ATOMIZATION AND COMBUSTION OF VISCOUS (BIO)FUELS

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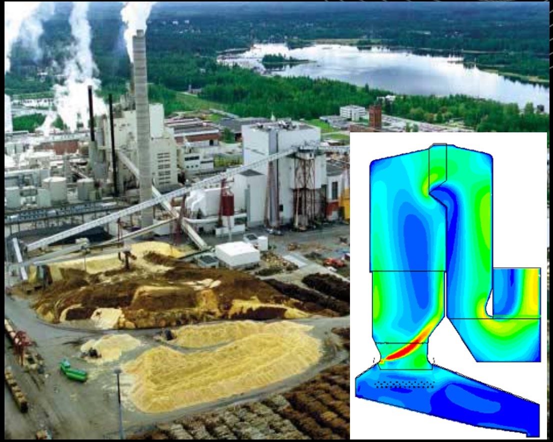
THERMAL ENGINEERING



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RESEARCH AREAS – THERMAL ENGINEERING

- ❑ Combustion dynamics
- ❑ Heat conversion and storage
- ❑ Solar energy
- ❑ Recycling of energy and materials from biomass
- ❑ Energy efficient processes in industry
- ❑ New materials for energy application

CONTENTS

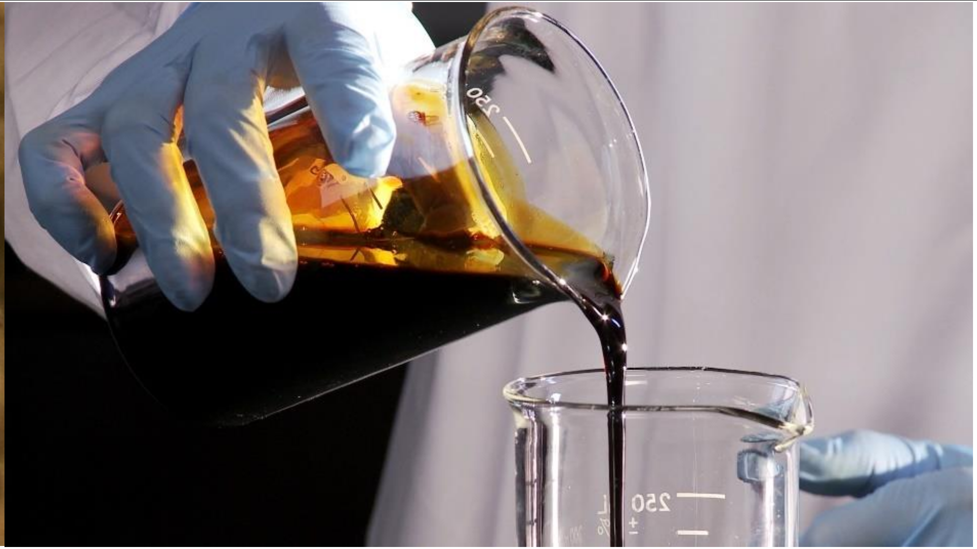
RESEARCH MOTIVATION

RESEARCH MOTIVATION

- **Transition from fossil fuels to renewable fuels**
  - Fuel and power shortage
  - Environmental issues

- **Requirements**
  - Burn anything what is available
  - Low emissions and high efficiency
  - Similar costs of manufacturing, operating and maintenance as in conventional devices

RESEARCH MOTIVATION



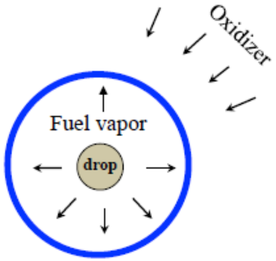
Pyrolysis: cracking of biomass at 450-550 °C in inert environment.

Pyrolysis oil: low heating value, high viscosity and low pH.

PROBLEM DEFINITION

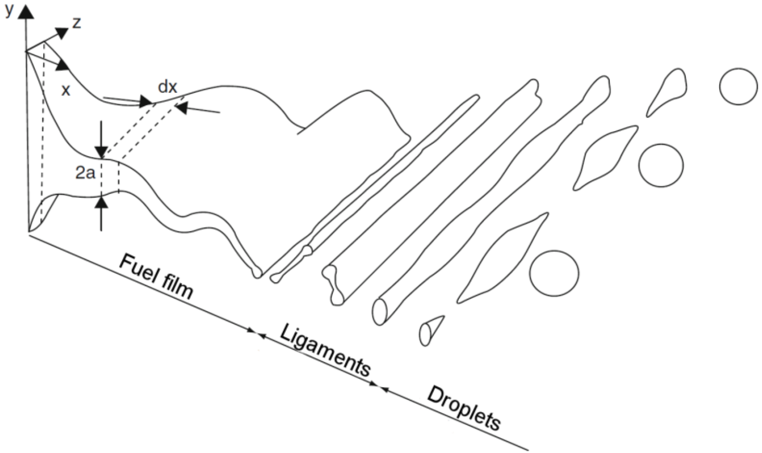
- ***Atomization*** → breaking liquid fuel into mist of small droplets to <u>maximize the surface area-to-volume ratio</u>

- ***Good atomization***
  - Small droplets with narrow size distribution
  - High rate of <u>gas/liquid mixing</u>
  - Enhanced evaporation
  - Reduced emissions



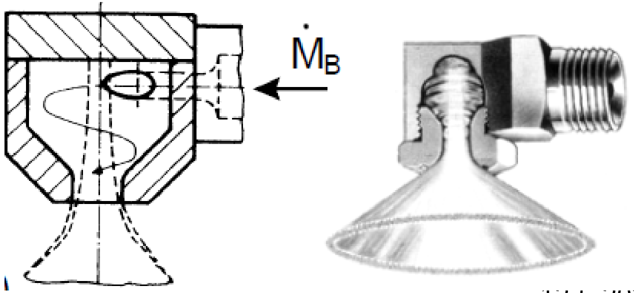
PROBLEM DEFINITION

- ***Classical break-up mechanism*** – wavy-sheet disintegration
- In turbulent flow, the effect of the radial components of velocity (instabilities) is bigger than ***surface tension*** forces → break up
- ***Viscosity*** reduces the instabilities, delaying the break-up process



