Generation of carbon monoxide in fires partially suppressed through water mist application

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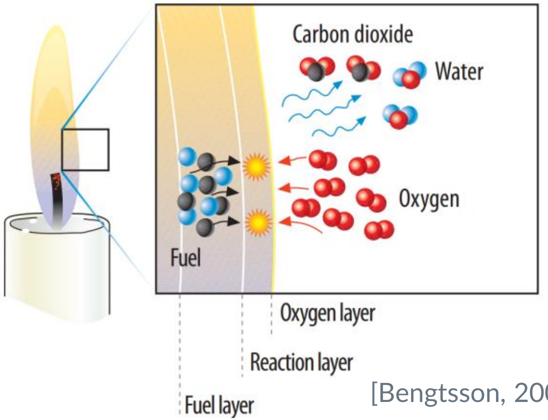
1.

Project background

Diffusion flames

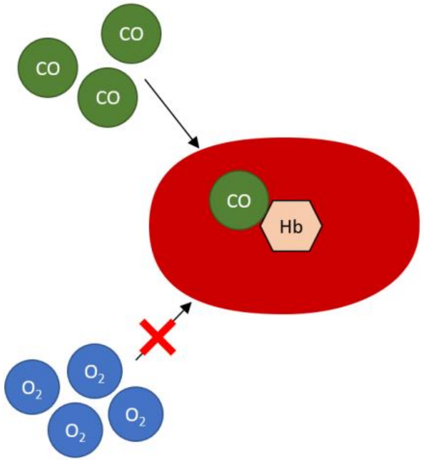
- Most prevalent for built environment fires
- Molecular diffusion of fuel and oxygen
- Inefficient mixing leads to generation of by-products, including CO



[Bengtsson, 2001]

Carbon monoxide

- Asphyxiant – Anaemic hypoxia
- Lowers oxygen delivery capacity of blood
- Accounts for 2/3 of fire deaths within enclosures
- Particularly important for scenarios with extended egress conditions



Fire suppression by water

- Increased prevalence of fire suppression systems due to progression to bigger/more complex buildings
- Research focused on factors behind suppression through water on extinction/suppression
  - Limited consideration of factors involved
- Complex physio-chemical process with many mechanisms

2.

Aim and objective

Aim

- To contribute knowledge of fires subject to suppression by water droplets;
  - specifically, the interaction of fine water droplets on the gas phase chemistry of fire, the interruption of the combustion chemical process and resulting generation of carbon monoxide

Objective

- To experimentally assess the factors which influence the rate, and significance, of carbon monoxide generation within partially suppressed fires
- Factors considered:
  - Water droplet size
  - Rate of water
  - Fuel type
  - HRR

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3.
Methodology

Methodology

- Literature review
  - Existing analogous experimental studies
  - Suppression/species production mechanisms
- Design experimental set-up
- Perform experiments
  - Analyse consistency and trends of results
- Compare trends in data with theory to determine key influencing factors

4.
Literature review

Physical and Chemical Mechanisms

- Droplets interact with combustion through:
  - Cooling
  - Inerting
  - Thermal radiation attenuation
  - Inhibiting
  - Blanketing
  - Flame blow-off
- Droplet size/speed determines applicability of each mechanism
- Combustion processes consist of many thousands of elementary reactions

Existing analogous experimental studies

- 20 studies of droplet interaction with fire
  - Focused on HRR and temperatures
  - Diverse range of fuels, scales, ventilation conditions and droplet sizes
- Majority of studies show:
  - Significant short duration peak in CO concentrations detected
  - Typically water sprays reduce heat release rate, quantity of combustion, and therefore possible reactions to generate products of combustion
- Smaller characteristic diameter sprays have larger increases in CO concentrations

