28èmes journées du GDR Feux

EFFECTS OF VENTILATION FLOW RATE AND FUEL PAN DIAMETER ON THE DEVELOPMENT OF FIRE IN A CONFINED AND MECHANICALLY UNDER-VENTILATED FACILITY

Yessica Montero, J.C. Sautet, A. Coppalle,
UMR 6614 CORIA, INSA Rouen

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Planning

General Context → Parameters Estimation → Experimental Setup → Operational Conditions → Results → Conclusions and Perspectives

General Context - Fire in confined environments

Mechanically ventilated compartments are interesting:

- Nuclear plants
- Dangerous substances (toxic materials).

The confined nature of this installations creates a particular problem in the fire event.

- Identify the conditions under which the flames are maintained:
  - Function of the combustion conditions (dimensions and type of fuel)
  - In a function of the ventilation conditions

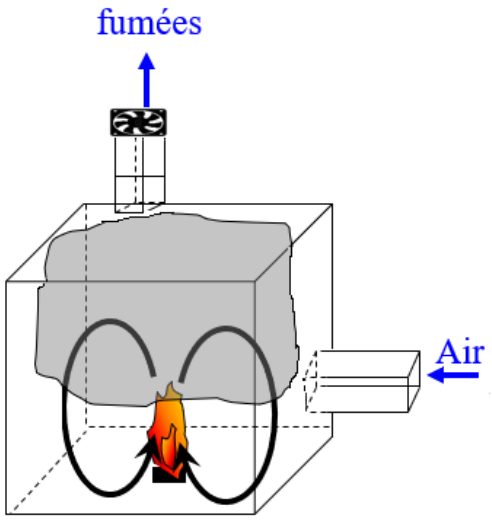


Fig. 1- Controlled Ventilation

Study under-ventilated combustion

→ Characterize the combustion products

→ Know the influence of ventilation → Fuel pan size

Parameter Estimation

- **Mass Loss Rate:**

$$1.\ \dot{m}_{fuel} = \frac{dm}{dt}\ (\frac{g}{s})$$

$$2.\ MLR = \frac{1}{A}\dot{m}_{fuel}\ (\frac{g}{sm^2})$$

- **Heat Release Rate:**

$$3.\ HRR = \dot{m}_{fuel} * \Delta H\ (kW)$$

- **Global equivalence Ratio:**

$$4.\ GER = \frac{\dot{m}_{fuel}/\dot{m}_{Air}}{\left(\dot{m}_{fuel}/\dot{m}_{Air}\right)_{st}}$$

$\mathbf{GER = 1}$: **Stoichiometric**
$\mathbf{GER < 1}$: **Over ventilated**
$\mathbf{GER > 1}$: **Under – ventiladed**

- **Species Yield:**

$$5.\ Y_i = \frac{X_i MW_i(\dot{m}_{fuel} + \dot{m}_{Air})}{\dot{m}_{fuel} MW_{Air}}$$

Nomenclature:

- $\dot{m}_{fuel}$: Fuel burning Rate (g/s)
- **MLR:** Fuel burning rate ($\frac{g}{sm^2}$)
- $\dot{m}_{Air}$: Air inlet flow rate (g/s)
- ΔH: Heat Combustion (kJ/g)
- **GER:** Global Equivalence Ratio [1]
- Y_i: Species Yield (%) [1]
- X_i: Measured species mole fraction (%)
- MW_i: Species molecular weight (g/mol)
- MW_{Air}: Air molecular weigh (g/mol)

[1] Wieczorek, C. J., Vandsburger, U., & Floyd, J. (2004). Evaluating the global equivalence ratio concept for compartment fires: Part II–Limitations for correlating species yields. *Journal of Fire Protection Engineering*, *14*(3), 175-197.

