Investigating the performance of the FLEX-PNC diffusion charger PN and PM measurement system

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Introduction to the 3DATX FLEX-PNC®

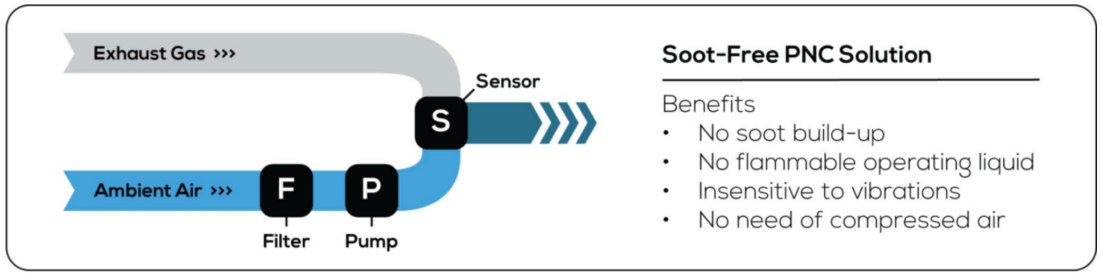
- Pollutants:
  - PN (23 and 10 nm cutoffs + VPR ~ SPN),
  - PM,
  - CO, CO_2, HC, O_2, NO & NO_2.
- ECU reader: Vehicle speed, engine speed, mass air flow, throttle position, lambda, fuel rate, absolute throttle position, air intake temperature.
- GPS and ambient monitor: Ambient temperature, ambient pressure and humidity, latitude, longitude, altitude, speed, heading, etc.

	Non-Dispersive Infrared Spectrometer (NDIR)			Individual Electro-Chemical Cells			Diffusion Charger	
	CO_2	CO	HC	O_2	NO	NO_2	PN	PM
Measurement Range	0-20%	0-15%	0-4000 ppm	0-100%	0-5000 ppm	0-300 ppm	1000-1x10^7 #/cm3	0.1µg/m^3 - 15mg/m^3
T_{90} Response Time	< 3.5 s	< 3.5 s	< 3.5 s	< 6 s	< 5 s	< 35 s	< 10 s	< 10 s
Resolution	0.01 %	0.0001 %	1 ppm	0.01 %	1 ppm	0.1 ppm	200 #/cm^3	0.1 µg/m^3
Accuracy	±0.3% abs ±3% rel	±0.02% abs ±3% rel	±8 ppm abs ±3% rel	±0.1% abs ±2% rel	±15 ppm abs ±2% rel	±5 ppm abs ±2% rel	±5,000 #/cm^3 abs ±25% rel	TBC
Repeatability	±0.1% abs ±2% rel	±0.02% abs ±2% rel	±6 ppm abs 2% rel	±0.1% abs ±2% rel	±5 ppm abs ±2% rel	±5 ppm abs ±2% rel	±10,000 #/cm^3 abs ±8% rel	TBC

FLEX-PNC diffusion charger overview

➢FLEX-PNC incorporates an NMi, METAS, and PTB certified particle number concentration sensor, based on the extended diffusion charging principle.

