FROM RESEARCH TO INDUSTRY

Comparative Assessment of Air Cleaners:

Lessons Learnt and Perspectives

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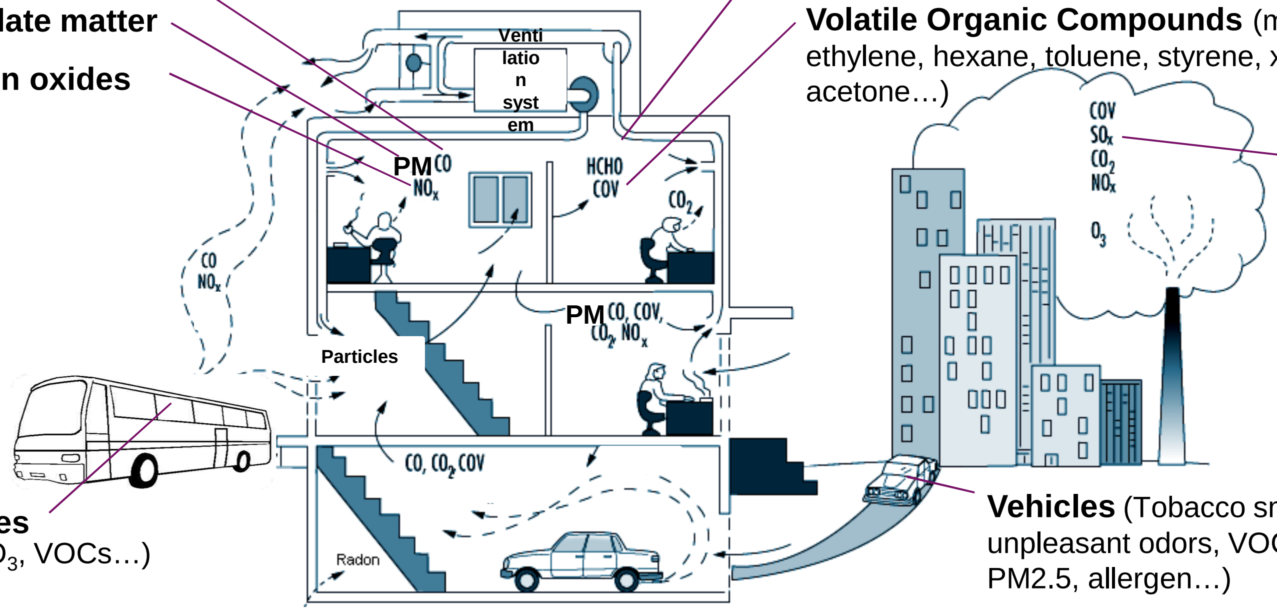
PLATE-FORME NANO SÉCURITÉ

OUTLINE

Comparative Assessment of Air Cleaners: Lessons Learnt and Perspectives

- Introduction to air pollution
- Air cleaners’ market overview with some IPR figures
- Terminology and general considerations
- Current research and innovation trends
- Comparative assessment of two systems for air cleaning
- Experimental set-up and main results
- Key findings and Perspectives

INTRODUCTION TO AIR POLLUTION

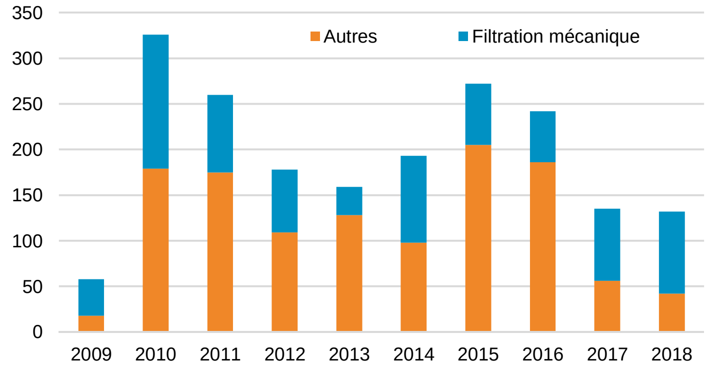


- Fine particles is thought to cause 48 000 premature deaths each year in France
- People spend more than 80% of their time in closed spaces
- Ultrafine particles is the indoor air pollutant having the highest socio-economic cost

[1] Etude quantitative d'impact sanitaire (EQIS) publiée par Santé publique France, 2016.
[2] ANSES. Etude exploratoire du coût socio-économique des polluants de l'air intérieur – ANSES – OQAI, Avril 201. 2011-CRD-11 .
[3] ANSES. Polluants "emergent" dans l'air ambient – ANSES, Juin 2018. 2015_SA_0216

AIR CLEANERS: MARKET FIGURES

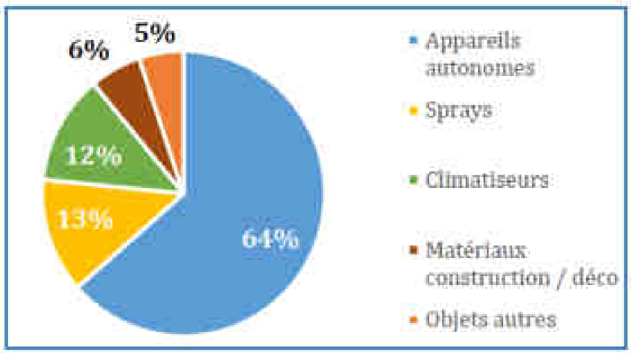
- Growing market with the worldwide development of mobile indoor air cleaners (>8B$ in 2016 ; 10 to 15% growth in Asia)



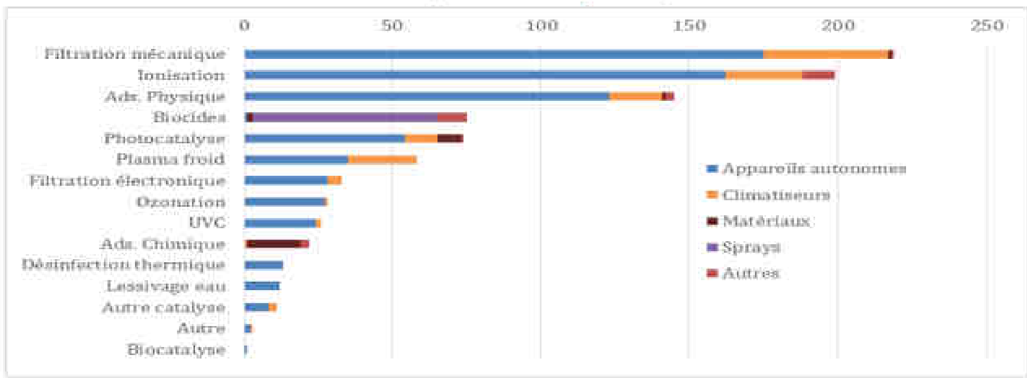
Number of certificates delivered annually by the State of California since 2009 [2]

> 2000 references linked to brands such as Whirlpool, Sharp, Samsung, Rowenta, Philips, Molekule, LG, Honeywell, Electrolux, Dyson, De'Longhi, Daikin, Panasonic

- French market is still emerging: 500 devices identified in 2017 with a cost range from 50 € to 2000 € targeting various indoor air pollutants (VOCs, bioaerosols and particles) [3]

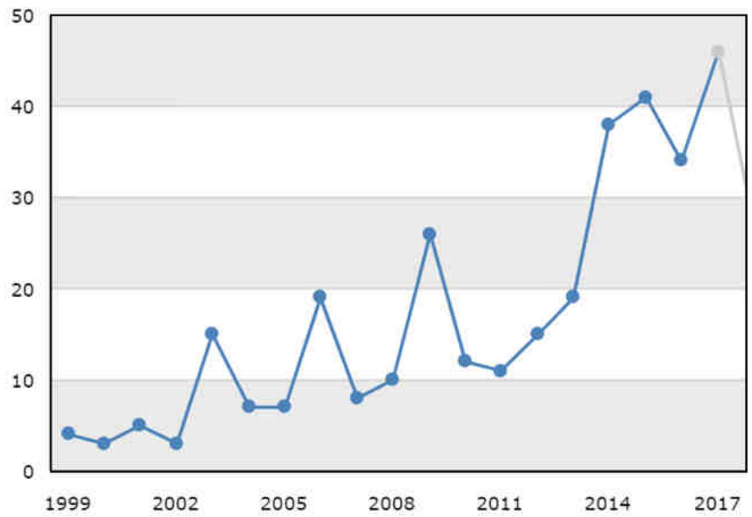


Nombre de références par technologie d'épuration utilisée :