Experimental Setup

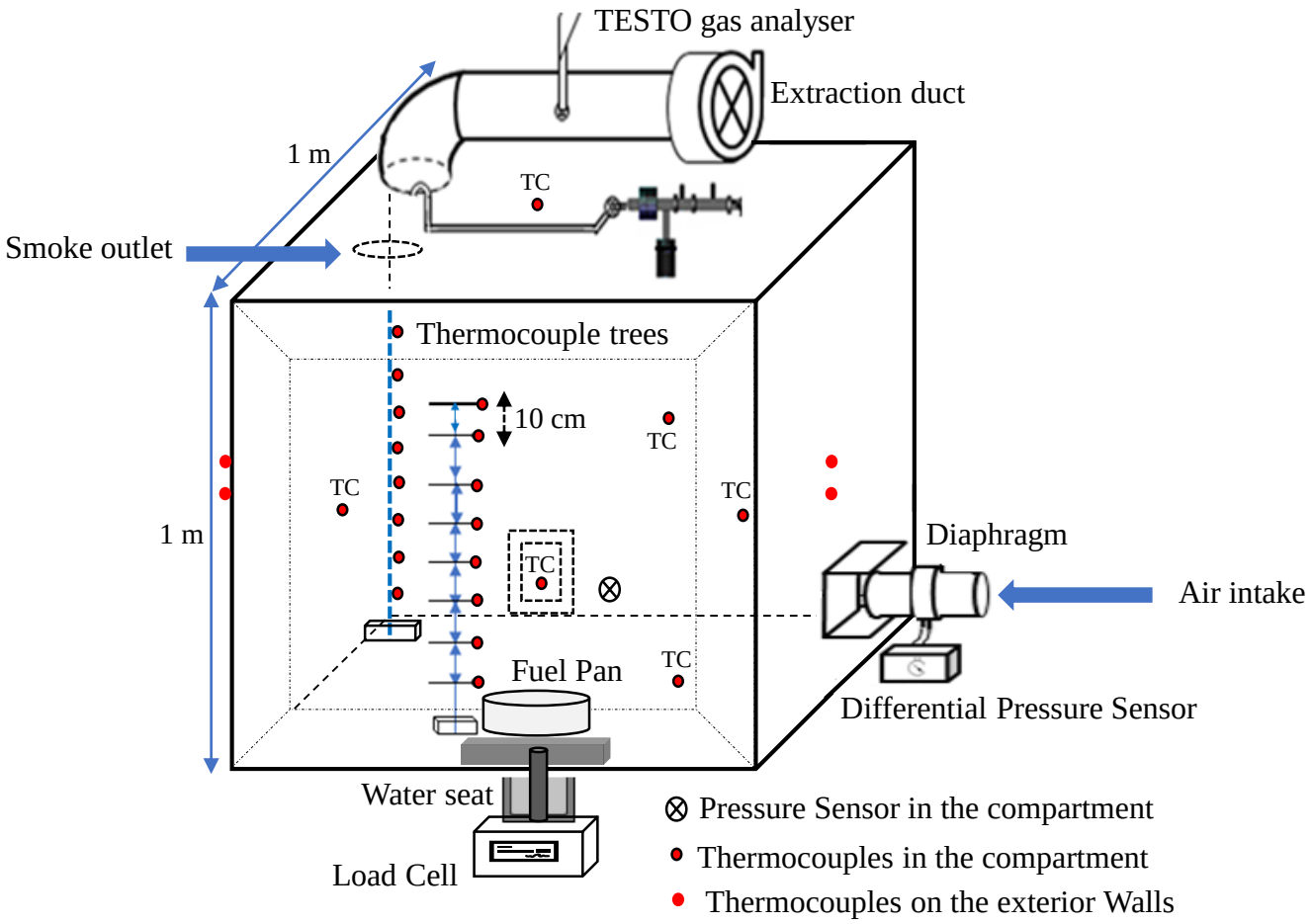


Fig. 2- Scheme of the experimental Setup.

Devices:

- Diaphragm IRIS-80
- 2 Pressure sensor
- TESTO 350 gas analyzer (Extraction duct)
- 26 Thermocouples type K, 1 mm
- Weighing Scale

Experimental Setup - Fuel properties

Table 1. Fuel properties

Experiment	Heat Combustion (kJ/g)	Heat Vaporization (kJ/g)	Flash Point (°C)	Boiling Temperature (°C)	Smoke point height (cm)
Pure n-Heptane [2]	46.4	0.365	-4	98	14.7
Technical Dodecane [2]	49.9	0.361	71	170 - 195	13.7
Mobil DTE Oil [3]	42.1	-	218 - 234	300 - 400	-

[2] Loo, A. X., Coppalle, A., Yon, J., & Aîné, P. (2016). Time-dependent smoke yield and mass loss of pool fires in a reduced-scale mechanically ventilated compartment. *Fire Safety Journal*, *81*, 32-43.

[3] Saario, A., Rebola, A., Coelho, P. J., Costa, M., & Oksanen, A. (2005). Heavy fuel oil combustion in a cylindrical laboratory furnace: measurements and modeling. Fuel, 84(4), 359-369.

