Estimation of soot temperature and radiation from spray flames

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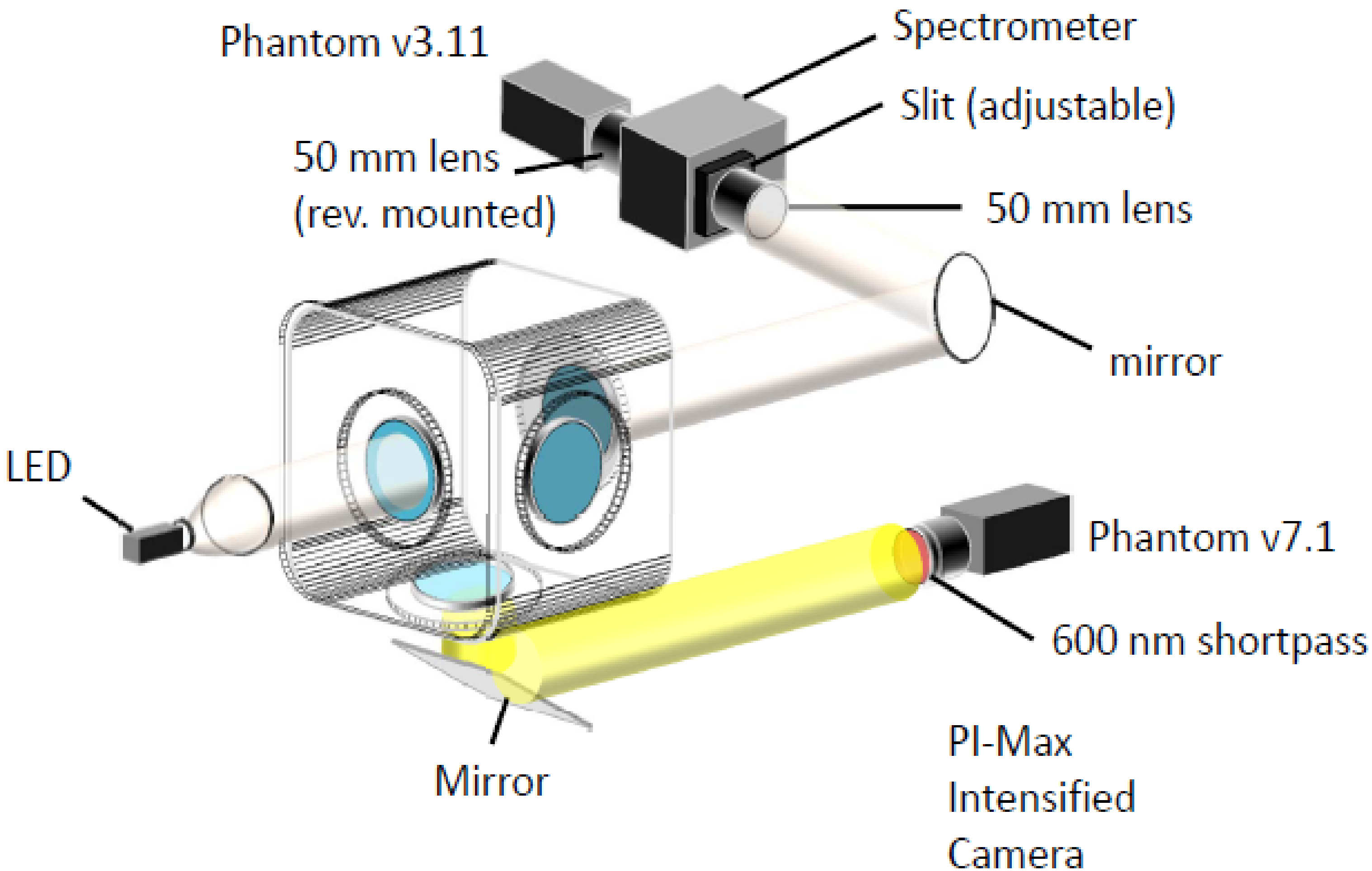
Soot thermometry