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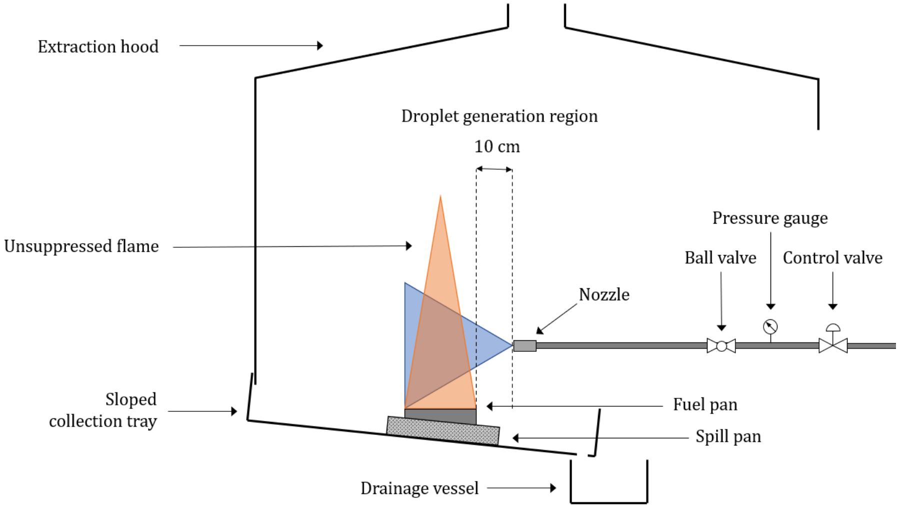
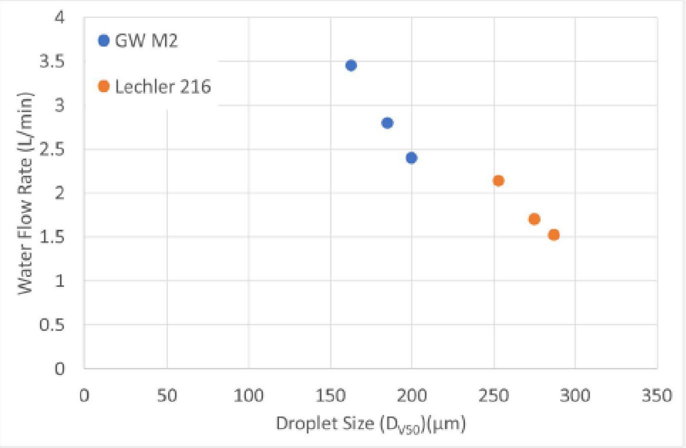
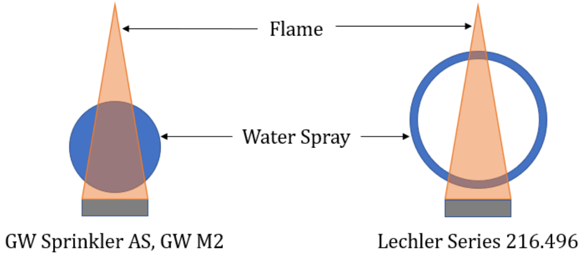
5.
Experimental set-up

Experimental set-up

- Gas phase chemistry
  - Perpendicular discharge
- Droplet size and flow rate
- Fuels – Heptane, propane
- Fire size – 40-80 kW
- Nozzles – Solid cone, hollow cone



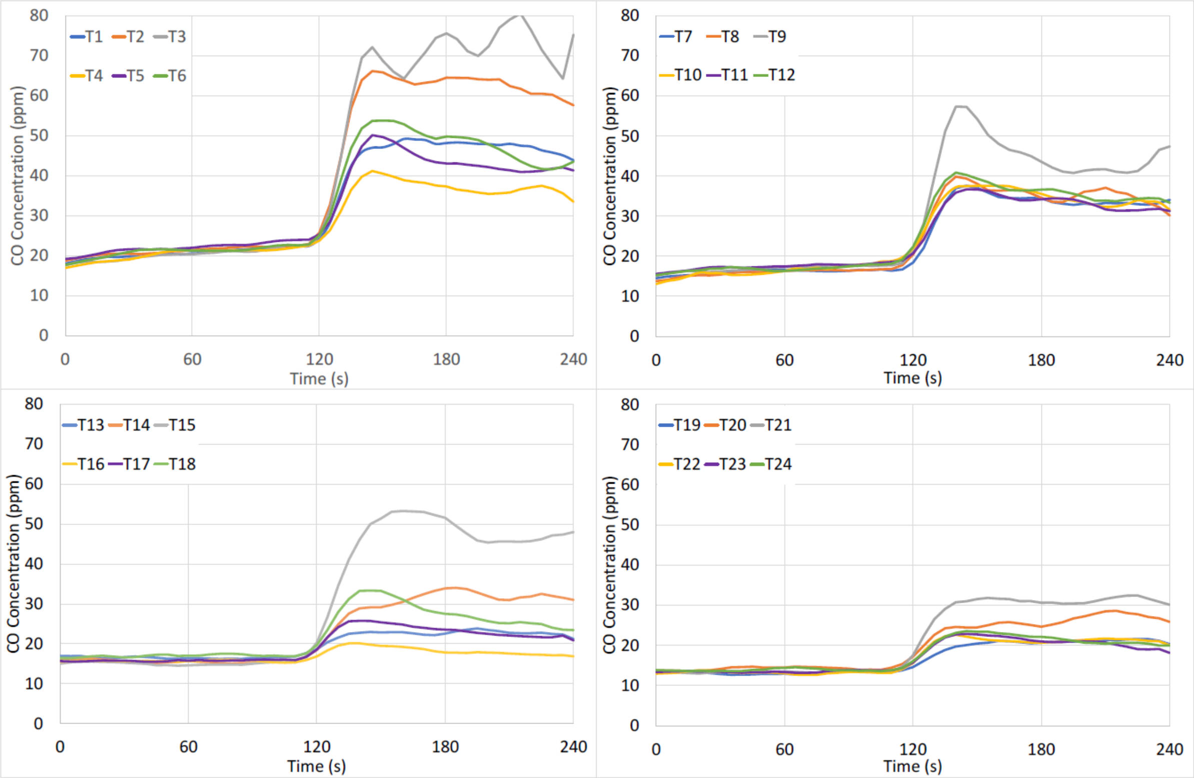




6.

