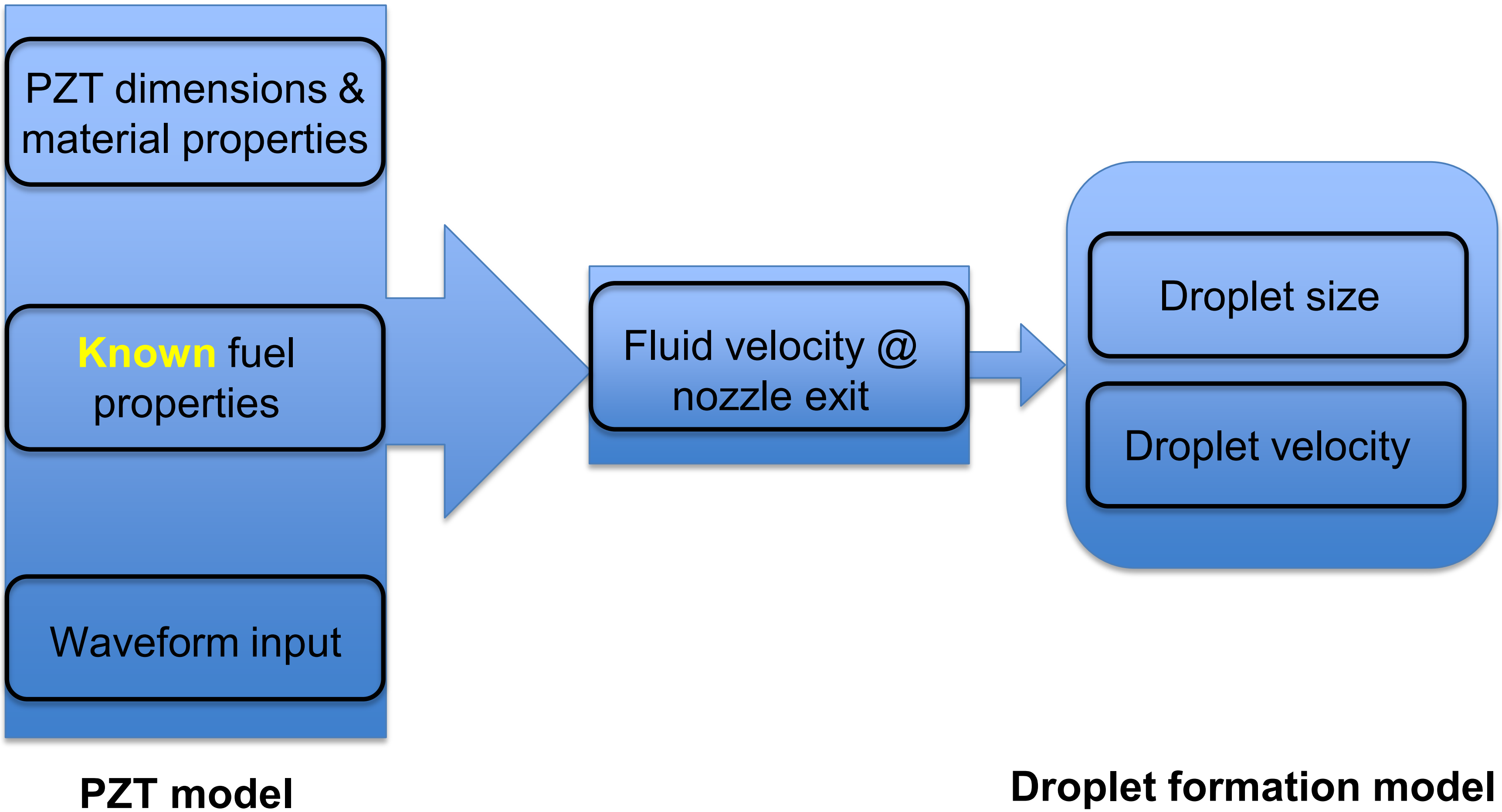
Results – Fuel Delivery

- Effect of dwell time

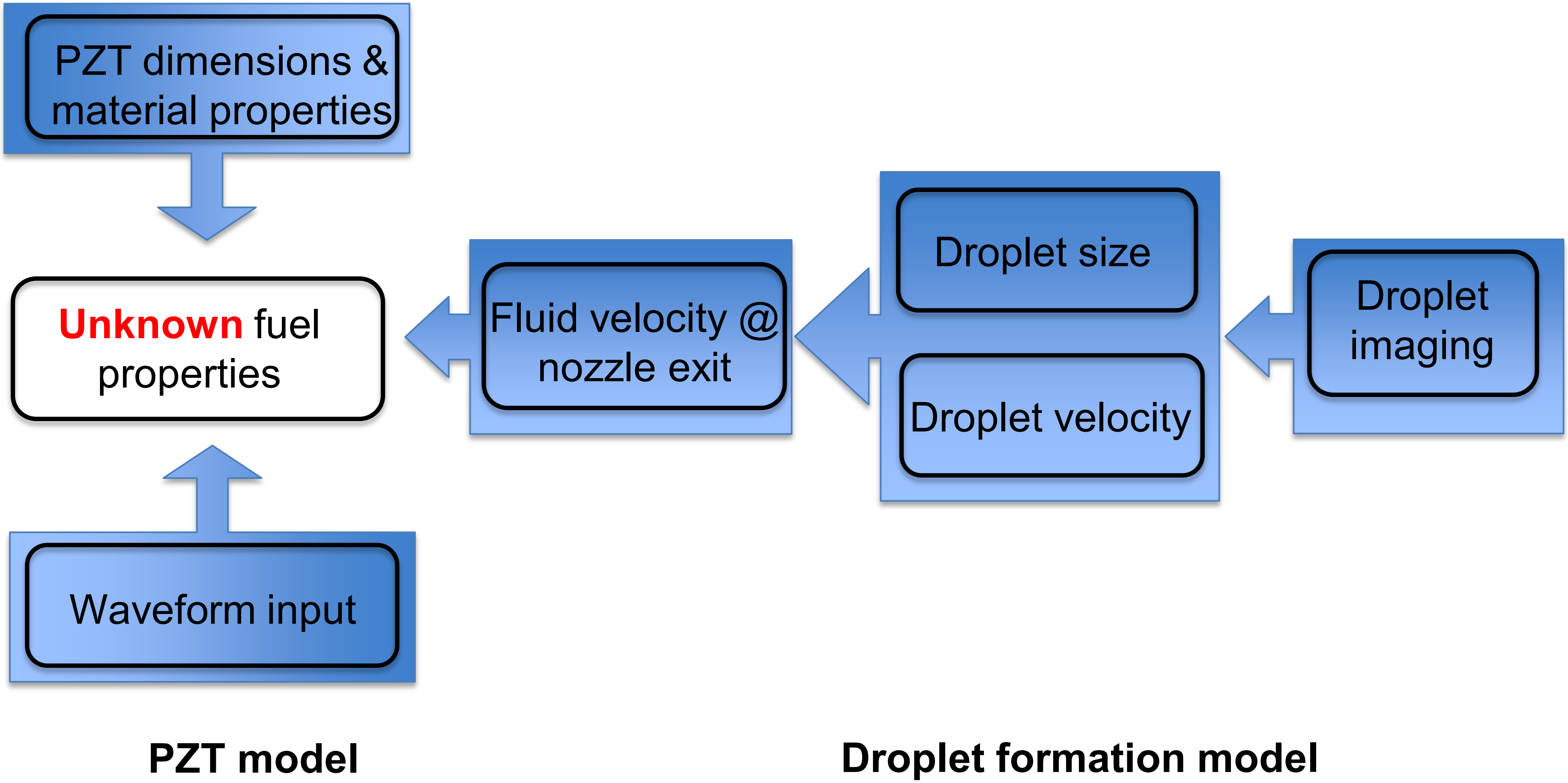




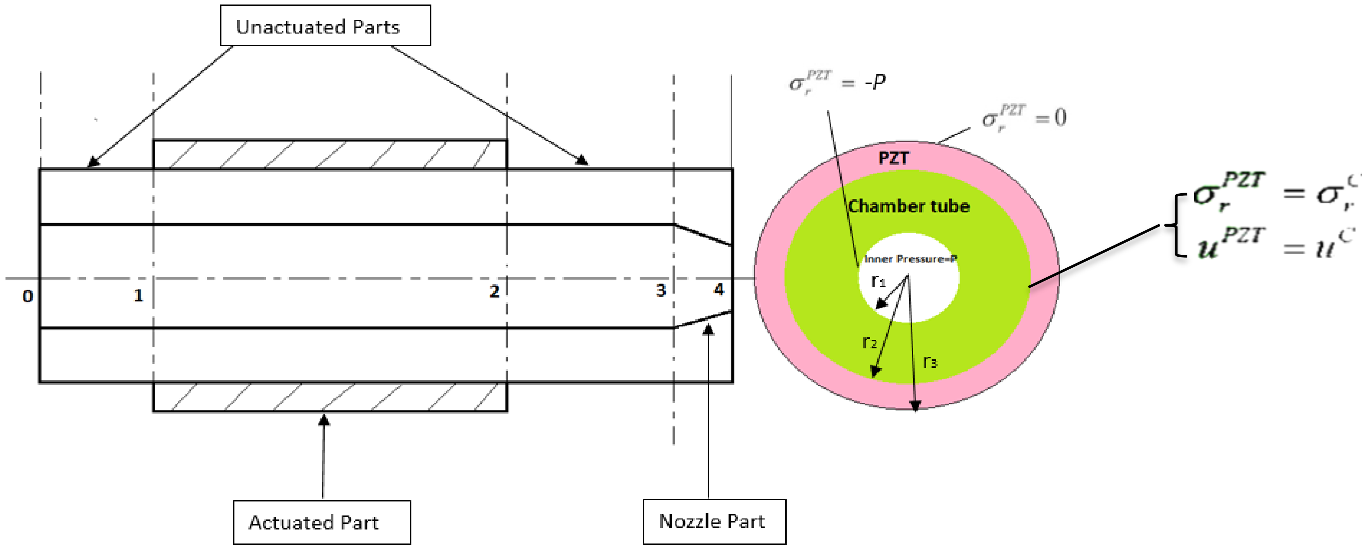
