1. Prologue

UNIVERSITY OF CAMBRIDGE

CAMBRIDGE COMBUSTION RESEARCH CENTRE

Combustion Properties of Alternative Liquid Fuels

21 JULY 2011

Cheng Tung Chong, Simone Hochgreb

Content

2. Biodiesel

Transesterification process - Vegetable oil+methanol → Methyl esters+glycerol

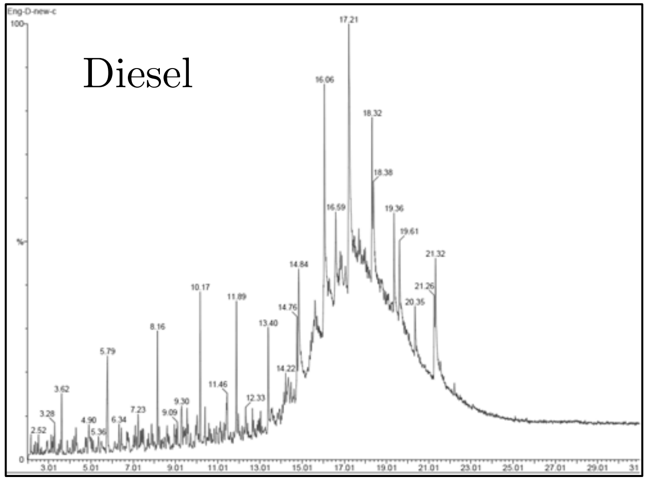
Biodiesels are mixtures of methyl esters (ME). ME are long-chain esters.

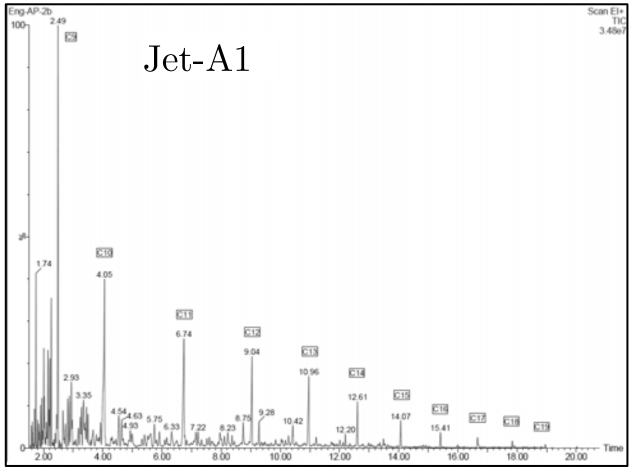
Example :

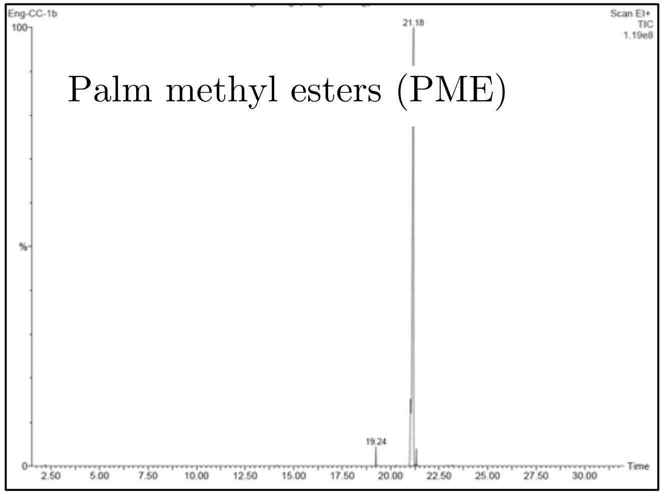
Methyl palmitate ($C_{17}H_{34}O_2$)

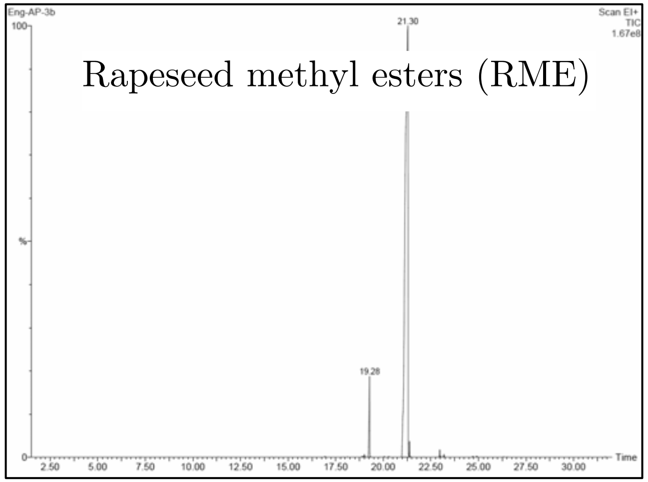
Fatty acids	(carbon: bond)	Composition (%)			
		Rapeseed	Soybean	Jatropha	Palm
Lauric	(C12:0)	-	0.1	-	0.2
Myristic	(C14:0)	1.0	0.1	0.1	0.8
Palmitic	(C16:0)	3.5	10.2	15.6	**39.5**
Stearic	(C18:0)	0.9	3.7	10.5	5.1
Oleic	(C18:1)	**64.1**	22.8	42.1	**43.1**
Linoleic	(C18:2)	22.5	**53.7**	30.9	10.4
Linolenic	(C18:3)	8.0	8.6	0.2	0.1
Others		-	0.8	0.6	0.8

- Difference between biodiesels and conventional fuels









Gas chromatography

Fuel properties

Properties	Jet-A1	Diesel	PME	RME
Approx. formula	$C_{11}H_{21}$	$C_{16}H_{34}$	$C_{19}H_{36}O_2$	$C_{19}H_{36}O_2$
H/C ratio*	1.98	1.9	1.89	1.89
C/O ratio*	-	-	9.83	10.06
Boiling range (°C)	166-266	190-360	>215	>200
Spec. grav. 15°C	0.81	0.85	0.88	0.88
Pour point (°C)	-	-20	-18	-10
Flash point (°C)	38	60-72	174	170
Viscosity (cSt) 40°C	-	2.6	4.5	4.83
LHV (kJ/kg)	43150	43090	36770	36800
Cetane number	-	52	62.6	51

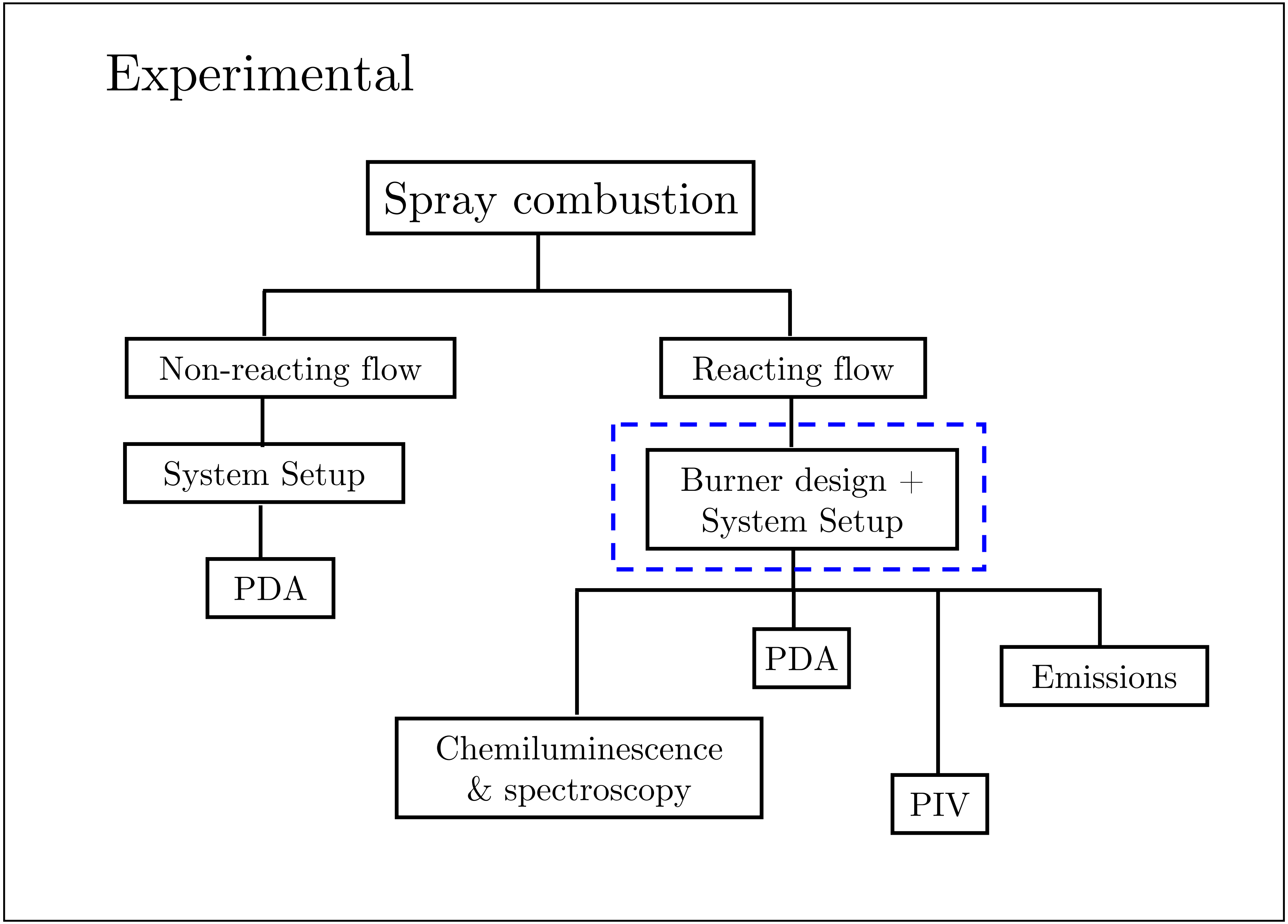
- Yes, the FUEL properties are different, so HOW do we test the fundamental combustion properties?
- What kind of experiment and under what conditions?

Objectives - Investigation of the combustion properties of biodiesels under a gas turbine type combustor
- Develop a methodology to test alternative fuels

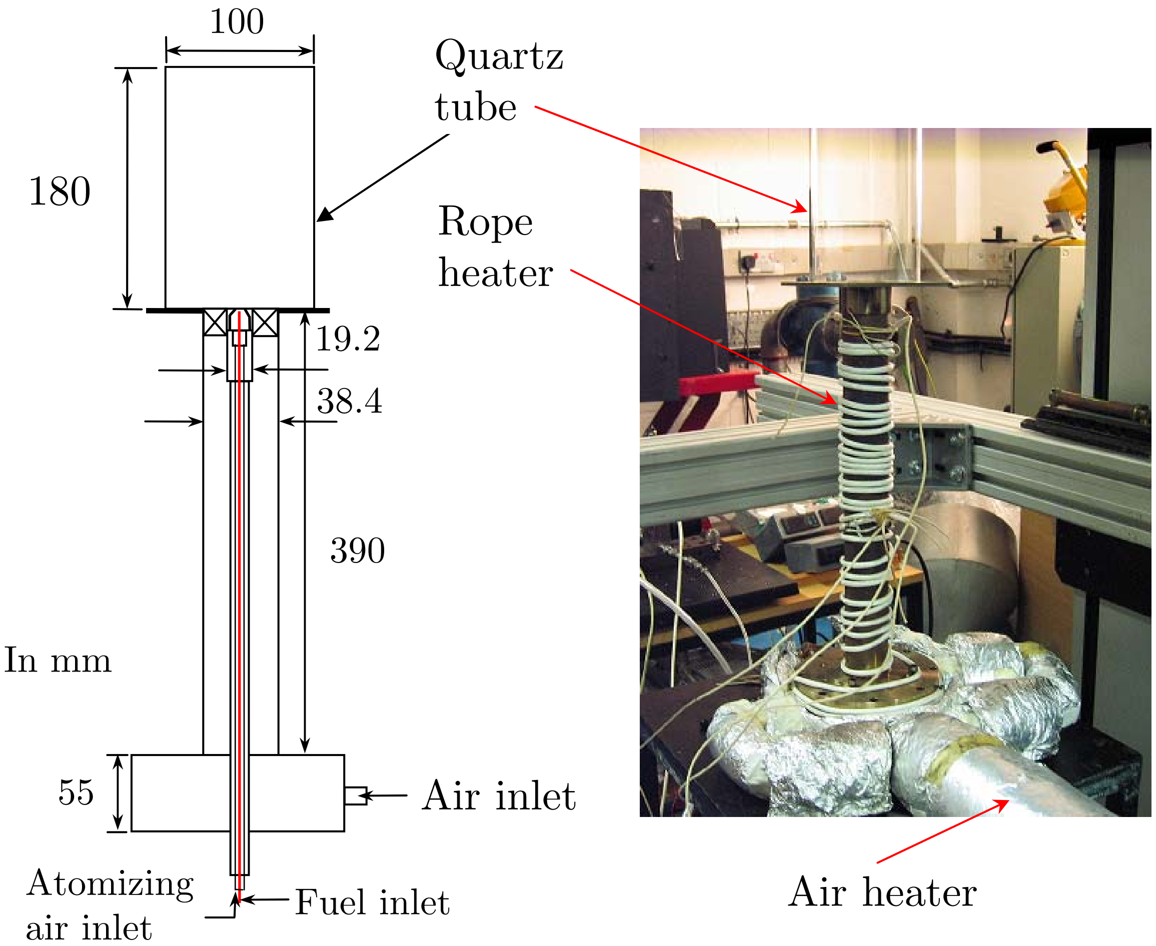
WHY gas turbine-type combustor??