Results

Liquid and gaseous fuels – CO Conc



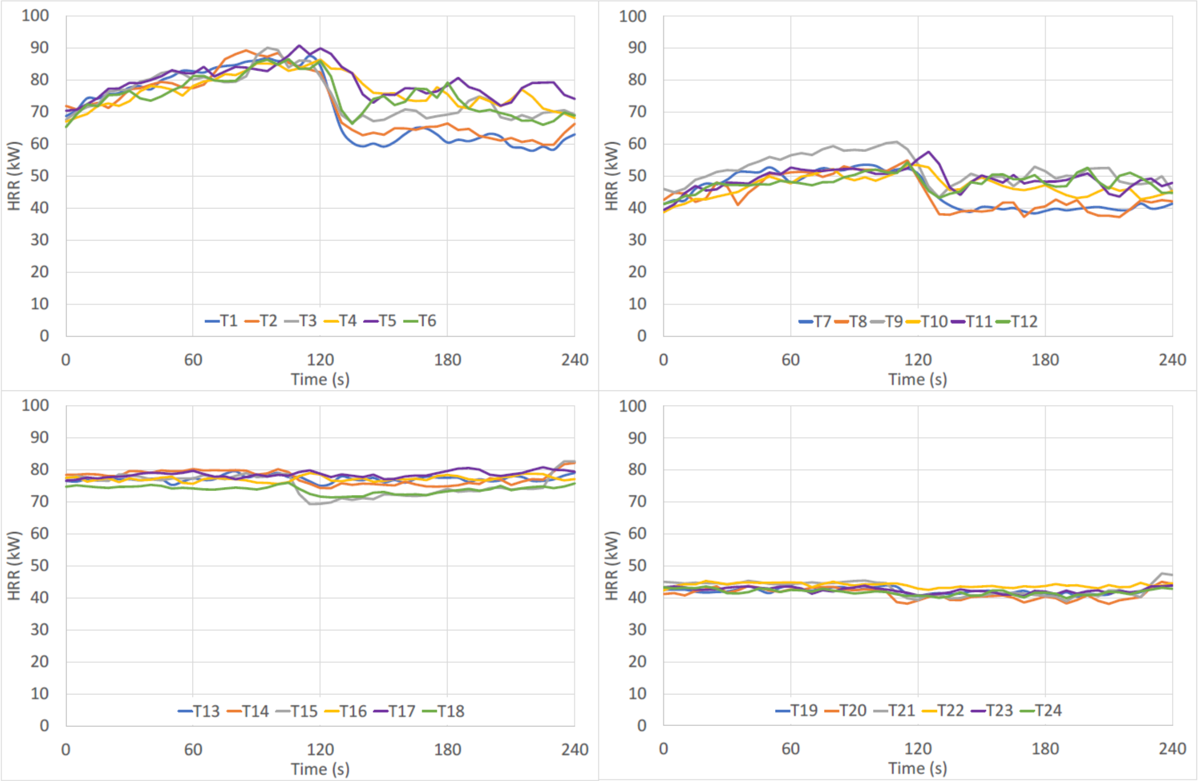
Top left: 80 kW Heptane;

Top right: 40 kW Heptane;

Bottom left: 80 kW Propane;

Bottom right: 40 kW Propane

Liquid and gaseous fuels – HRR



Top left: 80 kW Heptane;

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Water interacting with flame

- Water flux only relevant where it directly interacts with combustion
- Droplet-flame interaction volume proportional to volume evaporated