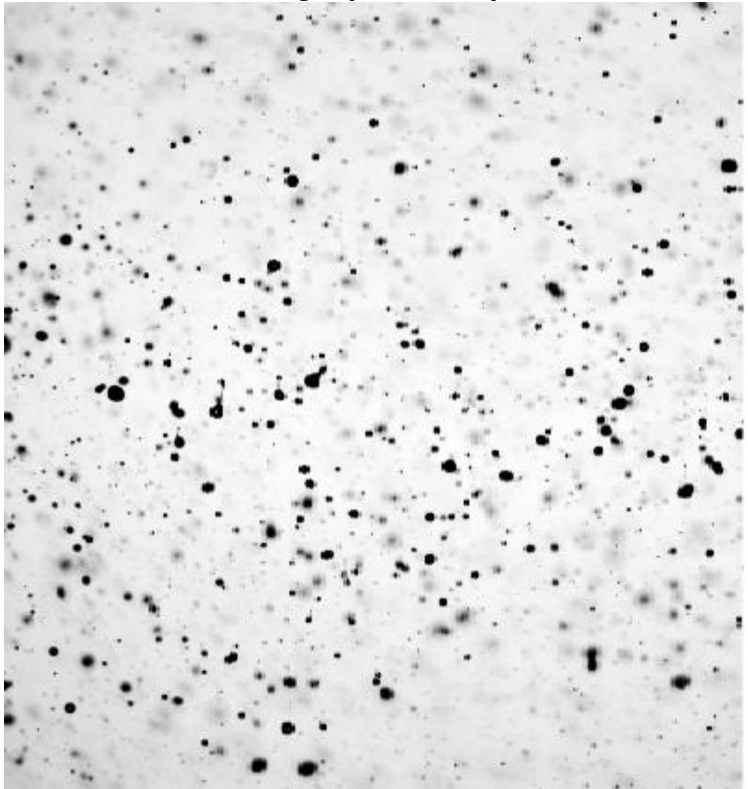
PROBLEM DEFINITION

- ***Pressure (swirl) atomizers*** – atomization due to change of pressure difference into kinetic energy (high velocity). Sensitive to fuel viscosity
- For viscous fuels high ***pressure difference*** is needed to have the same droplet size as in case of low viscosity fuels (more energy for atomization is needed)
- Turndown ratio (max. firing rate to min. firing rate) of 1.5:1



RESEARCH MOTIVATION

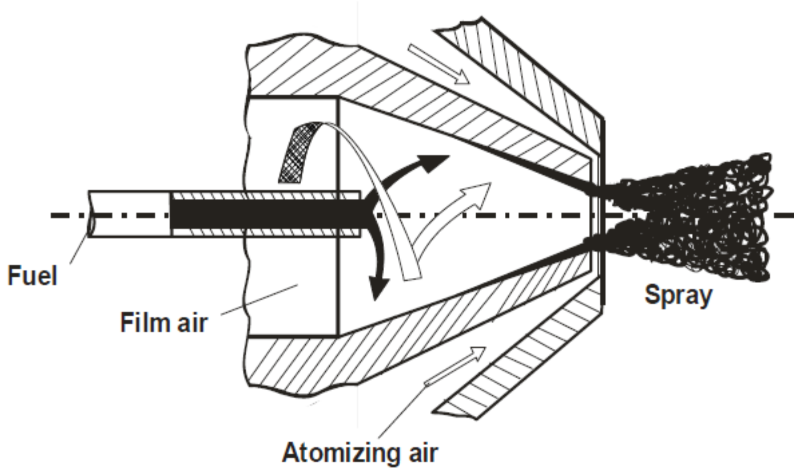
Low viscosity (2.84 cP)



High viscosity (e.g. 200 cP)

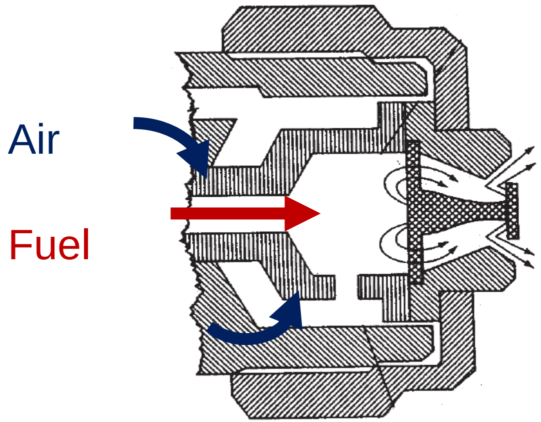
PROBLEM DEFINITION

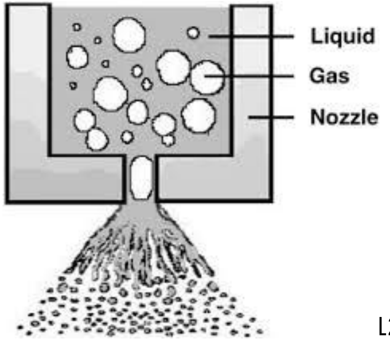
- ***Prompt break-up mechanism*** - very rapid break up of the liquid jet at the nozzle exit as effect of e.g. extremely high fuel velocity or high velocity air jet impinging at the fuel (twin liquid atomizers)



PROBLEM DEFINITION

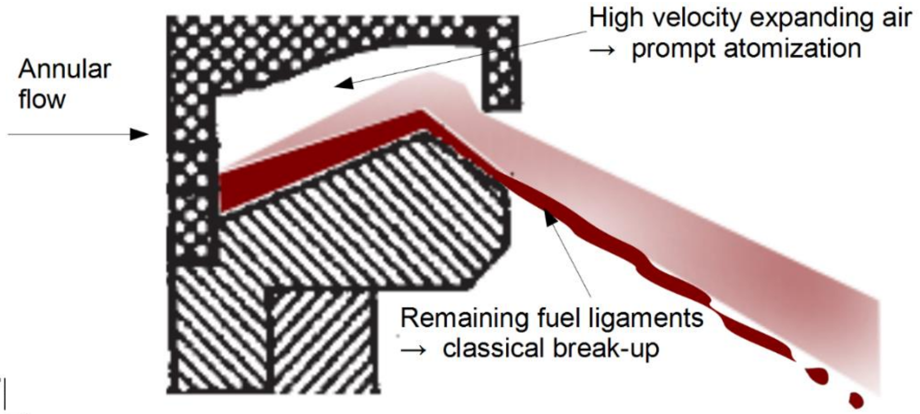
- A ***second fluid*** (air or steam) is used to produce the shear necessary to break up the oil into droplets.
- Family of ***twin-fluid atomizers***: air-blast (high volume flow of air at low pressure), air-assisted (small amount of air at very high pressure), effervescent (bubbling flow – high pressure air in the fuel line), flow blurring (mixing at nozzle exit), etc.