Approach - Property Measurement



Approach - Property Measurement



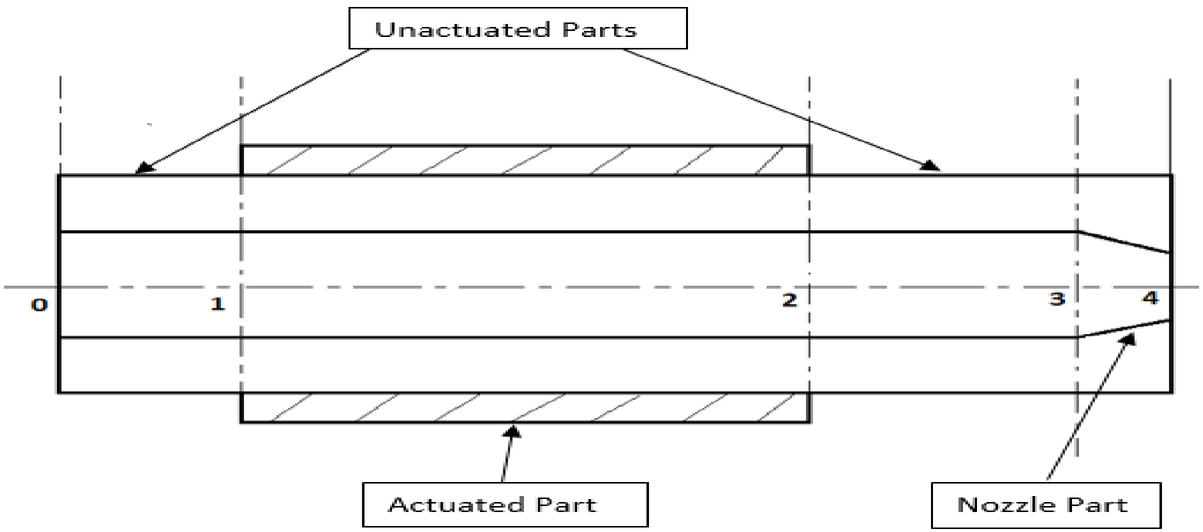
Approach - Property Measurement



- **Analytical modeling of piezo-electric droplet generation**
  - 1-D axisymmetric, Pressure & velocity → $f(r, z)$
  - No outer radial stress of the PZT tube
  - Neglect shear stresses
  - Neglect longitudinal motion of tube
  - Plane strain assumption