Swirling spray flame

- Potential to be used in Gas turbines
- Spray flame present in many applications
- Obtain an experimental database for modelling

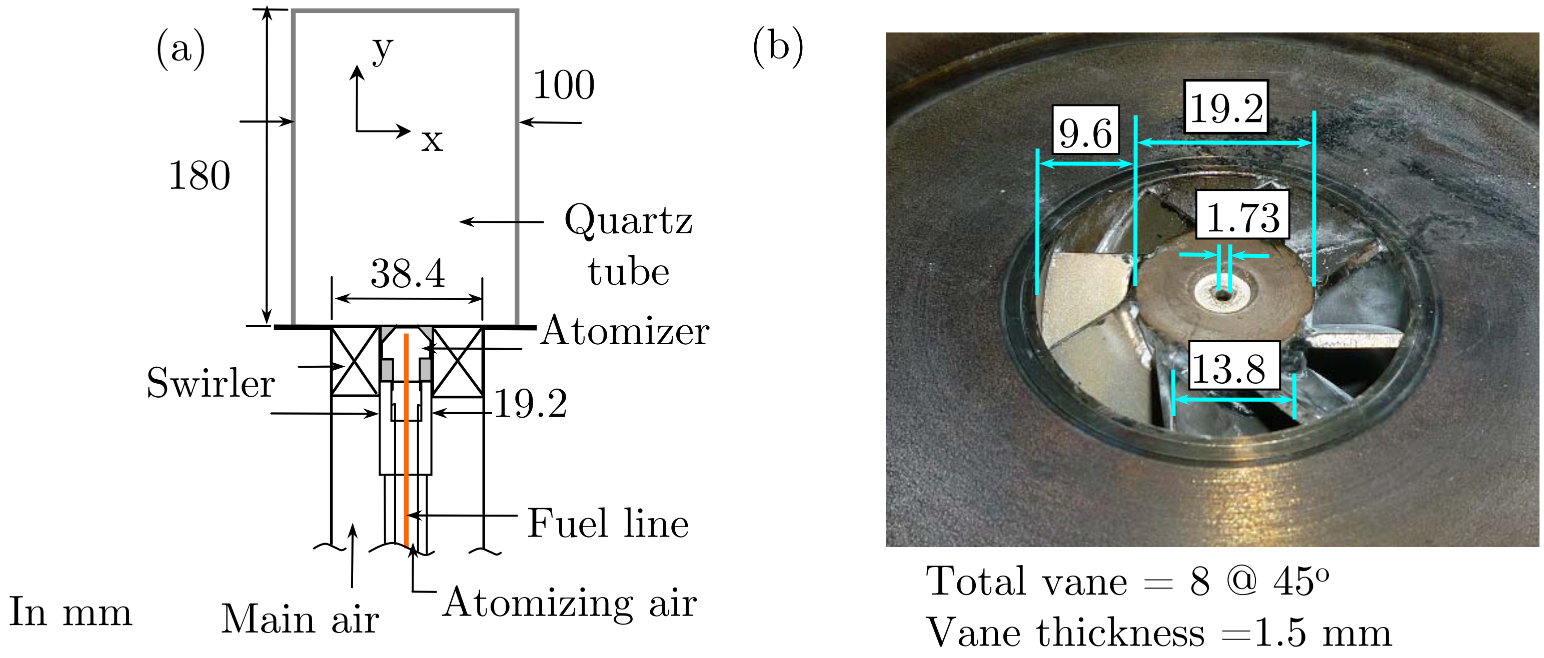

Experimental
Spray combustion
Non-reacting flow
Reacting flow
System Setup
Burner design +
System Setup
PDA
PDA
Emissions
Chemiluminescence
& spectroscopy
PIV

3. Swirl burner configurations



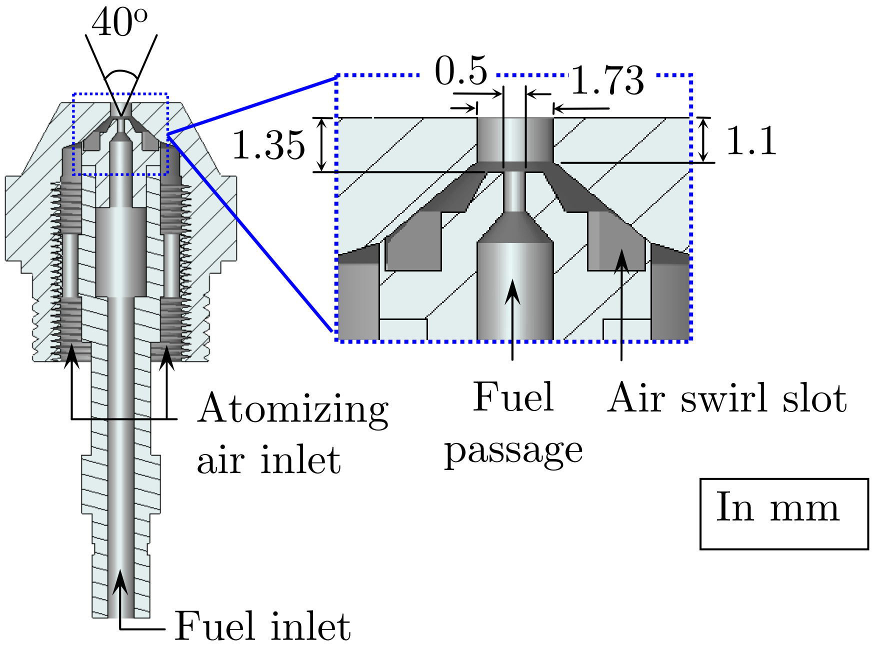
Schematic of the (a) swirl burner and (b) Setup for liquid spray flame measurement

Burner geometry and flow delivery



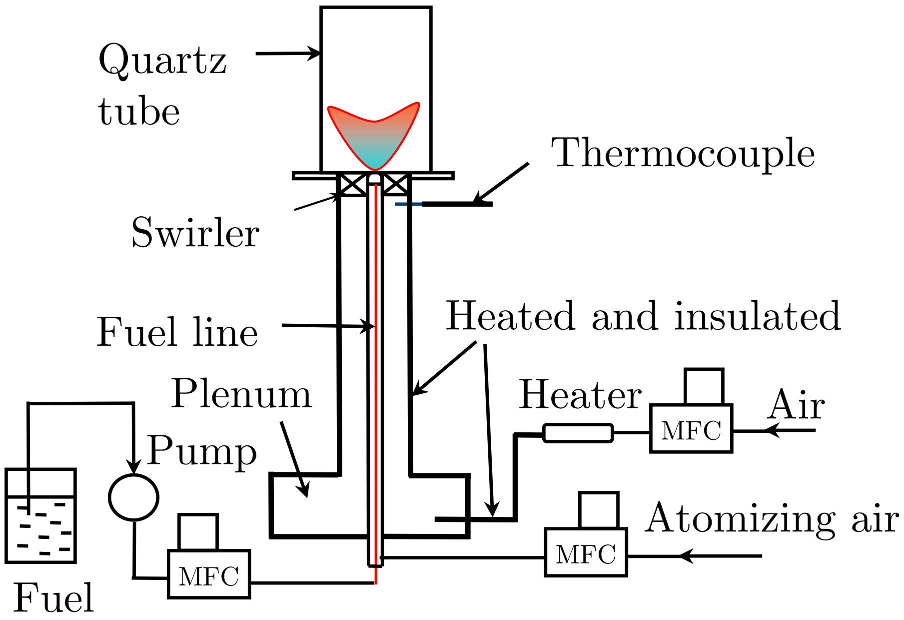
Geometry description of the swirl (a) burner and the (b) swirler