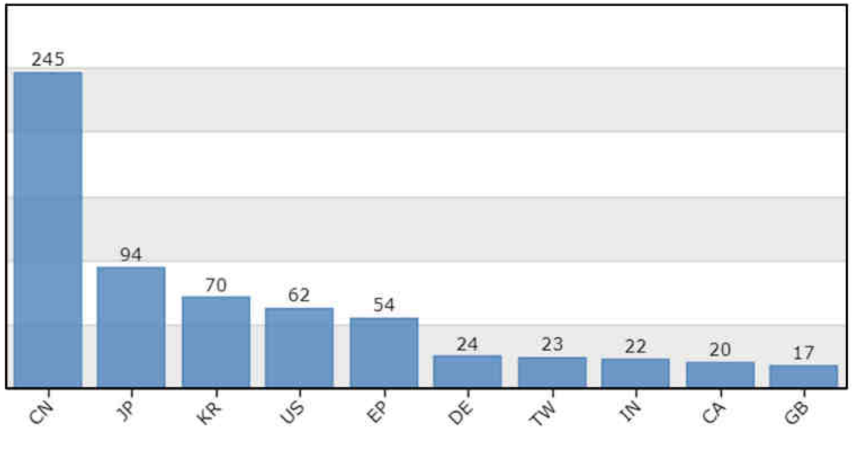
[1] Source Etude « Air Purification Equipment », Global Industry Analysts, 2016.
[2] https://www.arb.ca.gov/research/indoor/aircleaners/certified.htm
[3] ANSES. Identification et analyse des différentes techniques d'épuration d'air intérieur émergentes. ANSES, Septembre 2017. Avril 201. 2012-SA-0236.

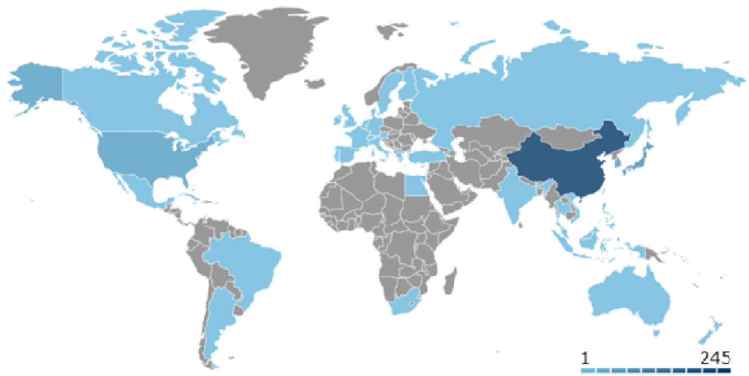
AIR CLEANERS: IPR FIGURES



Number of patent families (including granted patents and patent applications) per year of submission, for the keywords **'corona ionization electrostatic indoor air cleaner'** research using ORBIT© research tool

Geographic origin of patent families (including granted patents and patent applications since 1999)





TERMINOLOGY AND GENERAL CONSIDERATIONS

- **Collection efficiency:** the single pass efficiency of a particulate air filter can be defined as the ratio of collected particles over incoming particles:

$$E = \frac{C_u - C_d}{C_u} \times 100$$

with Cu being the upstream particle concentration and Cd the downstream concentration.

- **Most Penetrating Particle Size** (MPPS) is the particle diameter at which the minimum efficiency occurs

Typical performance of a fibrous filter

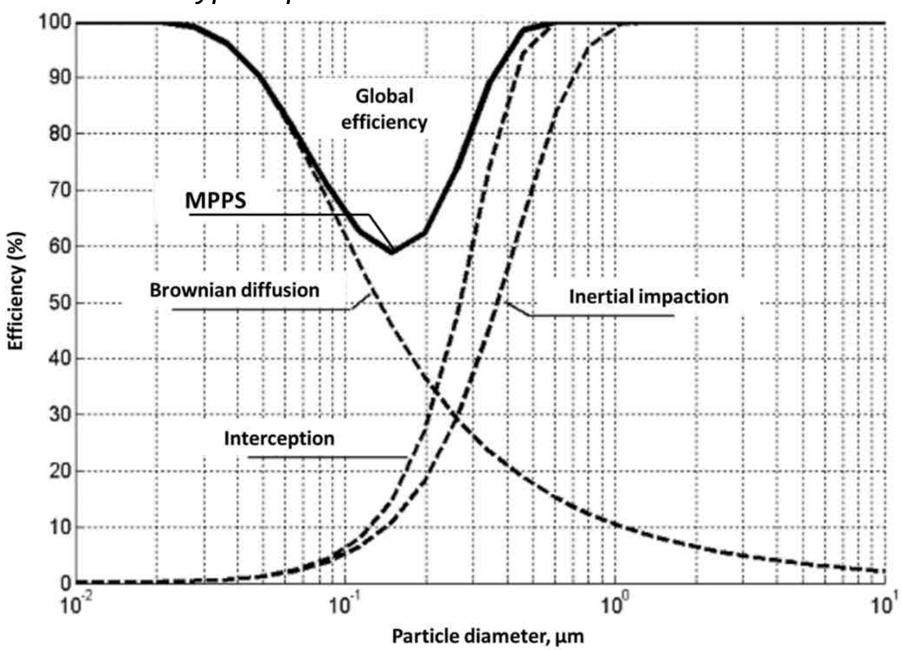
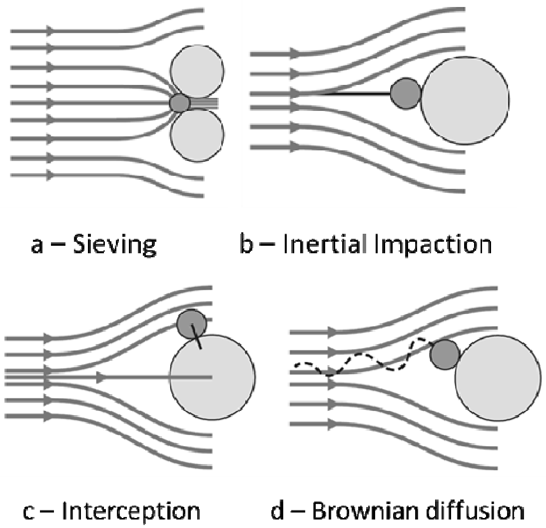
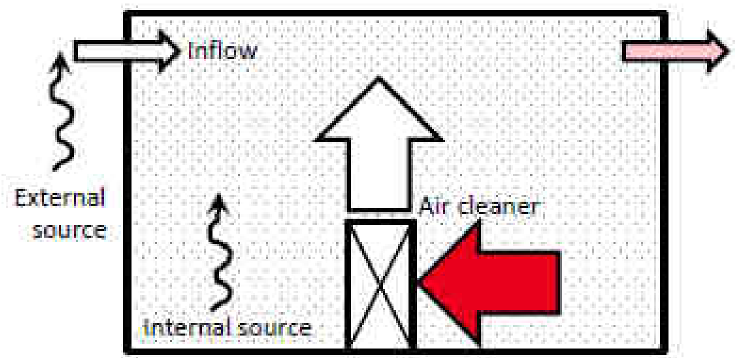


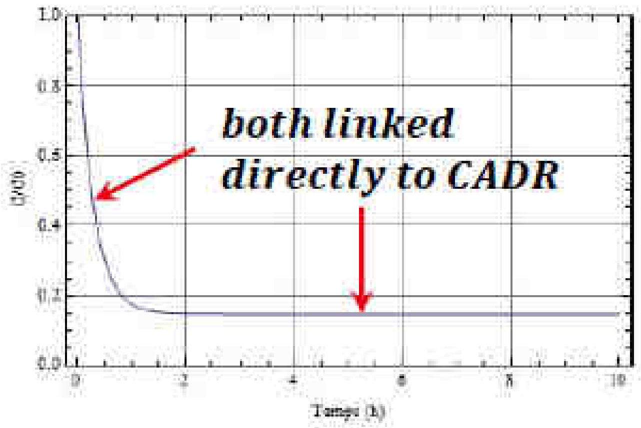
Illustration of mechanical collection mechanisms



- As air passes through the fibrous media, fibers cause a flow resistance that is reflected by a loss of static pressure between the front and rear surface of the filter. This **pressure drop** across the filter (ΔP) is a crucial parameter since it substantially contributes to sizing of the airflow system, and more specifically to the backpressure managed by the fans.