*Shin, D. Y., Grassia, P., & Derby, B. (**2004**)*

Approach - Property Measurement



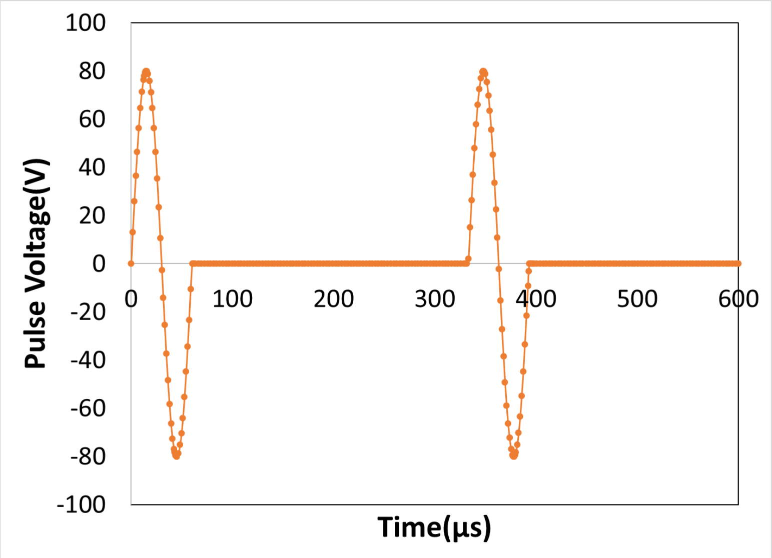
- **Analytical modeling of piezo-electric droplet generation**
  - Continuity and N-S equations evaluated at points 1→ 4
  - Match pressure and velocity at points 1→ 4
  - Apply B.C's & input waveform profile
  - Solve for fluid velocity at nozzle exit using Maple

*Shin, D. Y., Grassia, P., & Derby, B. (**2004**)*

Results – Property Measurement

Co-Optimization of Fuels & Engines

- Fuel – Ethylene glycol
- Nozzle-diameter **60**μm
- Sine wave actuation voltage (Amplitude = 80 V)
- Period = 30 μs
- Bipolar Pulse Waveform
- PZT material properties & dimensions from reference

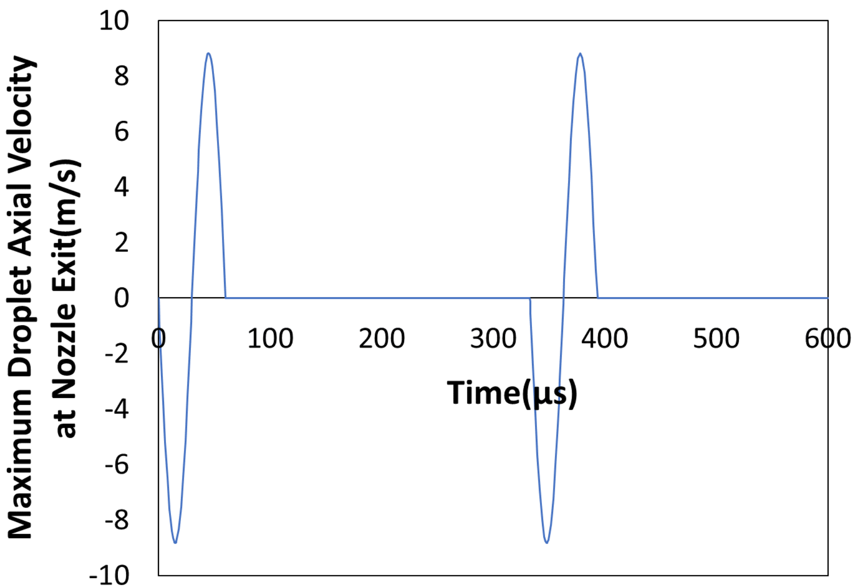


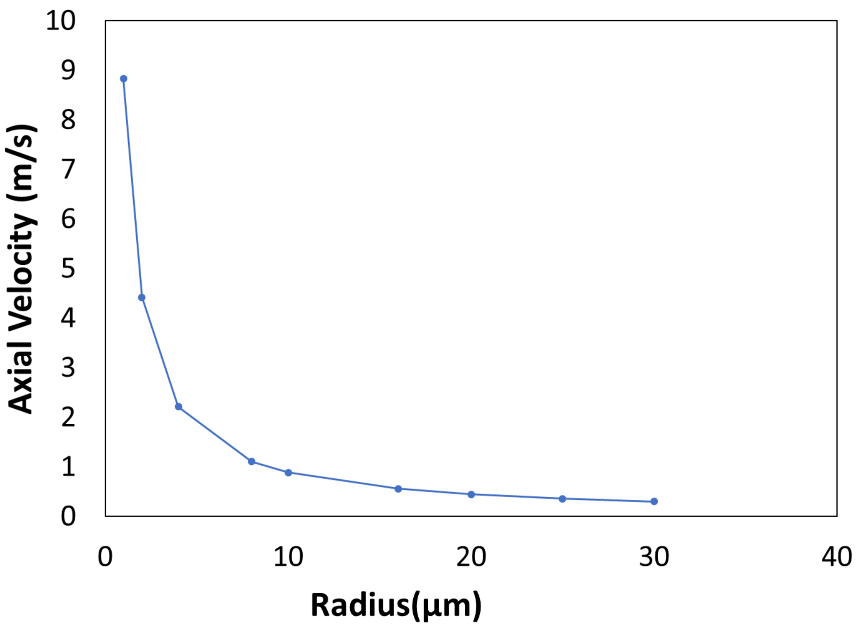
Physical property	Value	Unit
Dynamic viscosity	0.02	Pa.s
Density	1113	kg/m^3
Speed of sound	1680	m/s
Surface tension	0.05	N/m