Injector – Plain-jet airblast type

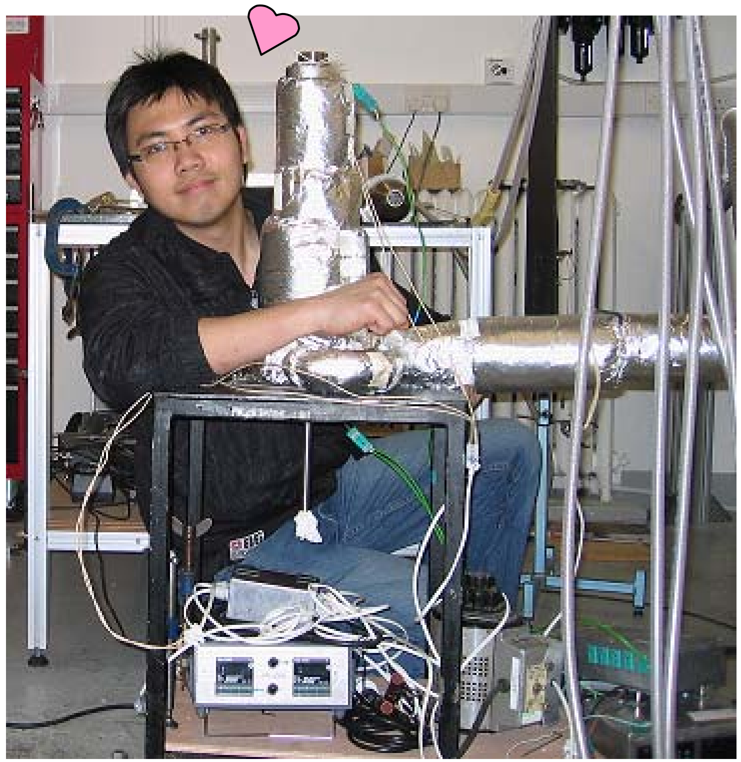


Schematic of the internal geometry of plain-jet airblast atomizer

Burner and flow delivery



Schematic of the single swirl flame burner

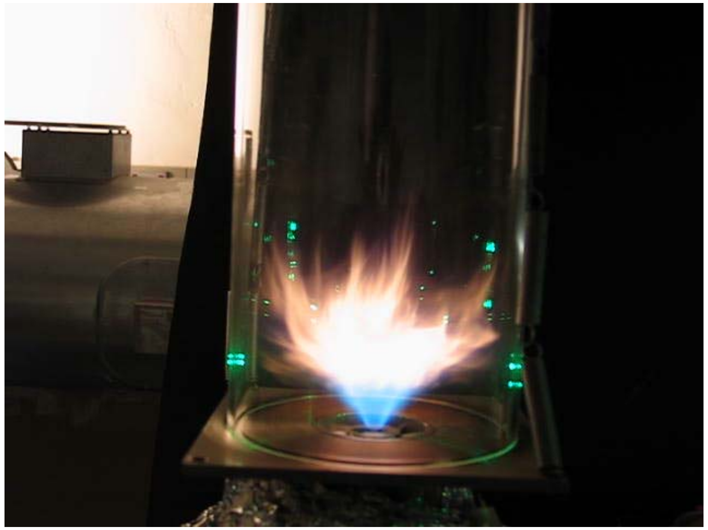


Man in love with his burner

Swirling spray flame

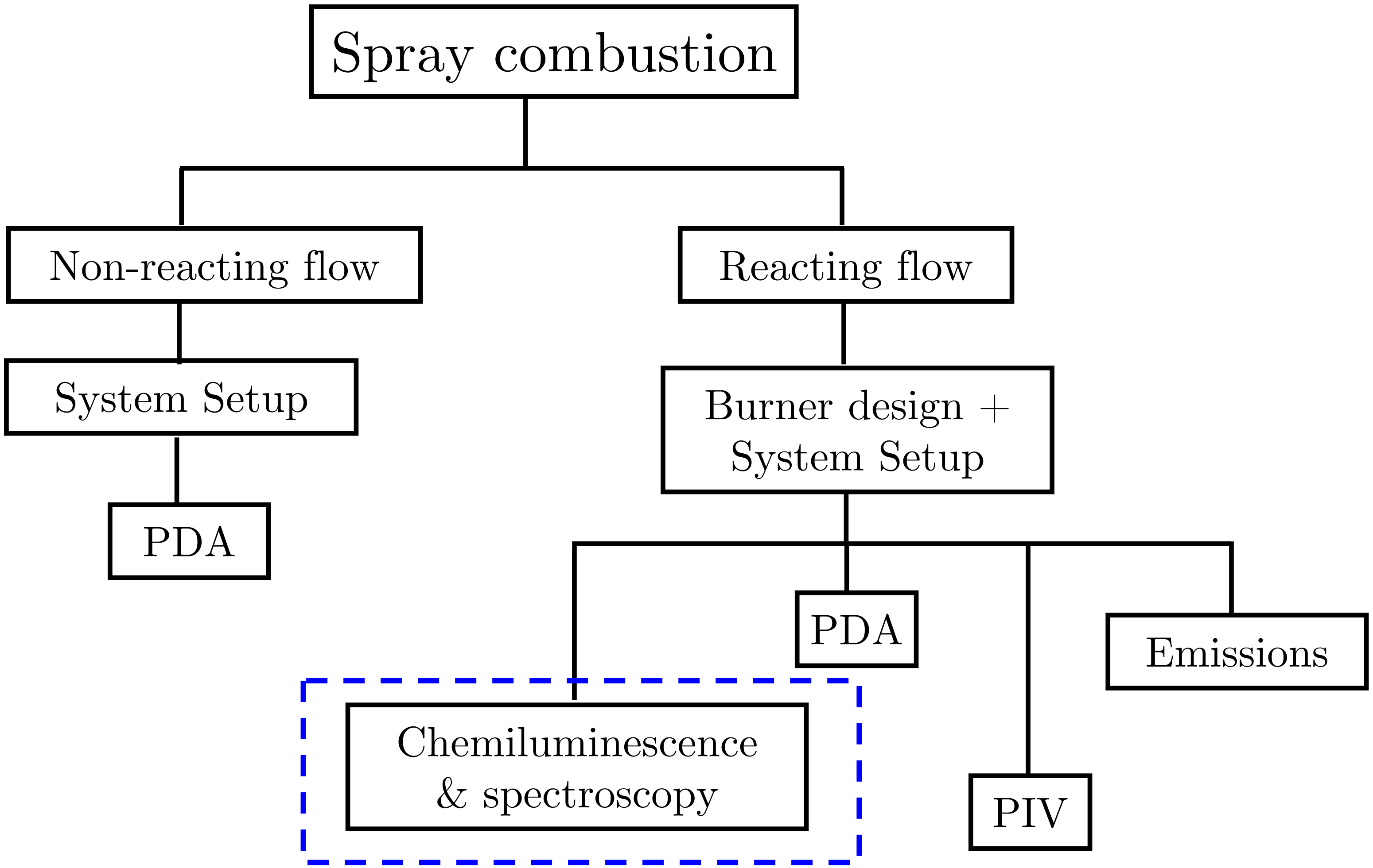
Operating conditions

Fuel	ϕ	AFR	Air (g/s)	Fuel (g/s)	Power (kW)
Diesel	0.47	31.80	4.43	0.14	6.0
Jet-A1	0.47	31.42	4.37	0.14	6.0
PME	0.47	26.75	4.37	0.16	6.0
RME	0.47	26.75	4.36	0.16	6.0

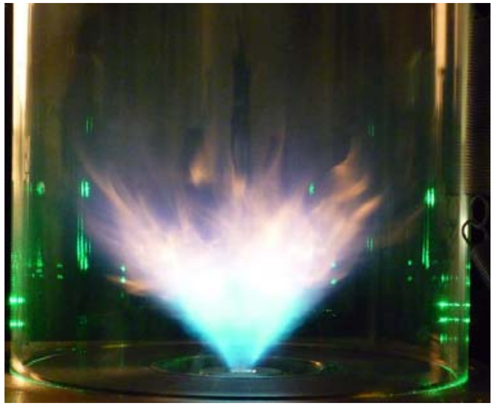


Can you guess what fuel is used?