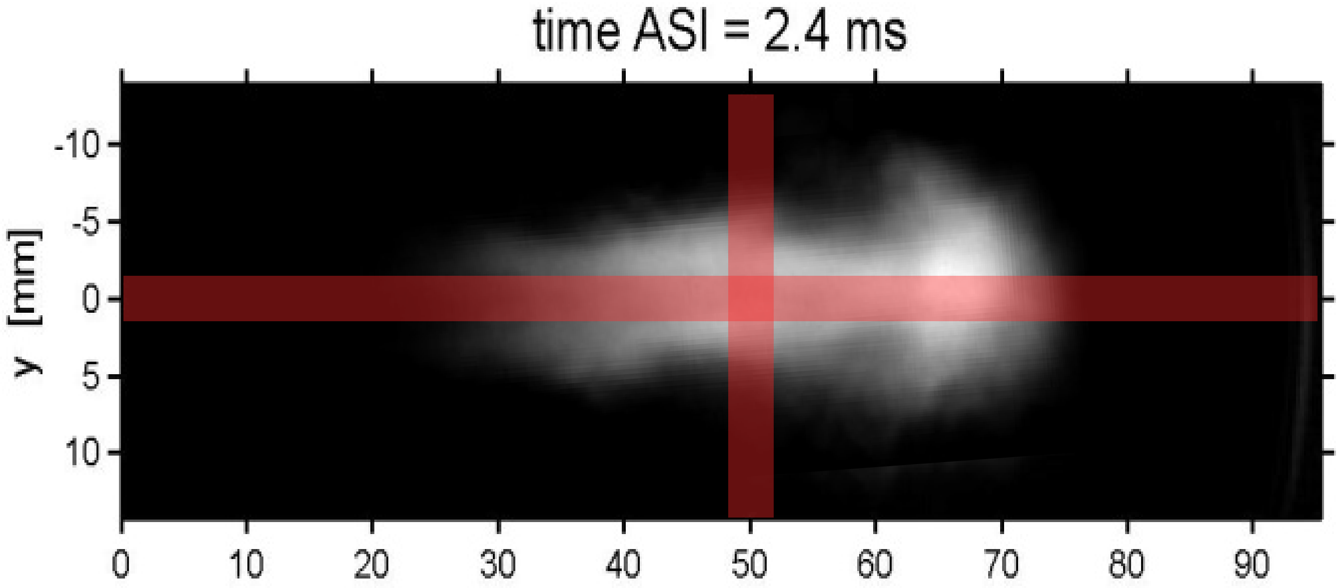
Emission absorption method
vs.
color method

- Both methods -> Low temperatures (100-300 K)
- Color method -> Very low optical thickness

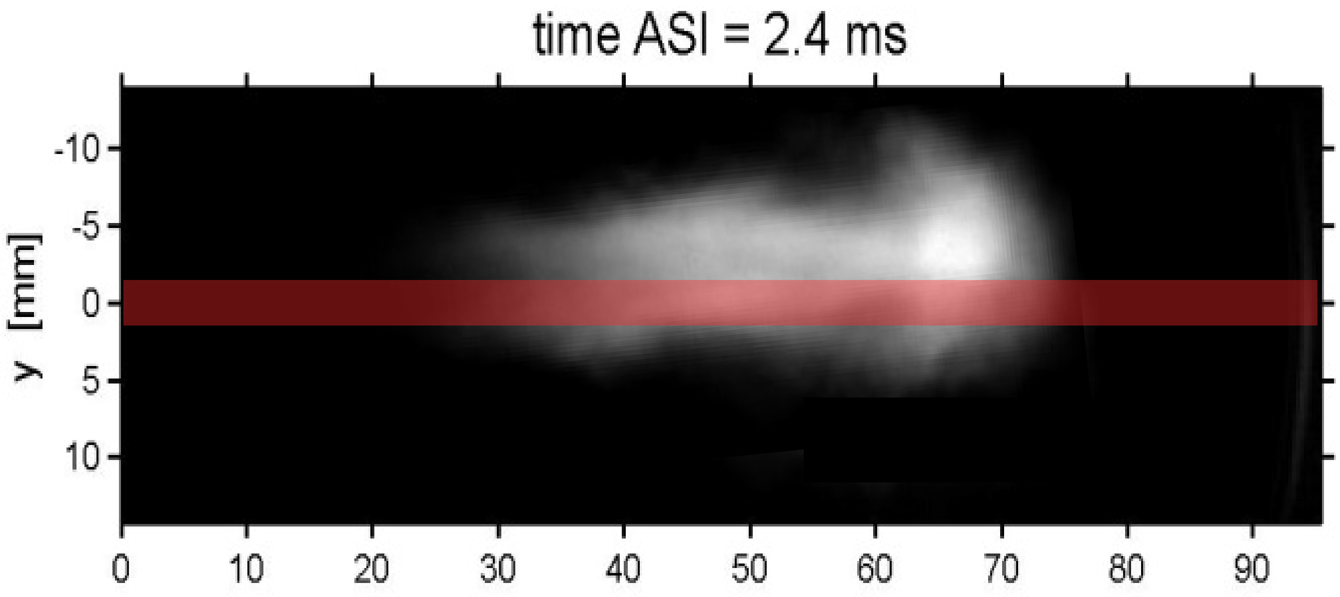
High speed soot thermometry



Choice of slit direction



Pointing of the spray



The Spectral Pyrometry Methods

Blackbody spectral radiance (Planck's Law):

$$\mathrm{I}_b = \frac{2hc^2}{\lambda^5}\frac{1}{e^{hc/\lambda k_B T} - 1}$$

Spectral radiance of media:

$$I_\lambda = \varepsilon_\lambda(k_\lambda L, \lambda) I_b(T_s, \lambda)$$

Beer-Lambert's law:

$$\tau = 1 - \varepsilon$$

The Color method:

$$\varepsilon_\lambda(KL, \lambda) = 1 - e^{-\frac{KL}{\lambda^\alpha}}$$

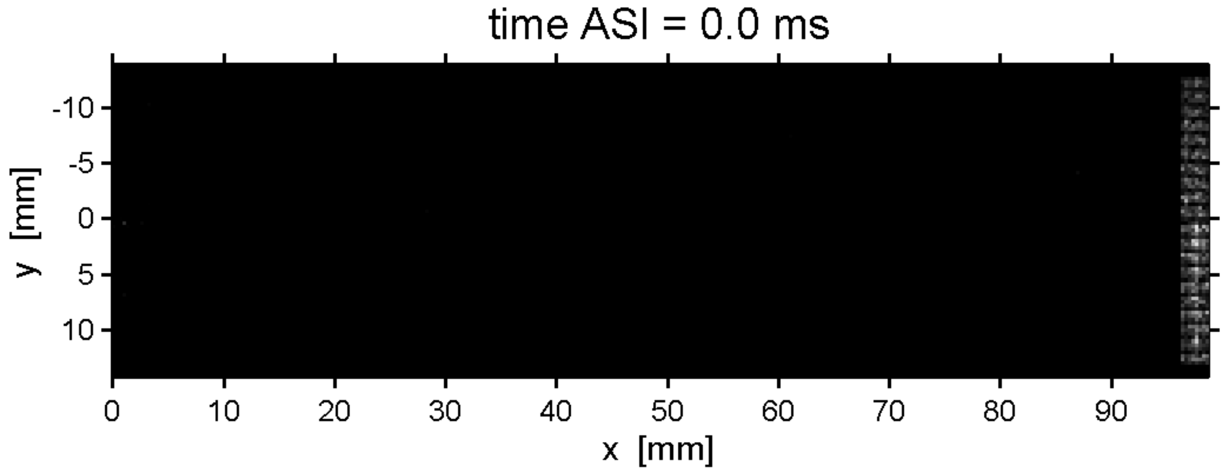
$$\alpha = 1.22 - 0.245\ln(\lambda\ [\mu m])$$

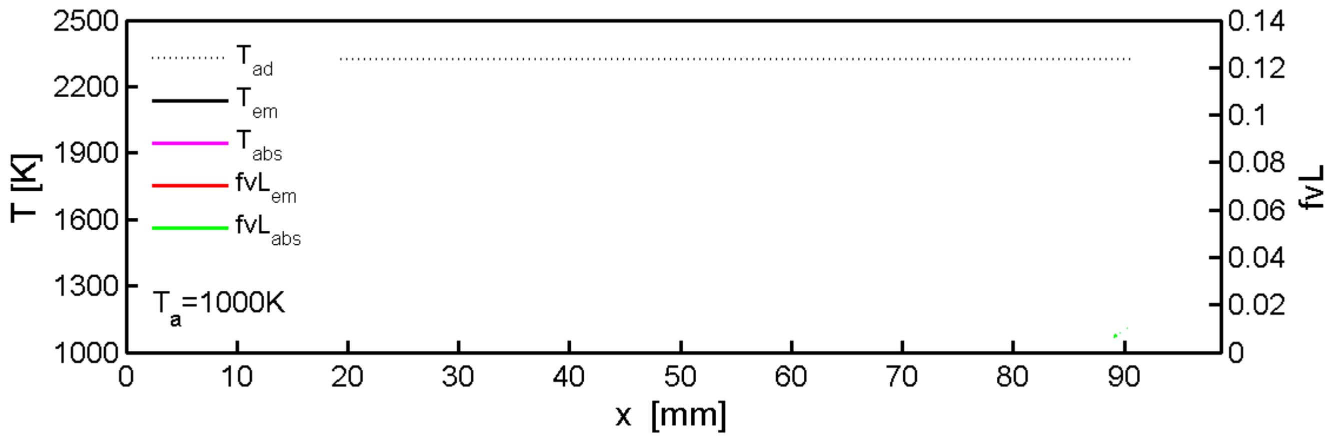
The emission absorption method:

$$\tau_{meas}(\lambda) = \frac{I_{fs}(\lambda) - I_f(\lambda)}{I_s(\lambda)}$$

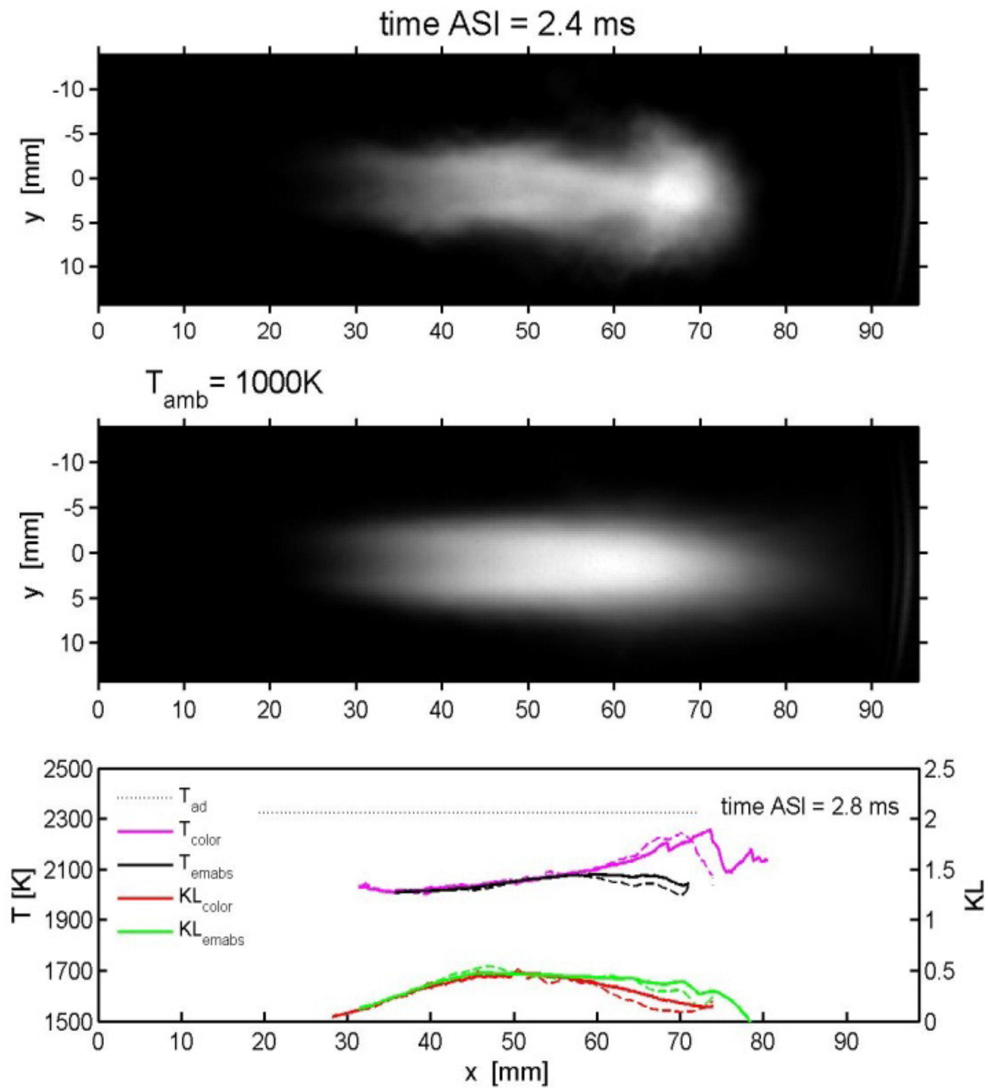
$$T(\lambda) = \left(\frac{\lambda k}{hc}\ln\left(\frac{\varepsilon(\lambda, T)2hc^2}{I_f(\lambda, T)\lambda^5} + 1\right)\right)^{-1}$$

