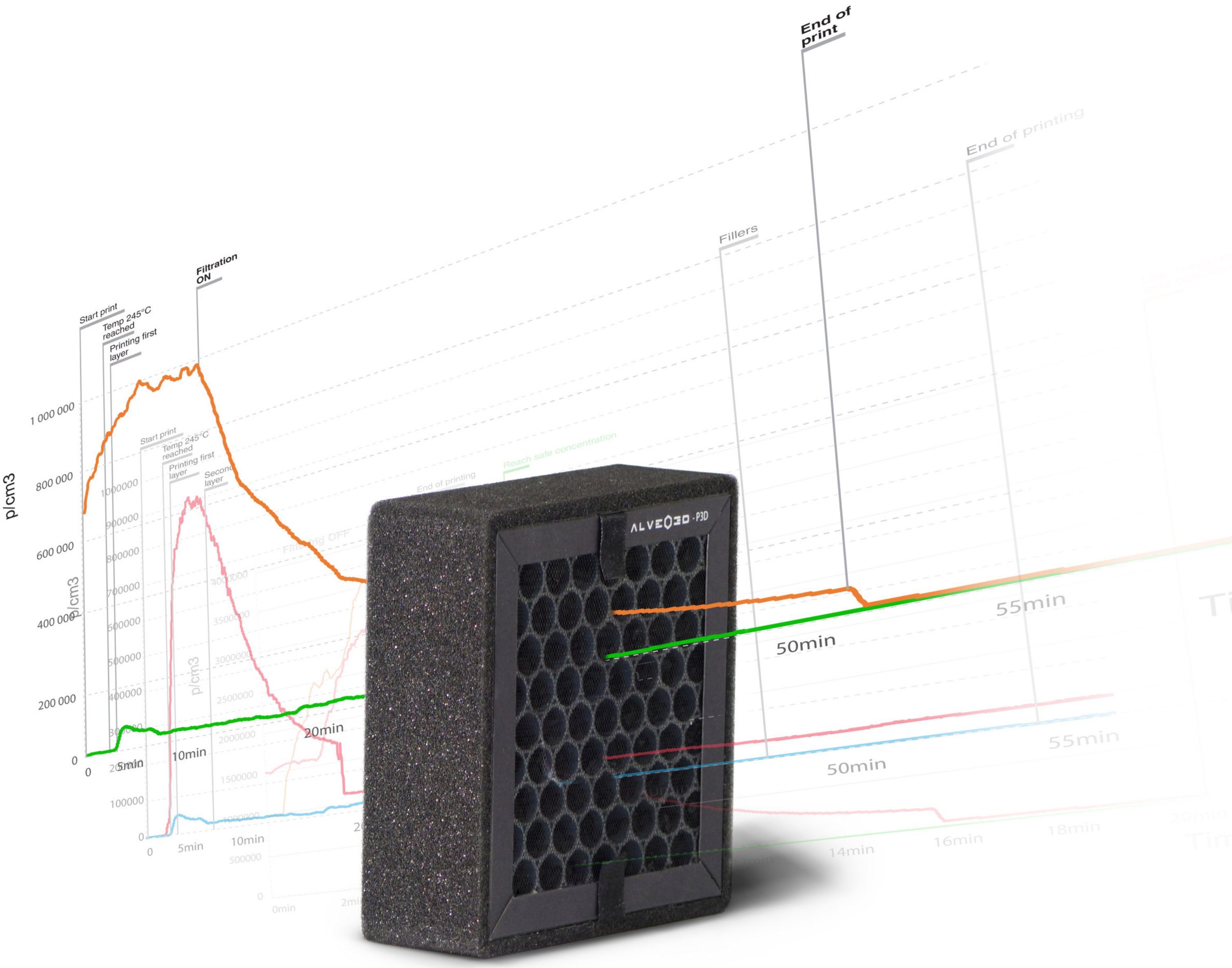
ALVEO3D

Written by **Lucas Martini**

Nanoparticle emissions
in additive manufacturing
and
efficiency measurements of P3D filters



www.**alveo3d**.com

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1. Introduction

Additive manufacturing by Fused Deposition Modeling (FDM) has shown a potential health risk for operators and people exposed to pollutant emissions related to the melting of heated plastic in poorly ventilated or unventilated rooms. These pollutant emissions are made of VOCs and nanoparticles.

Many of the studies that have already been published on this topic point out that the majority of nanoparticles produced vary in size from 10 to 100 nm, whereas the formation of particles between 100 and 500 nm is far less common.

We decided to start a study in February 2021 with the primary goal of counting the number of nanoparticles generated while printing in a 3D printer chamber. The next step was to determine the P3D filter's effectiveness regarding the particle concentration inside the 3D printer enclosure.

To achieve these objectives, we followed the detailed protocol below.