4. Experimental



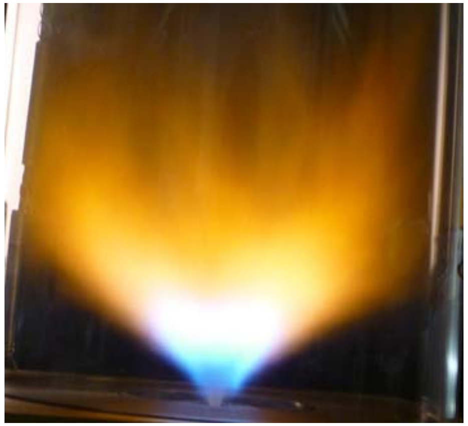
Flame imaging



Diesel

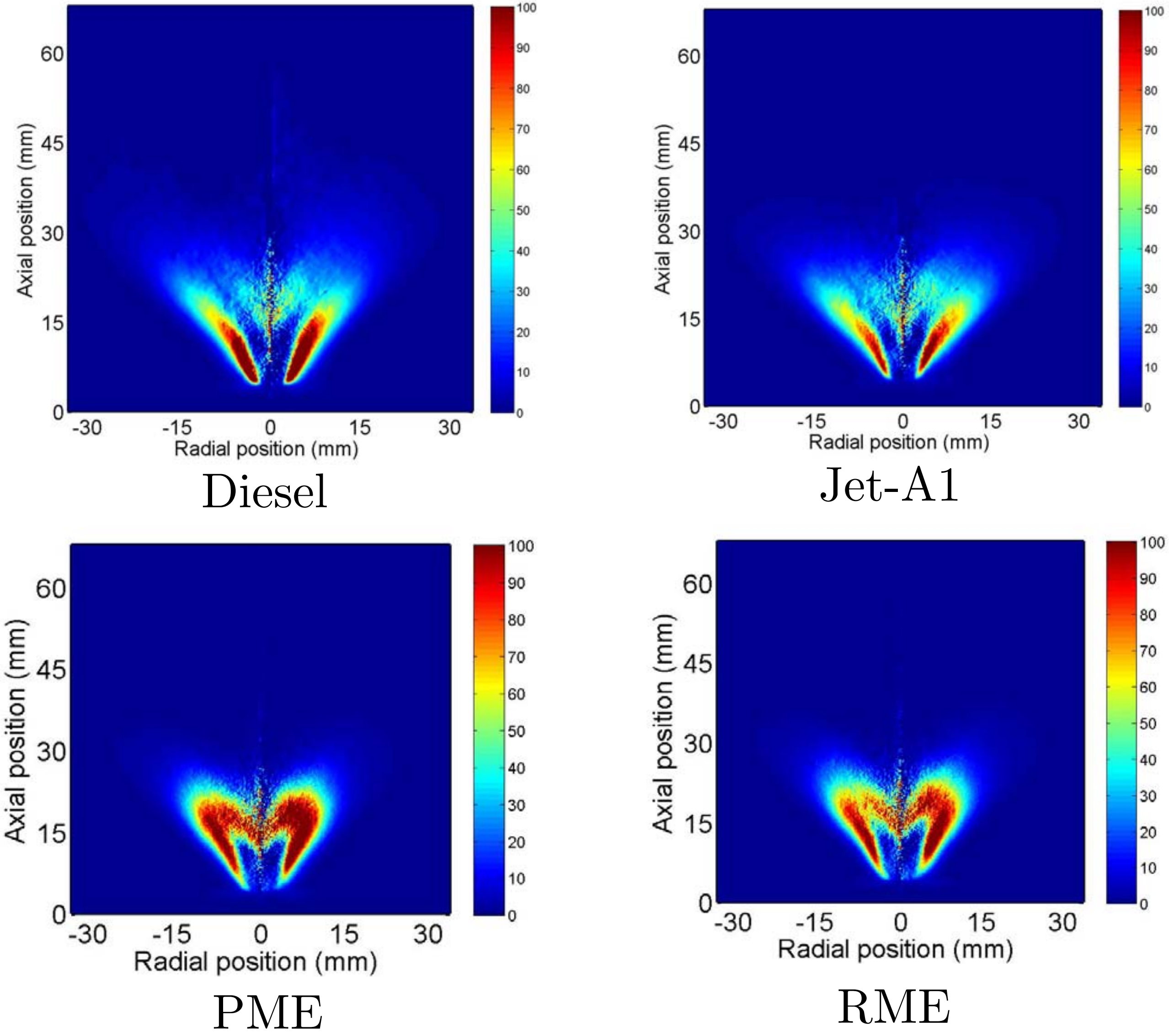
Jet-A1

PME

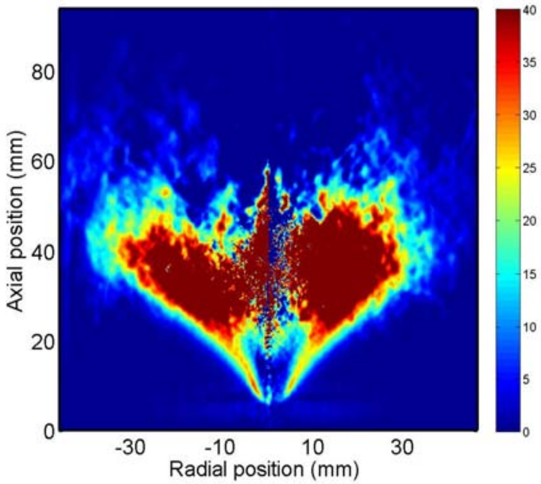


RME

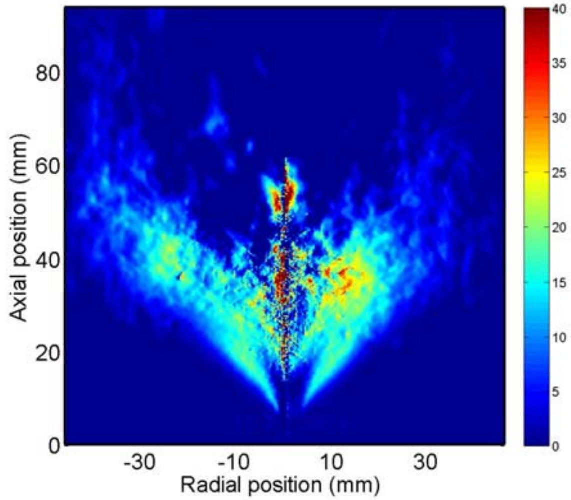
CH* Chemiluminescence imaging



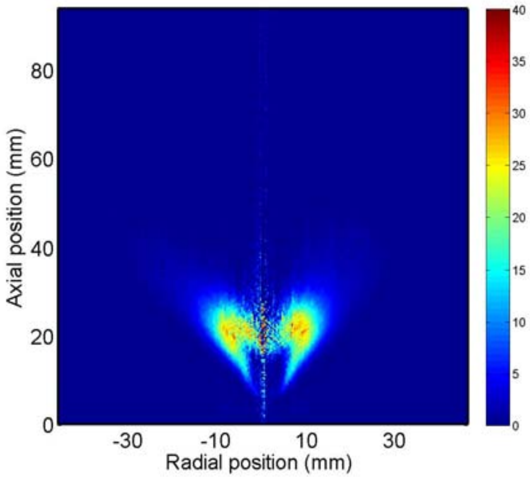
Long Band pass >550 nm



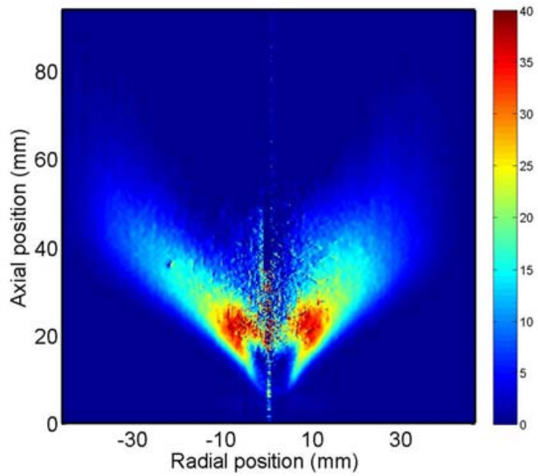
Diesel



Jet-A1

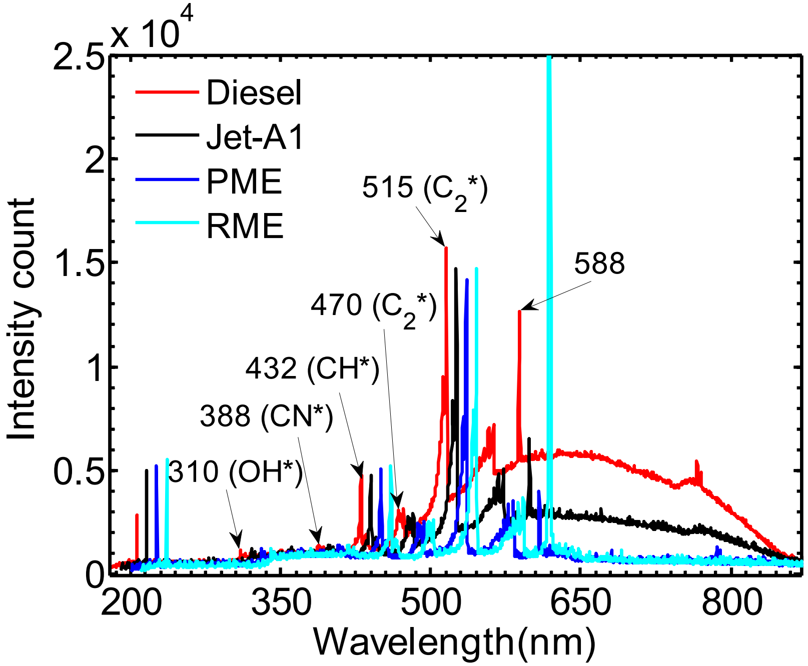


PME

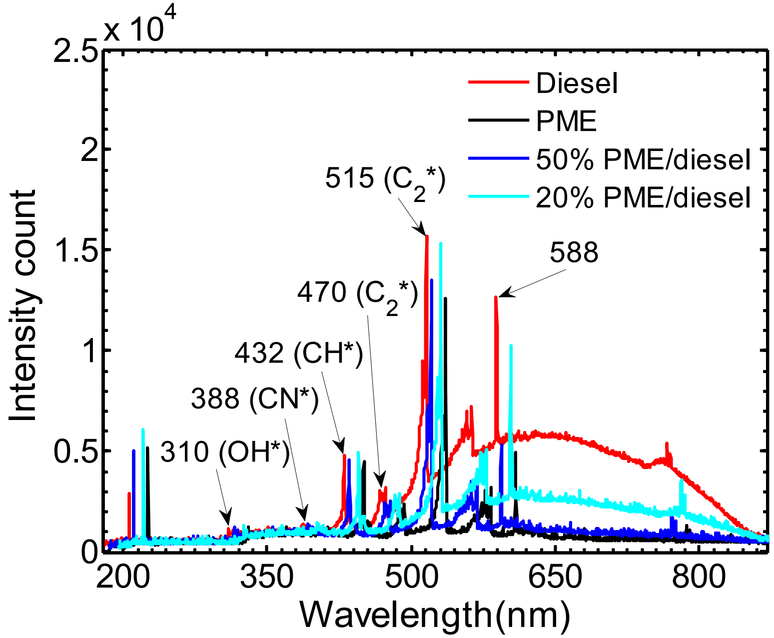


RME

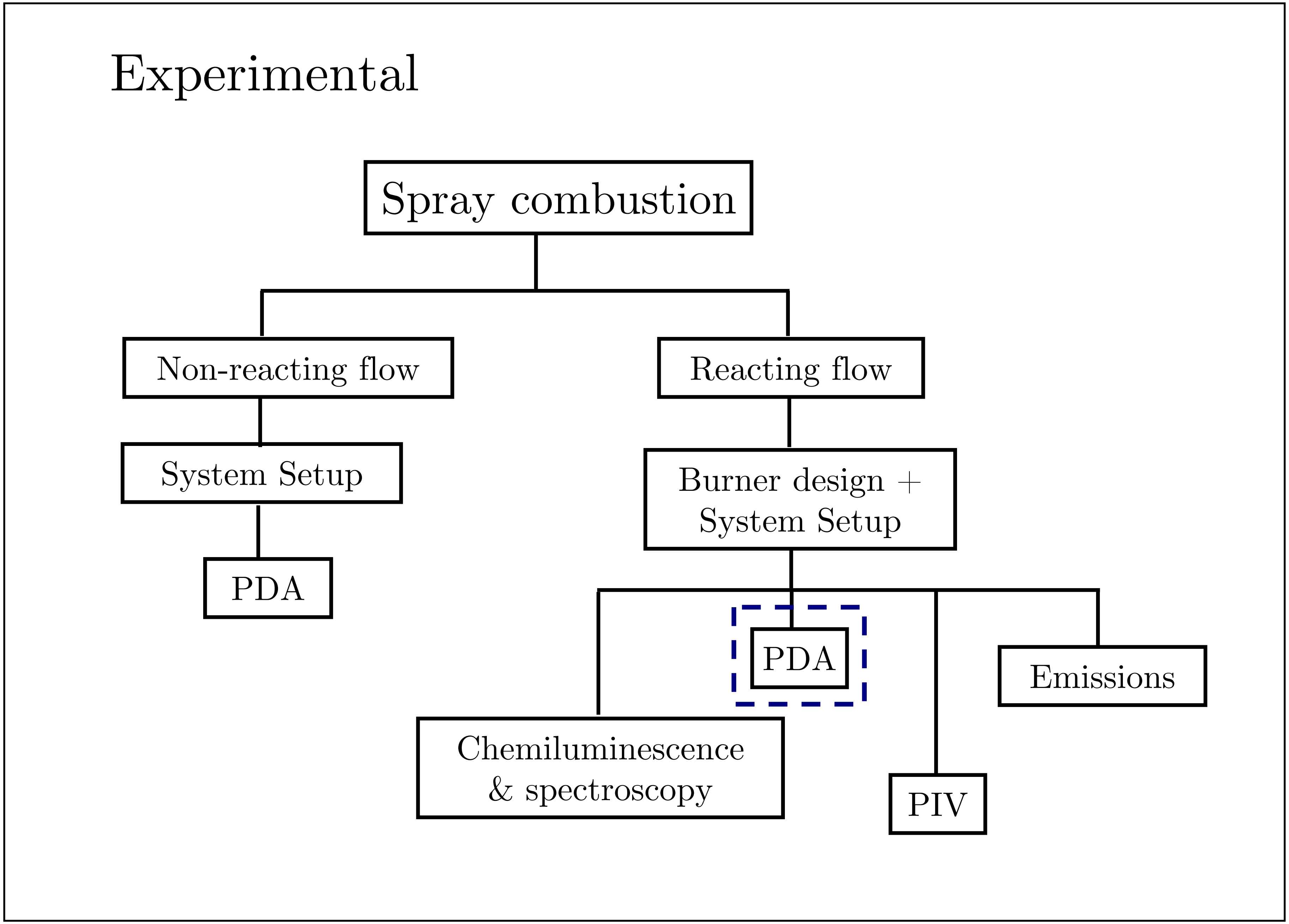
Flame spectroscopy



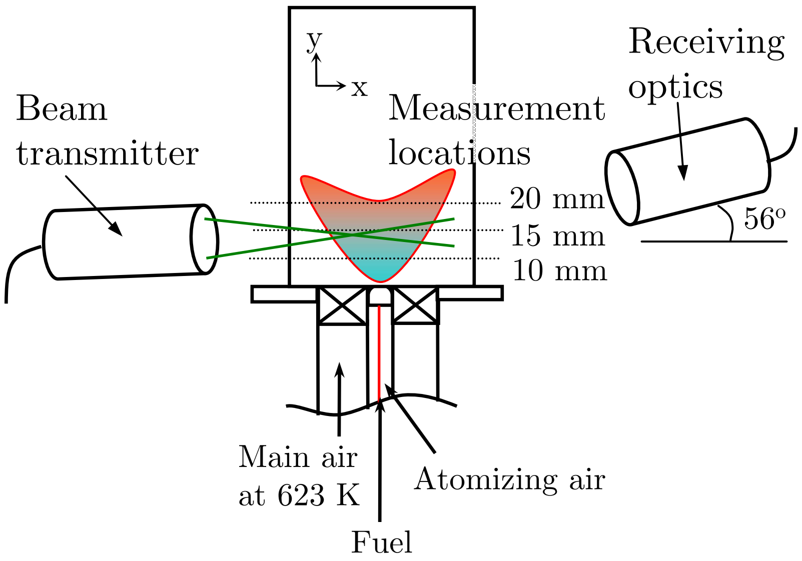
Flame emission spectroscopy measurements of four fuels



Flame emission spectroscopy of diesel, PME, blends of 20% and 50% PME with diesel


Experimental
Spray combustion
Non-reacting flow
Reacting flow
System Setup
Burner design +
System Setup
PDA
PDA
Emissions
Chemiluminescence
& spectroscopy
PIV