*Shin, D. Y., Grassia, P., & Derby, B. (**2004**)*

Results – Property Measurement

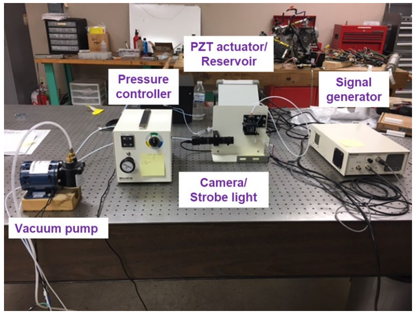
- Maximum velocity at nozzle exit
- Velocity as a function of radius at t=15μs

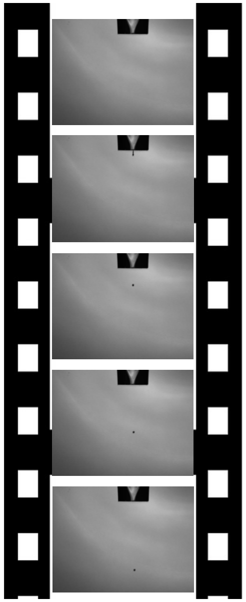


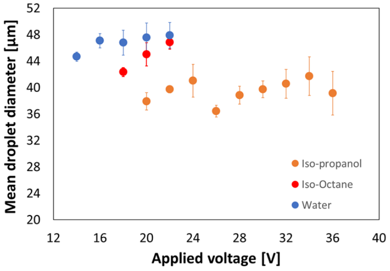


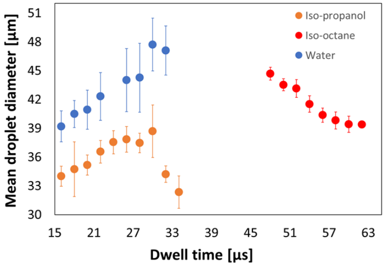
Conclusions

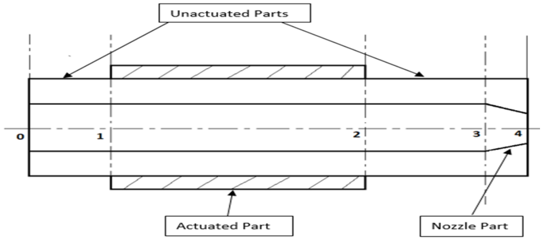
- A piezoelectric droplet generator is being implemented as a high vapor-pressure fuel delivery system to a micro-combustor.
- Droplets generated at 1 atm with water, iso-propanol, & iso-octane.
- Effects of varying voltage & dwell time on droplet size & velocity studied.
- Implementing a model to calculate droplet size & velocity from PZT generator.
- Initial results for fluid velocity at nozzle exit look promising.

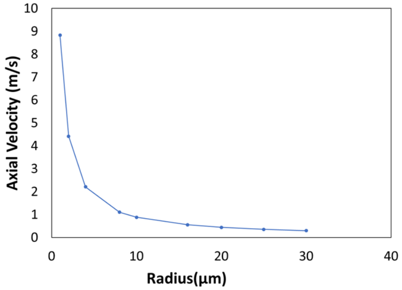












Future Work

- Droplet generation at higher pressures
- Air-fuel mixing manifold with optical access
- Extension of model to calculate droplet size & velocity
- Reverse problem of computing fuel properties

Acknowledgement

This research was conducted as part of the Co-Optimization of Fuels & Engines (Co-Optima) project sponsored by the U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE), Bioenergy Technologies and Vehicle Technologies Offices.