Transient results

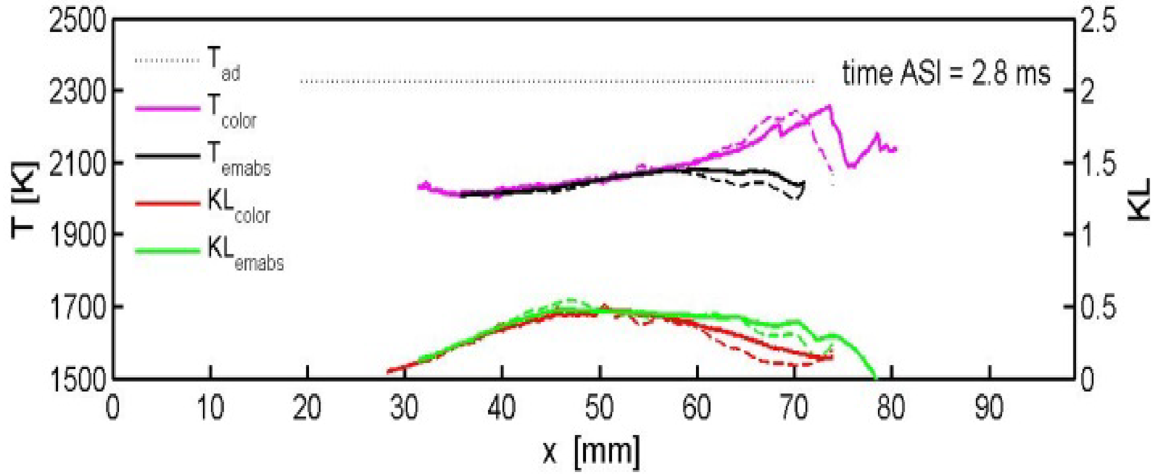


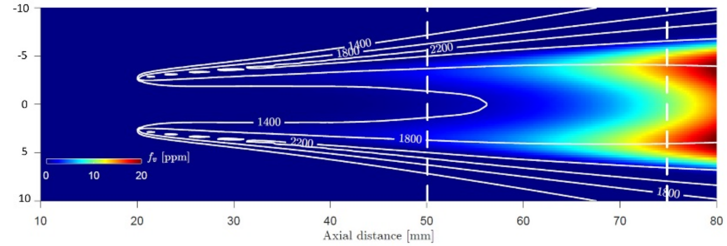


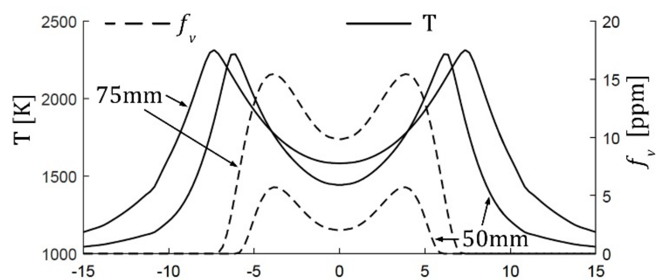
Quasi-Steady results



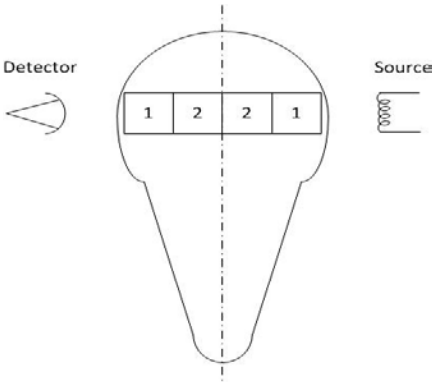
Comparing with CFD







Layer effects



		Flame Zone Model			Solution	
		zone 1 outer layer	zone 2 flame center	$\bar{T}$ / $\overline{KL}$	color method	emabs method
a)	T	2200	2200	2200	2200	2202
	KL	0.38	0.38	1.5	1.5	1.46
b)	T	2200	2200	2200	2200	2200
	KL	0.02	0.73	1.5	1.5	1.5
c)	T	2200	2200	2200	2200	2205
	KL	0.73	0.02	1.5	1.5	1.41
d)	T	1600	2400	0000	2291	2241
	KL	0.38	0.38	1.5	0.92	1.46
e)	T	2400	1600	2000	2351	2268
	KL	0.38	0.38	1.5	0.73	1.46
f)	T	2400	1600	2000	2127	1801
	KL	0.02	0.73	1.5	0.1	1.5
g)	T	1600	2400	2000	2005	1778
	KL	0.73	0.02	1.5	0.17	1.41
h)	T	1600	2400	2000	2396	2394
	KL	0.02	0.73	1.5	1.48	1.5
i)	T	2400	1600	2000	2398	2401
	KL	0.73	0.02	1.5	1.47	1.41

Highlights low values
Highlights high values

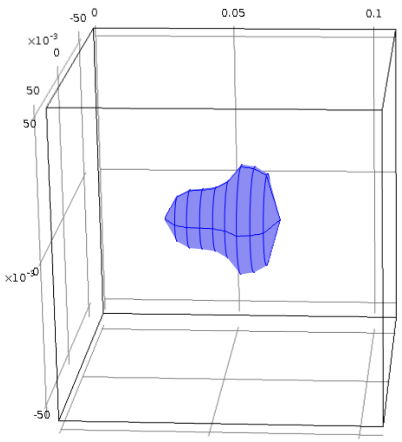
$\bar{T}$ = mean temperature
$\overline{KL}$ = total optical thickness