PDA setup for reacting flow

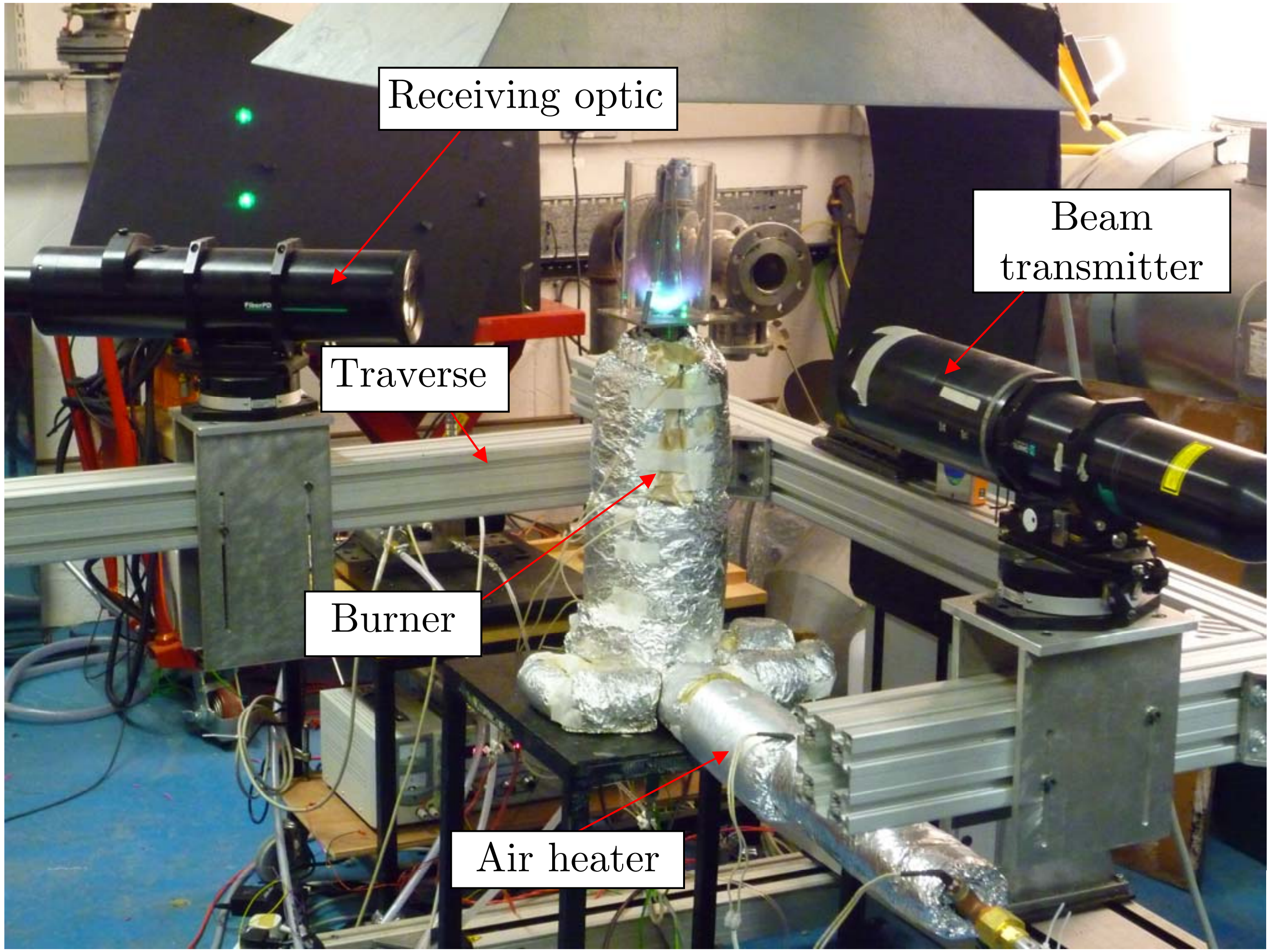


PDA setup and measurement locations

Table 3: PDA optical setting

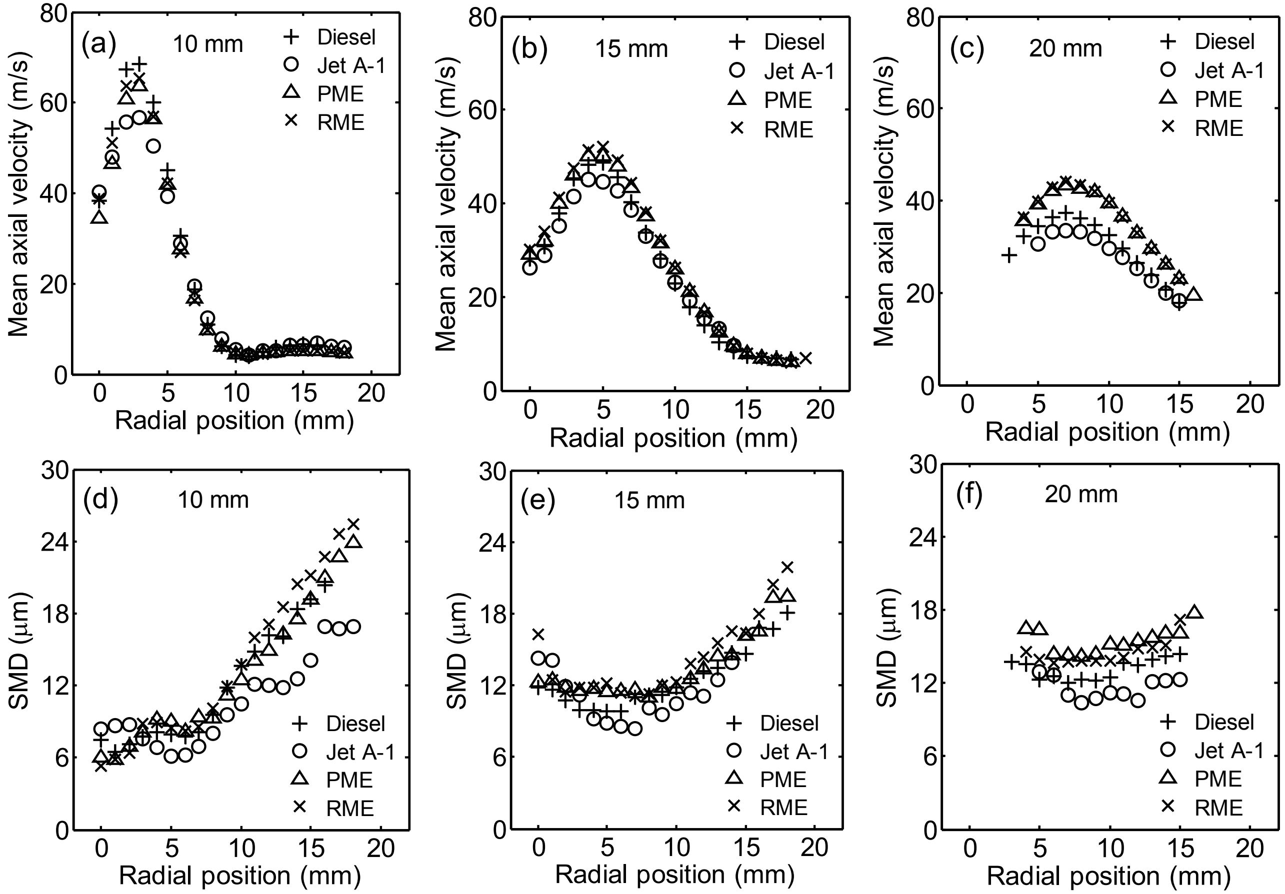
Transmitting optics	
Wavelength	514.5 nm
Power	0.8 W
Beam spacing	45 mm
Beam width	2.2 mm
Focal Length	500 mm
Number of fringes	26
Width of measurement vol.	0.149 mm
Length of measurement vol.	3.312 mm
Receiving Optics	
Focal length	310 mm
Scattering angle	56^o