Operational Conditions – Fires scenarios

1. Varying ventilation flow rate

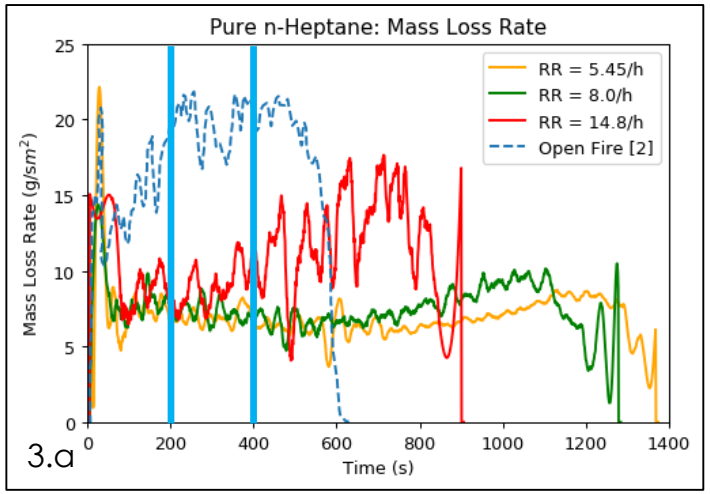
- Renewal Rate: 5.45; 8.0 and 14.8 h^{-1}
- Fixed parameters:
  - Fuel Pan Diameter: 0.19 m
- Fuels:
  - Pure n-Heptane - $\mathbf{C_7H_{16}}$: (Initial mass 266.5 g) = 400ml
  - Technical dodecane- $\mathbf{C_{12}H_{26}}$: (Initial mass 290.2 g) = 400 ml
  - Mobil DTE Lubricant Oil: (Initial mass 156.8 g) = 180 ml
- Comparison between:
  - Fuel Mass Los Rate (MLR)
  - Species Concentration in the extraction duct (O2 and CO)
  - CO Yield (%)

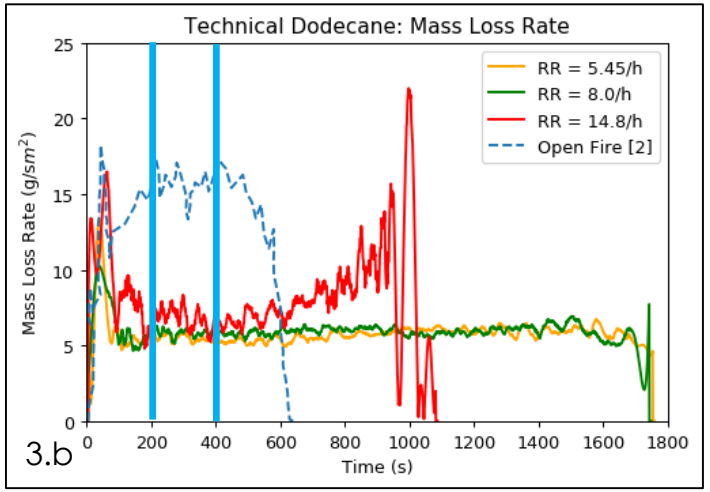
2. Varying fuel pan size

- Fuel Pan Diameter: 0.115; 0.14 and 0.19 m
- Fixed parameters:
  - Renewal Rate: 8.0 h^{-1}
- Fuels:
  - Pure n-Heptane- $\mathbf{C_7H_{16}}$: (Initial mass 266.5 g) = 400ml
  - Technical dodecane- $\mathbf{C_{12}H_{26}}$: (Initial mass 290.2 g) = 400 ml
  - Mobil DTE Lubricant Oil: (Initial mass 156.8 g) = 180 ml
- Comparison between:
  - Fuel Mass Los Rate (MLR)
  - Species Concentration in the extraction duct (O2 and CO)
  - CO Yield (%)

Results: Effects of ventilation flow rate on the development of Fire - Mass Loss Rate (MLR)

Fixed parameter
- Diameter: 0.19 m





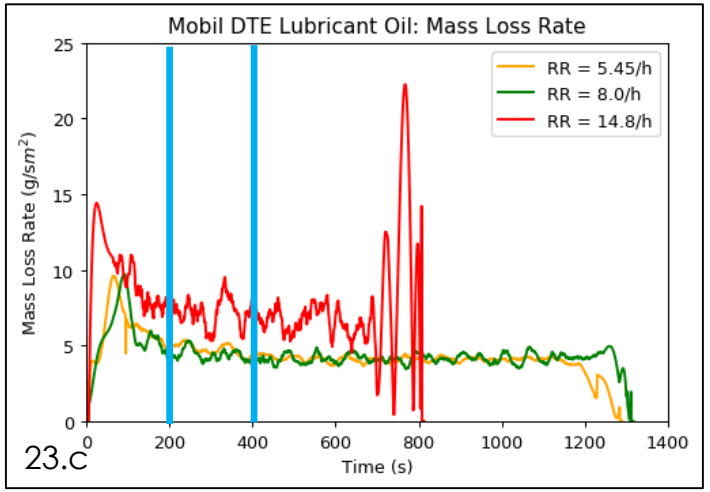
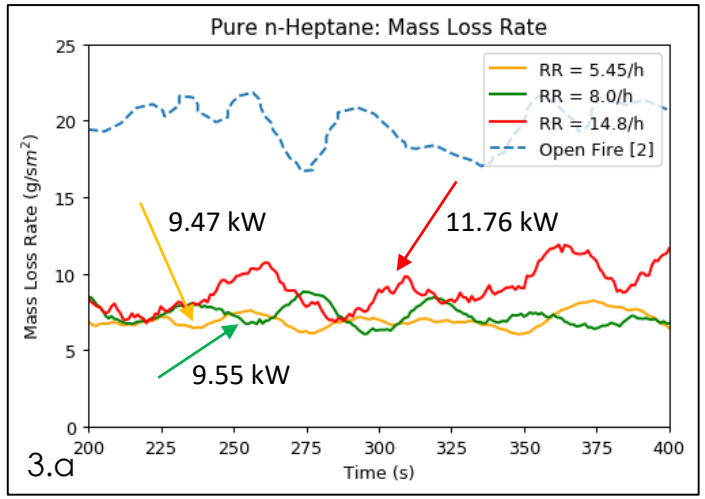


