Definition of protocol for vehicle in-cabin air quality measurments

Presented by:

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- UTAC : Hanaa ER-RBIB
- ARIAMIS : Patrick CHEVRIER

SUMMARY

- The context
- The objective of the study
- Airtight chamber for vehicle housing (the bubble)
- Numerical investigation of the flow topology in the enclosure (CFD)
- Experimental characterization of the airtight enclosure
- Conclusion

PRESENTATION

Thesis: Nadir HAFS

Date : Octobre 2020 – Septembre 2023

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Direction : Benoit SAGOT

Technical supervision:

UTAC : Hanaa ER-RBIB

ARIAMIS : Patrick CHEVRIER

Title: Definition of protocol for vehicle in-cabin air quality measurements.

CONTEXT

- The transport sector is often a source of various and varied pollution, and which results in exposure of commuters.

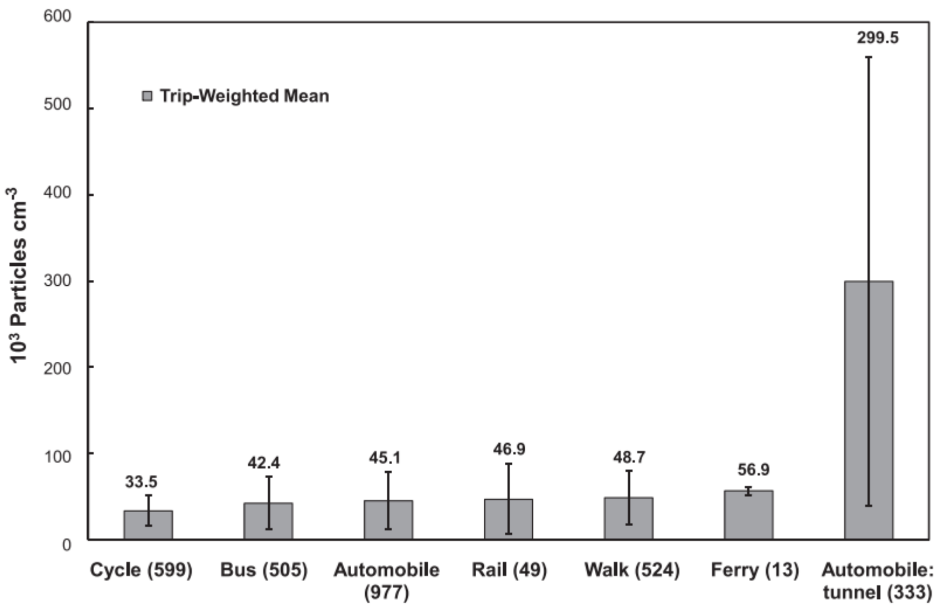


Fig. 2: Path-weighted average of ultrafine particle concentrations in each mode of transport. The number of trips made in each mode is shown in parentheses. (Luke D. Knibbs)

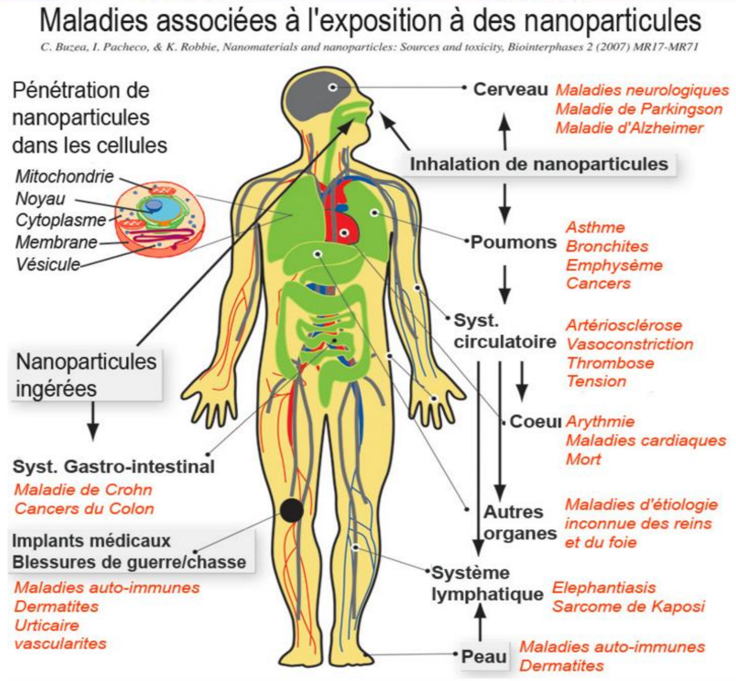


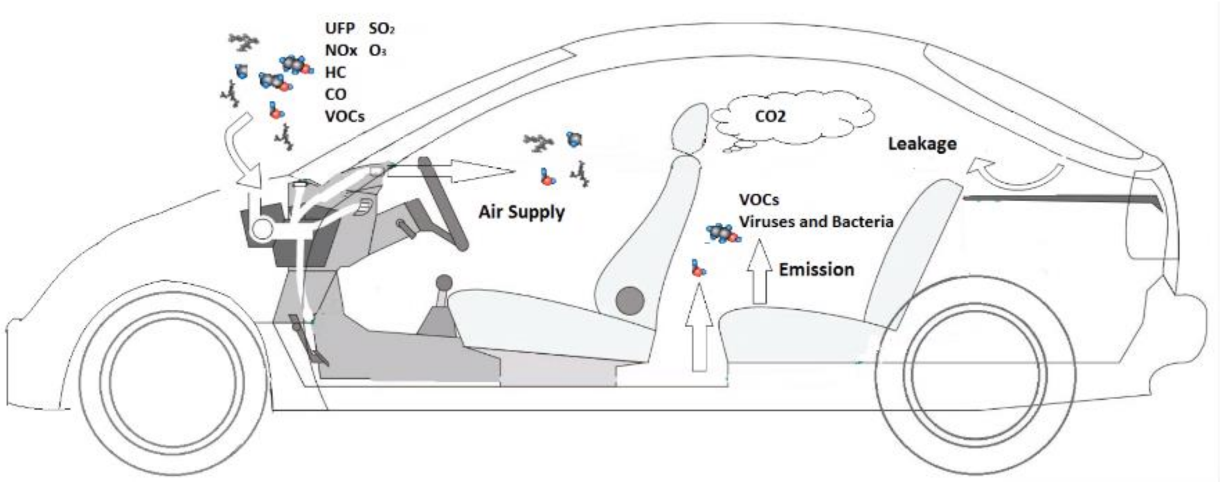
Fig.1 Diseases associated with exposure to nanoparticles (Buzea et al., 2007)

- Inhalation of nanoparticles can cause diseases such as neurological disease, asthma, cancer, bronchitis, blood pressure, heart disease, etc.

- *Cristina Buzea; Ivan I. Pacheco; Kevin Robbie (2007) Nanomaterials and nanoparticles Sources and toxicity*
- *Luke D. Knibbs; Tom Cole-Hunter; Lidia Morawska (2011)* A review of commuter exposure to ultrafine particles and its health effects

OBJECTIVES OF THE STUDY

- Proposal of an innovative chamber for the control of air pollution concentration level outside of car cabins
- Investigation and proposal of a protocol for better concentration measurements of pollutants (VOC, NOx, Particulate, O3) and CO2 into car cabins.
- Determine the representativeness of measurements of general concentrations of VOCs compared to measurements by speciation



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AIRTIGHT CHAMBER FOR VEHICLE HOUSING

Fig.4 structure of the measuring bubble

Fig.5 bubble equipment

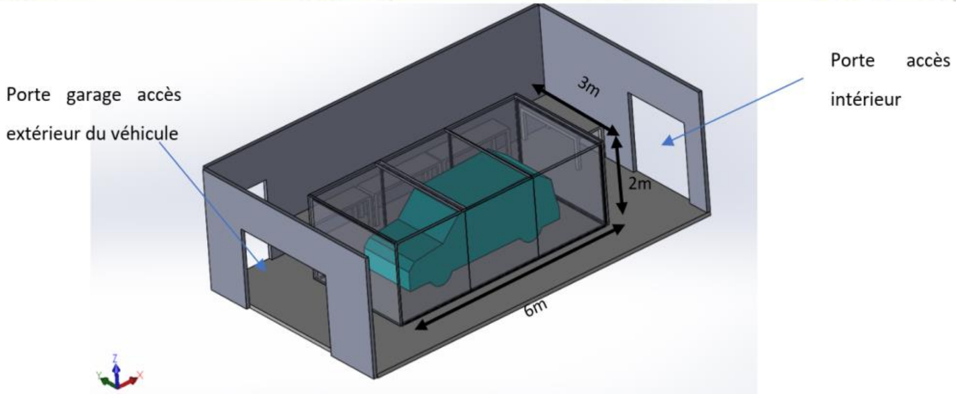
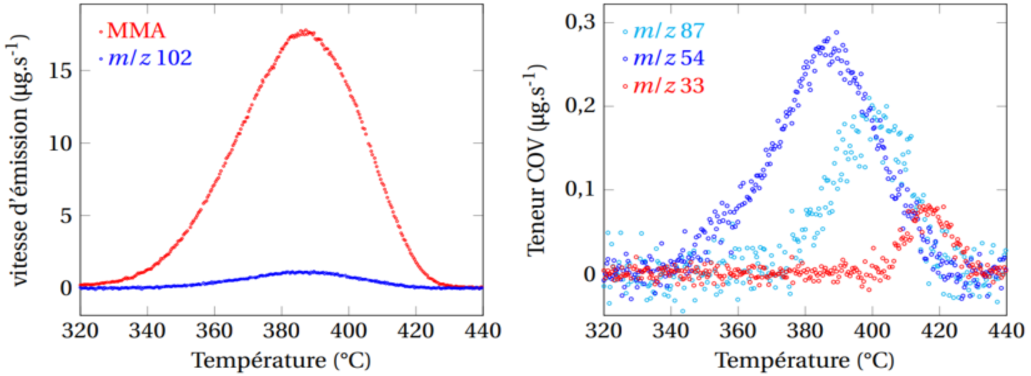


Fig.3 CAD of the bubble and the measurement room

The dimensions of the bubble :

- 6 m long, 3 m wide and 2 m high. The room is equipped with worktables, a fan and a gauze extractor.