PDA Setup for Reacting Flow



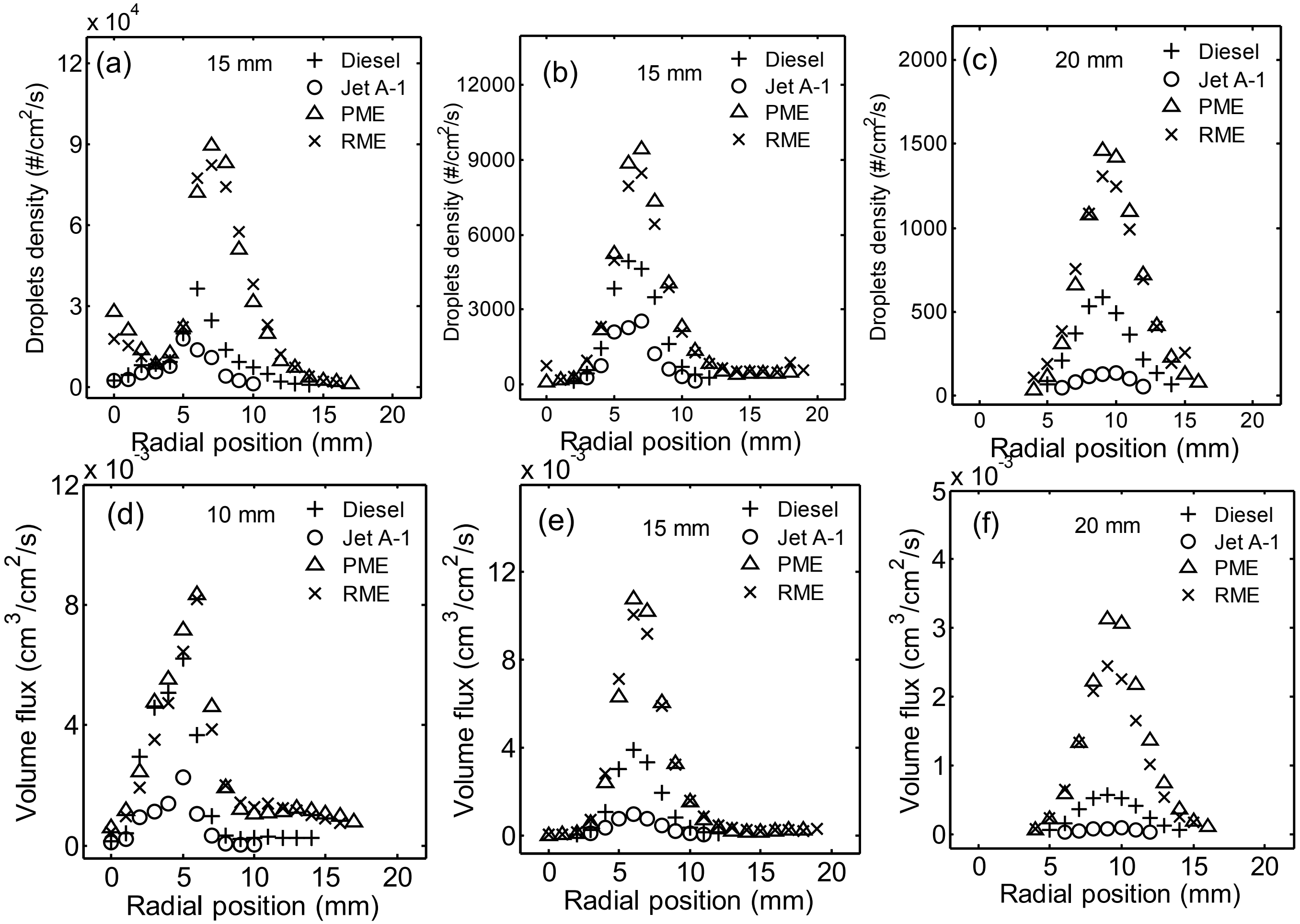
Setup for PDA measurements

Droplet velocity and SMD



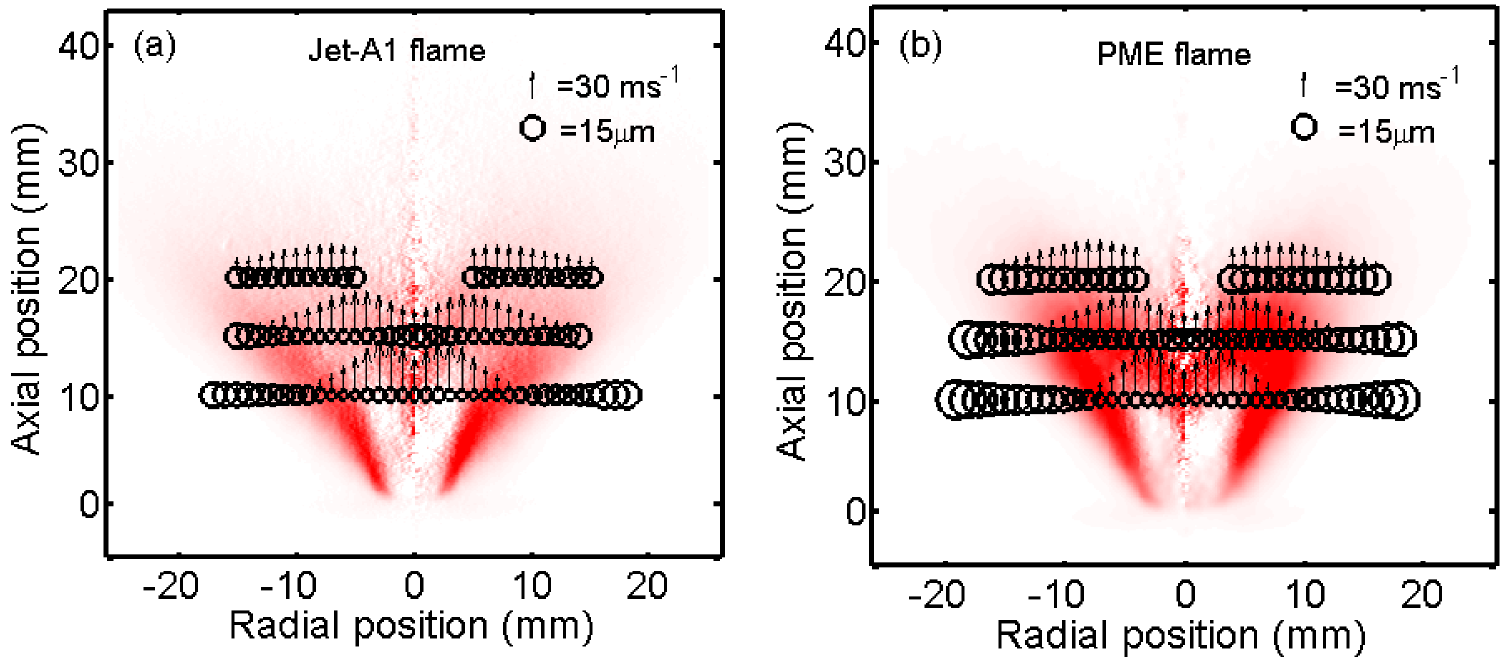
Droplet profiles at axial distance 10, 15, 20 mm from the atomizer tip

Droplet concentration and volume flux



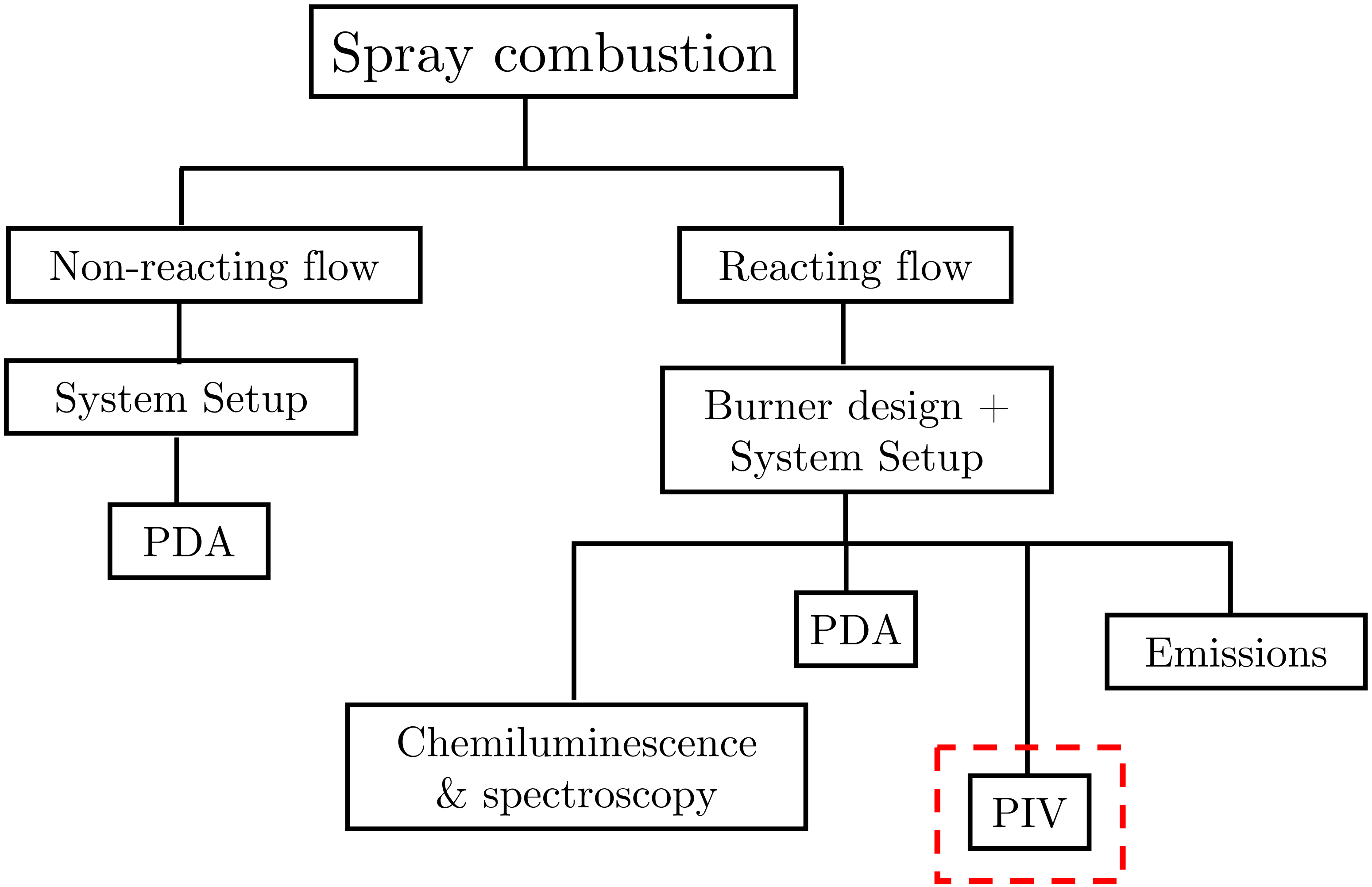
Droplet number density and volume flux at axial distance 10, 15, 20 mm from the atomizer tip