Fig. 3- Effect of fuel Renewal Rate (RR) on the time variation of the Mass Loss rate for the 0.19 m diameter pool fire at RR = 5.45; 8.0 and 14.8 h^{-1}.

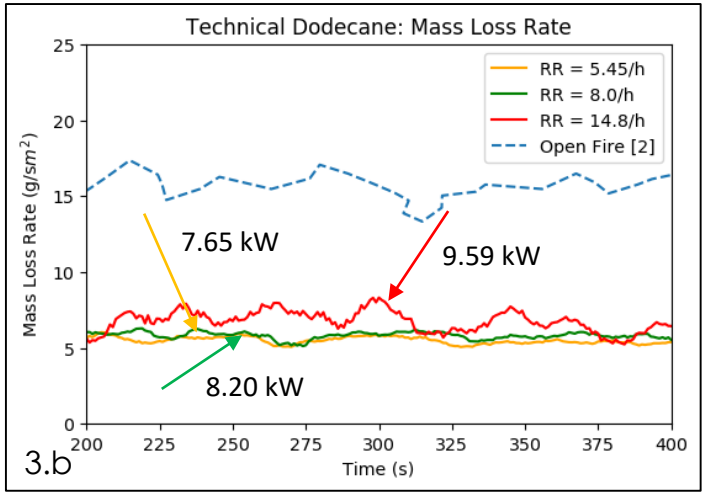
Results: Effects of ventilation flow rate on the development of Fire - Mass Loss Rate (MLR)

Fixed parameter
- Diameter: 0.19 m

GER > 1 for ventilation rate



GER > 1 for 5.45/h and 8.0/h
GER < 1 for 14.8



GER > 1 for 5.45/h
GER < 1 For 8.0/h and 14.8

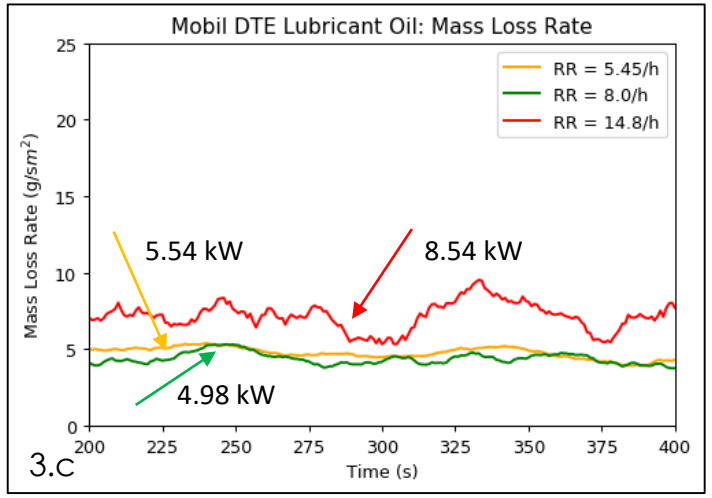


Fig. 3- Effect of fuel Renewal Rate (RR) on the time variation of the Mass Loss rate for the 0.19 m diameter pool fire at RR = 5.45; 8.0 and 14.8 h^{-1}.