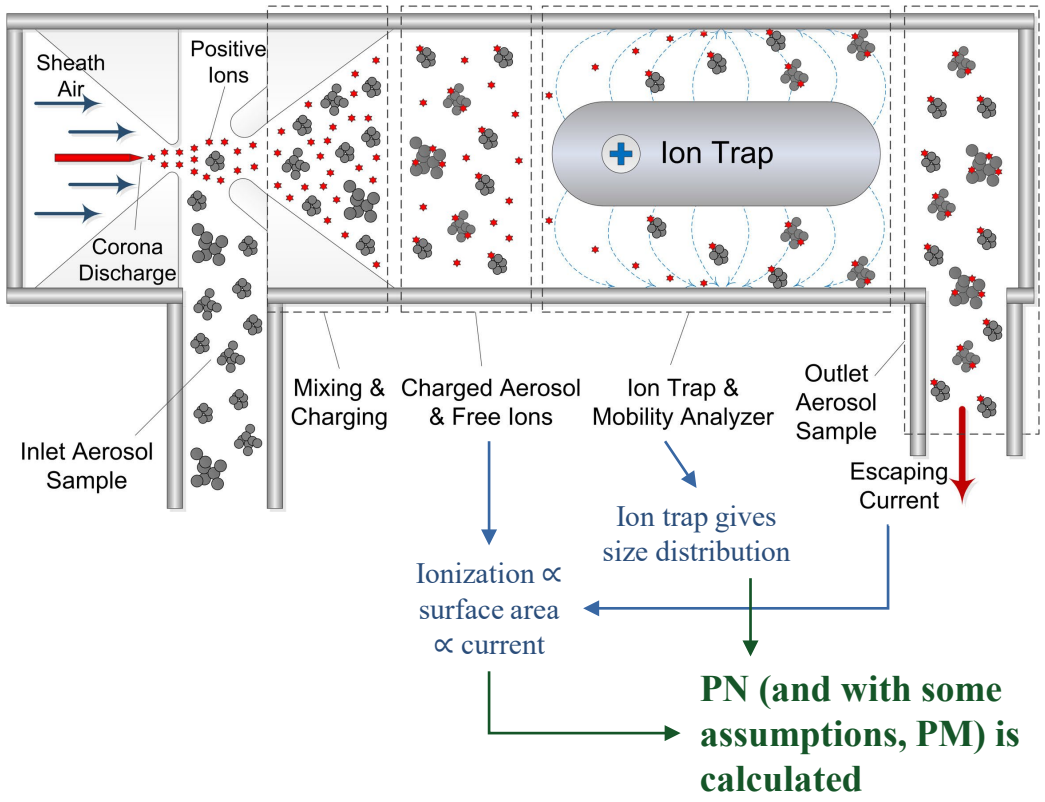
Capelec, 2023



PNC		10nm cutoff	23nm cutoff
Range		1,000 - 100x10^6 #/cm^3	
Resolution		200 #/cm^3	
Accuracy		5,000 #/cm^3 absolute or ± 25% relative	
Counting Efficiency	10 nm ± 5%	30 – 50 %	N/A
	23 nm ± 5%	75 – 100 %	34 – 60 %
	50 nm ± 5%	71 – 101 %	71 – 101 %
	80 nm ± 5%	97 – 127 %	97 – 127 %
PM Size Range		Particulate up to ~300 nm diameter*	

*Accuracy decreases above 300 nm diameter

*S. Amanatidis et al. / Journal of Aerosol Science **92** (2016)*



Results

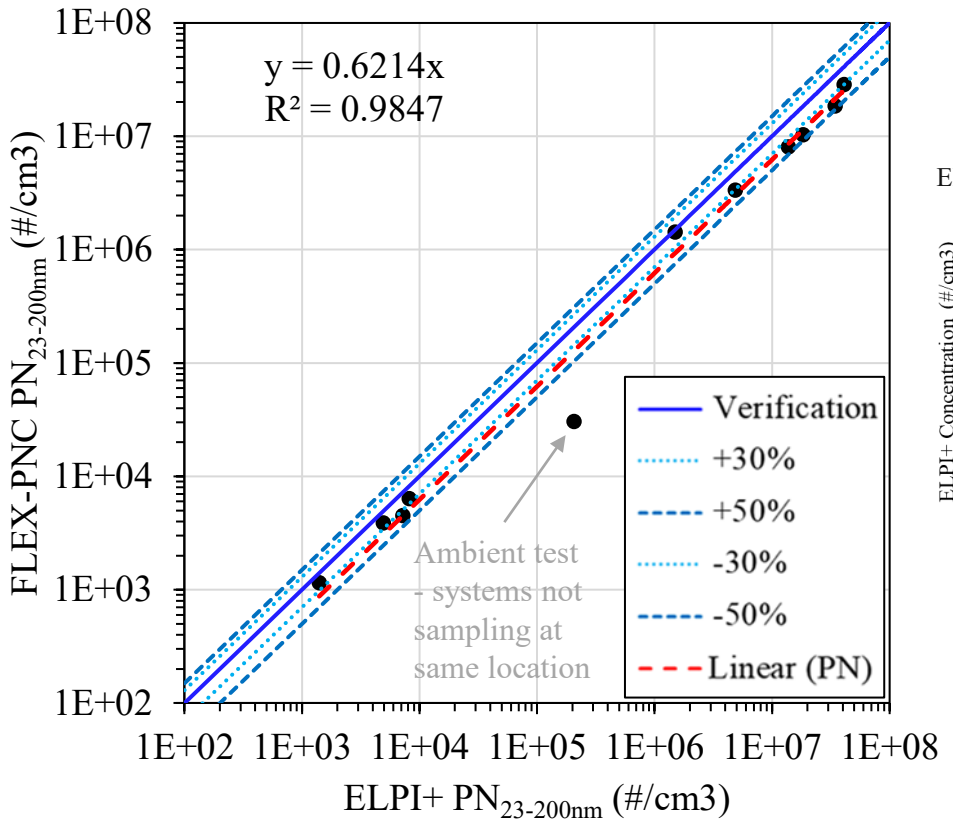
Note that in 2024, an adjustment was made to the firmware of the diffusion charger which improved particle counting. Tests performed before this time (i.e. those dated 2023) were retrospectively adjusted to account for this firmware upgrade, with small changes to PN values resulting.