Droplet distribution in flame

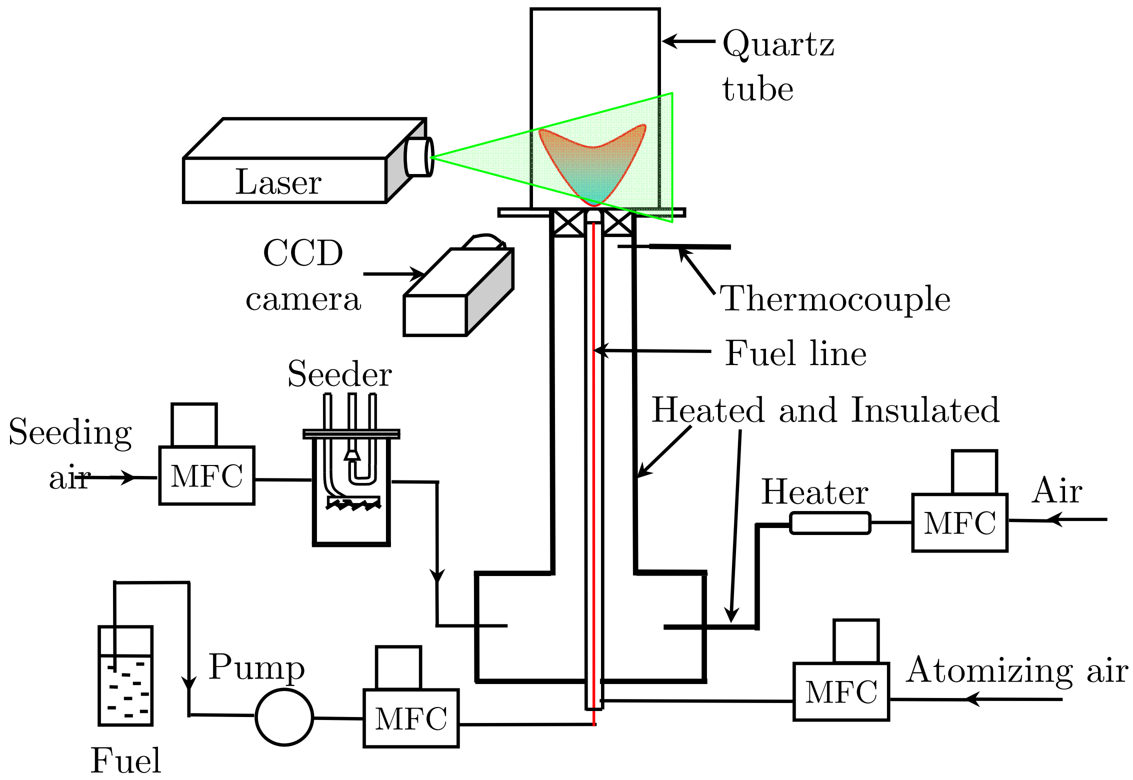


Droplet distribution in (a) Jet-A1 and (b) PME flame

Experimental

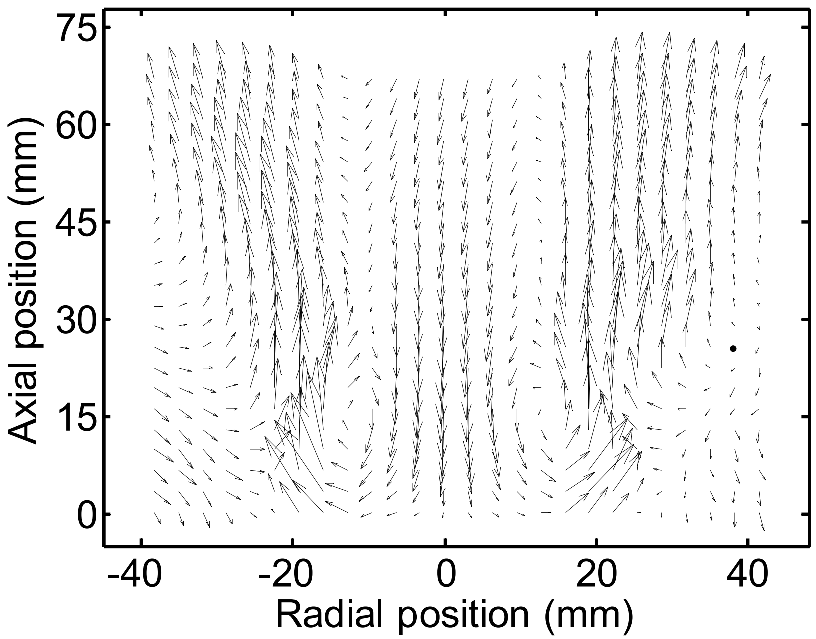


Particle imaging velocimetry

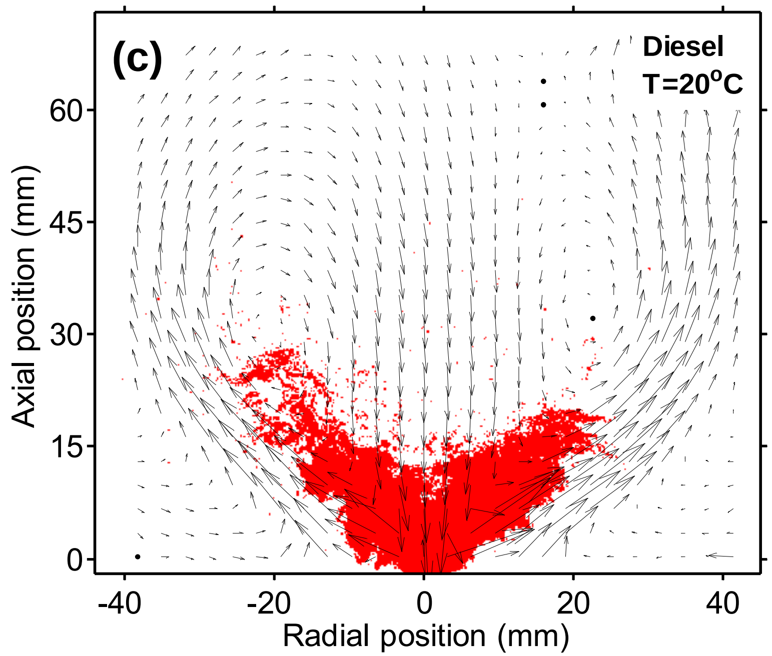


Schematic of the flow delivery single swirl flame burner

Non-reacting flow PIV measurement

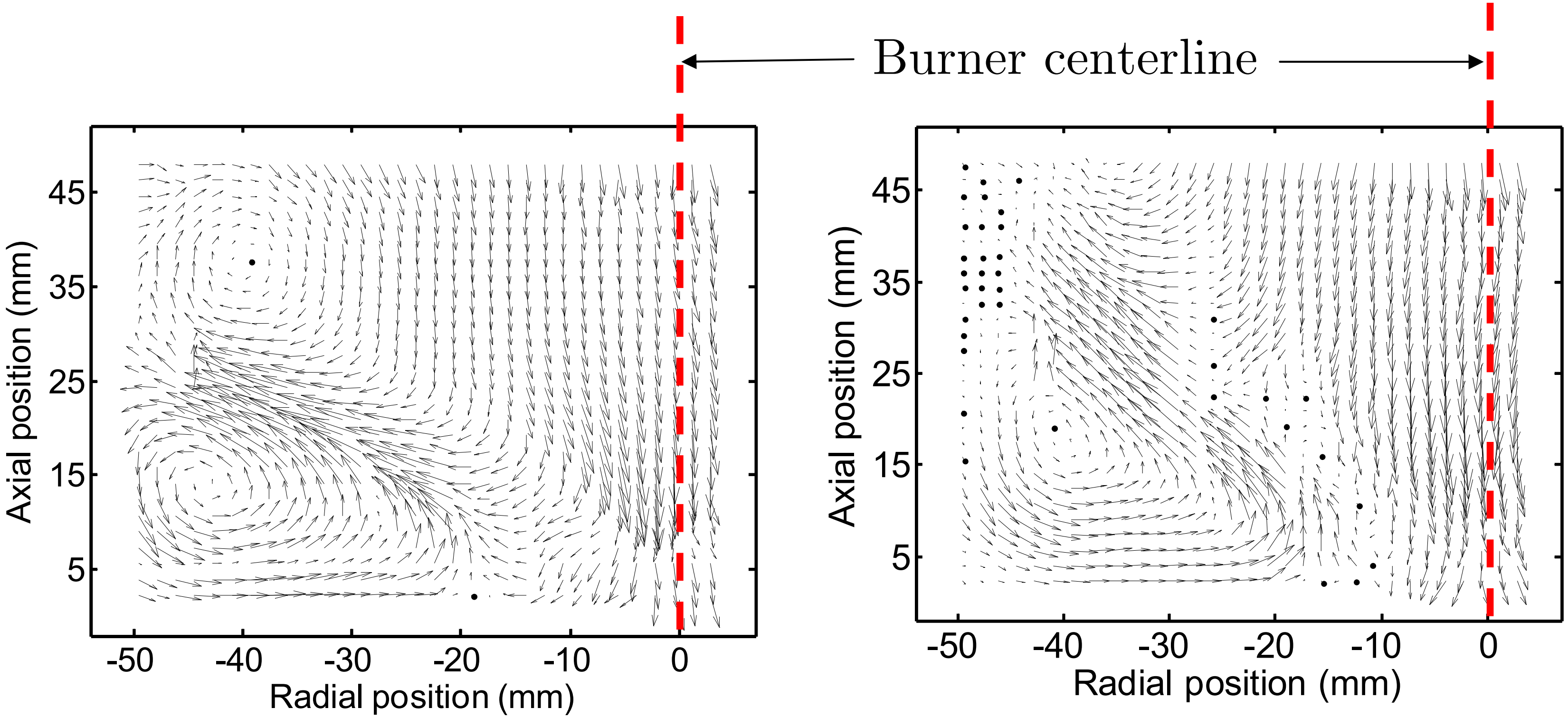


Non-reacting flow at open air



Main flow + spray at open air

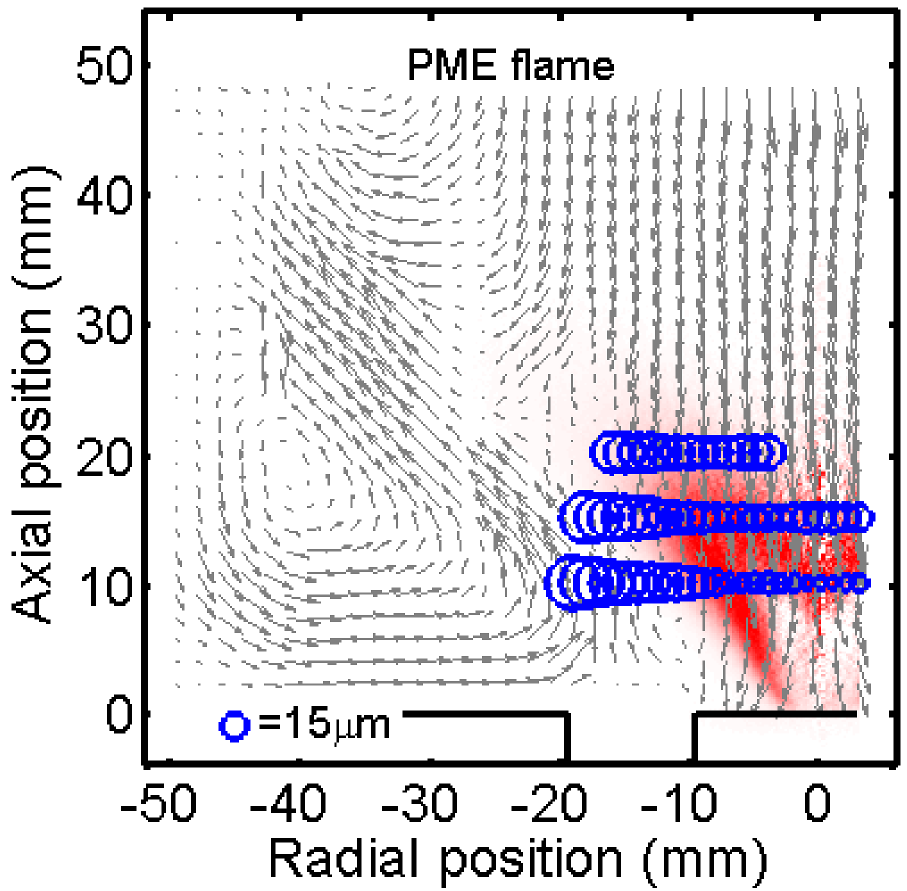
Flow field in enclosure



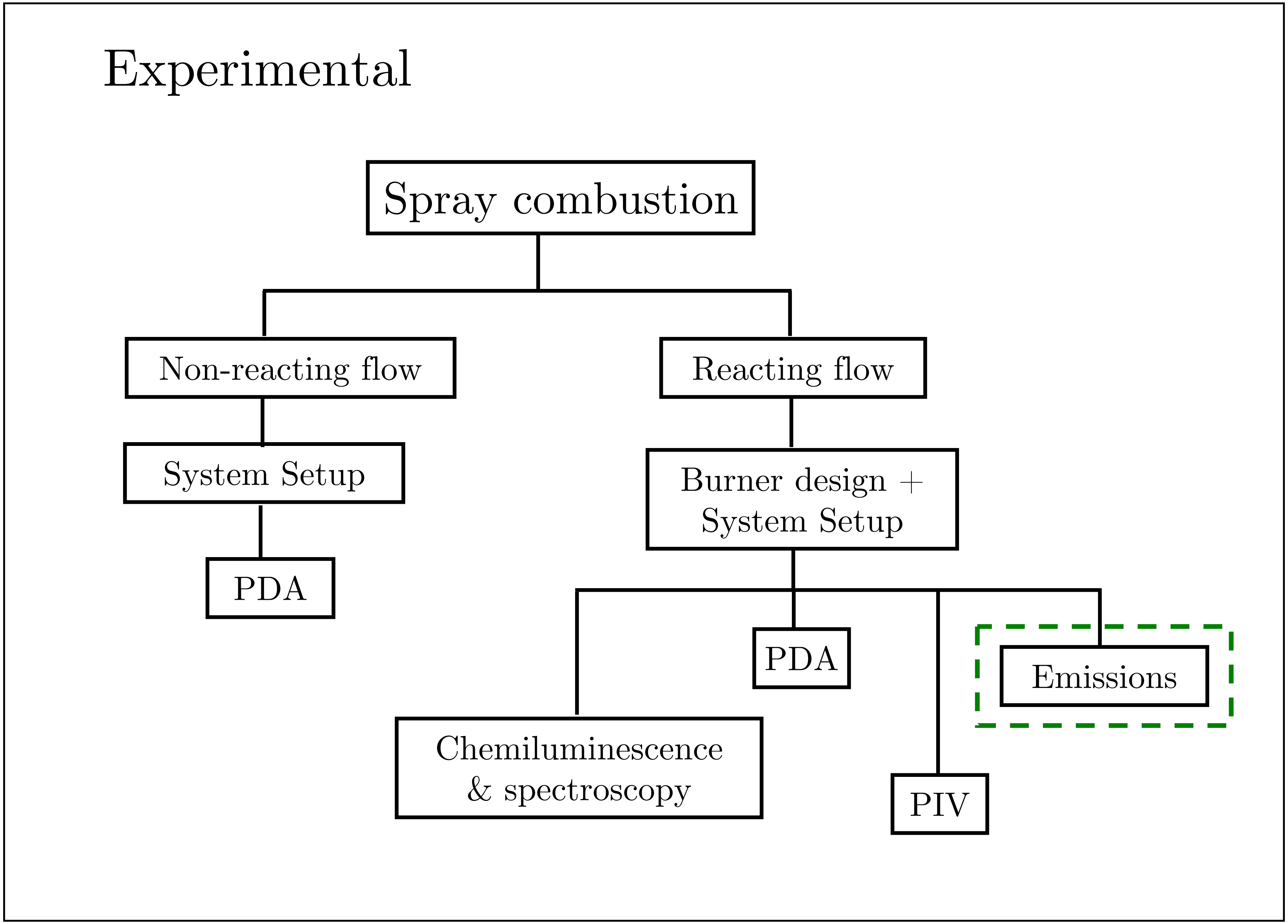
Cold spray + main air + spray + enclosure

Reacting spray flame with enclosure

Flow field and droplet distribution in flame

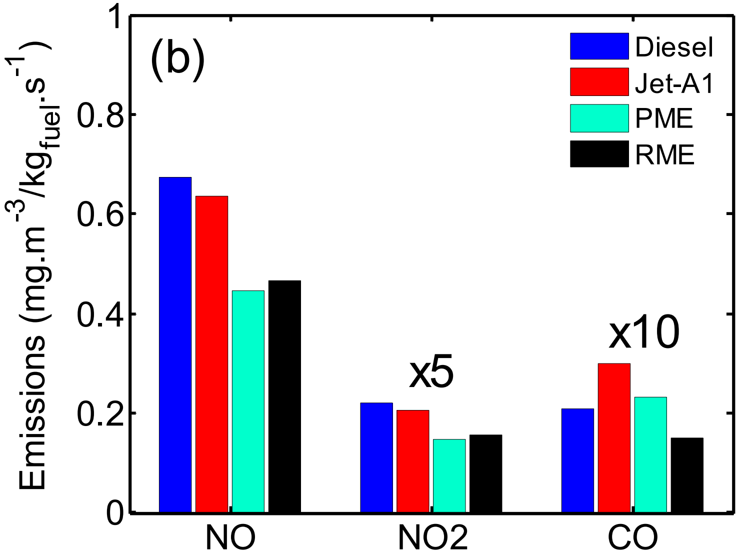


PME flame + flow field + flame reaction zone


Experimental
Spray combustion
Non-reacting flow
Reacting flow
System Setup
Burner design +
System Setup
PDA
PDA
Emissions
Chemiluminescence
& spectroscopy
PIV