Results: Effects of ventilation flow rate on the development of Fire - O2 Concentration

Fixed parameter
- Diameter: 0.19 m

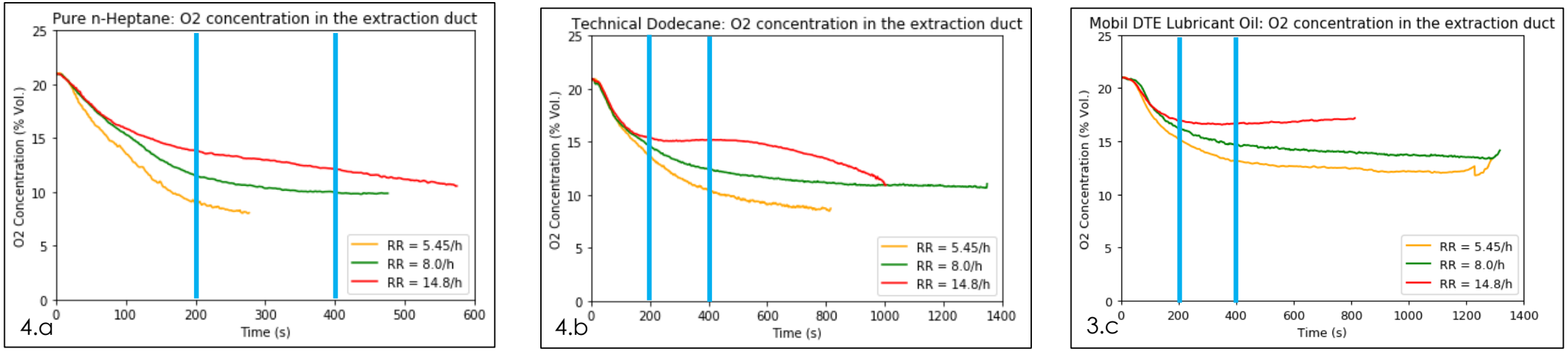


Fig. 4- Oxygen concentration as function of time in the extraction duct for the 0.19 m diameter pool fire at RR = 5.45; 8.0 and 14.8 h^{-1}.

Results: Effects of ventilation flow rate on the development of Fire - CO Concentration

Fixed parameter
- Diameter: 0.19 m

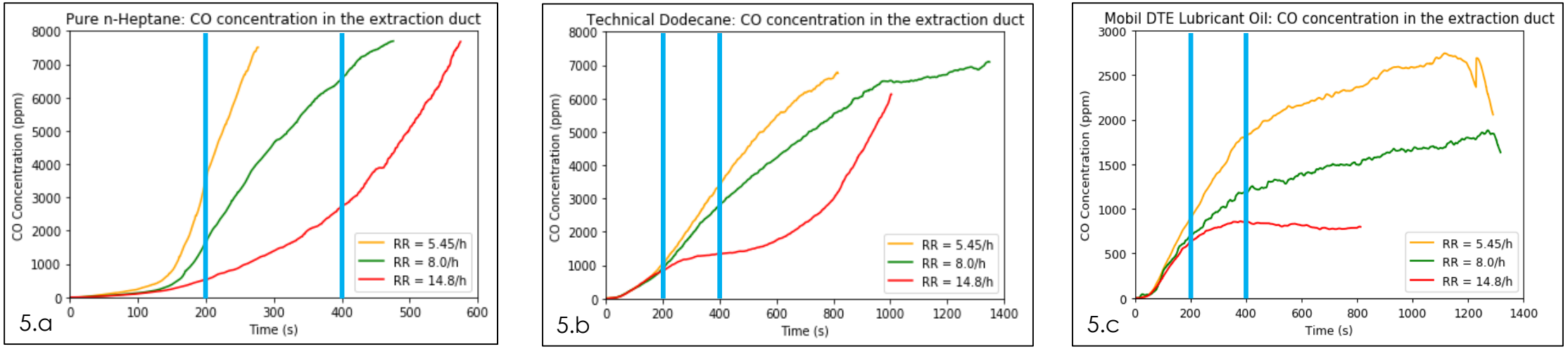


Fig. 5- Carbon monoxide concentration as function of time in the extraction duct for the 0.19 m diameter pool fire at RR = 5.45; 8.0 and 14.8 h^{-1}.

Results summary: Effects of ventilation flow rate on the development of fire

Table 2. Results summary - Effect of ventilation flow rate

Experiment	Initial mass (g)	RR (h^{-1})	Final mass (g)	D (m)	GER	CO Yield-Max (%)
Pure n-Heptane	265.5	5.45	0	0.19	1.74	7.20
		8.0	0		1.35	12.56
		14.8	0		1.04	15.02
T. Dodecane	290.2	5.45	0		1.34	5.29
		8.0	0		1.35	9.74
		14.8	**41.1**		0.74	7.03
Mobil DTE Oil	156.8	5.45	0		1.04	-
		8.0	0		0.66	-
		14.8	0		0.64	-

Results: Effects of fuel pan size on the development of fire - Mass Loss Rate (MLR)