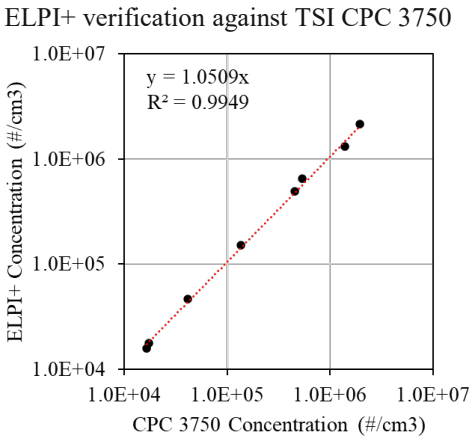
FLEX-PNC *vs* ELPI+ (CAR, Colombia, 2023)

- FLEX-PNC had acceptable (av. 30% lower) correlation to ELPI+ for 23-200 nm measurement range from 5 (LD & HD) vehicles tested at idle and high idle.
- An ambient test showed an 85% decrease, but the sample sites were not the same.

5% are super-200nm fraction

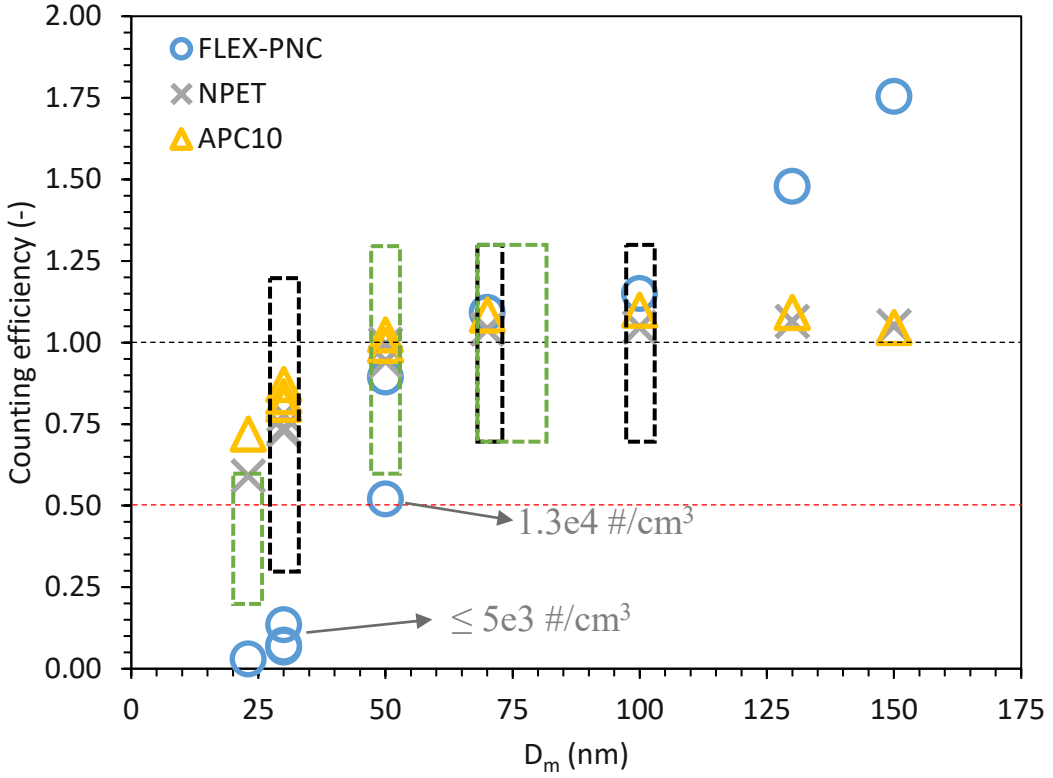
53% are sub-23nm fraction



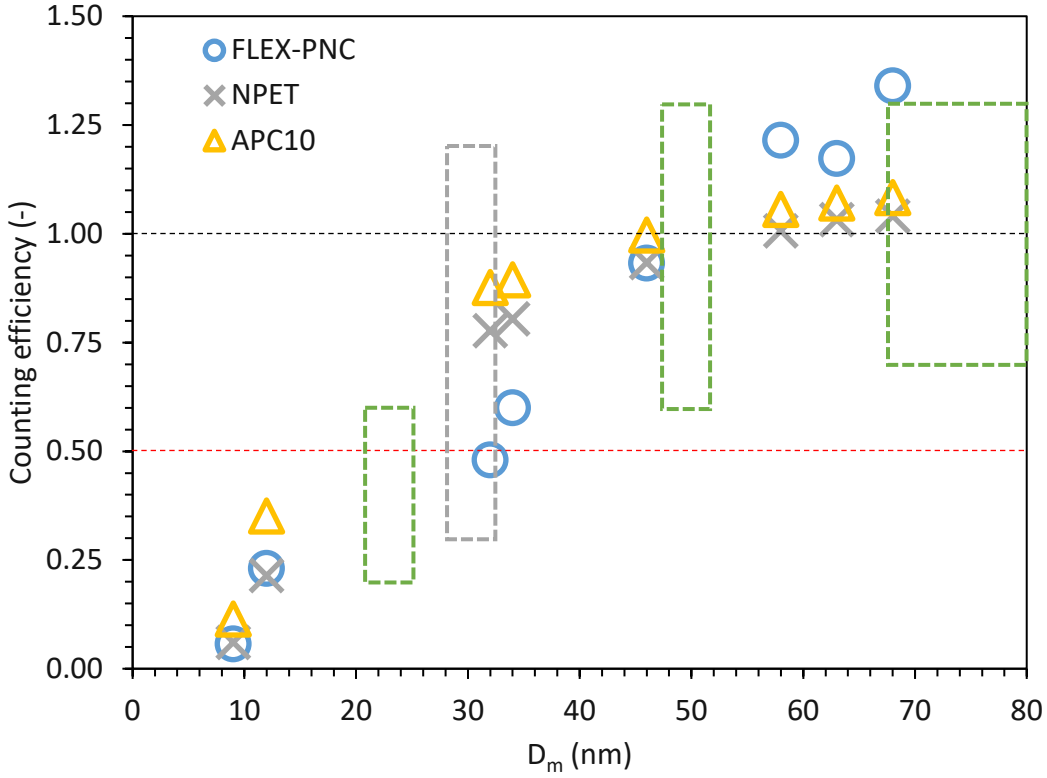


FLEX-PNC counting efficiency *vs* NPET and APC10, using the TSI CPC 3752 (JRC, Italy, 2023)

Monodisperse graphite (PALAS)