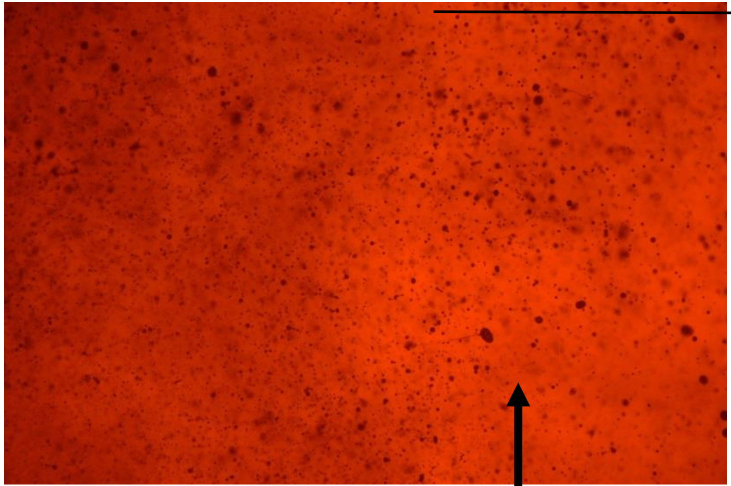


PROBLEM DEFINITION

- Air assisted atomizer can effectively atomize high viscosity liquids
- Expensive to operate (air compression needed), but it can deliver higher turndown ratio, approx. 5:1.
- In most of twin fluid atomizers both break-up mechanisms are present

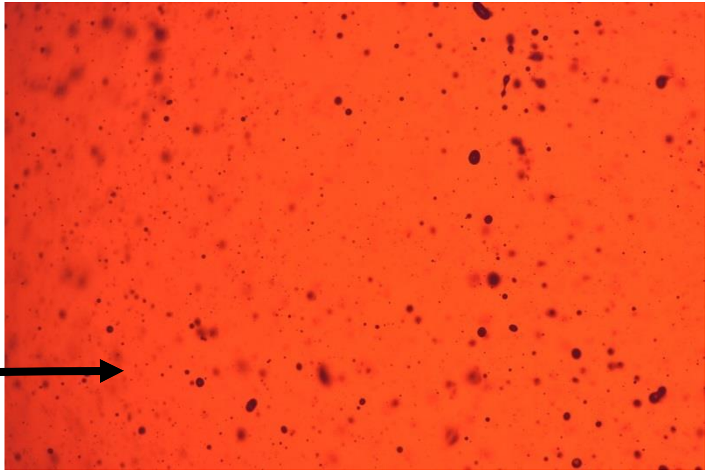


PROBLEM DEFINITION



- Air assisted vs pressure atomizer:
  - More dense
  - Smaller droplets
  - Bigger droplet span size

Air assisted



Pressure swirl

PROBLEM DEFINITION

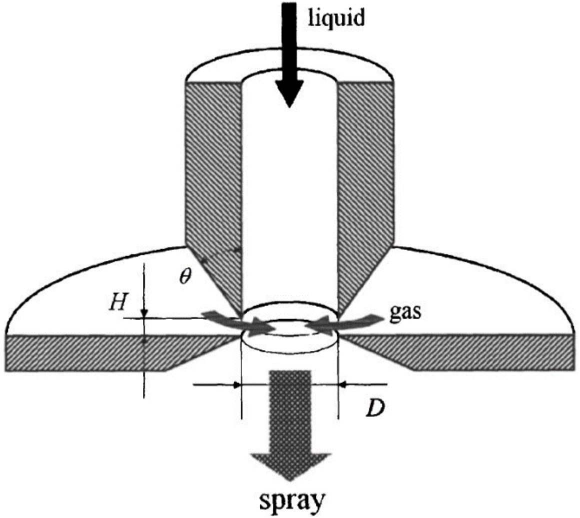
- Conventional atomizers unable to achieve fine, high quality sprays with high viscosity fuels like pyrolysis oil.

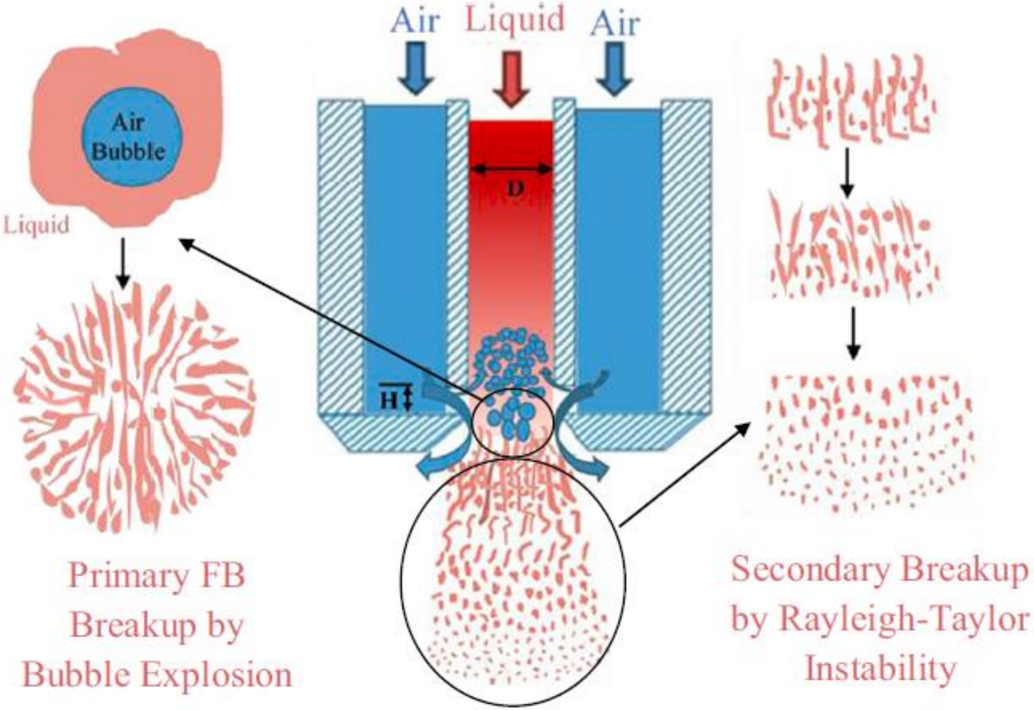
- Alternative atomization mechanisms are sought.