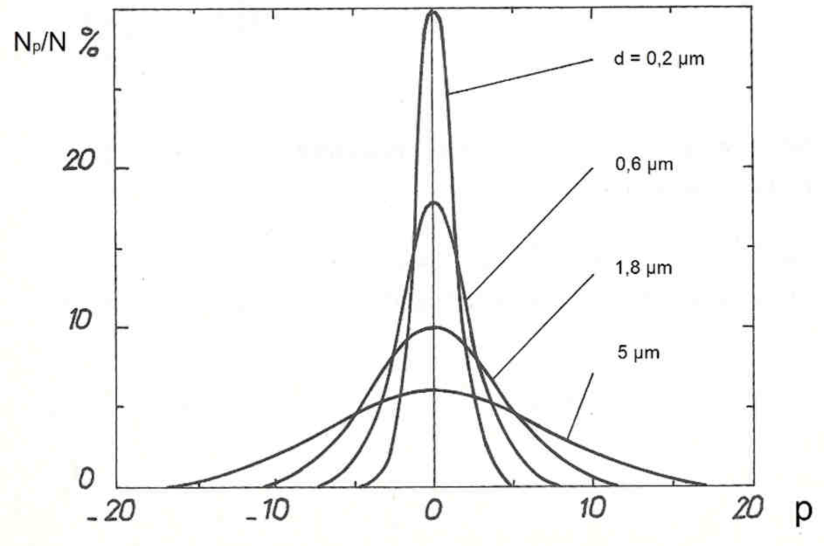
- **Clean Air Delivery Rate** (CADR) is a performance indicator assigned by the Association of Home Appliance Manufacturers (AHAM), which helps consumers determine air purifier effectiveness. CADR can be expressed as Volumetric flow rate x Filtration efficiency.





[1] ANSI/AHAM. “Method for Measuring Performance of Portable Household Electric Room Air Cleaners - ANSI/AHAM AC-1-2015,” 2015.
[2] Standardization administration of the People’s Republic of China. “Air Cleaner - GB/T 18801-2015,” 2015.
[3] AFNOR. Epurateurs d’air autonomes pour applications tertiaries et residentielles – Méthodes d’essai – Performances intrinsèques – NF B 44-200, 2016.

- Particle ionisation



Charge distribution of particles in a bipolarly ionized fluid, where N_p/N is the number of particles with p charges divided by the total number of particles

M. Pourprix, "Un nouveau précipitateur électrostatique - Application à l'étude de la charge des aérosols par diffusion d'ions bipolaires," Thèse doc. ing., Paris, 1973.

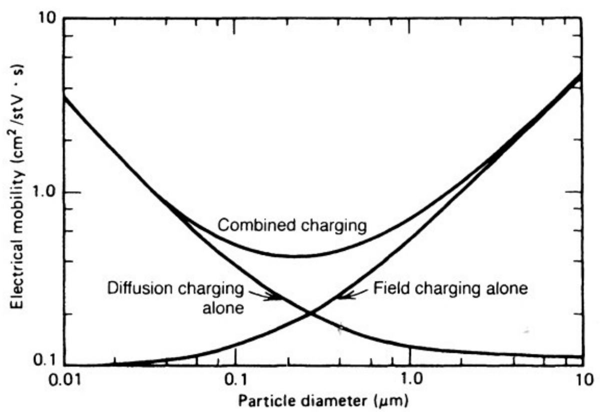
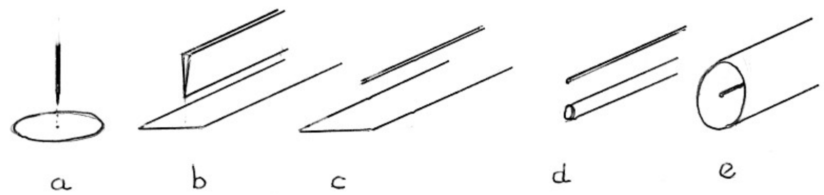


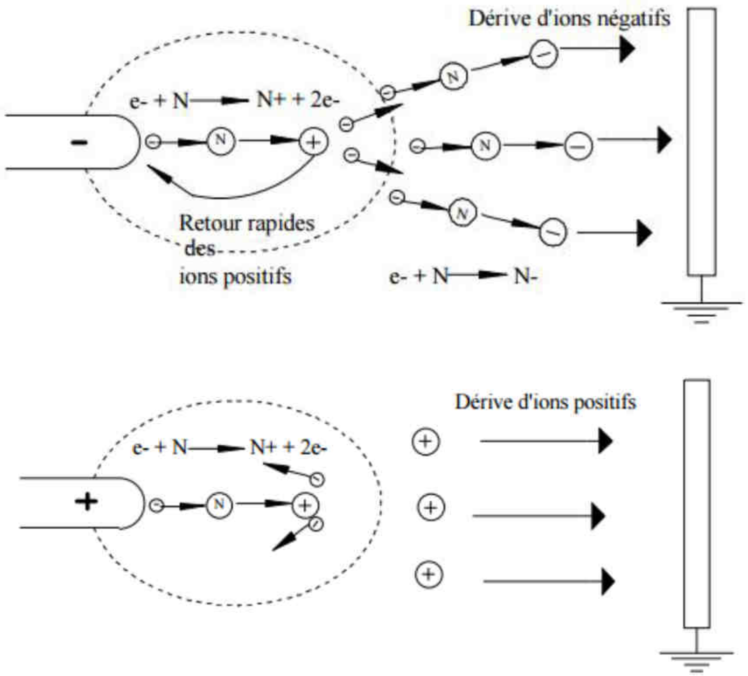
FIGURE 15.4 Electrical mobility versus particle size for diffusion, field, and combined charging at $E = 500$ kV/m [5 kV/cm] and $N_i t = 10^{13}$ s/m³ [10^7 s/cm³].