Real-time monitoring of VOCs resulting from the thermal degradation of PMMA (Latappy (2004))

Hubert Latappy. Étude des COV issus de la dégradation thermique et oxydative des matériaux polymères. Polymères. Université Paris Sud - Paris XI, 2014.

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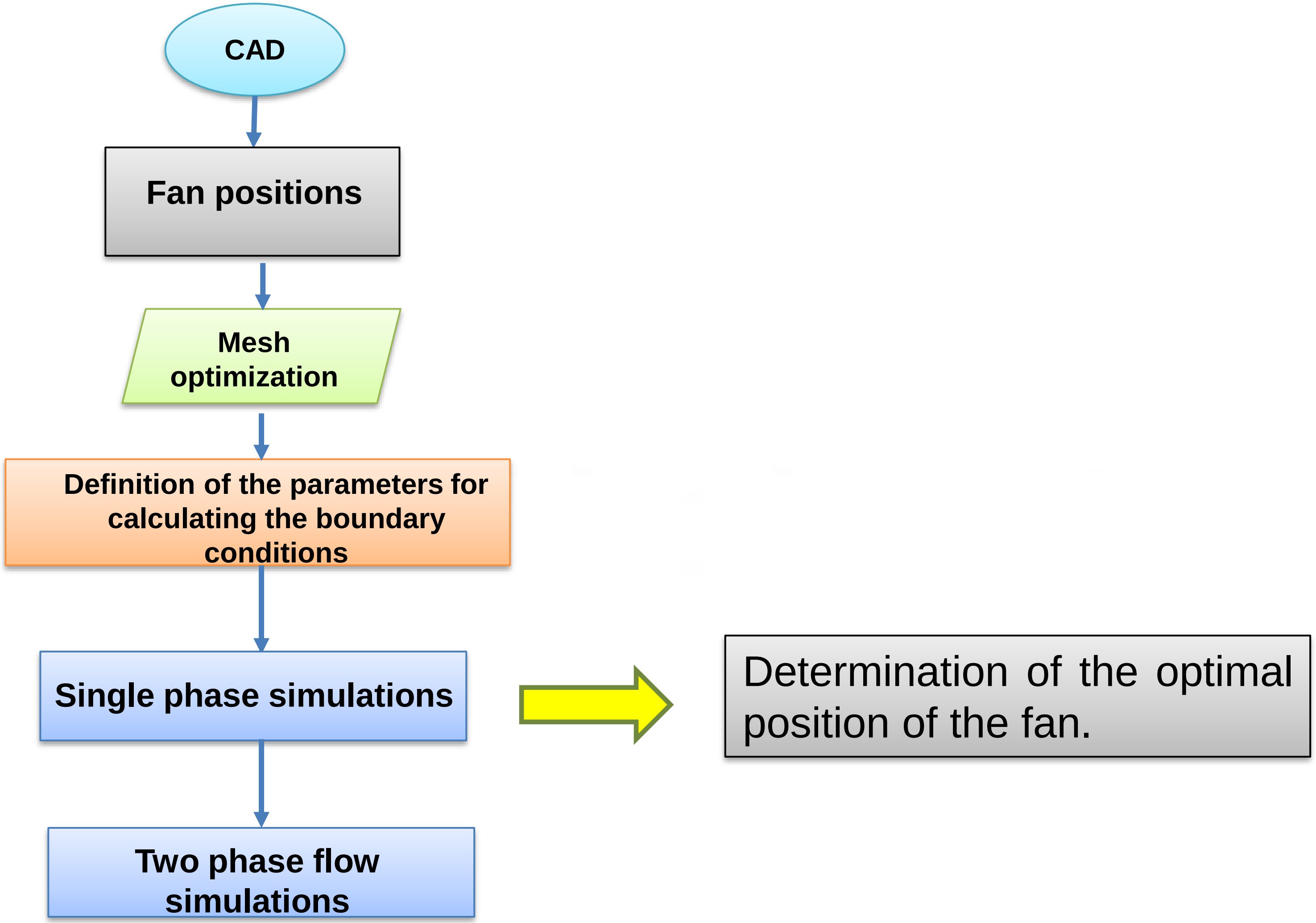
NUMERICAL INVESTIGATION OF THE FLOW TOPOLOGY IN THE BUBBLE (CFD)

NUMERICAL APPROACH PROCEDURE



VEHICLE CAD

- Design of the car CAD
- Fusion of facets of the car(more than 20,000 facets)
- Mesh optimization

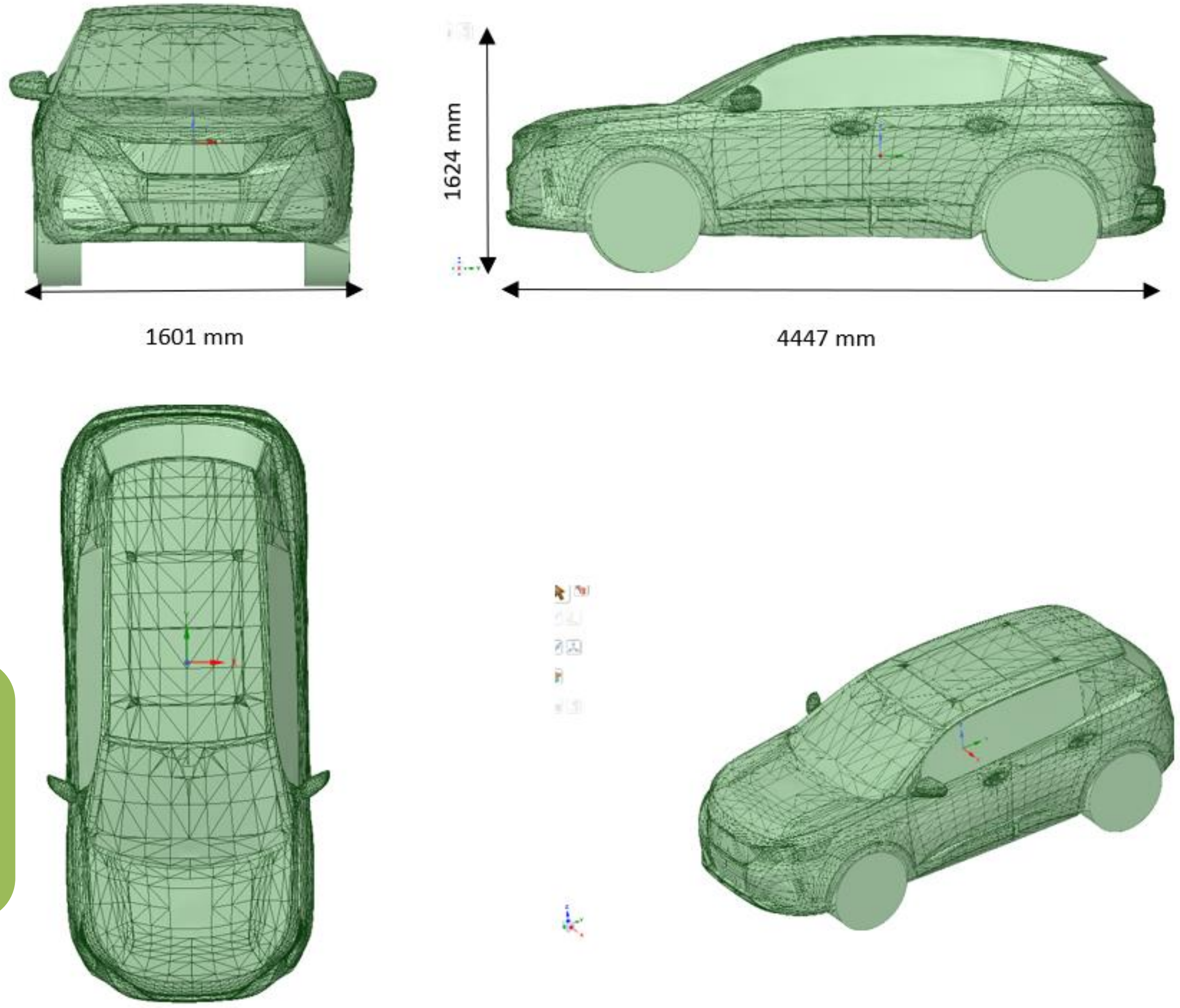
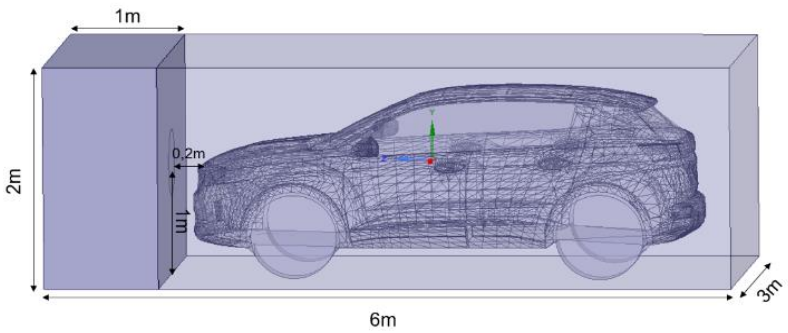