→ Flow blurring atomization

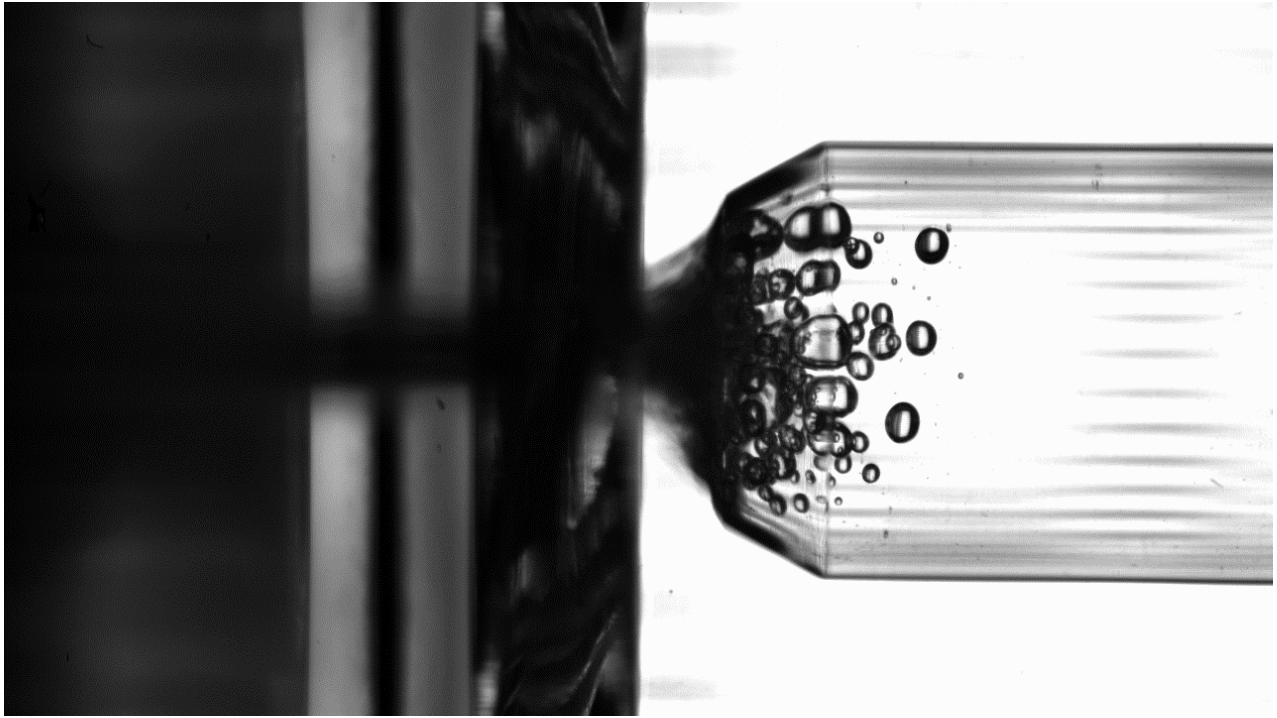
FLOW BLURRING ATOMIZATION

Ganan-Calvo (2005)