Typical geometries of ionization electrodes



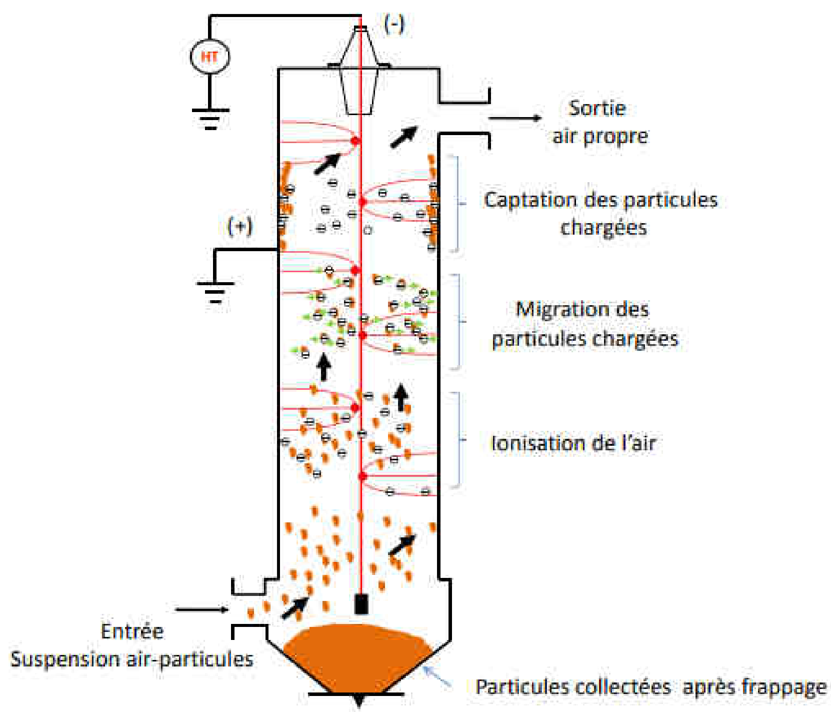
ELECTROFILTRATION, GENERAL PRINCIPLES

- Particle collection



Any charged airborne particle flowing through a region where an intense electric field is applied drift within the field toward a collection plate at a velocity determined by their electrical mobility.

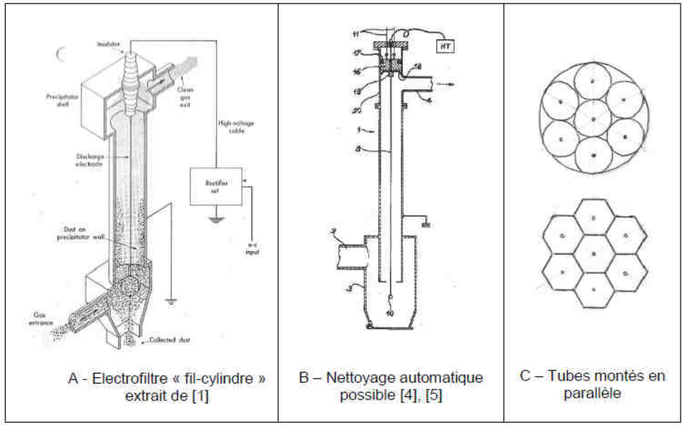
Principal steps occuring during the operation of an electrofilter

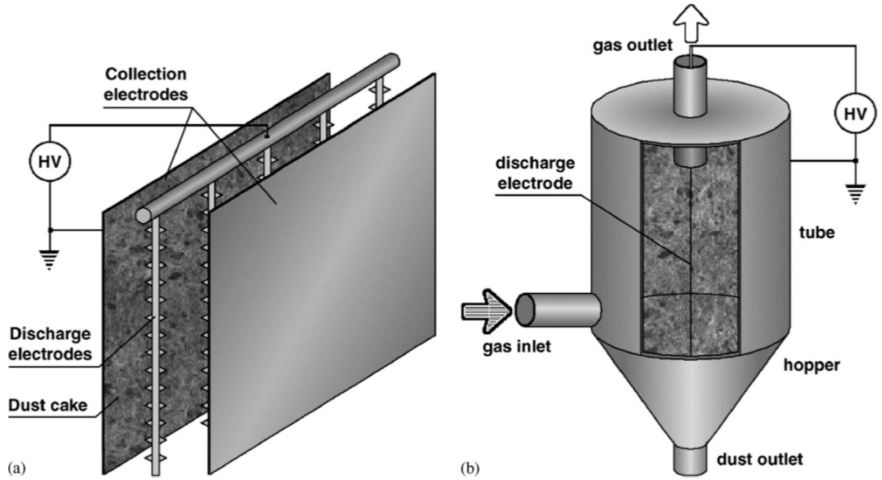


Thèse Boni DRAMANE, 2009

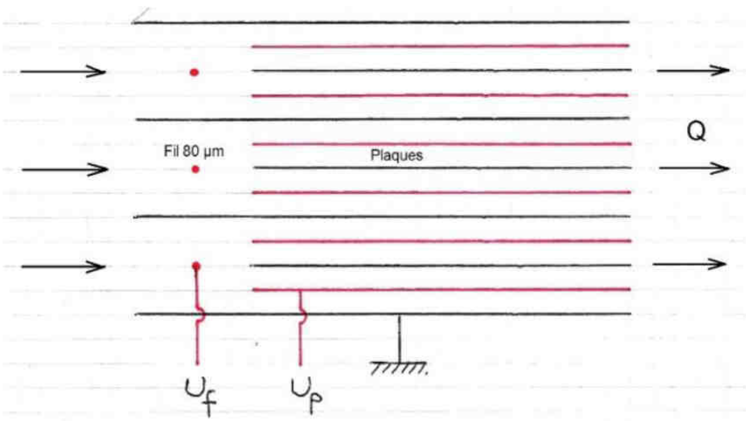
ELECTROFILTRATION, GENERAL PRINCIPLES

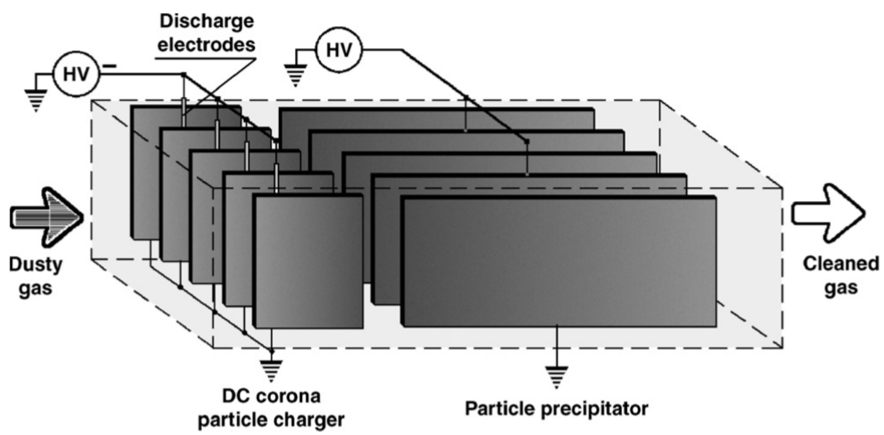
- Single stage geometry





- Two-stage geometry





A. Jaworek et al., "Modern electrostatic devices and methods for exhaust gas cleaning: A brief review," Journal of Electrostatics 65, 133–155, 2007

CURRENT RESEARCH AND INNOVATION TRENDS

- **Overcome the limitations due to ozone generation**
  O_3 may be harmful for the respiratory system even at low level of exposure ; it initiates reactions with VOCs (terponoids) to form secondary aerosols.

  => Positive corona is prefered to negative corona

  => Optimisation of the charging stage of the ESP participates to lower O_3 emissions: wire nature, size, temperature …

  => Post-processing of emitted O_3 : catalytic converter …

- **Improve the collection efficiency**

  => Improve charging and/or collection rates: combination of corona discharge with soft X-ray irradiation

  => Minimize re-entrainment while mainting high charging and collection rates: modification of the collecting electrodes, hybrid systems (ESP + coarse filter) …

- **Maintain low pressure drop**

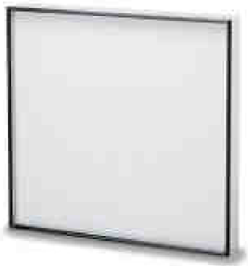
COMPARATIVE ASSESSMENT OF TWO SYSTEMS FOR AIR CLEANING

- Electrostatic precipitator: Hexaone from Nectar

Product size (WxDxH): 155 x 130 x 280mm
Net weight: 1.4 kg
Air flow rate up to 200 m^3/h
CADR 110 m^3/h
Power consumption 8 W

I. BOTVINNIK, et al., « High-Efficiency Portable Electrostatic Air Cleaner with Insulated Electrodes », *Vol 44 n°2*, oo, p. 512 / 516, janv-2007.