Polydisperse silver and graphite

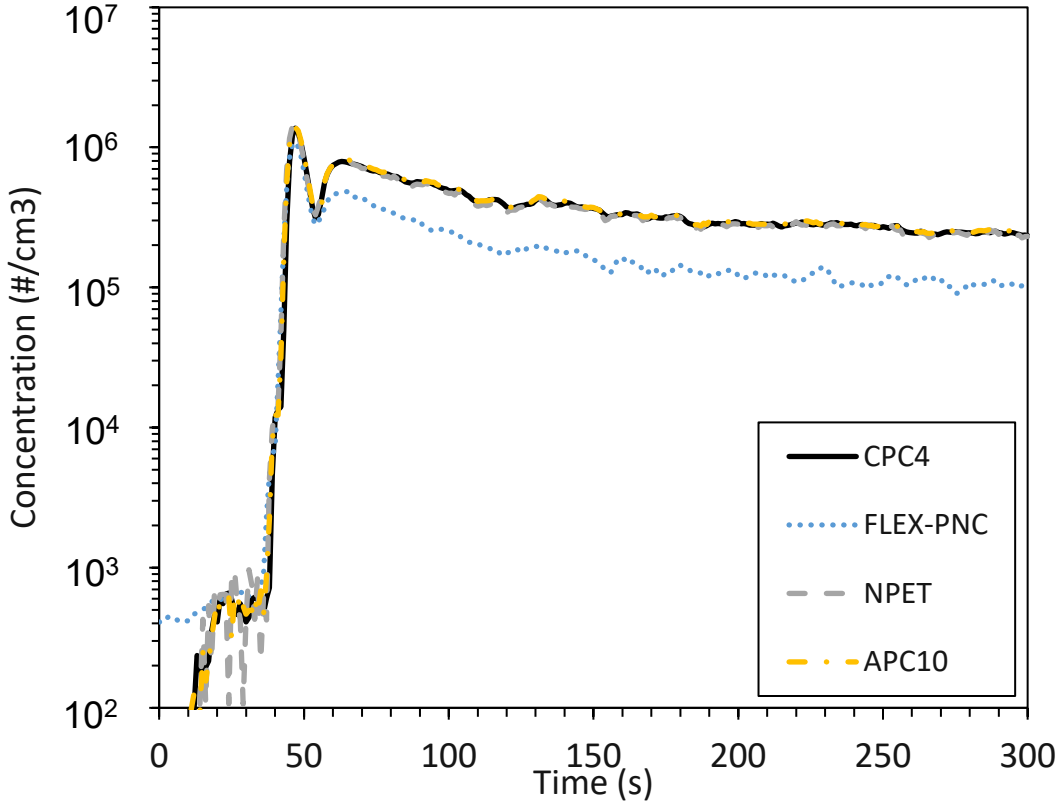


Green boxes show the minimum requirements for PN-PTI instruments, black boxes the additional PEMS requirements.

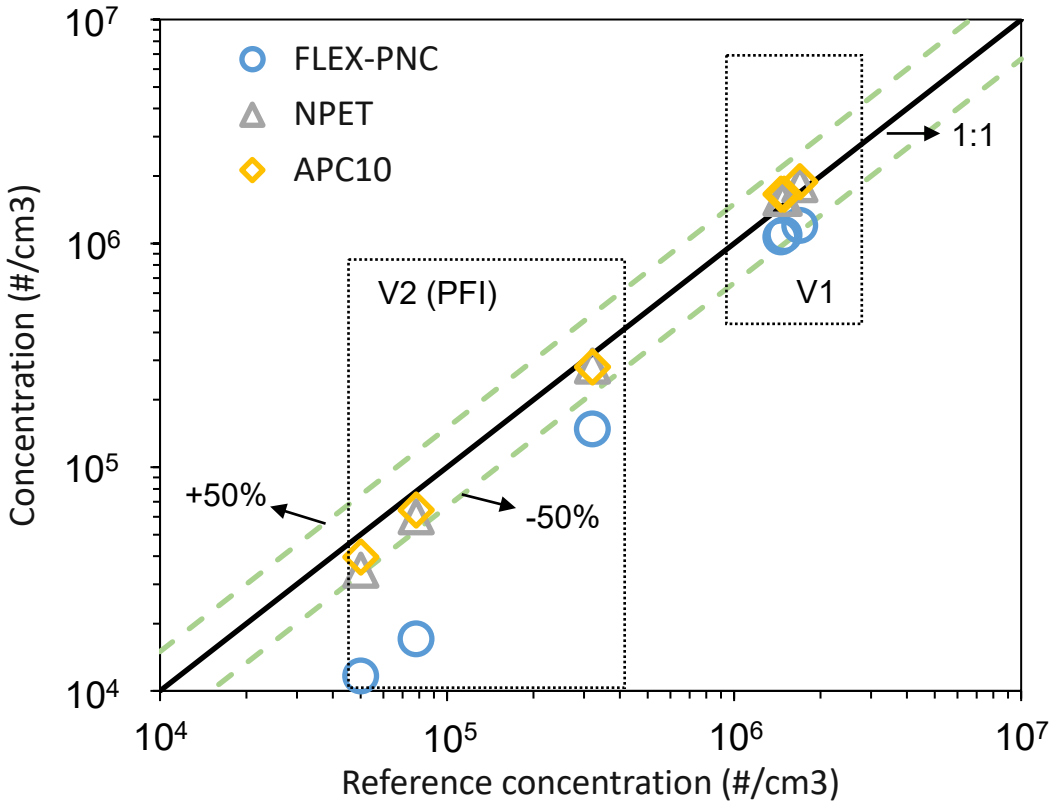
CE was within limits for 50-100 nm monodisperse and 30-50 nm polydisperse.