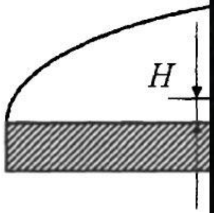


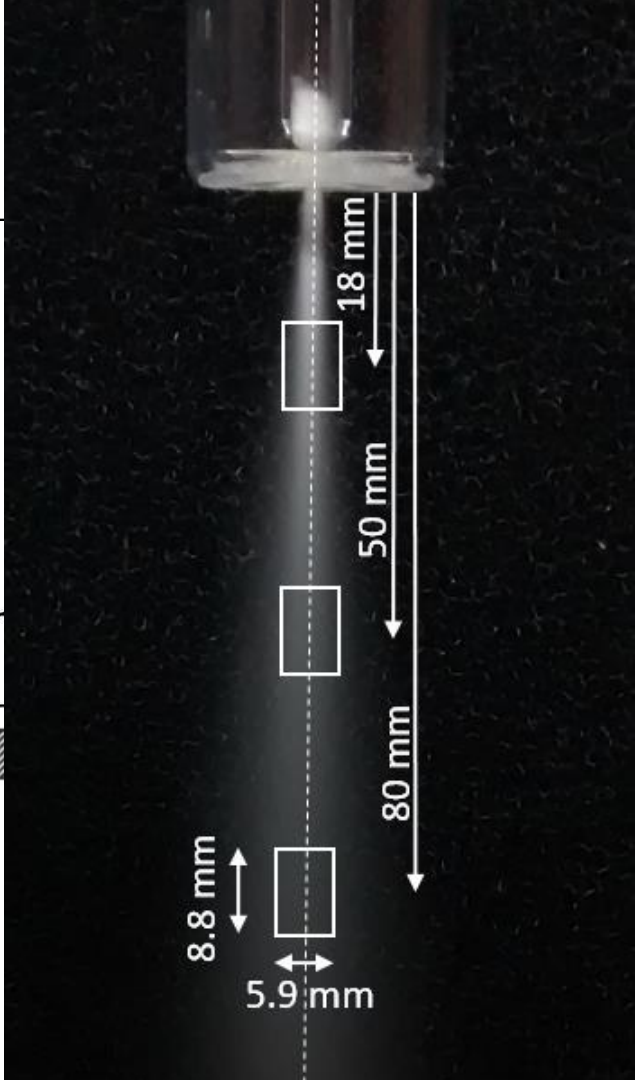
FLOW BLURRING ATOMIZATION



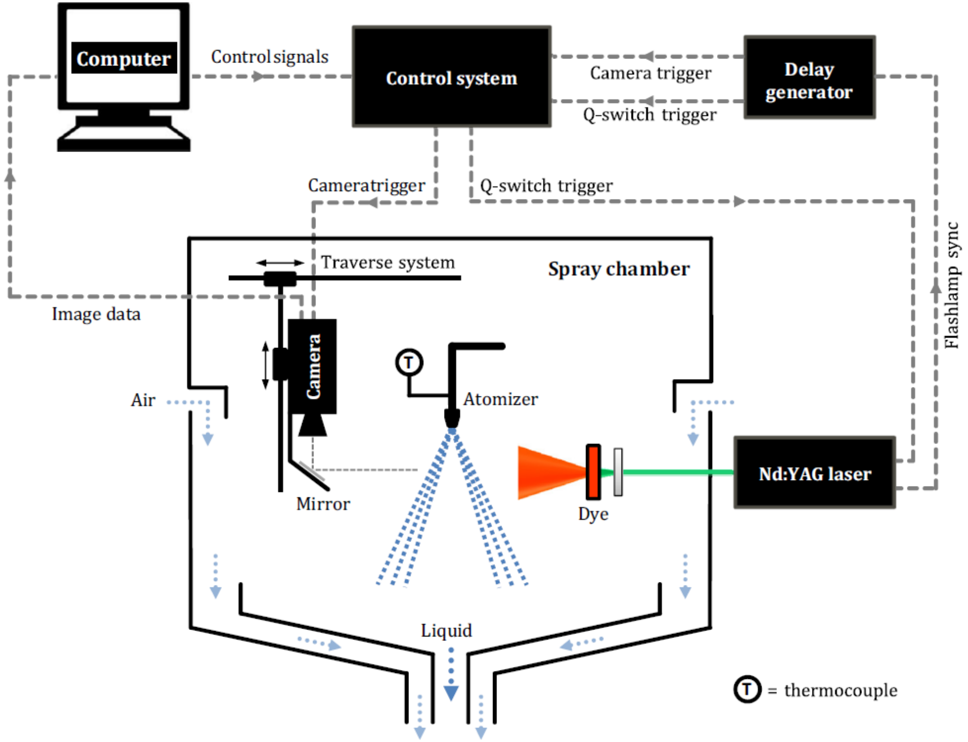
TEST CONDITIONS

- Atomizer configuration:
  - Diameter: 4 and 7 mm.
  - Ψ = H/D = 0.15 and 0.25.
- Measurement location: 18, 50 and 80 mm.
- Test fluids: 1 – 60 cP