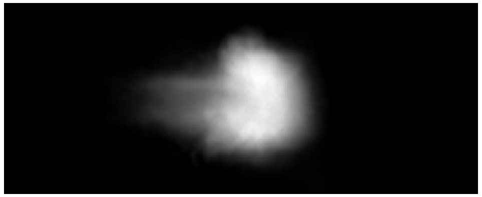
Getting our own spray combustion vessel

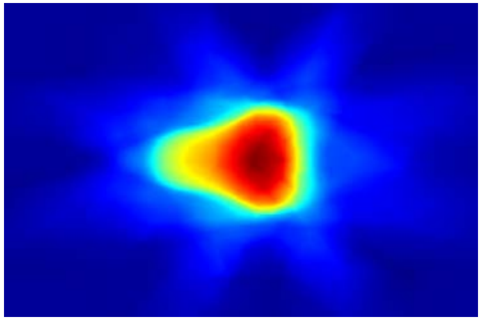
sasol

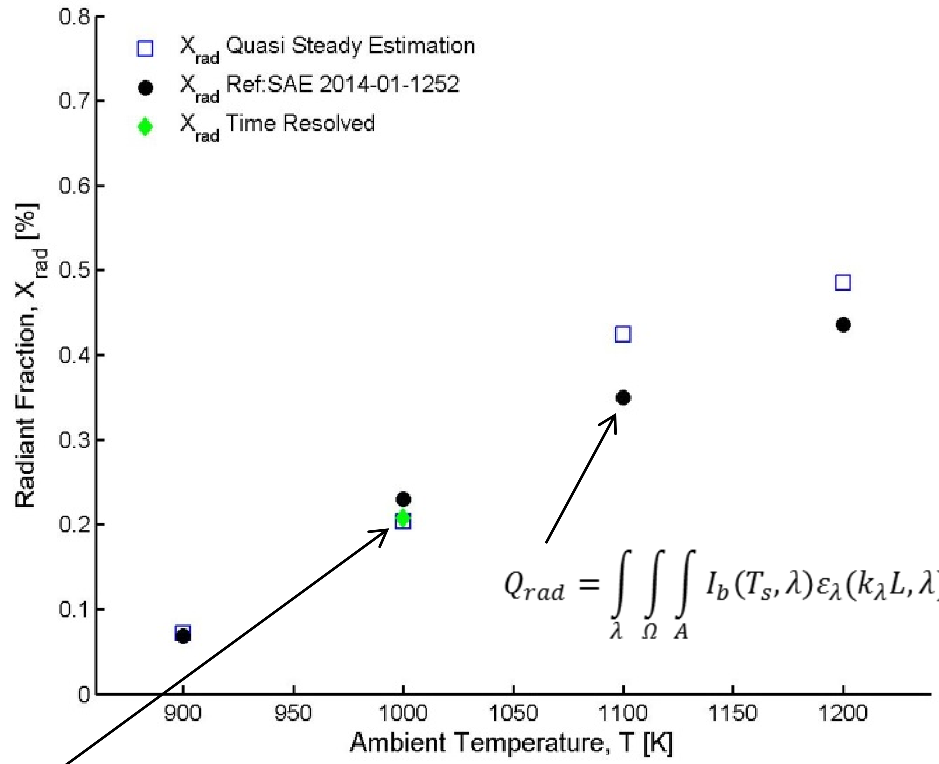
Heat loss by soot radiation

Comsol Multiphysics FEM model



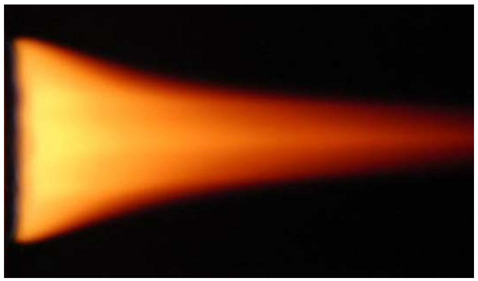


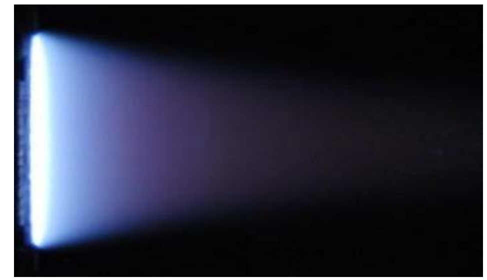


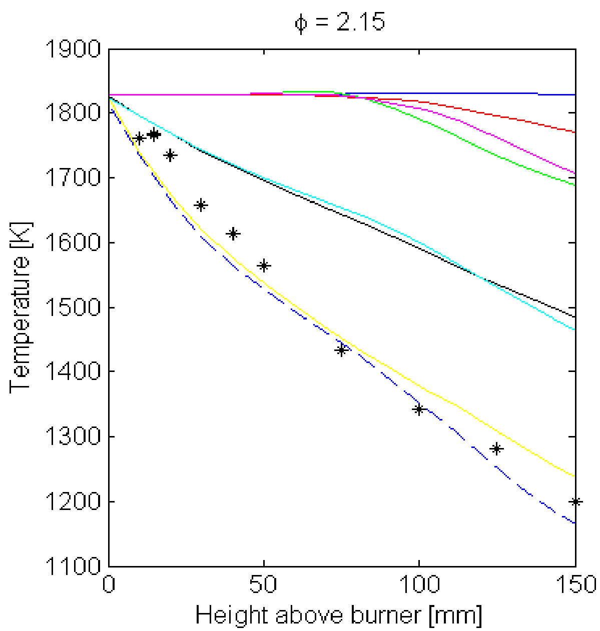


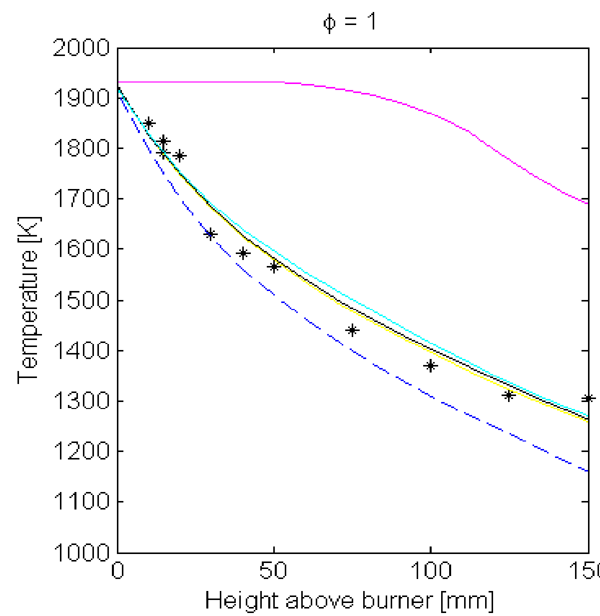
$$Q_{rad} = \int_{\lambda}\int_{\Omega}\int_{A} I_b(T_s,\lambda)\varepsilon_{\lambda}(k_{\lambda}L,\lambda)\; dA d\Omega d\lambda$$