FLEX-PNC *vs* TSI CPC 3752, NPET and APC10 during vehicle testing (JRC, Italy, 2023)

Transient plot – V1 (GDI)

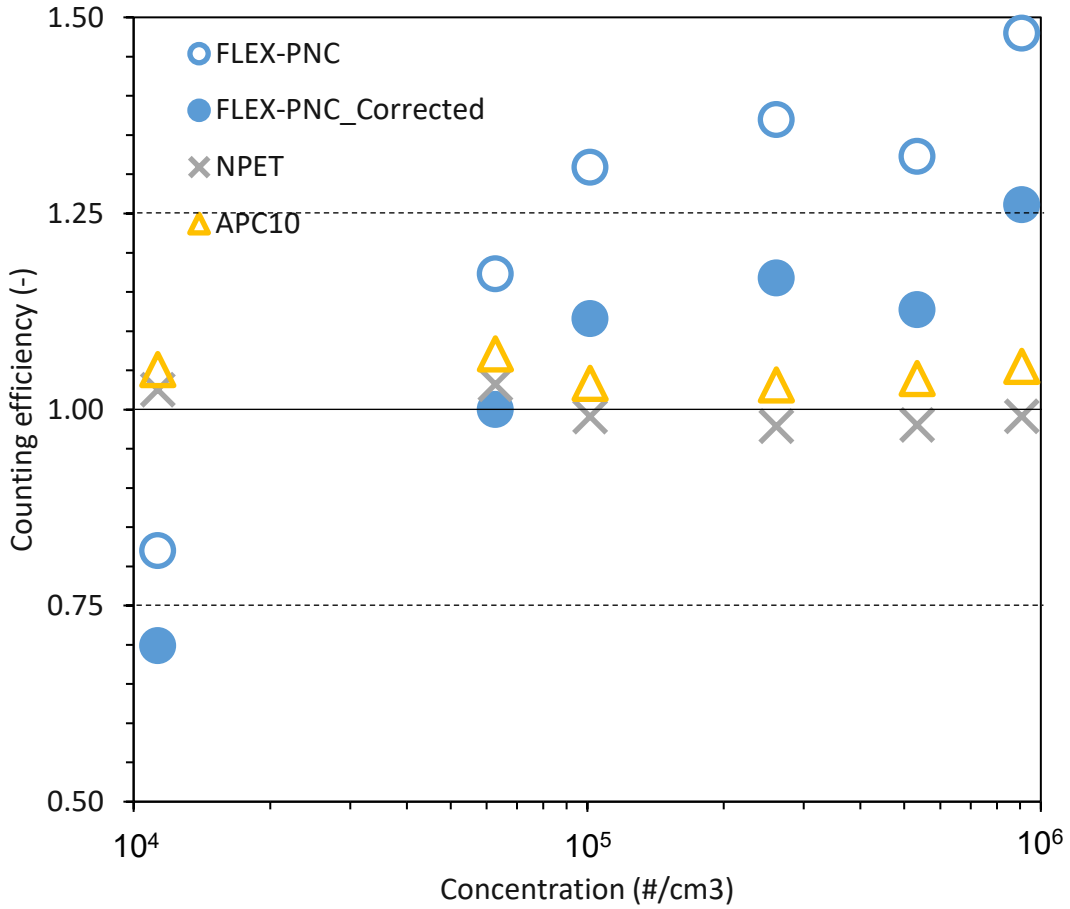


Hard accelerations



FLEX-PNC to be within 25% from hard acceleration GDI vehicle ("V1") testing (within 55% for low idle) but underestimated the low PN concentration from a PFI vehicle ("V2").