SPRAY IMAGING SETUP

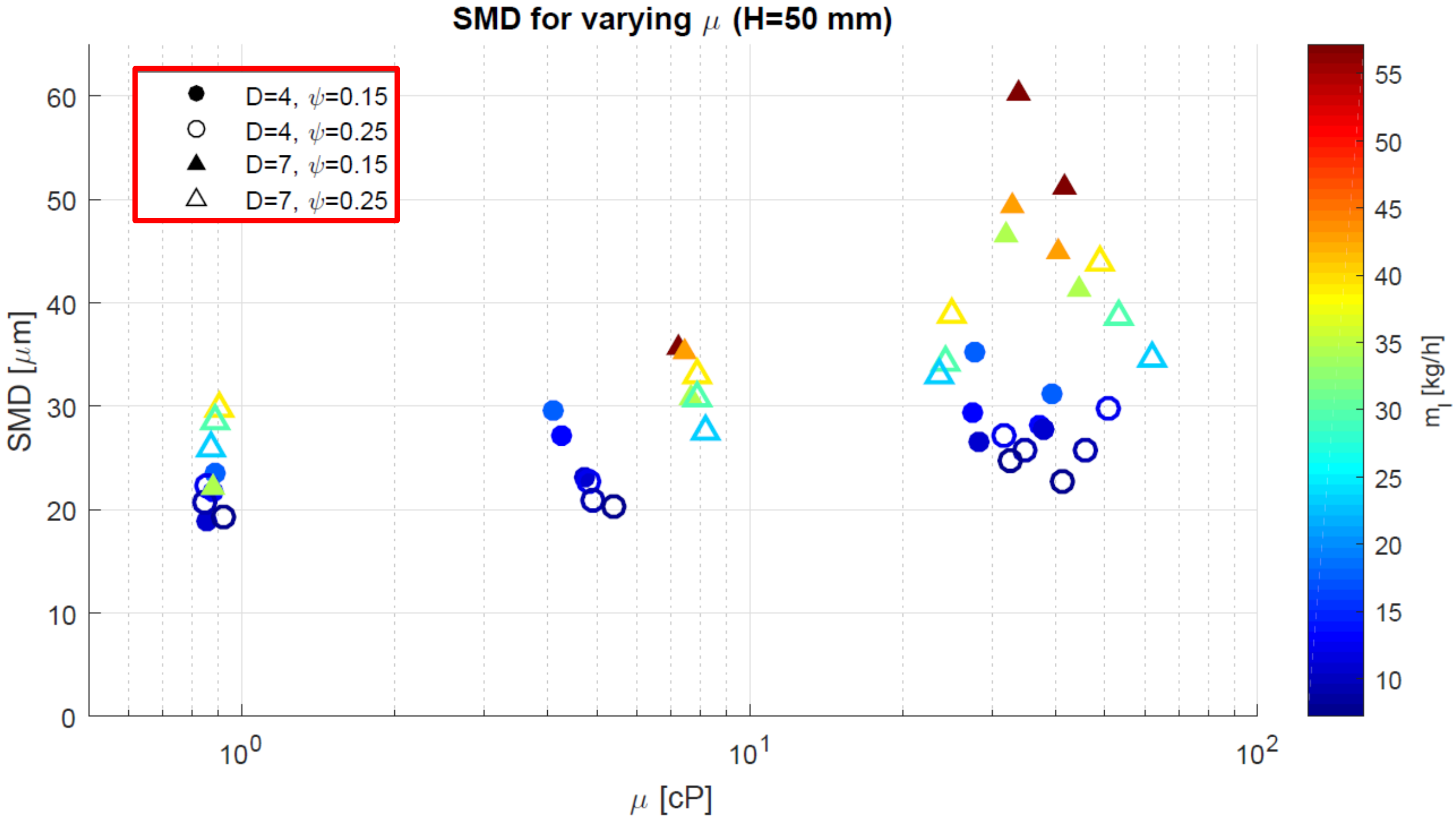


SPRAY QUALITY

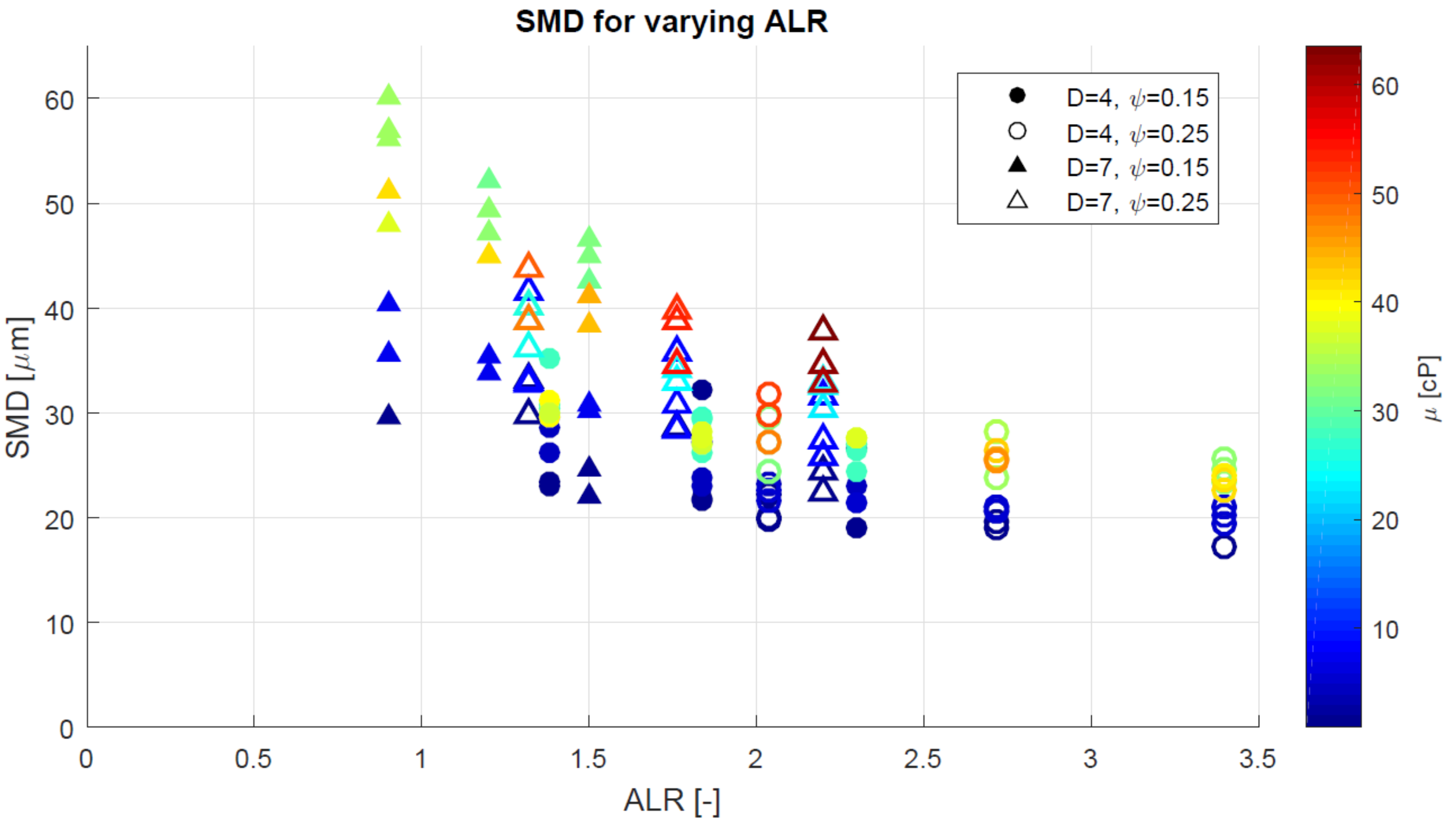
Spray quality indicators:

- Sauter Mean Diameter: $$SMD = \frac{\sum D_{drop}^3}{\sum D_{drop}^2} \quad [\mu m]$$
- Normalized Ligament Area: $$NLA = \frac{\sum A_{c,lig}}{\sum A_{c,lig} + \sum A_{c,drop}} \quad [-]$$
- Mean Ligament Size: $$MLS = \frac{\sum A_{c,lig}}{N_{lig}} \quad [\mu m^2]$$