Fixed parameter
- Renewal Rate: 8.0 h^{-1}

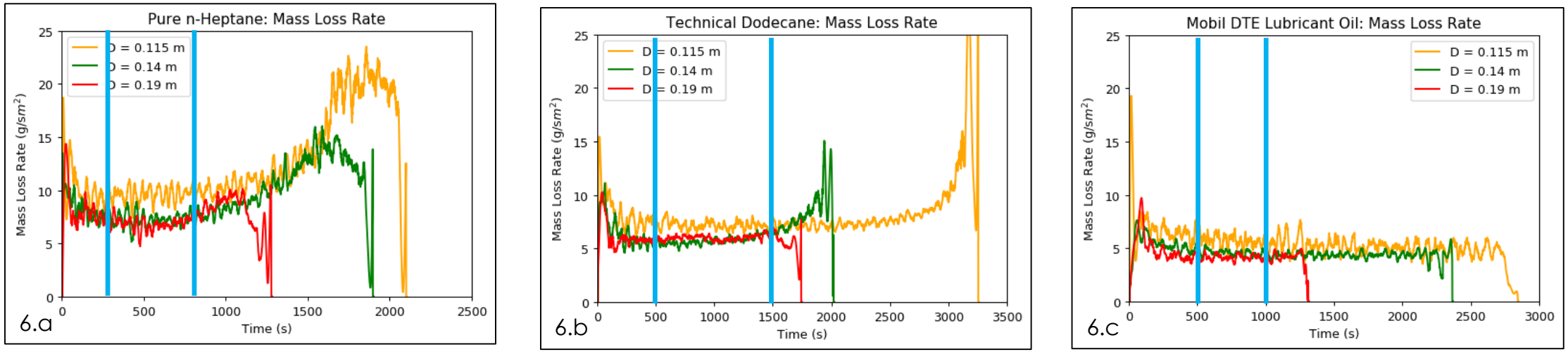
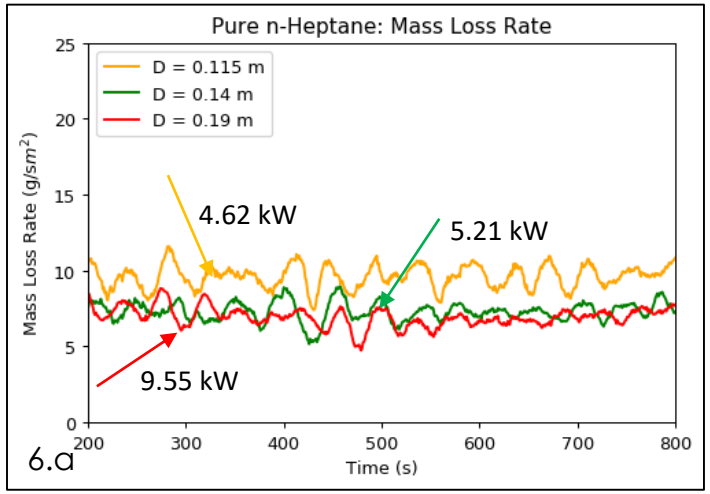


Fig. 6- Effect of fuel pan size on the time variation of the Mass Loss rate for the 0.115; 0.14 and 0.19 m diameter pool fire at RR = 8.0 h^{-1}.

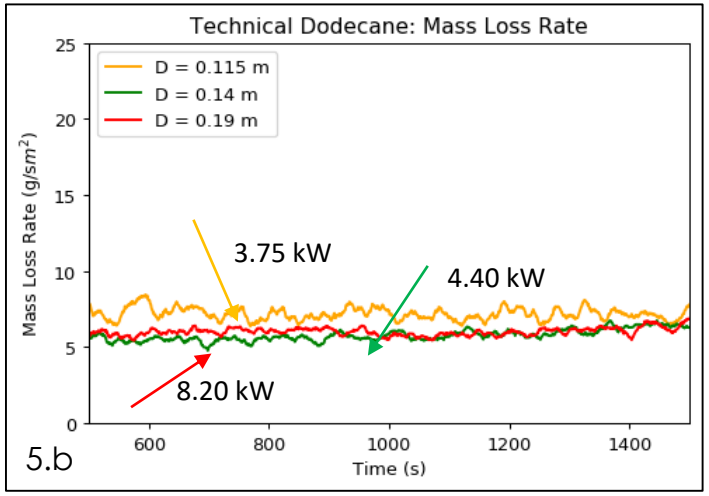
Results: Effects of fuel pan size on the development of fire - Mass Loss Rate (MLR)