- Fibrous filters from CAMFIL: Efficiency Particulate Air filter (E10 & E12) and High Efficiency Particulate Air filter (H14)



Filter Group Filter Class	Integral value		Local value [a b]	
	Efficiency (%)	Penetration (%)	Efficiency (%)	Penetration (%)
E 10	≥ 85	≤ 15	---[c]	---[c]
E 11	≥ 95	≤ 5	---[c]	---[c]
E 12	≥ 99,5	≤ 0,5	---[c]	---[c]
H 13	≥ 99,95	≤ 0,05	≥ 99,75	≤ 0,25
H 14	≥ 99,995	≤ 0,005	≥ 99,975	≤ 0,025
U 15	≥ 99,999 5	≤ 0,000 5	≥ 99,997 5	≤ 0,002 5
U 16	≥ 99,999 95	≤ 0,000 05	≥ 99,999 75	≤ 0,000 25
U 17	≥ 99,999 995	≤ 0,000 005	≥ 99,999 9	≤ 0,000 1

[a] See 7.5.2 and EN 1822-4.

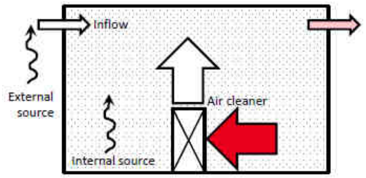
[b] Local penetration values lower than those given in the table may be agreed between supplier and purchaser.

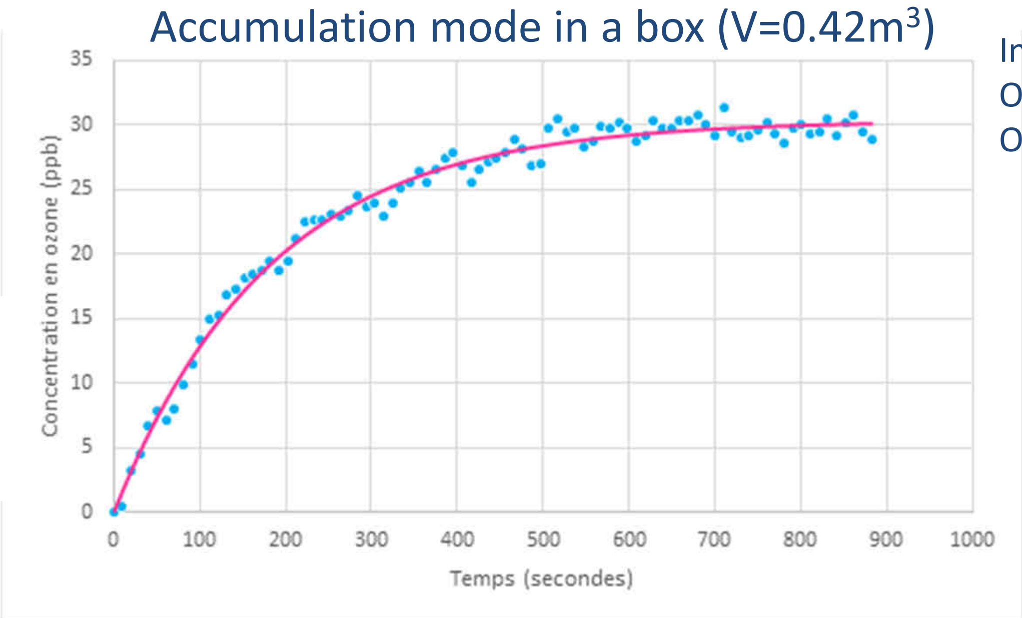
[c] Group E filters (Classes E10, E11 and E12) cannot and shall not be leak tested for classification purposes.

Classification of EPA, HEPA and ULPA filters, reproduced from EN1822-1: 2010

3 filters: E10, E12, H14
Product size: 260 x 260mm
Nominal flow rate 110 m^3/h

Determination of the ozone emission rate





Infiltration flowrate Q

Ozone volumetric flowrate q

Ozone volumetric concentration c

$$V\frac{dc}{dt} = q - Qc$$

$$c = \frac{q}{Q}\left(1 - e^{-\frac{Qt}{V}}\right)$$

Ozone emission rate = 0.25 cm^3/h

Determination of the power consumption

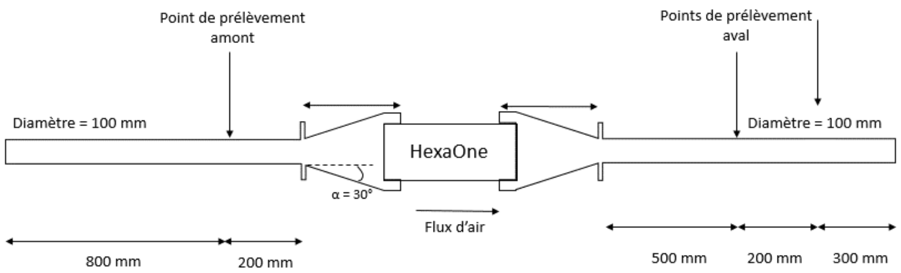
Measured value = 8.6 W ; from manufacturer 8.2 W

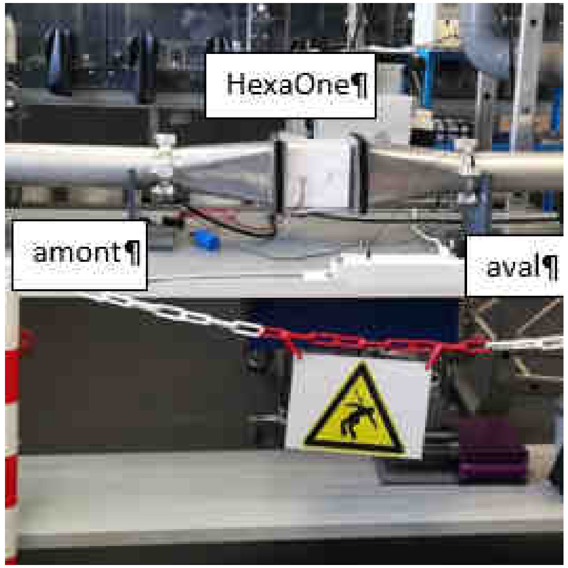
Modified version to pilot HV < 15W

EXPERIMENTAL SET UP

- Comparative assessment of two systems for air cleaning

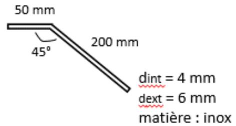
Banc de caractérisation pour le module d'adaptation Nectar



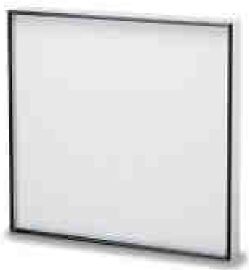


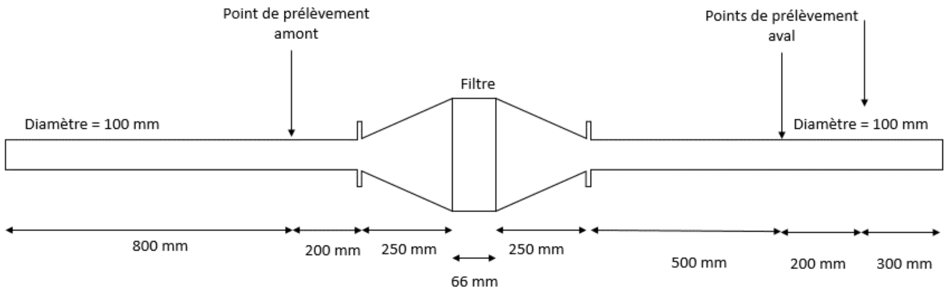
Matériau du banc : tôle ou aluminium (conducteur électrique)