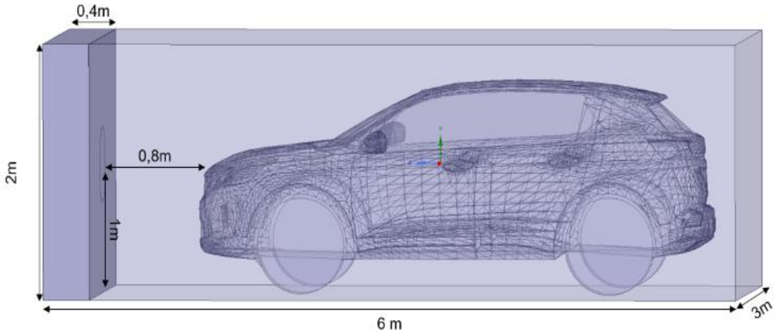
Fig.6 CAD representation of the vehicle

SIMULATIONS CONFIGURATIONS

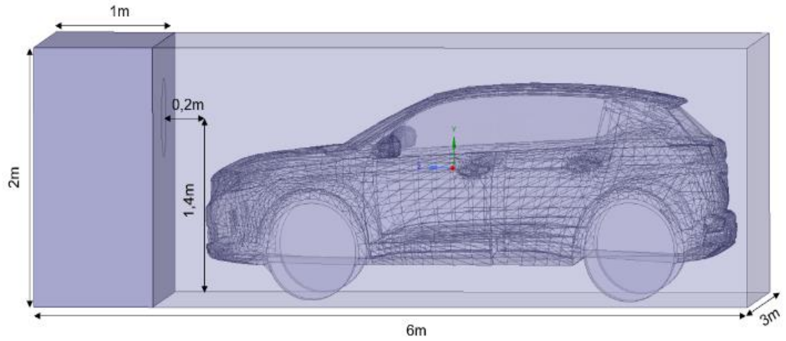
- Creation of 4 fan positioning configurations.
- Study of the the influence of the fan position on the flow structure around the vehicle.



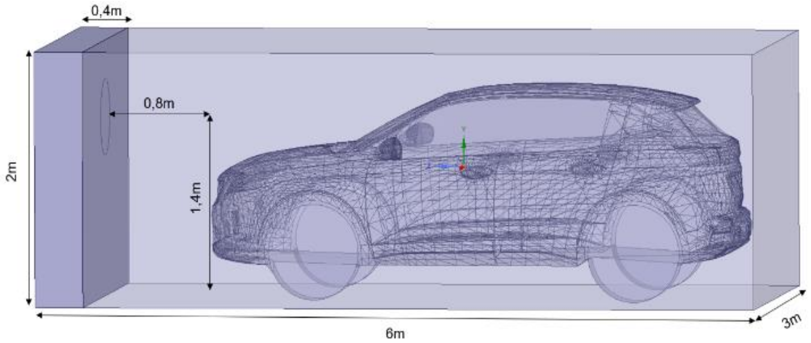
Position 1



Position 2



Position 3



Position 4

Fig. 7 : Location of the fan center for the four configurations studied

MESHING

- an unstructured triangular surface meshing and tetrahedral volume mesh was applied.
- 8-layer inflation-type mesh for boundary layers.
- Mesh cells number between (3-15 millions cells)

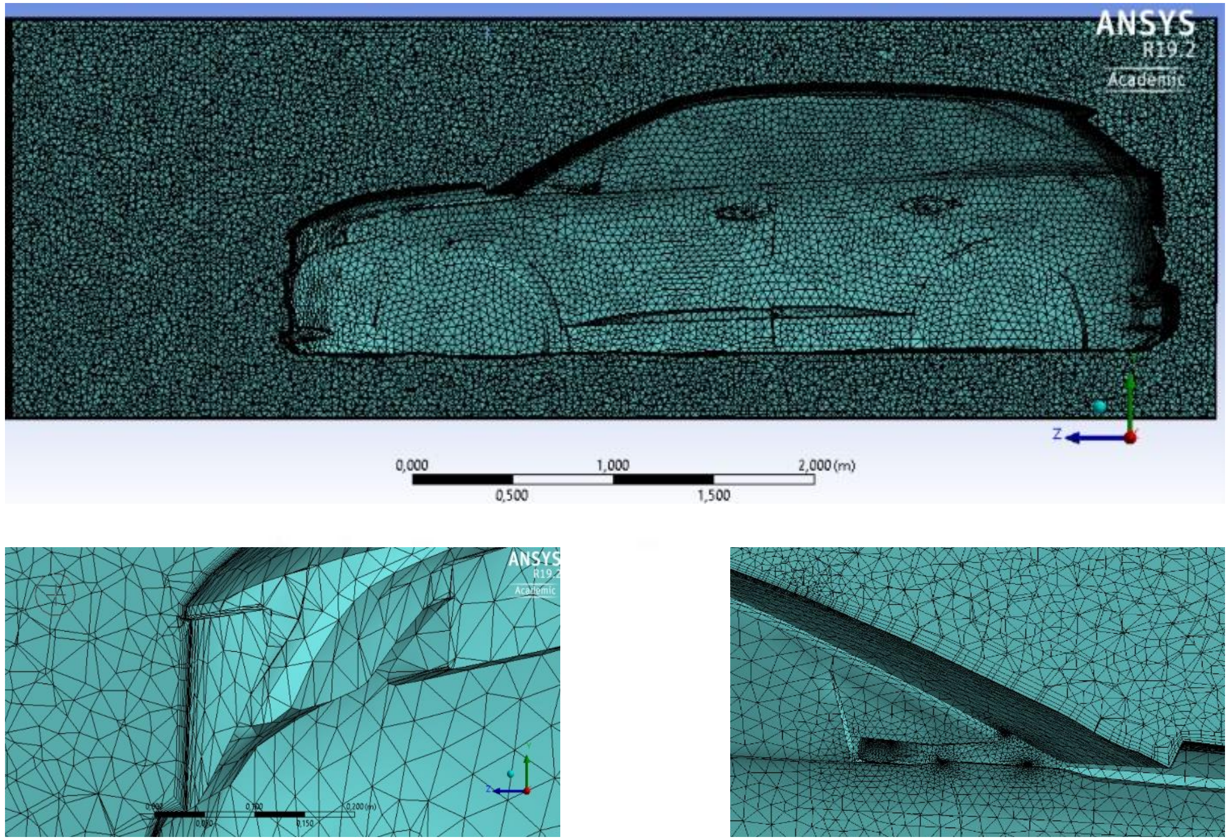


Fig.8 Global mesh of the fluid volume in the bubble and around the vehicle.

SIMULATIONS CONDITIONS

- **Single phase flow (air flow)**

➢ The turbulence model used is the K-omega SST

➢ For the boundary conditions the surfaces of the bubble and of the vehicle were considered as "WALL" conditions.

➢ The fan is considered using "FAN" condition

➢ The pressure jump in the fan is : 294 pa.