Fixed parameter
- Renewal Rate: 8.0 h^{-1}

GER < 1 for 0.115 and 0.14 m
GER > 1 for 0.19 m



GER < 1 for 0.115 and 0.14 m
GER > 1 for 0.19 m



GER < 1 for all fuel pan size

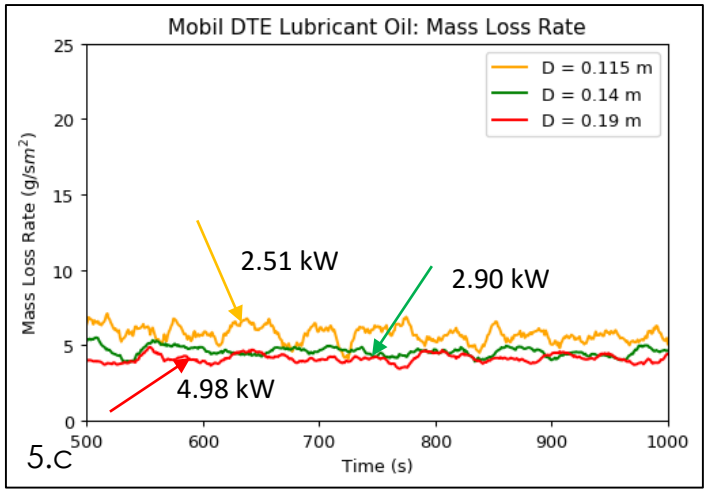


Fig. 6- Effect of fuel pan size on the time variation of the Mass Loss rate for the 0.115; 0.14 and 0.19 m diameter pool fire at RR = 8.0 h^{-1}.

For small diameter (0.115 and 0.14m) the compartment behaves as over ventilated (GER <1)

Results: Effects of fuel pan size on the development of fire - O2 Concentration

Fixed parameter
- Renewal Rate: 8.0 h^{-1}

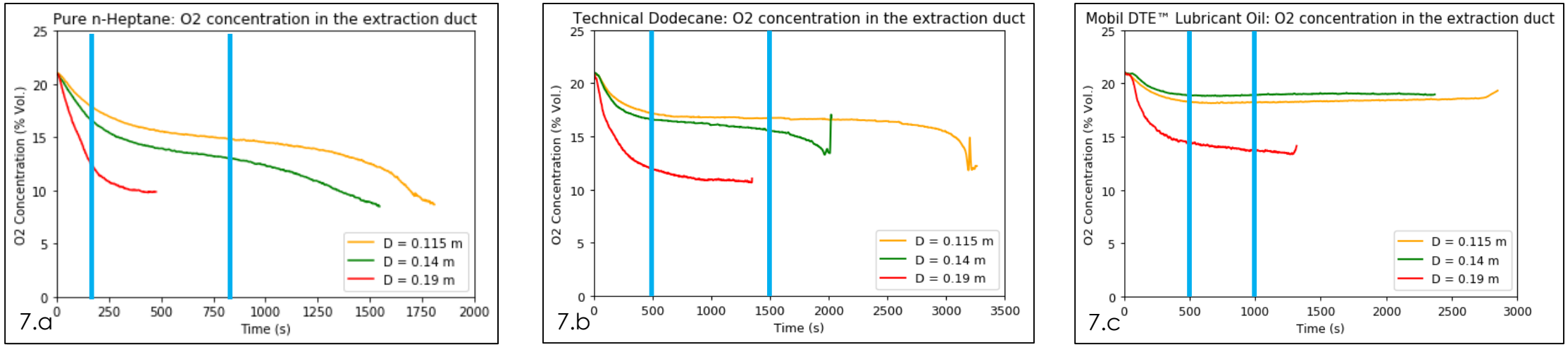


Fig. 7- Effect of fuel pan size on the O2 Concentration in the extraction duct and for the 0.115; 0.14 and 0.19 m diameter pool fire at RR = 8 h^{-1}.