Points de prélèvement : tubes de piquage avec gaine



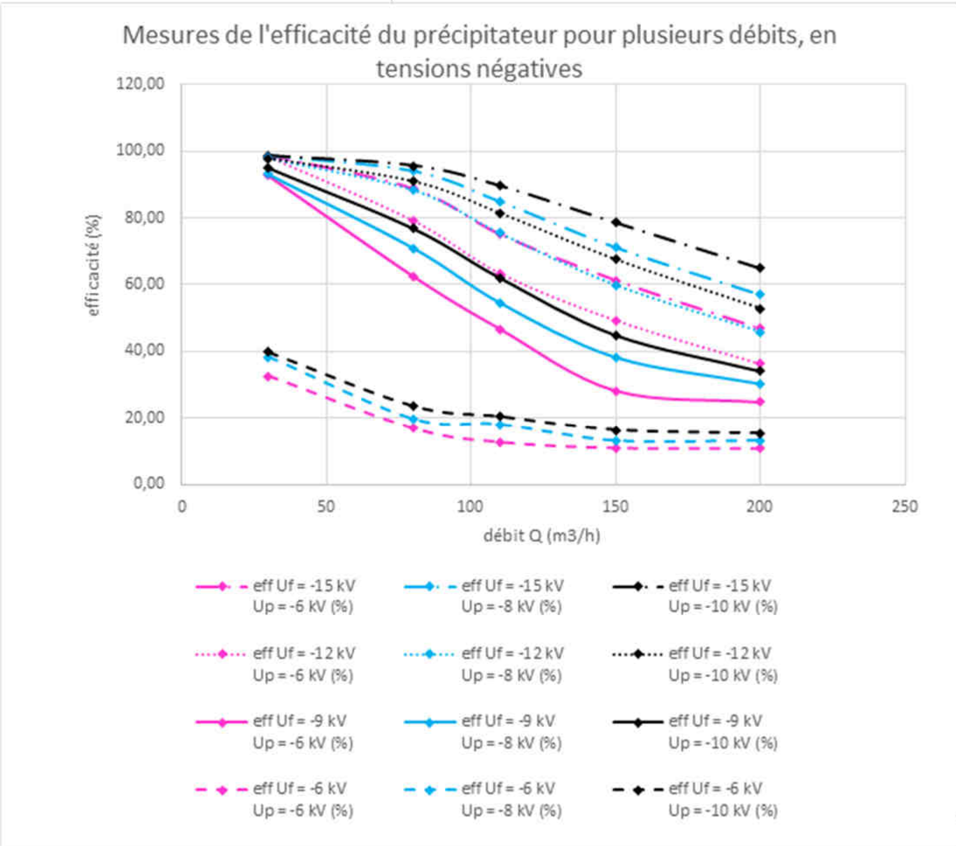
Banc de caractérisation pour le module d'adaptation Camfil

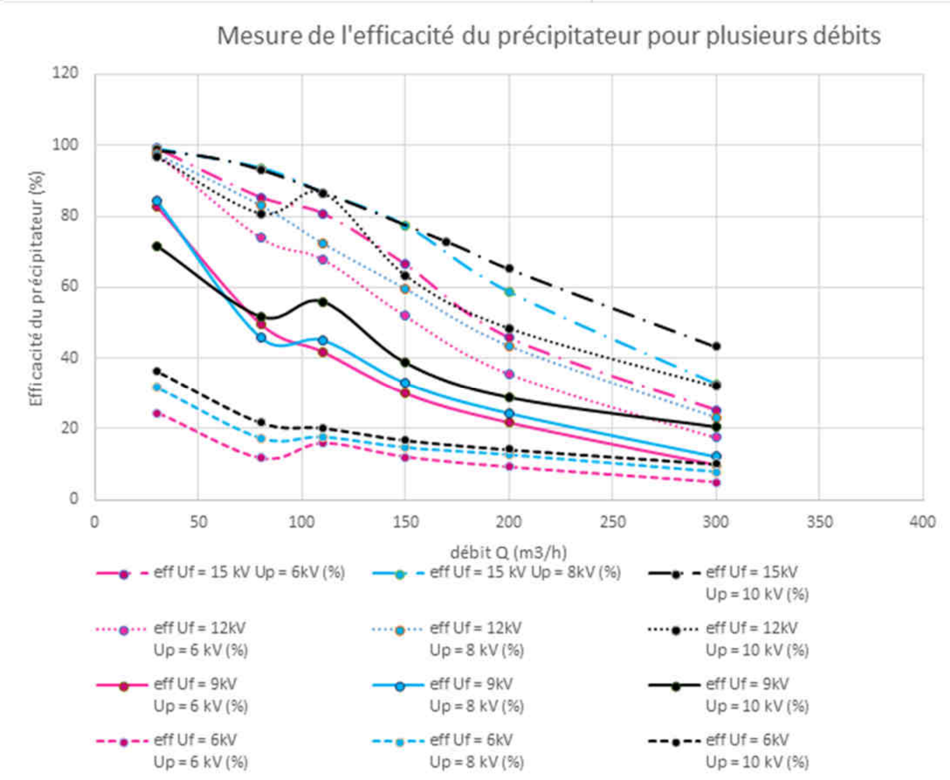




COMPARATIVE ASSESSMENT: COLLECTION EFFICIENCY

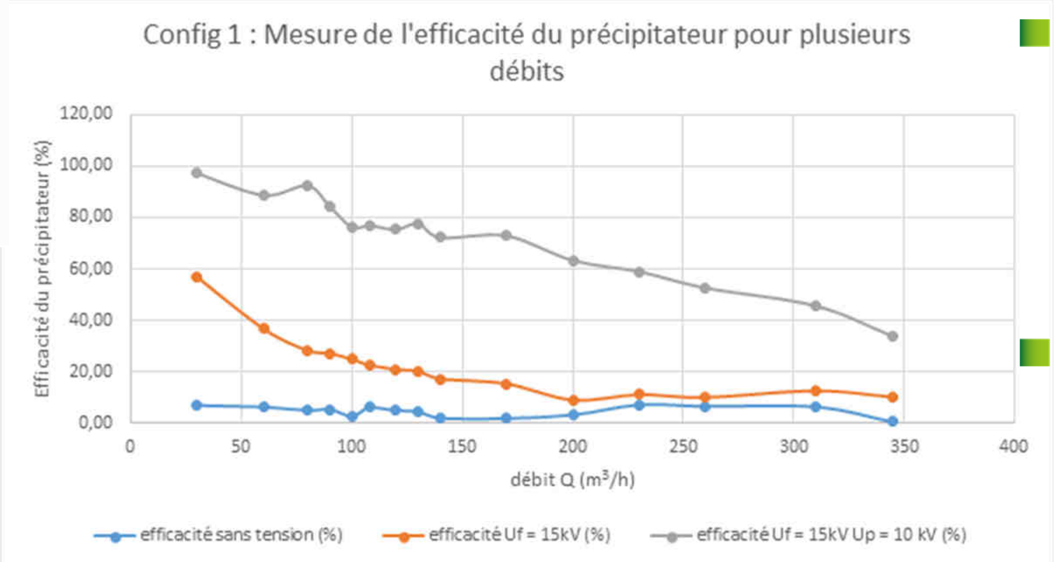
- Assessment of the ESP collection efficiency from negative to positive HV
  - Ionisation wires: - 15 kV to + 15 kV
  - Collection plates: - 10 kV to + 10 kV