- **Unsteady two phase flow (With particles)**

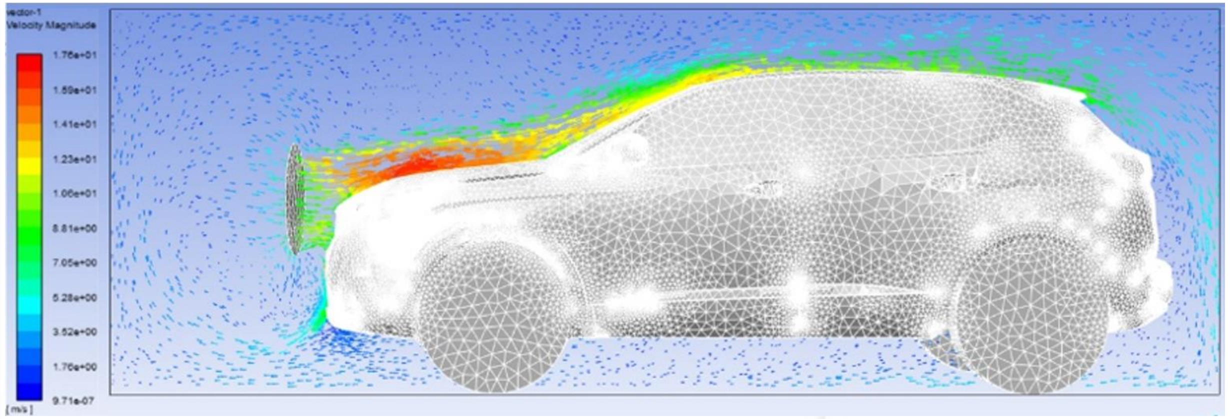
➢ Lagrangian approach used

➢ Particle injection speed (15 m/s) same as that of the discharged air (measured experimentally)

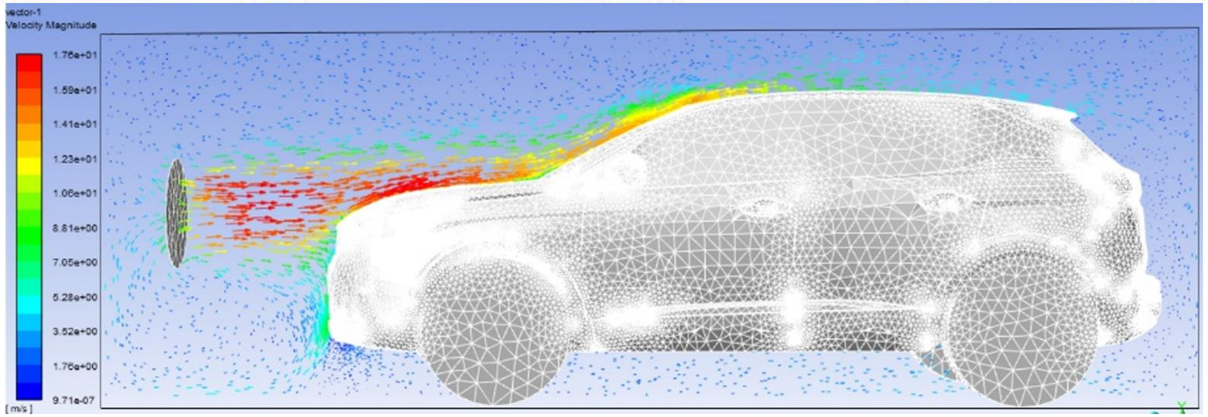
➢ The size of the particles studied are 2.5 µm, 1 µm and 0.1 µm.

➢ Forces taken into account: Gravitation, Brownian, Saffman Lift and Drag.

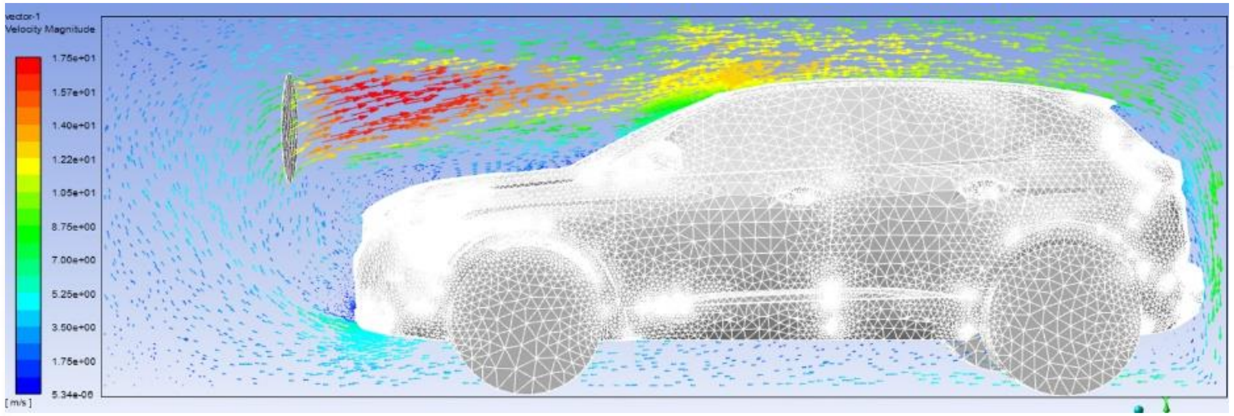
SINGLE PHASE FLOW SIMULATIONS RESULTS



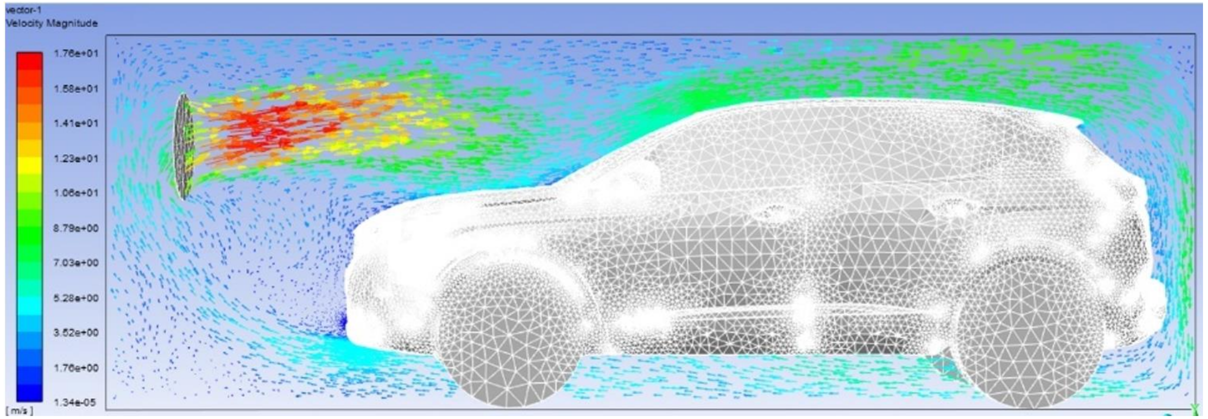
Position 1



Position 2



Position 3



Position 4

Fig. 9 Vectors fields of the velocity magnitude around the vehicle for position 1, position 2, position 3 and position 4 of the fan

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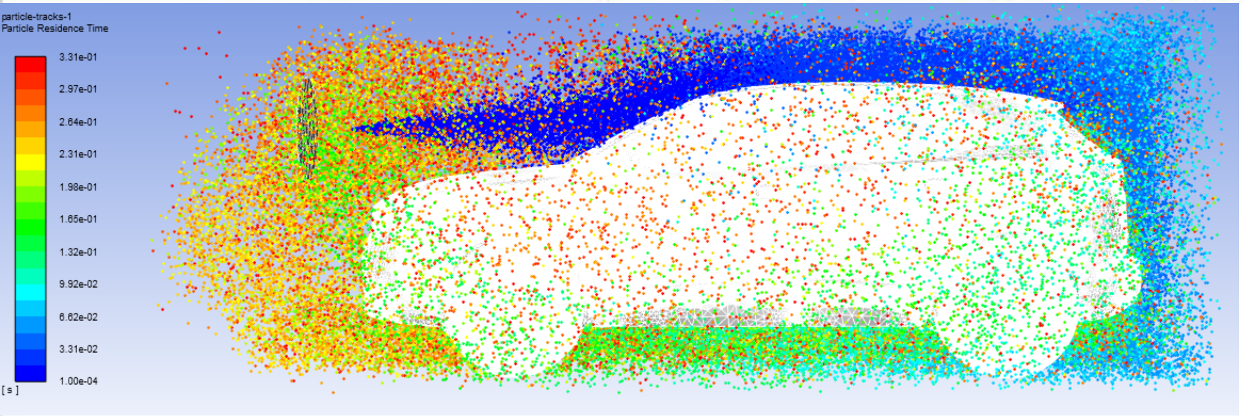
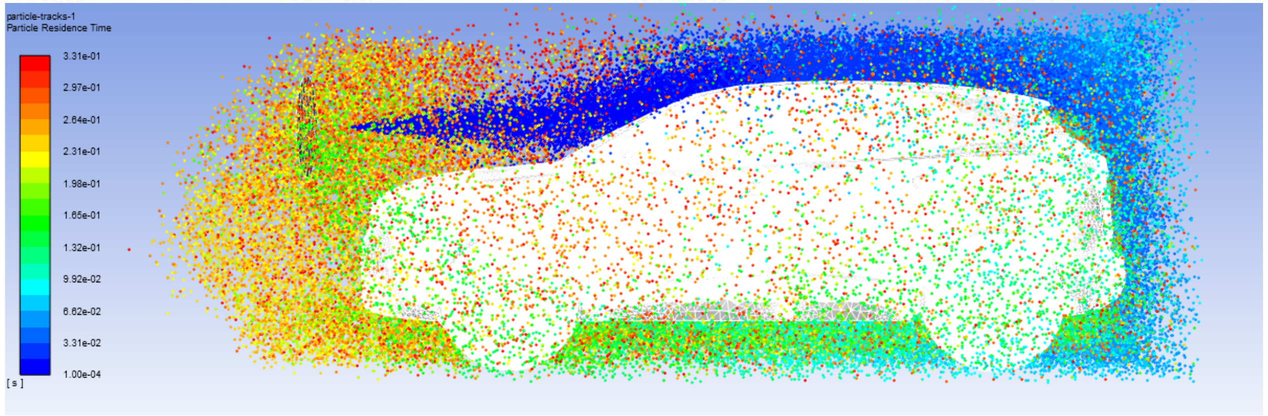
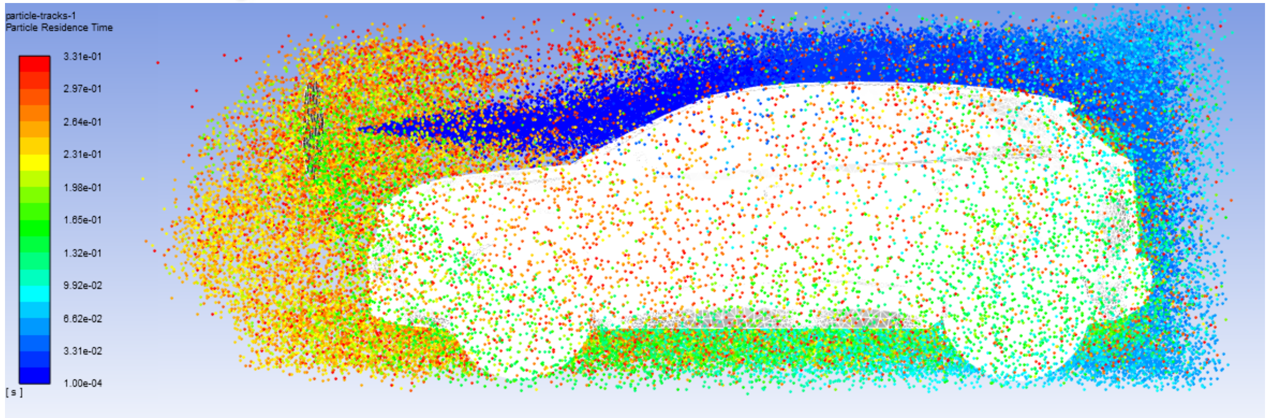
TWO PHASE FLOW SIMULATIONS RESULTS