Results: Effects of fuel pan size on the development of fire – CO Concertation

Fixed parameter
- Renewal Rate: 8.0 h^{-1}

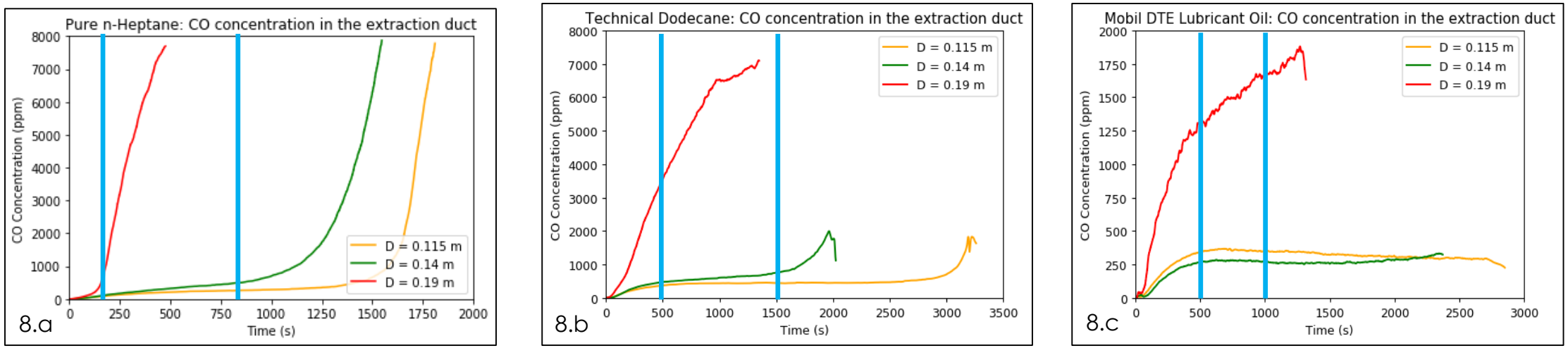


Fig. 8- Effect of fuel pan size on the CO Concentration in the extraction duct and for the 0.115; 0.14 and 0.19 m diameter pool fire at RR = 8 h^{-1}.

Results summary: Effects of fuel pan size on the development of fire

Table 3. Results summary - Effect of fuel pan size

Experiment	Initial mass (g)	D (m)	Final mass (g)	RR (h^{-1})	GER	CO Yield-Max (%)
Pure n-Heptane	265.5	0.115	0	8.0	0.57	9.87
		0.14	0		0.71	9.45
		0.19	0		1.35	12.56
T. Dodecane	290.2	0.115	**25.6**		0.48	2.45
		0.14	**86.8**		0.54	2.42
		0.19	0		1.35	9.74
Mobil DTE Oil	156.8	0.115	0		0.32	-
		0.14	0		0.40	-
		0.19	0		0.66	-

Results: Comparison between Pure n-Heptane, Technical Dodecane and Heavy Oil - (MLR), O2 and CO Concertation

Fixed parameter
- Fuel pan diameter : 0.19 m
- Renewal Rate: 8.0 h^{-1}

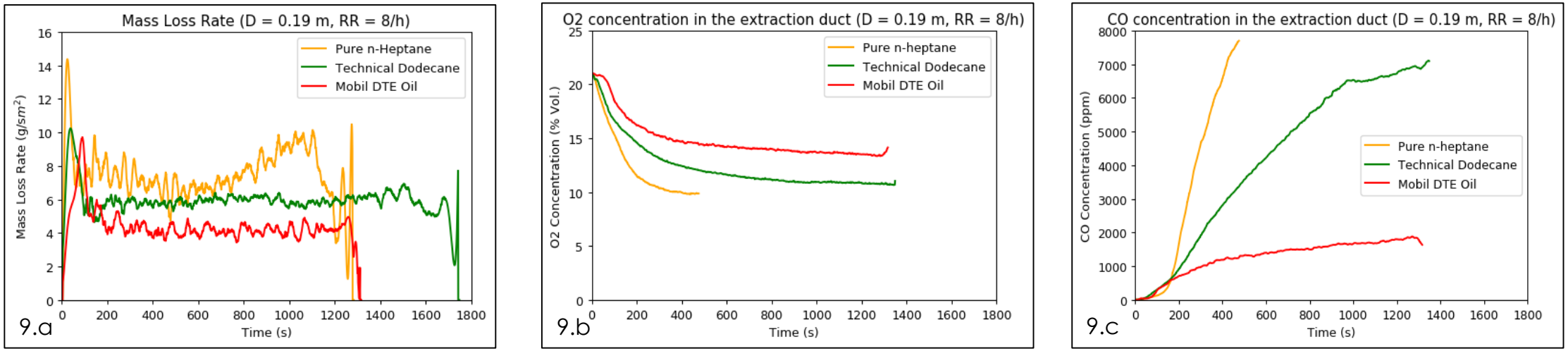


Fig. 9- Evolution of Mass Loss Rate, O2 and CO Concentration over time. Comparison between Pure n-Heptane, Technical Dodecane and Lubricant oil for the 0.19 m diameter pool fire at RR = 8.0 h^{-1}.

Conclusions and Perspectives

Conclusions:

- The increase of ventilation flow rate (Air Charged per Hour) contributes to the decrease in the time burning rate. The same behavior was observed in the case of the variation of the fuel pan size.
- The compartment behaves as under-ventilated (GER > 1) for small ventilation rate.
- The compartment behaves as over-ventilated (GER < 1) for small fuel pan size.
- Carbon monoxide concentration depends strongly on the type of fuel (Pure n-Heptane > Technical dodecane > Hydraulic oil).

Perspectives:

- Continue measurements with heavy fuels.
- Perform measurements of flame properties and soot particles in smoke from under-ventilated fires.
- Perform measurements by changing the position of the air intake.