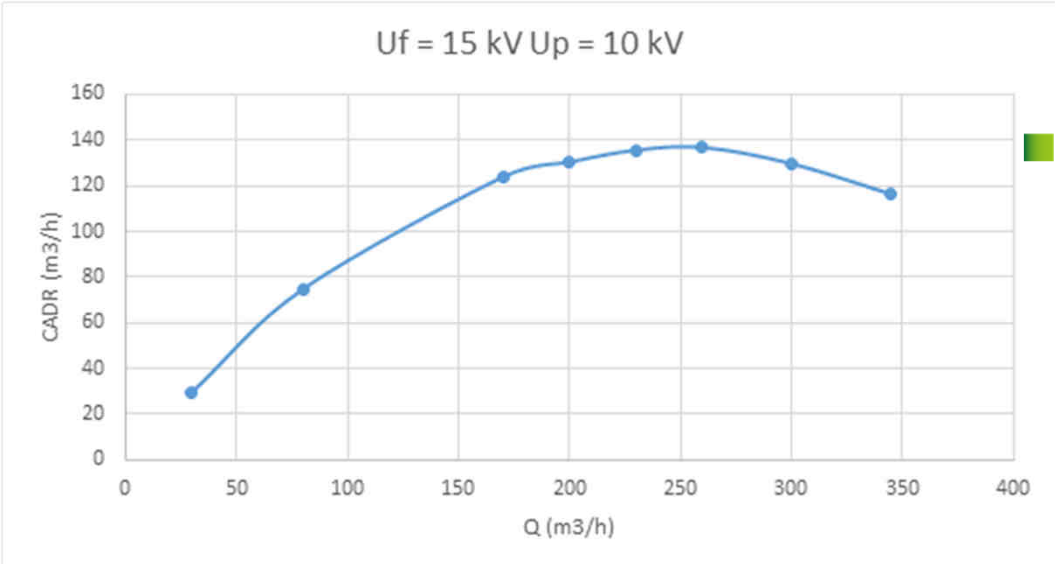




ıum efficiency: Uf=15kV and Up=10kV

COMPARATIVE ASSESSMENT: COLLECTION EFFICIENCY

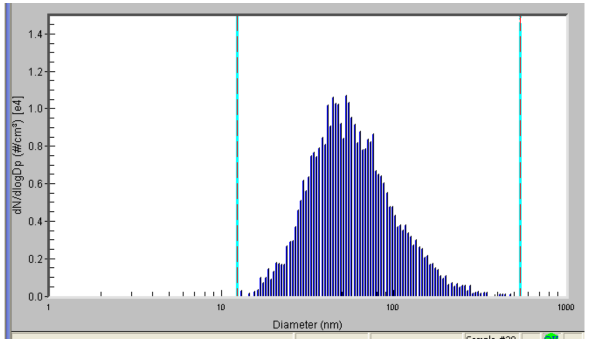




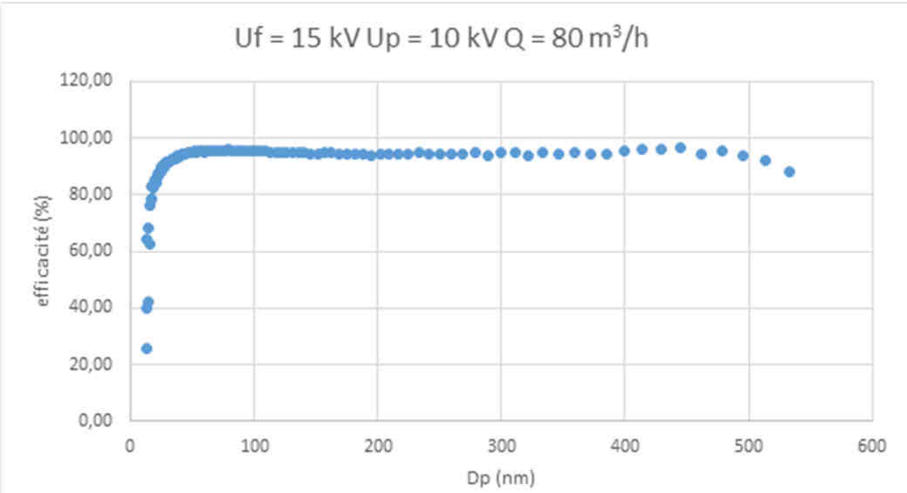
- Chosen parameters to reach optimum efficiency: Uf=15kV and Up=10kV
- Collection efficiency decreases with flowrate
- Highest CADR values in the 150-300 m^3/h flowrate regime

SIZE DEPENDENCE OF THE COLLECTION EFFICIENCY

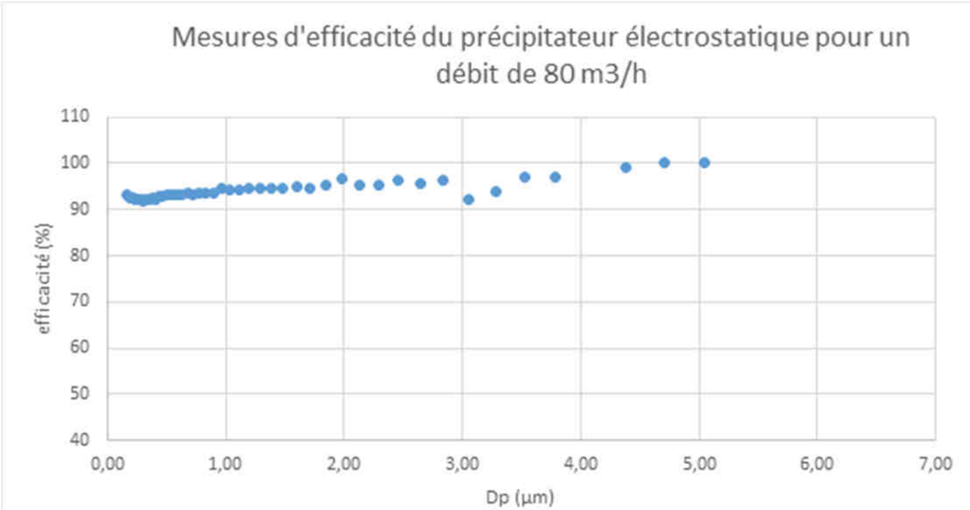
Atomisation of KCl suspension (10 g/L)



Data from SMPS granulometer

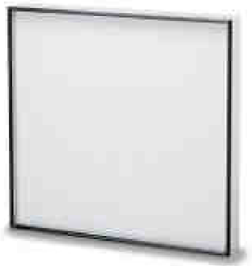


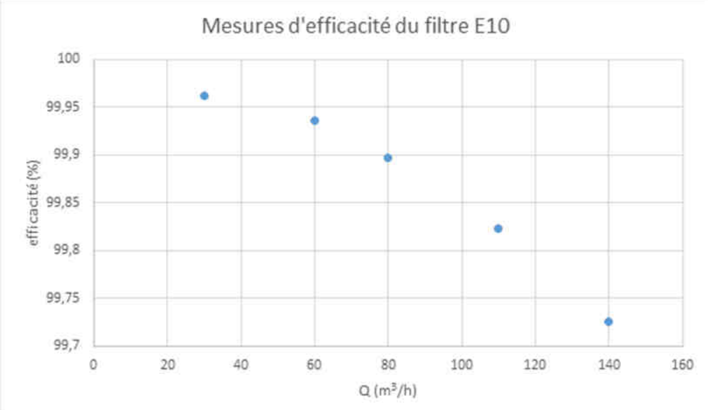
Data from FIDAS granulometer

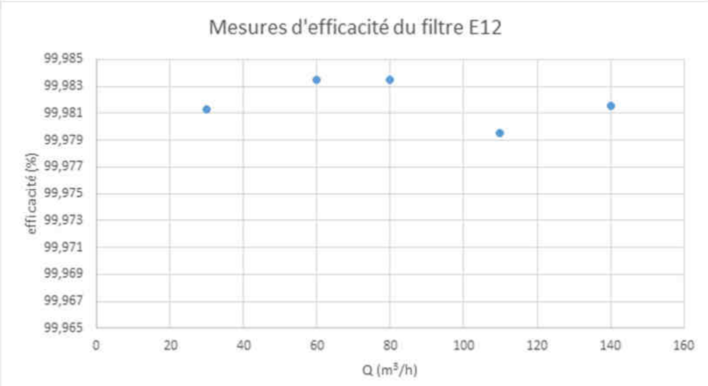


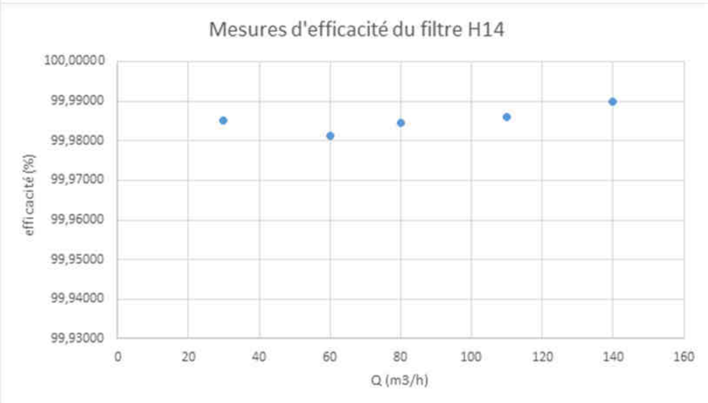
- Chosen parameters to reach optimum efficiency: Uf=15kV and Up=10kV
- MPPS appears for particle sizes below 40 nm