Particle 2,5 µm



Particle 1 µm



Particle 0,1 µm

Fig. 10 residence time of particles at physical time: 0.3 s

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FINAL FLOW CONFIGURATION

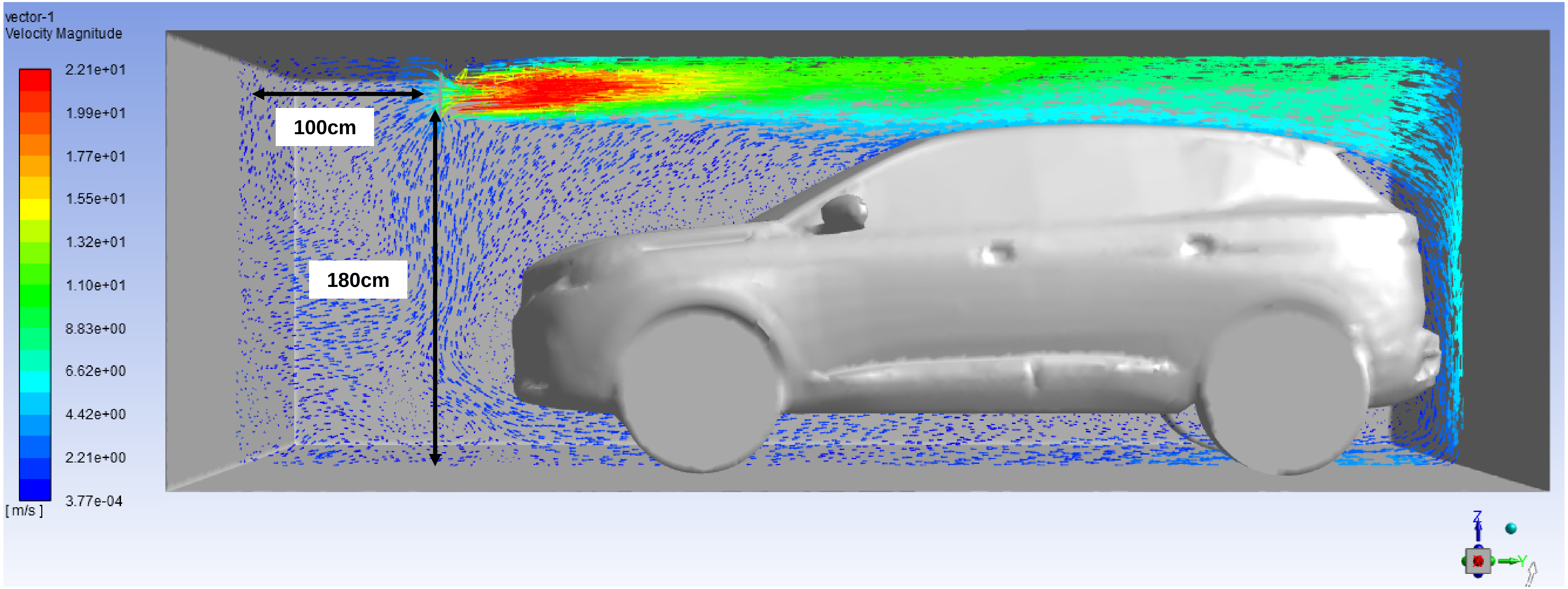

Fig. 11 representation of velocity vector fields

EXPERIMENTAL CHARACTERIZATION OF THE AIRTIGHT ENCLOSURE

MEASUREMENTS PROCEDURE

measurements without vehicle

- Without stirring
- With stirring

bubble characterization:

- background noise measurement
- tightness measurement
- Stability threshold measurement and homogeneity test

measurements with vehicle

- With/without injection of particles
- With/without stiring

measurement in the bubble and in car cabin:

- ventilation and recirculation mode deactivated
- ventilation and recirculation mode activited
- without ventilation, recirculation mode active / desactivated

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MEASURING POINTS

Left door		Rigth door
1G	1	1D
2G	2	2D
CG	Centre	CD
3G	3	3D
4G	4	4D

Fig.13 representative table of measurement positions

(top view of the bubble)

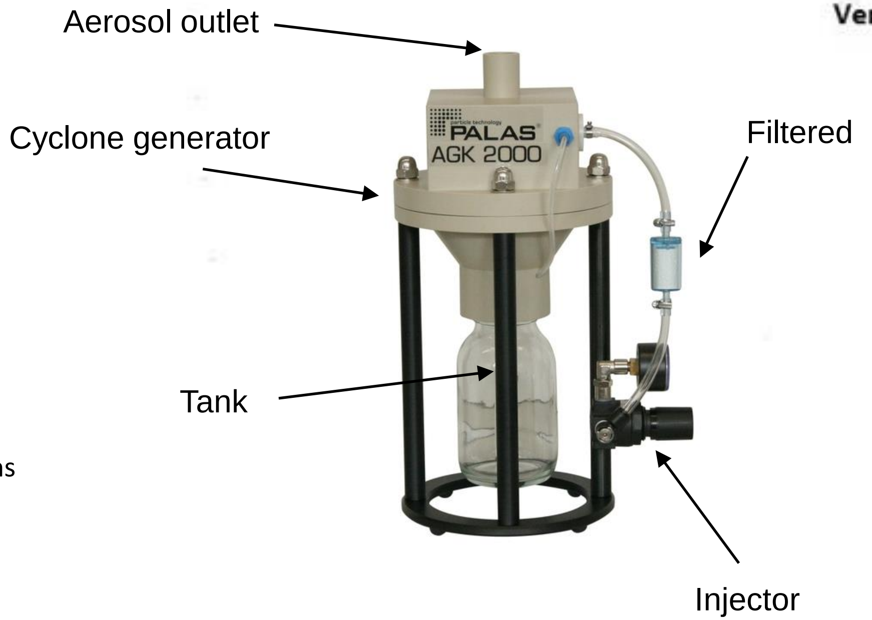

Fig.12 AGK 2000 particle generator

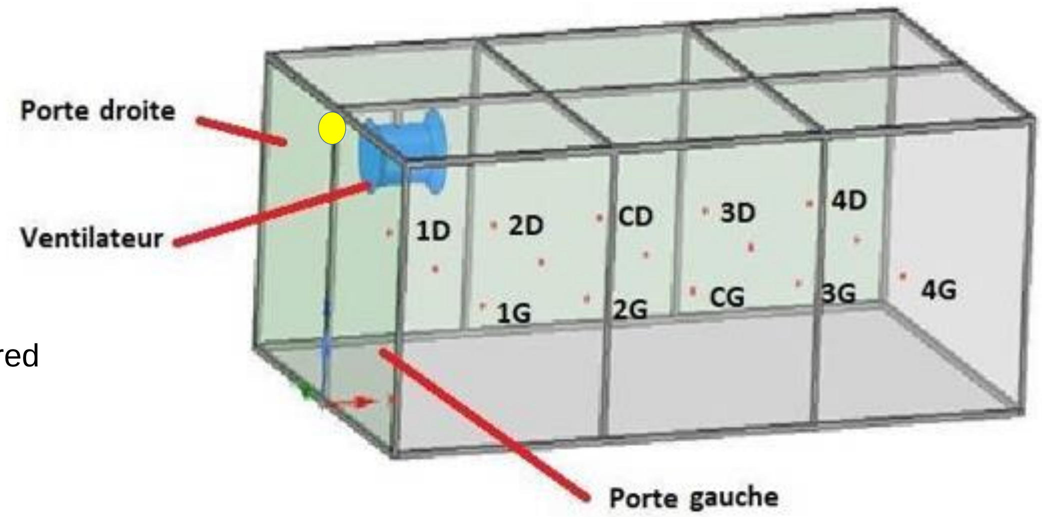

Fig.11 Positioning of measurement points in the bubble

- Flow rate: 4 to 10 l / min
- Injected particle size range: 10nm to 15µm

INSTRUMENTATION

Fine and ultra fine particle measuring instruments

PTrack

- Particle size measurement in nbr/cc in real time *(optical technique)*
- Particles between(0.02 to 2µm)
- Acquisition frequency (1s)