Test ID	Fuel	HRR	Nozzle	Pressure (bar)	Volume Evaporated (L)
T1	Liquid	High	GW M2	1.5	1.19±0.05
T2	Liquid	High	GW M2	2	1.52±0.07
T3	Liquid	High	GW M2	3	2.02±0.22
T4	Liquid	High	Lechler 216	1.5	1.12±0.06
T5	Liquid	High	Lechler 216	2	1.25±0.07
T6	Liquid	High	Lechler 216	3	1.53±0.04
T7	Liquid	Low	GW M2	1.5	0.97±0.01
T8	Liquid	Low	GW M2	2	1.24±0.08
T9	Liquid	Low	GW M2	3	1.73±0.19
T10	Liquid	Low	Lechler 216	1.5	0.81±0.08
T11	Liquid	Low	Lechler 216	2	0.87±0.10
T12	Liquid	Low	Lechler 216	3	0.83±0.55
T13	Gas	High	GW M2	1.5	1.31±0.08
T14	Gas	High	GW M2	2	1.67±0.06
T15	Gas	High	GW M2	3	2.16±0.26
T16	Gas	High	Lechler 216	1.5	1.07±0.04
T17	Gas	High	Lechler 216	2	1.19±0.10
T18	Gas	High	Lechler 216	3	1.47±0.08
T19	Gas	Low	GW M2	1.5	1.01±0.05
T20	Gas	Low	GW M2	2	1.23±0.11
T21	Gas	Low	GW M2	3	2.04±0.71
T22	Gas	Low	Lechler 216	1.5	0.85±0.07
T23	Gas	Low	Lechler 216	2	0.74±0.09
T24	Gas	Low	Lechler 216	3	1.01±0.04

7.

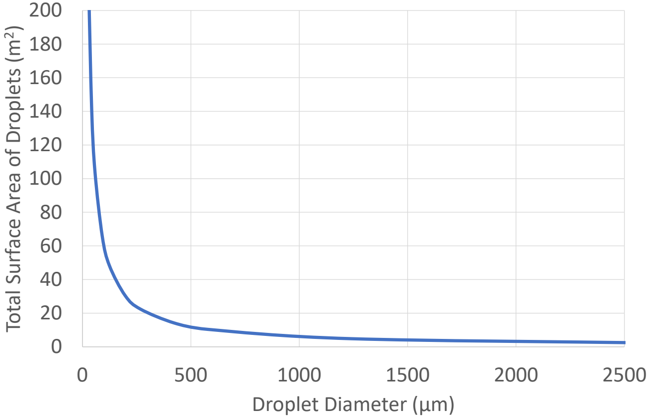
Discussion

Variable analysis

- Visualisation of trends

Variable analysis

- Smaller droplets
  - Absorb more heat cooling the reaction
  - Generate more inert H_2O vapour



Variable analysis

- Higher water flux
  - More droplets to absorb heat and evaporate

CO generation – Fuel chemistry

- Fuel pan and sandbox burner result in different flame shapes
- For a given HRR, similar amounts of water evaporated for both fuels. However, significantly higher levels of CO increase for heptane
- Fuels producing greater levels of CO under free burning conditions are more influenced by combustion interruption by water mist

Test ID	Volume Evaporated (L)	Volume Evaporated Difference	CO Conc. Increase (%)	CO Conc. Increase Difference
T1 - Heptane	1.19±0.05	10%	135±17	+255%
T13 - Propane	1.31±0.08		38±3	
T2 - Heptane	1.52±0.07	10%	200±20	+90%
T14 - Propane	1.67±0.06		105±9	
T3 - Heptane	2.02±0.22	7%	264±28	+17%
T15 - Propane	2.16±0.26		226±10	
T4 - Heptane	1.12±0.06	4%	86±23	+514%
T16 - Propane	1.07±0.04		14±2	
T5 - Heptane	1.25±0.07	5%	101±16	+120%
T17 - Propane	1.19±0.10		46±2	
T6 - Heptane	1.53±0.04	4%	131±20	+122%
T18 - Propane	1.47±0.08		59±5	
T7 - Heptane	0.97±0.01	4%	112±12	+87%
T19 - Propane	1.01±0.05		60±6	
T8 - Heptane	1.24±0.08	1%	123±18	+45%
T20 - Propane	1.23±0.11		85±8	
T9 - Heptane	1.73±0.19	18%	164±17	+22%
T21 - Propane	2.04±0.71		134±4	
T10 - Heptane	0.81±0.08	5%	119±25	+98%
T22 - Propane	0.85±0.07		60±7	
T11 - Heptane	0.87±0.10	15%	95±12	+76%
T23 - Propane	0.74±0.09		54±4	
T12 - Heptane	0.83±0.55	22%	114±11	+111%
T24 - Propane	1.01±0.04		54±6	

Implications for fire engineering designs

- FSE designs on the basis of predicted toxicity dose potentially underestimate levels of toxic exposure
- Where mist suppression is sufficient to significantly reduce HRR, the rate of CO generation is significantly reduced
- Applicable fire scenarios are those featuring extended egress conditions and suppression systems
- Consideration of more conservative safety factor

8.

Conclusions

Conclusions

- Water droplets interrupt the combustion process and pathway to oxidation through many different mechanisms
- Minor reductions to heat release rate, with increases in CO concentrations up to 250%
- Most significant factors:
  - Droplet flame interaction volume
  - Characteristic size of water droplets
  - Water flux applied
- Suggestion of more conservative species yields in certain fire scenarios
- Proof of concept to a largely under explored phenomenon

9.
Questions

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10.

Additional figures

Droplet distribution