COMPARATIVE ASSESSMENT: COLLECTION EFFICIENCY





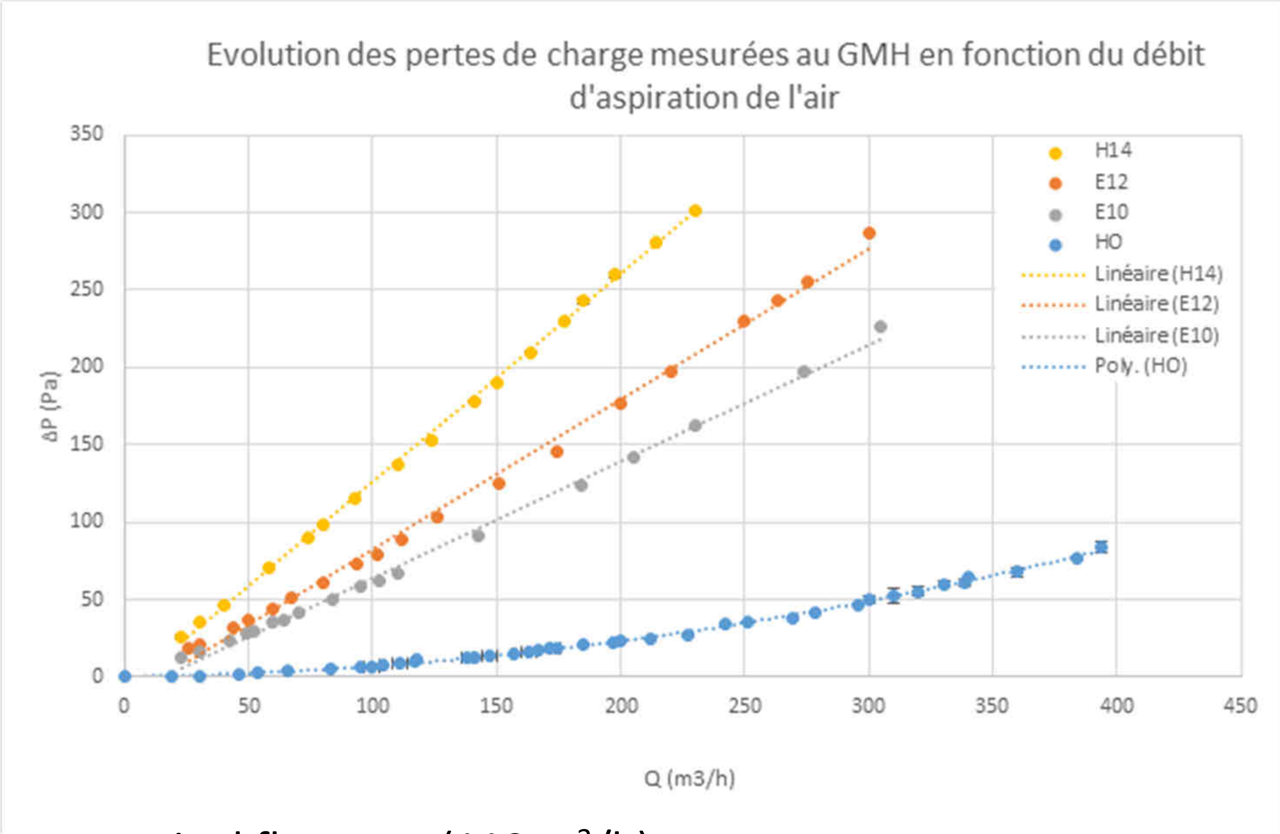




- E10: Efficiency decreases with flowrate

- E12 and E14 : Efficiency remain stable with flowrate (c.a. 99.98%)

COMPARATIVE ASSESSMENT: PRESSURE DROP



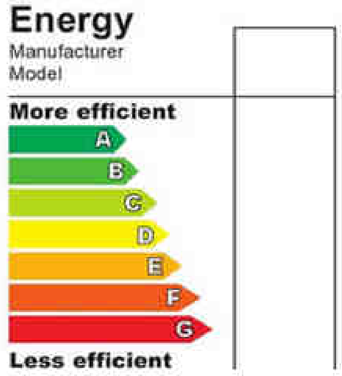
Pressure drop at nominal flow rate (110 m^3/h)

Filtre	ΔP from manufacturer (Pa)	ΔP measured (Pa)
E10	70	67
E12	85	86
H14	120	137

KEY FINDINGS: CHALLENGES IN AIR FILTRATION

- **High efficiency**

Clean Air Delivery Rate (CADR)
Most Penetrating Particle Size (MPPS)



- **Low pressure drop**

Energy consumption (kWh)
Key energy performance (KEP)

- **Long term stability**

Replacement and maintenance costs
Reentrainment
Biological contamination & proliferation

- **No by-product**

Ozone and secondary aerosols
Main issue of active systems

Based on those considerations, it appears that both particulate air filtration technologies (Mechanical filtration and ESP) present benefits and drawbacks, which have to be assessed regarding the targeted application.

PERSPECTIVES

- Optimisation of the charging stage of the ESP participates to lower O_3 emissions while enhancing charging rate
  - Evaluation of different wires (chemical nature, diameter)
  - Evaluation of different geometries (2, 3, 4 wires)
  - Evaluation of the local effect of temperature (wire)

- Optimisation of the collection stage of the ESP
  - To facilitate cleaning
  - To maintain low reentrainment and low pressure drop

The research leading to these results has received funding from CEA and the European Research Council under the European Union's H2020 Grant Agreement n°831963 (EC2S project).

Special thanks to Clemence Menguy who is conducting the experimental study.

Thank you for your attention !

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PLATE-FORME NANO SÉCURITÉ

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FROM RESEARCH TO INDUSTRY

KEY FINDINGS

HEPA filtration Vs Electrostatic Precipitation: Pros and Cons

- The energy consumption of fiber based air filtration systems mainly depends on the density of the fibrous filter. The particle accumulation on the filter leads to higher collection efficiency but simultaneously generates higher pressure drop over the lifespan of the filter. This pressure drop increase requires the filter to be replaced periodically to avoid damages on the air circuit.
- In contrast, with airflow occurring tangentially to the collected material, ESP are characterized by low-pressure drop and have lower power requirement. Generally speaking, ESP may be considered less efficient in removing particles from air stream than HEPA filters when very high collection is intended (>99.95%).
- However, the usefulness of ESP technology in mitigating both biological and non-living aerosols has been demonstrated, even for ultrafine particles. Regarding biological matter, it is well documented that mechanical filtration may present a risk of contamination because the surface of fibrous filters, where microorganisms and nutriments accumulates, can represent a suitable ecosystem for microorganisms growth. For ESP, research has shown that electrical charging impairs the survival rates of bacterial cells and spores, thus limiting their proliferation.
- As described by Wen et al. [53], a factor called 'Key Energy Performance' (KEP) involving both collection efficiency and energy efficiency can be used for filter performance evaluation. In their study, ESPs showed better efficiency/consumption balance, with significantly higher KEPs than fibrous medium filter.
- Based on those considerations, it appears that both particulate air filtration technologies (Mechanical filtration and ESP) present benefits and drawbacks, which have to be assessed regarding the targeted application.