Dust Track

- Mass concentration measurement mg/m3 *(technique optique)*
- Particles between (0.1 to 15 µm)
- Acquisition frequency (1s)

Grimm miniwras

- Particle size measurement and relative particle concentration *(Optical technology and electric mobility)*
- Particles between (10 nm to 35 µm)
- Acquisition frequency (1min)

Gaseous pollutant measuring instruments

IAQ-CALC™ modèle 7525

- CO_2 concentration measurement *(in ppm)*
- Measuring range *(0 to 5000ppm)*
- Acquisition frequency: every two min (470 points)

Thermoscientific 42i

- NOx concentration measurement *(in ppm, ppb or mg/m3)*
- *Measuring range: 0 to 100 ppm or 0 to 150 ppb lower detectable limit 0.40 ppb*
- Acquisition frequency: average over 60 seconds

CHARACTERIZATION OF THE BUBBLE

- **Background noise measurement**

	Mass concentration (µg/m³)			Concentration in number of particles (#/cm³)		
	Minimum	mean	Maximum	Minimum	Mean	Maximum
PM1	1	4	18	--	--	--
$PM_{2,5}$	1	4	18	--	--	--
PM_{10}	1	5	20	--	--	--
Total	1	4	18	1030	1403	1830

Tableau 2 : Description of average background noise concentrations.

- Measurement of particles concentration in the empty bubble
- Without injection and without mixing
- Measurements made with *Dust-Track* and *Ptrack*
- The result is used as a reference concentration throughout the measurement day.

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- **Bubble tightness study:**

- Particles Dynamics:

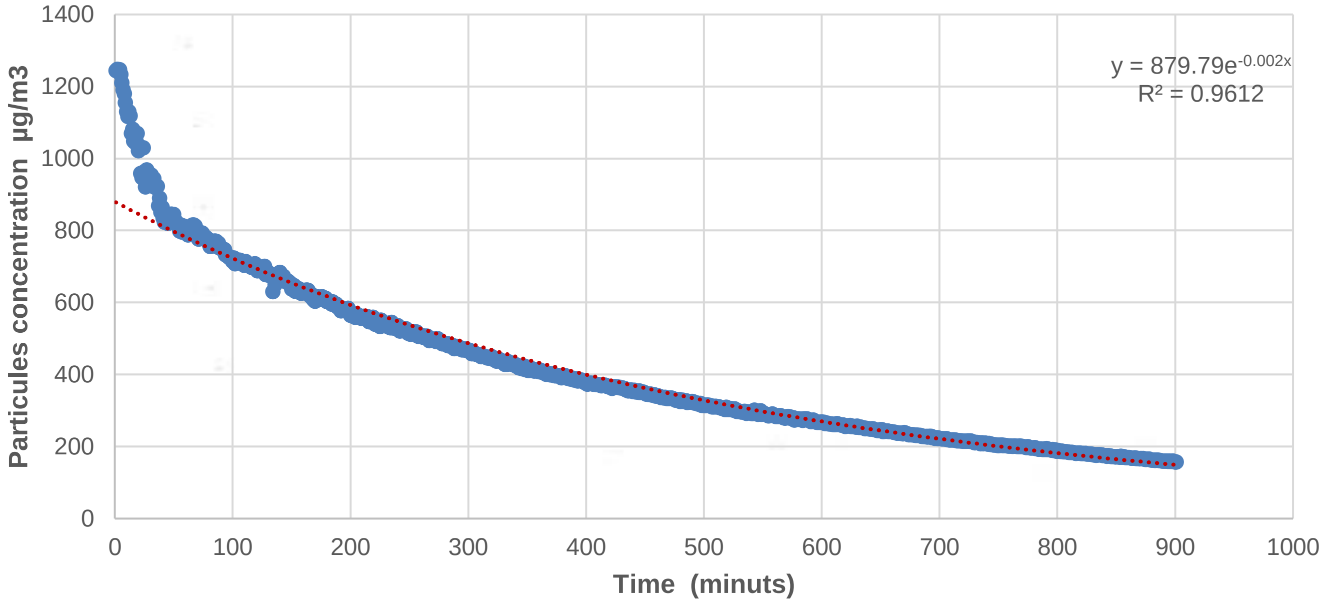

Figure 16 : Time evolution of the mass concentration of particles for 15 hours without brewing

- Two decay phases: transient (30 min) and steady (14H30.)
- From 1200 to 800 µg / m3 in 30min
- From 800 to 200 µg / m3 in 14H30.

CHARACTERIZATION OF THE BUBBLE

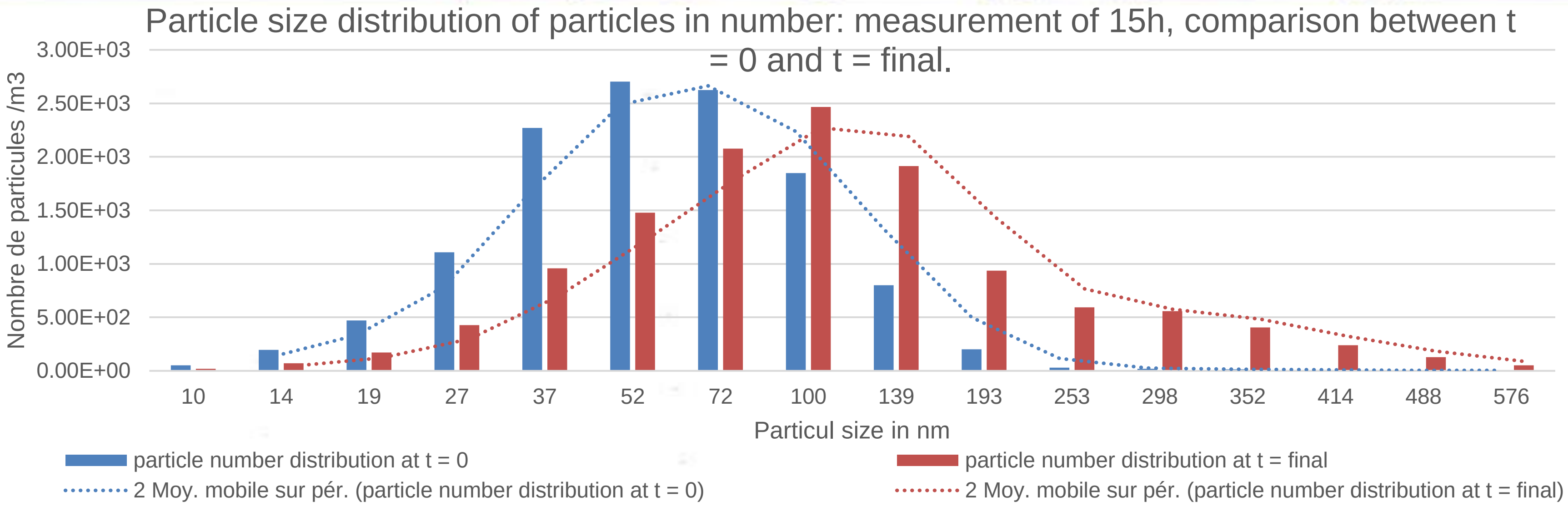

Figure 17: Particle size distribution of particles in number

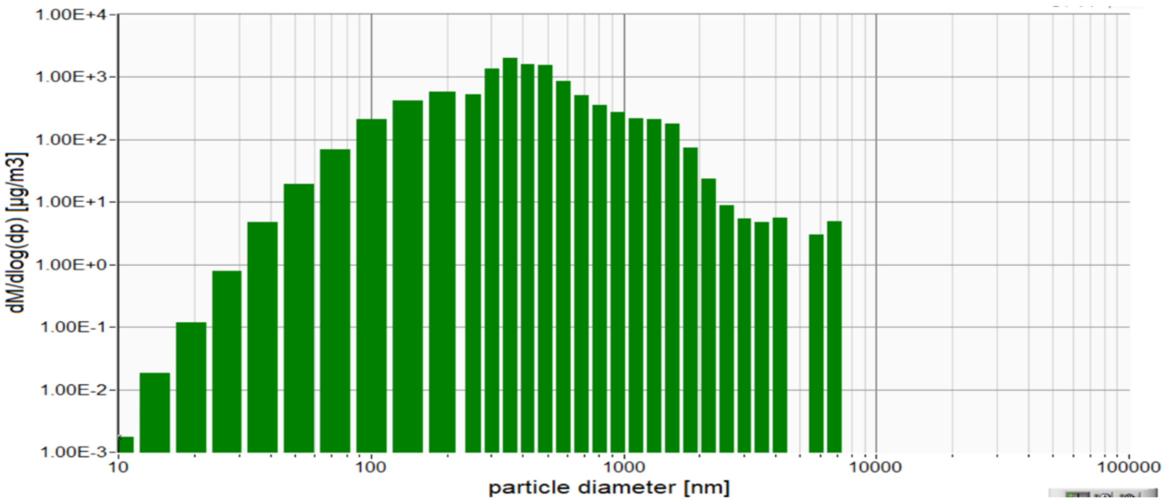

Figure 18: Particle size distribution of their mass concentration

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CHARACTERIZATION OF THE BUBBLE