Gas radiation



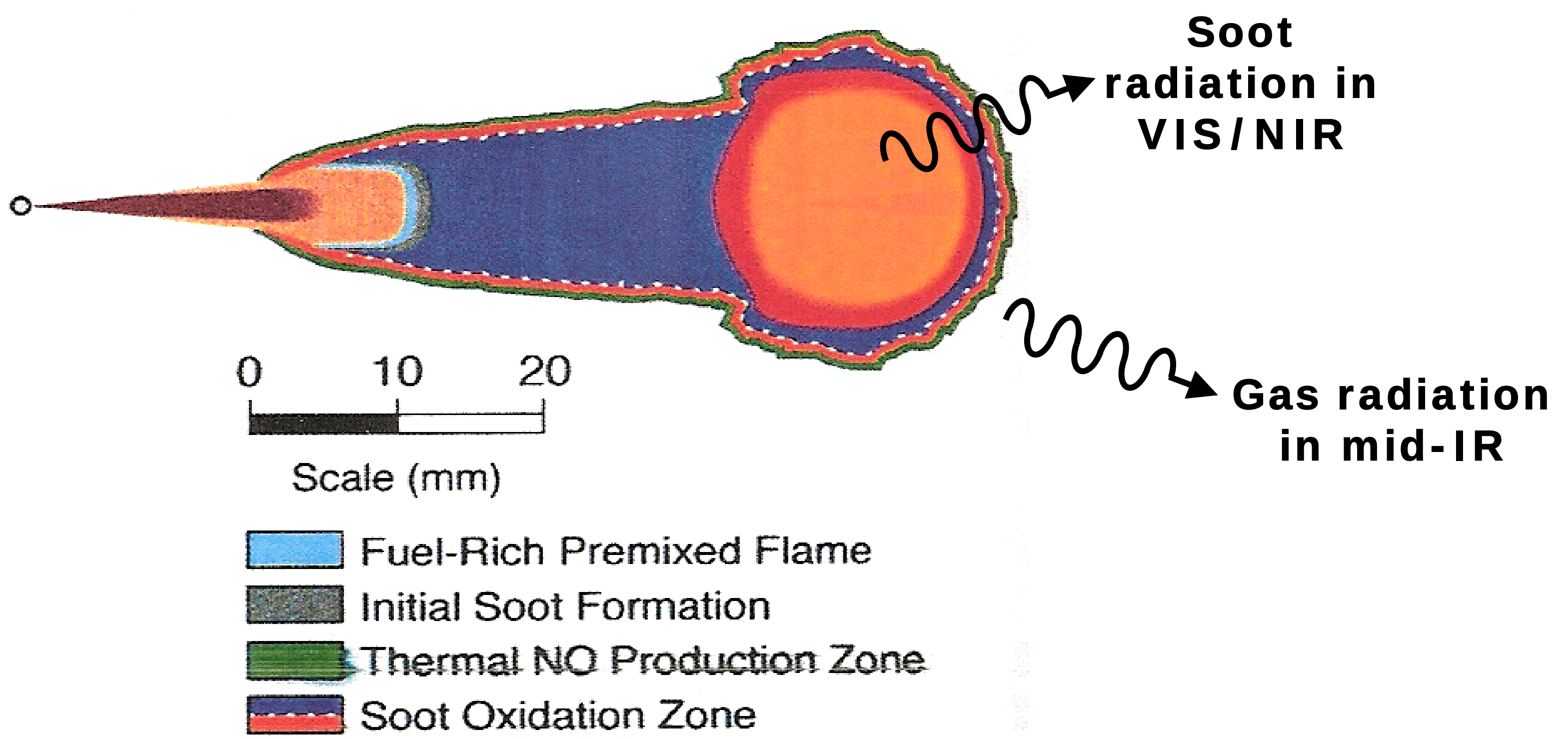






1 mm ≈ 1 ms ≈ 1 CAD

Gas vs. soot radiation from stratified flames

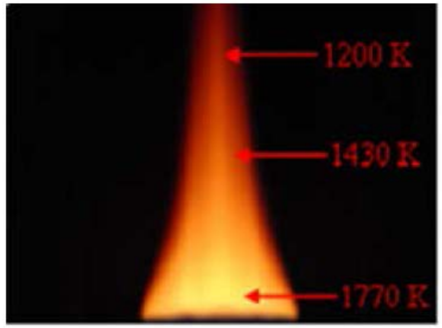


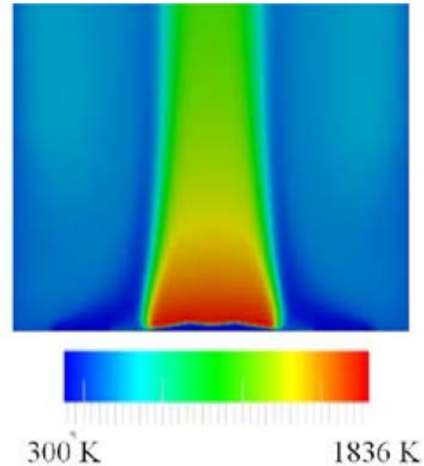
Box model

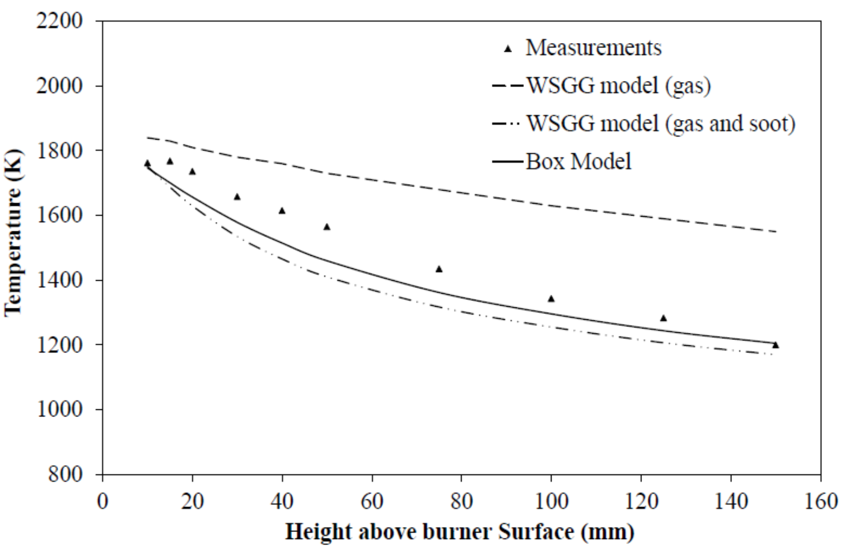
$$\overline{\kappa}_{\eta,g\ i} = c_0 + c_1 T + c_2 T^2 + c_3 T^3$$