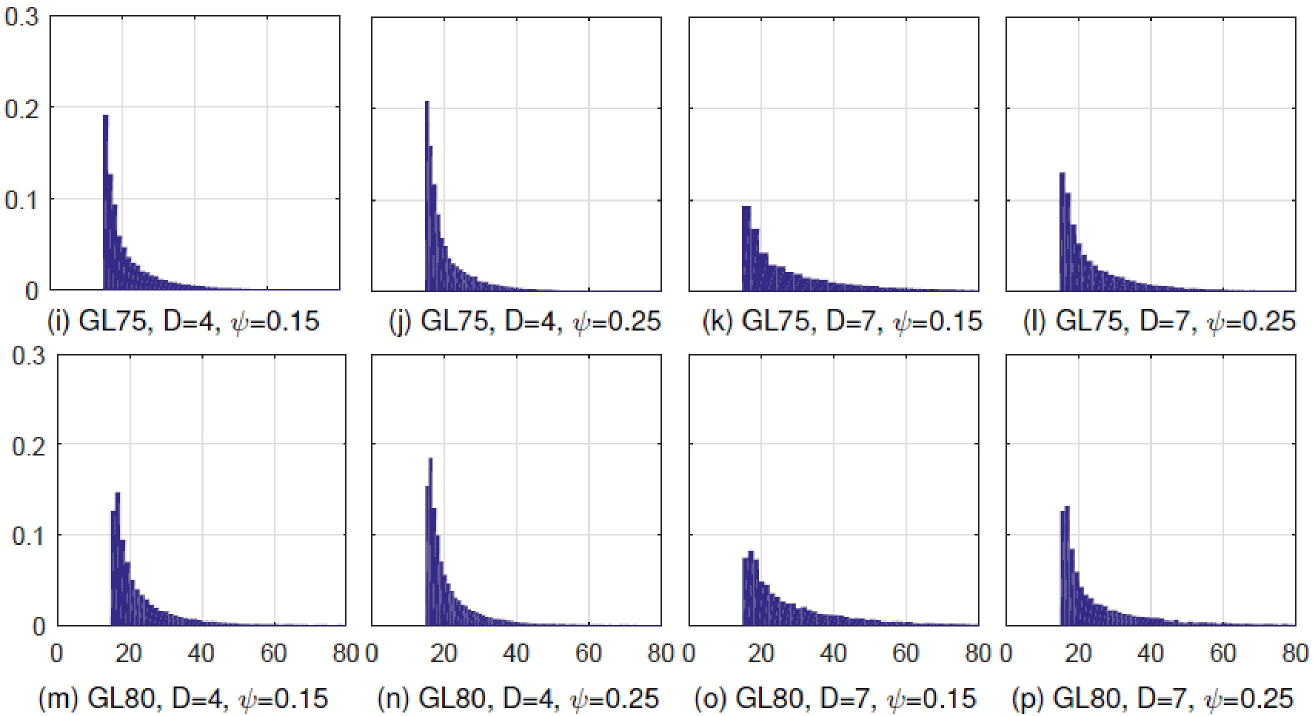
PARAMETRIC ANALYSIS - VISCOSITY



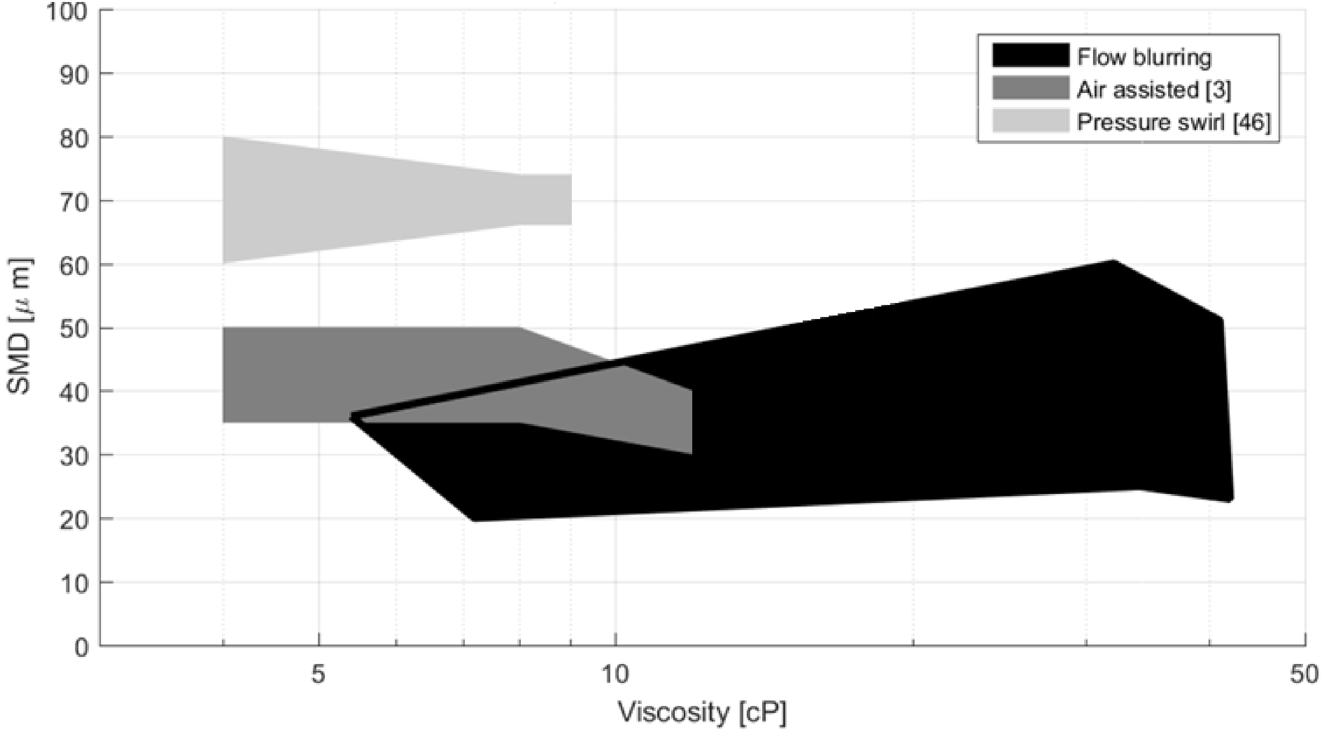
PARAMETRIC ANALYSIS - ATOMIZATION ENERGY



DROPLET SIZE DISTRIBUTIONS

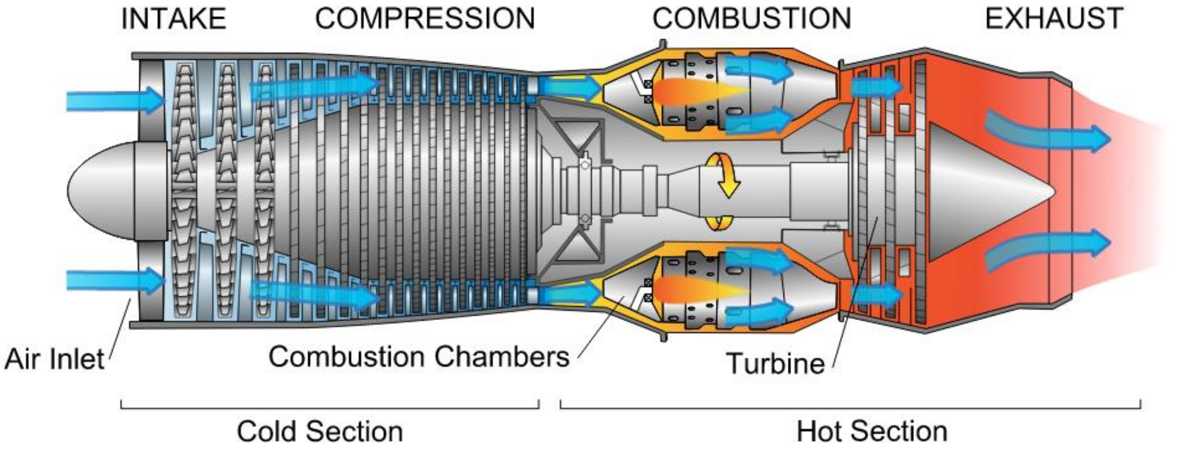


COMPARISON TO CONVENTIONAL ATOMIZERS - SMD



RESEARCH METHOD

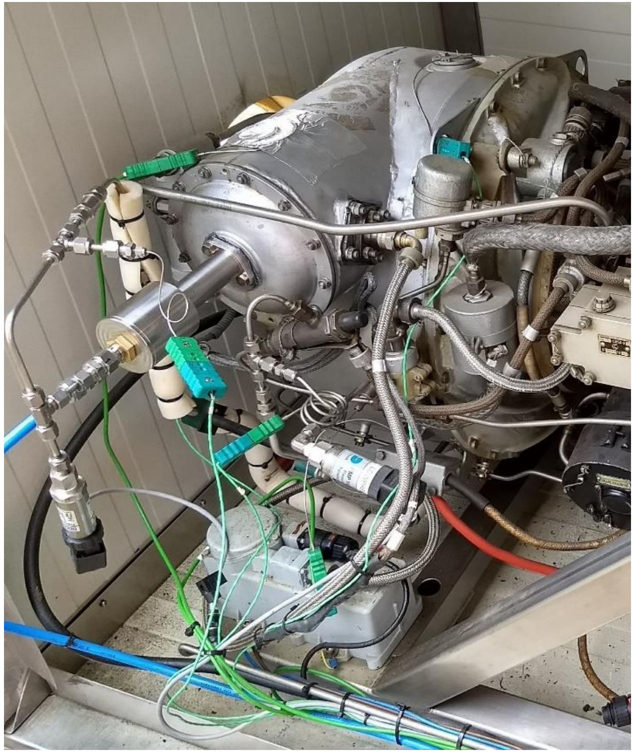
- Gas turbines
  - **Continuous combustion process**
  - High energy density
  - Robustness



RESEARCH METHOD

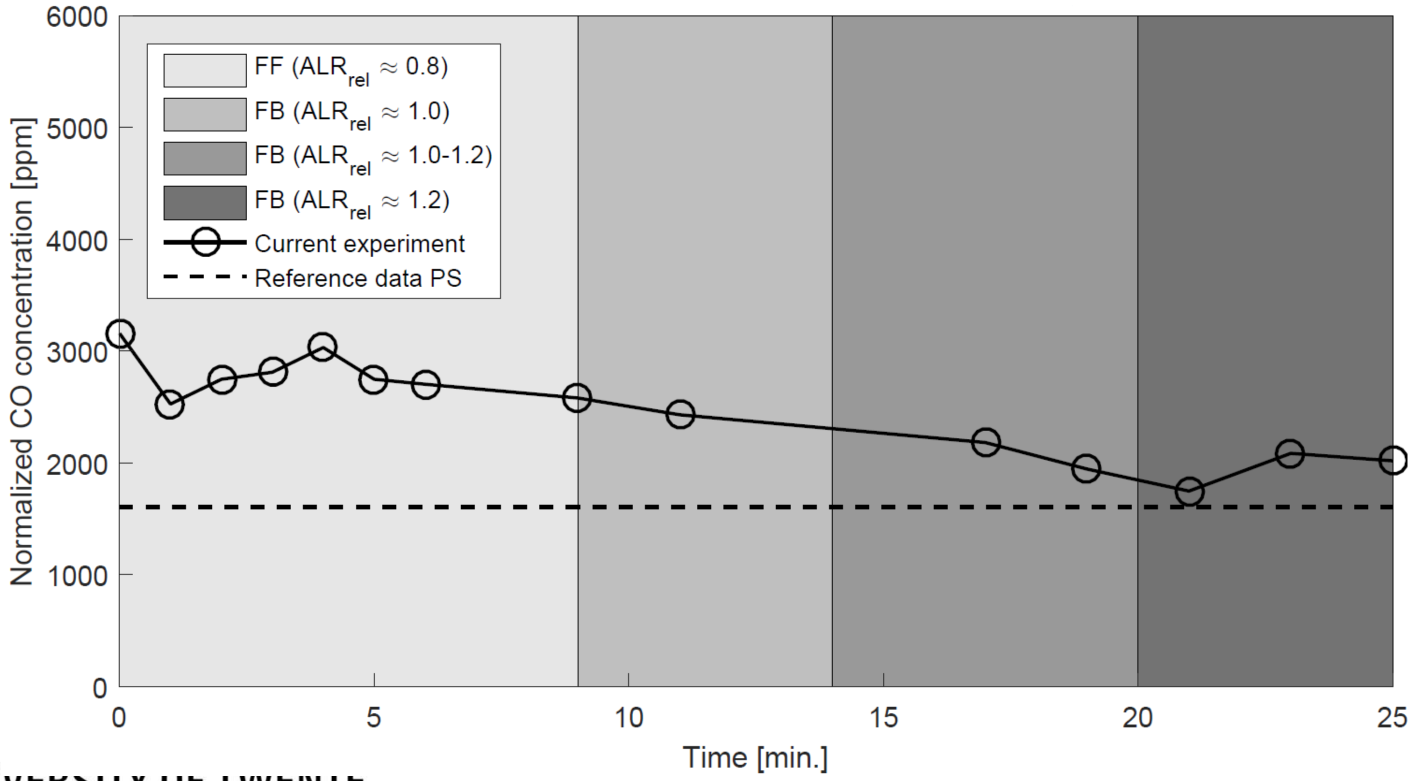
RESEARCH METHOD

- Stainless steel atomizers.
- GT: no load
  48 L/h diesel.
- CO emissions → combustion performance.
- Diesel #2



OPERATIONAL INSTABILITIES

NORMALIZED CO EMISSIONS FOR DIFFERENT ALR



CO EMISSIONS RELATED TO SPRAY QUALITY

$\mu\ [cP]$ $m_l\ [kg/h]$ $SMD\ [\mu m]$ $NLA\ [\%]$ $MLS^{0.5}\ [\mu m]$ $CO_{norm}\ [ppm]$

FB (D = 7, ψ = 0.15)				PS (RXT-0380)			
SMD $[\mu m]$	NLA $[\%]$	$MLS^{0.5}$ $[\mu m]$	CO_{norm} $[ppm]$	SMD $[\mu m]$	NLA $[\%]$	$MLS^{0.5}$ $[\mu m]$	CO_{norm} $[ppm]$
35.32	13.6	83	1950	77.08	0.6	128	1600

Combustion beyond viscosity limit of PS/AA (9/12 cP) should be possible

CONCLUSIONS

1. **Atomization of high viscous fluids with flow blurring atomizer is possible.**

2. **FB atomizer outperforms PS/AA for high viscosity fluids**

3. **Viscosity, fluid mass flow, atomization energy (ALR) and atomizer geometry** influence atomization performance. SMD's of (25-30 μm)/(30-60 μm)

4. **Decreasing of CO emissions** with increasing ALR troughout FF and FB regimes