- Tightness against CO_2:

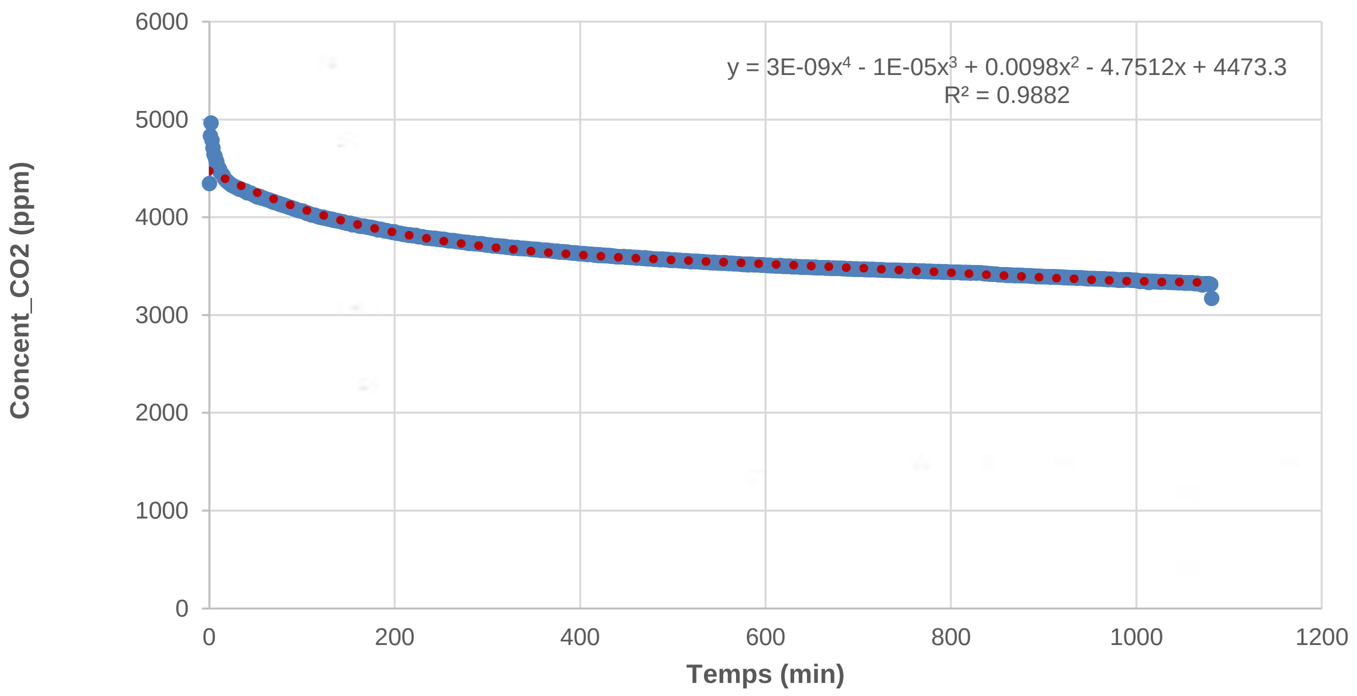
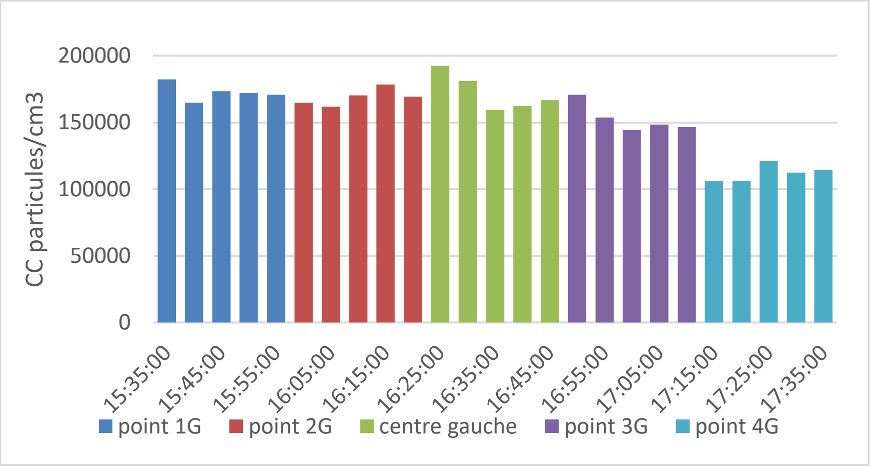


Figure 18 : Time evolution of the CO_2 concentration

- Decrease of 1 ppm / min therefore a relatively good bubble sealing

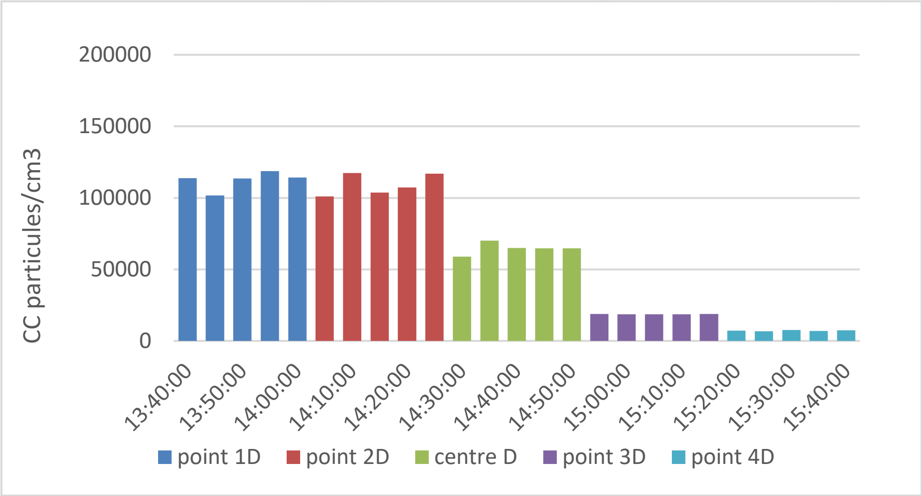
CHARACTERIZATION OF THE BUBBLE

- **Spatial homogeneity:**

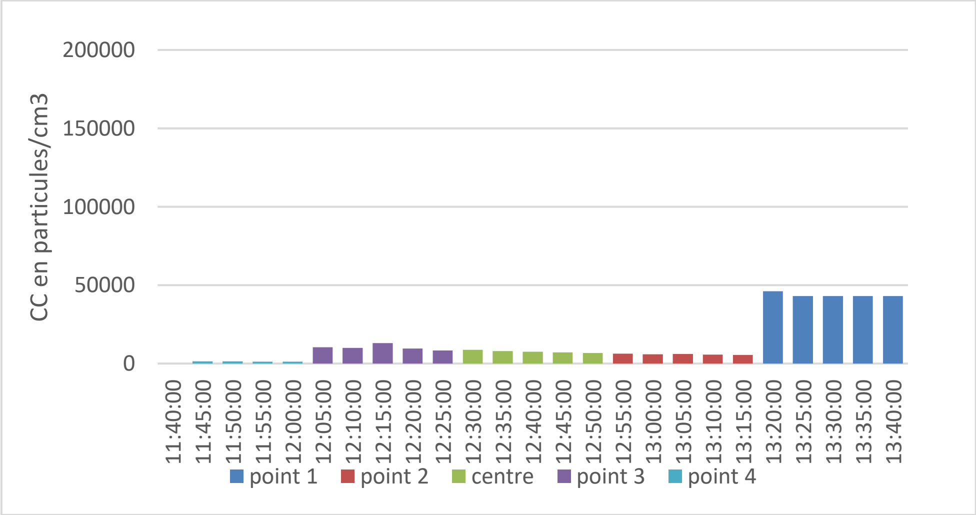


(a)

Left door		Right door
1G	1	1D
2G	2	2D
CG	Centre	CD
3G	3	3D
4G	4	4D



(c)



(b)

Fig. 22 Behavior of the particles **without mixing** inside the bubble along the longitudinal points (a) to the left of the bubble (b) in the center (c) to the right

