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

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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!
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

Biomass

Oil crops

Algae

Oleaginous yeast

Naphthenics

Carboxylic acids

Cyclic fatty acids

Furanics

Fatty acid methyl esters

Polyketides

Alkanes

Alcohols

Aldehydes

Ketones

Esters

Ethers

Aromatics

Isoprenoids

Terpenes
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
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, ...

\[ D_{\text{drop}}, V_{\text{drop}} = f(V, PZT_{\text{properties}}, Fuel_{\text{properties}}) \]

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

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

\[ D_{\text{drop}} = f(Fuel_{\text{properties}}, Air_{\text{properties}}) \]
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

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

Nozzle diameter = 30 µm

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

Machine vision camera with strobed delay
Results – Fuel Delivery

- Effect of applied voltage
  - $\uparrow$ Voltage $\rightarrow$ $\uparrow$ Droplet velocity
  - $\uparrow$ Voltage $\rightarrow$ $\uparrow$ Droplet diameter

![Graphs showing the effect of applied voltage on droplet velocity and diameter](image-url)
Results – Fuel Delivery

• Effect of dwell time

![Graphs showing the effect of dwell time on initial droplet velocity and mean droplet diameter for different fuels (Iso-propanol, Iso-octane, Water).]
Approach - Property Measurement

PZT dimensions & material properties

Known fuel properties

Waveform input

Fluid velocity @ nozzle exit

Droplet formation model

Droplet size

Droplet velocity

PZT model
Approach - Property Measurement

- PZT dimensions & material properties
- Unknown fuel properties
- Waveform input
- PZT model

Flowchart:
1. PZT dimensions & material properties
2. Unknown fuel properties
3. Waveform input
4. Fluid velocity @ nozzle exit
5. Droplet size
6. Droplet velocity
7. Droplet imaging
8. Droplet formation model
• Analytical modeling of piezo-electric droplet generation
  • 1-D axisymmetric, Pressure & velocity $\rightarrow f(r, z)$
  • No outer radial stress of the PZT tube
  • Neglect shear stresses
  • Neglect longitudinal motion of tube
  • Plane strain assumption

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

Results – Property Measurement

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

<table>
<thead>
<tr>
<th>Physical property</th>
<th>Value</th>
<th>Unit</th>
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<tbody>
<tr>
<td>Dynamic viscosity</td>
<td>0.02</td>
<td>Pa.s</td>
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<tr>
<td>Density</td>
<td>1113</td>
<td>kg/m³</td>
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<tr>
<td>Speed of sound</td>
<td>1680</td>
<td>m/s</td>
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<tr>
<td>Surface tension</td>
<td>0.05</td>
<td>N/m</td>
</tr>
</tbody>
</table>

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

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