FLEX-PNC linearity *vs* NPET and APC10, using the TSI CPC 3752 (JRC, Italy, 2023)



- In a wide range of concentrations (10^4-10^6 #/cm3) the counting efficiency of FLEX-PNC was in the range 0.8-1.48.
- Correcting for the counting efficiency at the specific GMD of the size distributions, the counting efficiencies were in the range 1-1.26 except for the lowest concentration (~0.7)

Summary

Conclusions

- The FLEX-PNC gave 30% lower PN than the ELPI+ during stationary idle and high idle LDV and HGV tests at Corporación Autónoma Regional de Cundinamarca (CAR)
- The FLEX-PNC generally performed within acceptable limits for PTI regulations during testing at JRC, except for in the case of very low test aerosol concentrations, where the counting efficiency decreased.
- FLEX-PNC is a field-proven instrument that has been operated from sea level to >2600 m altitude and from >0 °C to >40 °C (tested to 42 °C). It provides comprehensive measurement of ICE emissions under stationary or mobile conditions, integrating:
  - PN10 (EURO7) and PN23
  - PM (pre-Euro 5B and non-EU regions) – verification in progress (see next slide),
  - Gases: CO_2, CO, HC, NO, NO_2 and O_2,
  - Optional external measurements: Ambient conditions, GPS positioning and ECU data and other instruments (pressure sensors, temperature sensors, exhaust flow meter, Ammonia, …)

Future Work

- Initial trials of our FLEX-PNC PM measurement have been performed against a laboratory reference instrument using a particle generator. However, suspected charged characteristics of the particle source affected the comparison.
  - We are awaiting additional comparison trials with neutral particle sources, to fully validate the PM sensor.

Thank you for listening

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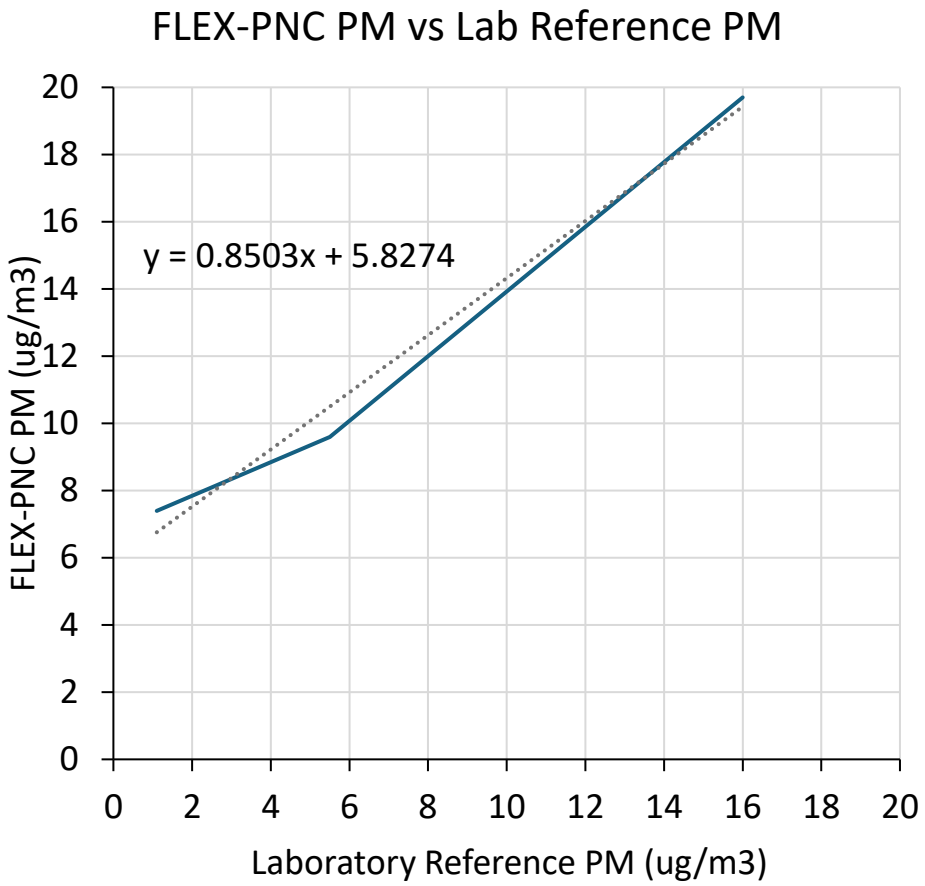
FLEX-PNC Initial Preliminary PM Results



- Initial trial of FLEX-PNC PM measurement against a laboratory reference instrument using a particle generator.
- Suspected charged characteristics of the particle source affected the comparison.
- Further tests with neutral particles are planned in the near future