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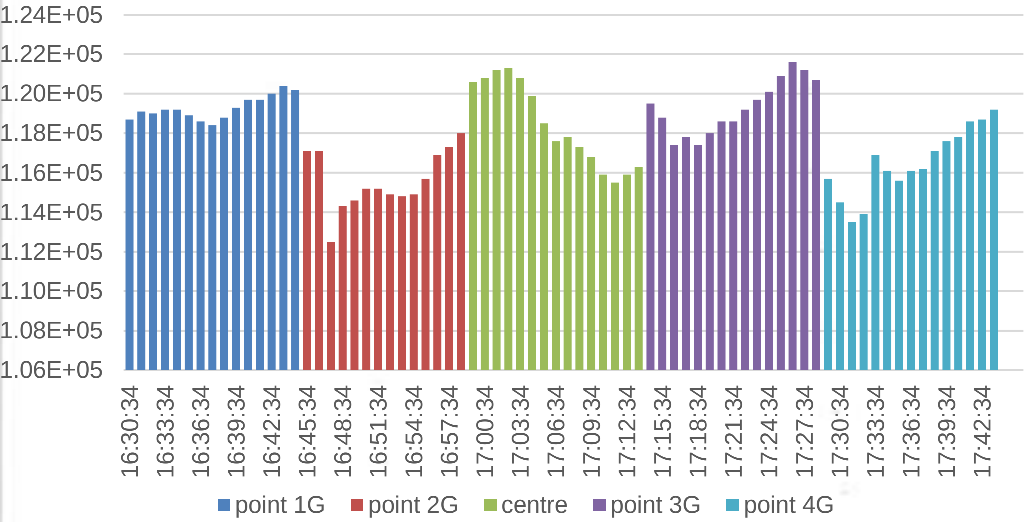
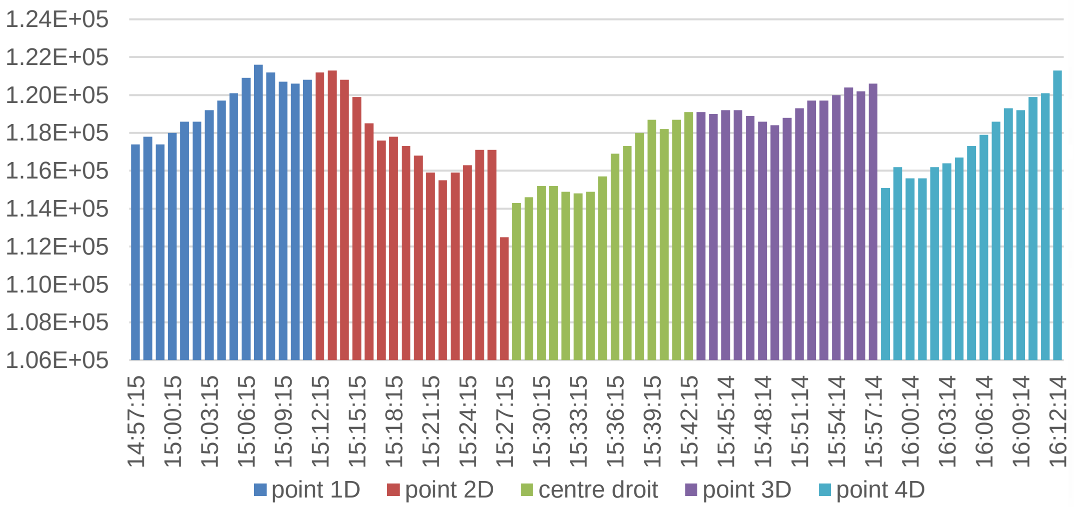
CHARACTERIZATION OF THE BUBBLE

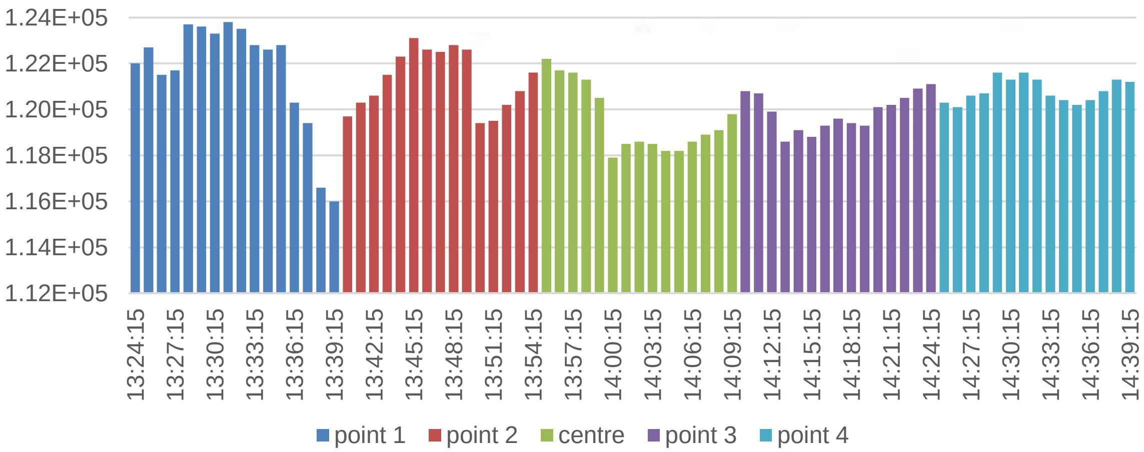


(a)

Porte gauche		Porte droite
1G	1	1D
2G	2	2D
CG	Centre	CD
3G	3	3D
4G	4	4D



(b)



(c)

Fig.23 Behavior of the particles **with mixing** inside the bubble along the longitudinal points (a) to the left of the bubble (b) to the right (c) in the center

FINAL PROTOCOL FOR MONITORING THE BUBBLE ENVIRONMENT

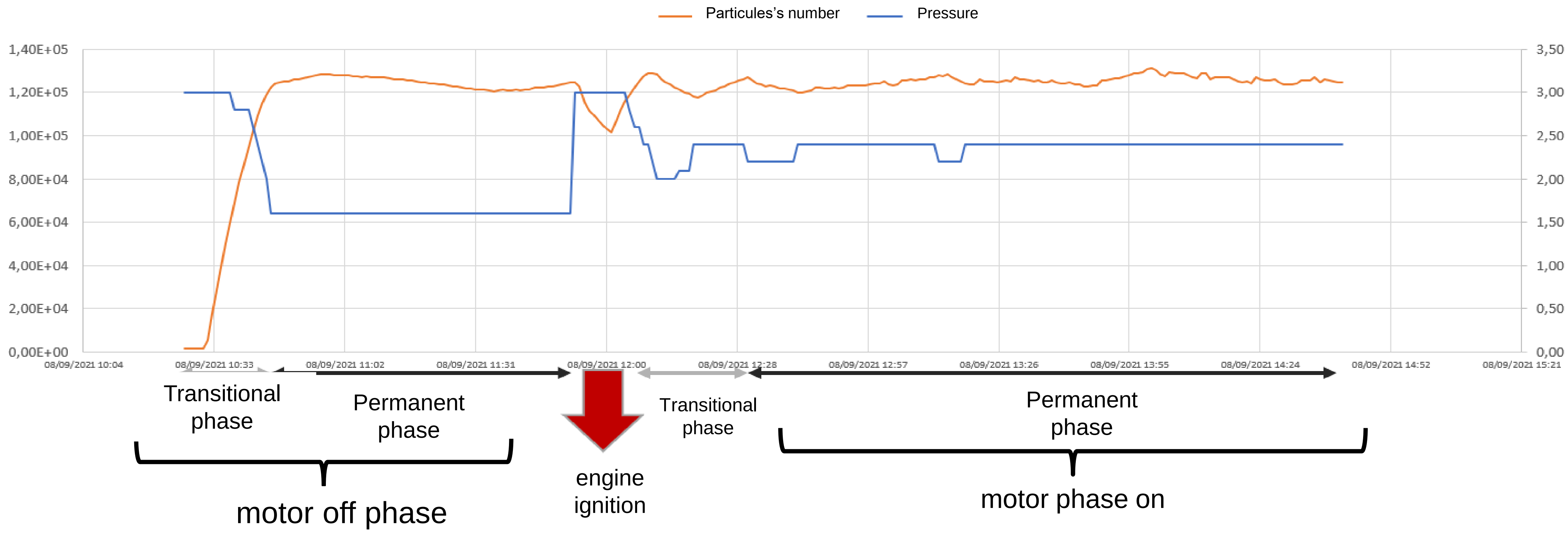


Fig. 24 Evolution of the concentration of total particles in number according to the injection rate (prepressure) of the AGK 2000 generator.

- ***Step 1: engine off***

- The transitional phase lasted 17 minutes.
- The target of 125,000 particles / cm3 was reached at 1.6 bar injection pressure (AGK2000).

- ***Step 2: engine on***

- The transitional phase lasted 31 minutes.L'objectif de 125000 particules/cm^3 a été atteint à **2,4** bars de pression d'injection (AGK 2000).

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CONCLUSION

Summary of the work of the first year of the present Phd thesis project:

- Bibliographic review
- Establishment of numerical flow simulations for flow in the bubble (CAD, bubble domain, mesh and flow characterization
- Design and assembly of the measuring chamber (bubble)
- Study and evaluation of the airtightness of the bubble, measurement of the distribution of the concentrations of particulate pollutants (PM1, PM2.5 and PM10) and CO_2 in different configurations
- Subsequently, a large campaign of measurements will be carried out, on the basis of the finalized air pollution generation protocol, to study the infiltration of pollutants and the release of VOCs into the passenger car cabins