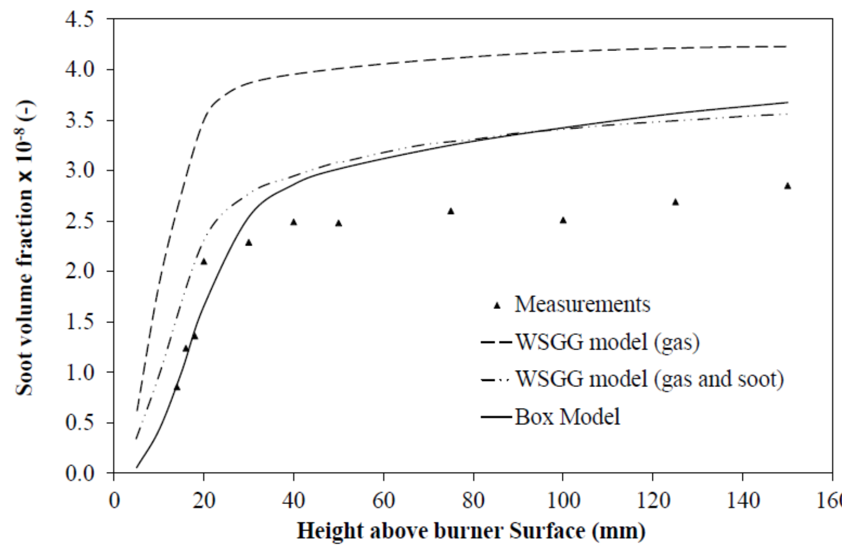
	Band, μm					
	2.43-2.64	2.65-3.0	4.13-4.53	4.54-8.33	12.5-18.18	18.34-25
CO_2						
c_0		2.237E+01	1.706E+03		1.349E+02	
c_1		-3.226E-02	-2.568E+00		-2.029E-01	
c_2		1.787E-05	1.422E-03		1.110E-04	
c_3		-3.365E-09	-2.642E-07		-2.039E-08	
H_2O						
c_0	3.252E+01	3.073E+01		4.032E+01	-1.927E+01	-4.343E+01
c_1	-4.990E-02	-3.981E-02		-6.008E-02	$9.0457\text{x}10^{-2}$	2.106E-01
c_2	2.777E-05	2.041E-05		3.324E-05	$-5.3833\text{x}10^{-5}$	-1.425E-04
c_3	-5.145E-09	-3.654E-09		-6.173E-09	$9.1218\text{x}10^{-9}$	2.722E-08

Validation with flat flame measurements

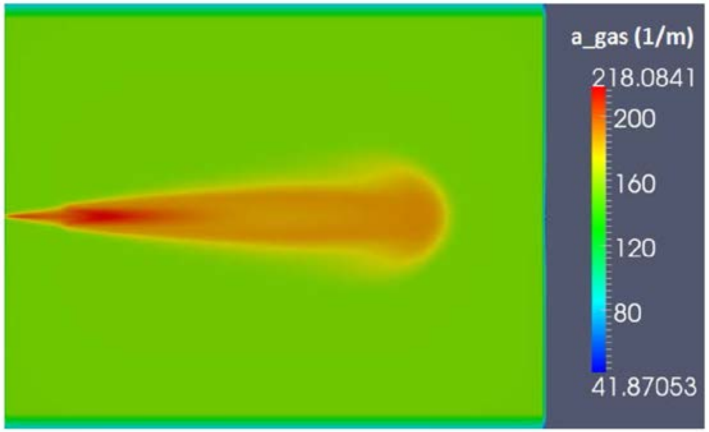






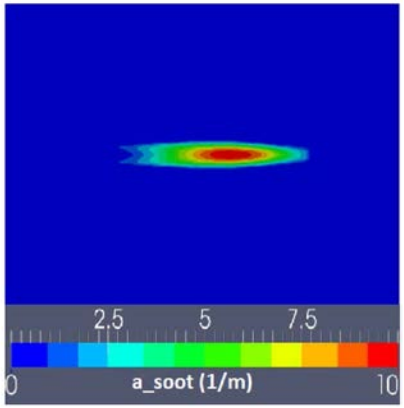


Modelling of spray flame with box radiation model



CO_2 and H_2O
KL ≈ 3
ε ≈ 0.95

N-Heptane
30 kg/m^3
10 % O_2
T_{amb} = 1000 K
T_{ad} = 2010 K



Soot
KL ≈ 0.05
ε ≈ 0.05