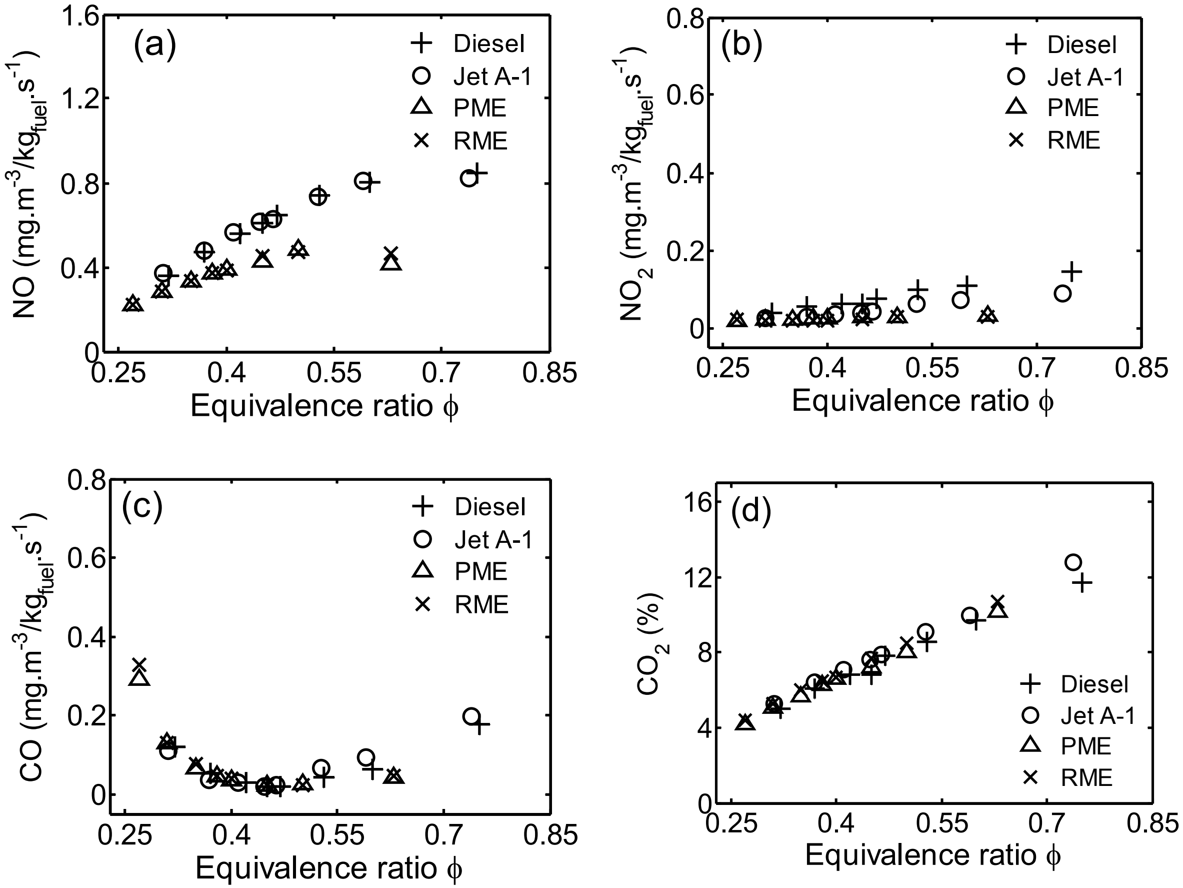
Emission measurement

- Measure the emission across the burner outlet.
- Average the spatial values.
- NO, NO_2, CO, O_2 and CO_2 are measured



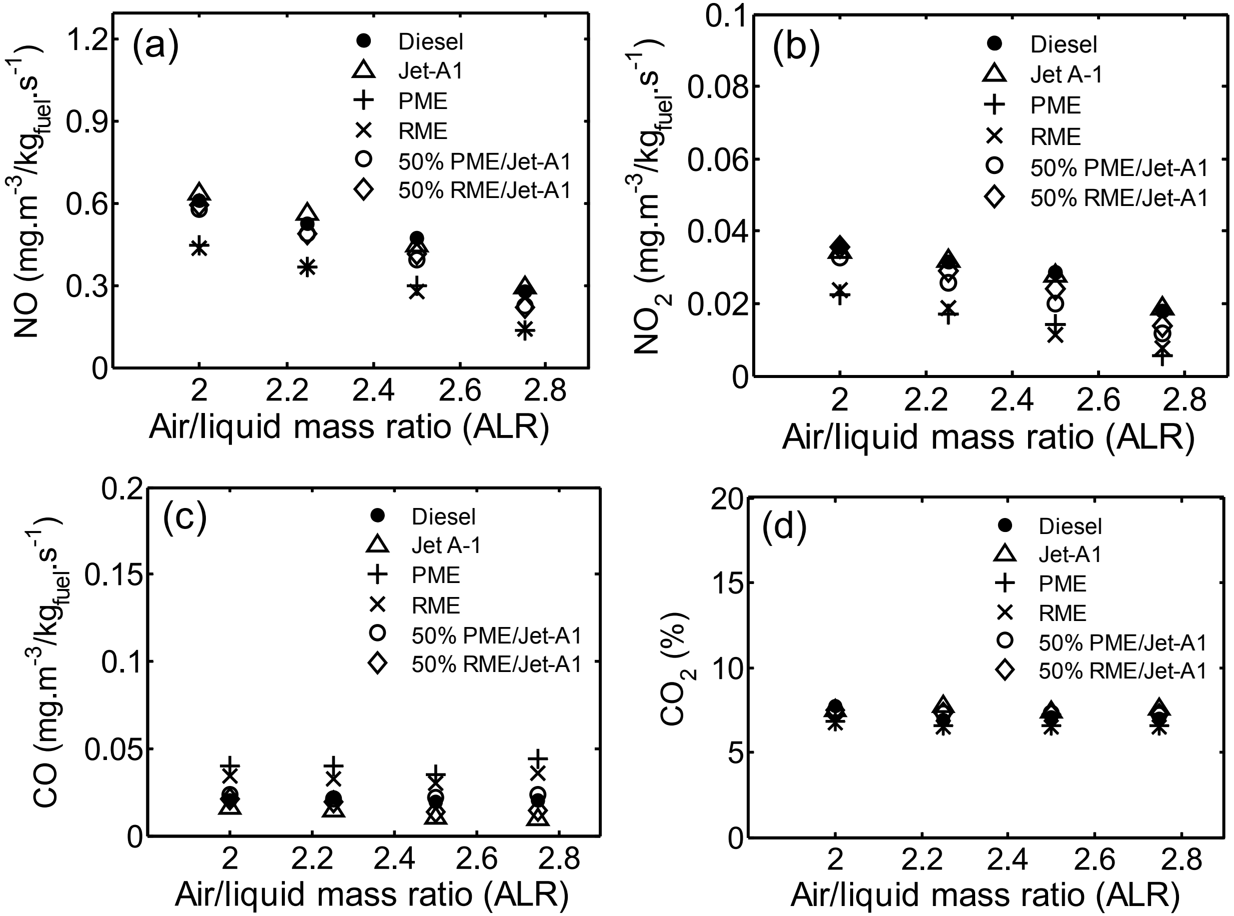
Emissions under the same power output condition

Emission measurement (i)



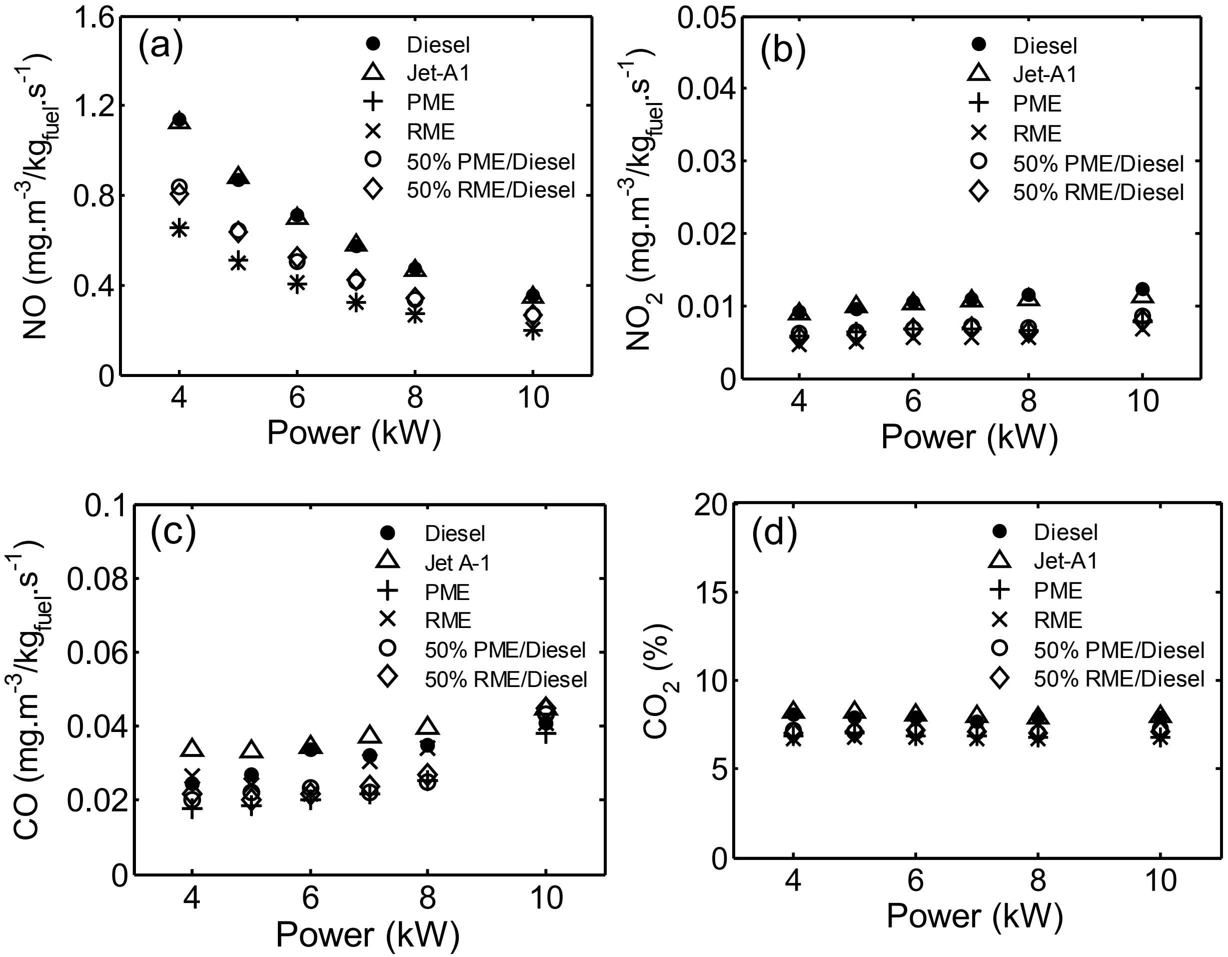
Emissions as a function of equivalence ratio

Emission measurement (ii)



Emissions as a function of air-liquid-mass ratio

Emission measurement (iii)



Emissions as a function of burner power output

5. Summary and conclusion

- Combustion properties of alternative fuel can be significantly different.
- A methodology is developed to systematically measure the combustion properties of alternative fuels.
- Advanced modelling of fuel and combustion requires experimental data.

Thank you!

MOSTI-MIGHT
Rolls Royce
UTM
Cambridge University
Carotino Sdn. Bhd. (PME)
ADM International Sarl, Switzerland (RME)