2. Protocol

We conducted a measurement campaign inside Alveo3D's facilities.

We used a CPC Palas counter model: ENVI-CPC-100, to measure the production of these elements on a measuring bench that has been specifically created for the study of particles. The instrument can measure 7-5000 nm with accuracy up to 100,000 p/cm3. The measurement range of the device is from 7 to 5000 nm with an accuracy of 5% up to 100 000 p/cm3 and 10% past that.

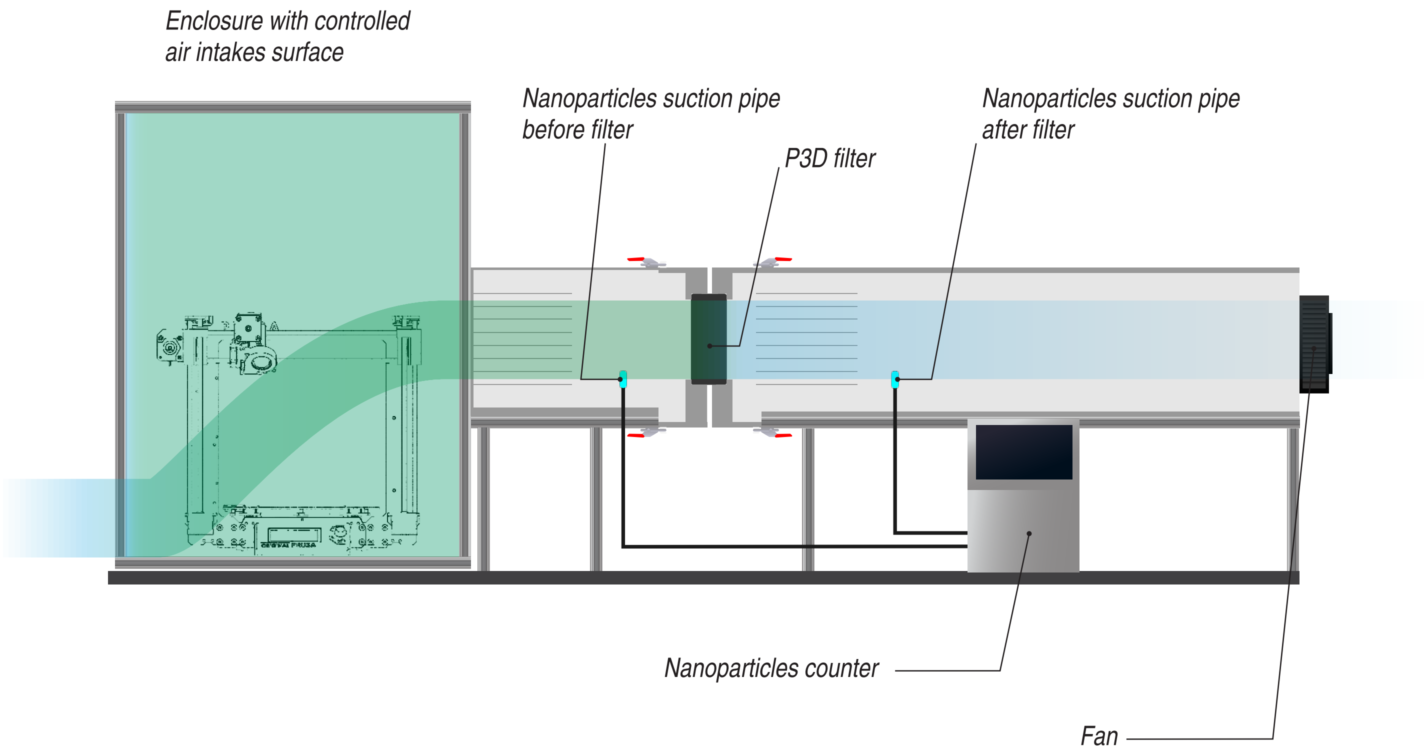
A Prusa MK3S 3D printer was used in a controlled airflow chamber set on an Alveo3D measuring bench to generate the particles.

The measuring bench was still under development at the time of the study, in 2021, and measurements were conducted manually, upstream and downstream of the filter, in the duct.

The upstream section of the filter permits particle measurements in the 3D printer enclosure. This configuration is very comparable to the actual usage conditions of 3D printers equipped with ALVEO3D safety enclosures. The downstream section of the duct represents the "clean" air leaving the filter.

A first series of measurements was conducted for each frequently used plastic of the PRUSAMENT brand, including PLA, PETG, and ABS.

Each 3D printing process was programmed with the same GCODE file, (a programming language that allows the machine to understand the instructions needed to produce the final part). Furthermore, the extrusion temperatures applied were within the range recommended by the manufacturer.



Then, during the same print run, a second series of measurements was conducted to quantify the effectiveness of the filters using alternating samples before and after filtering.

3. Measurements

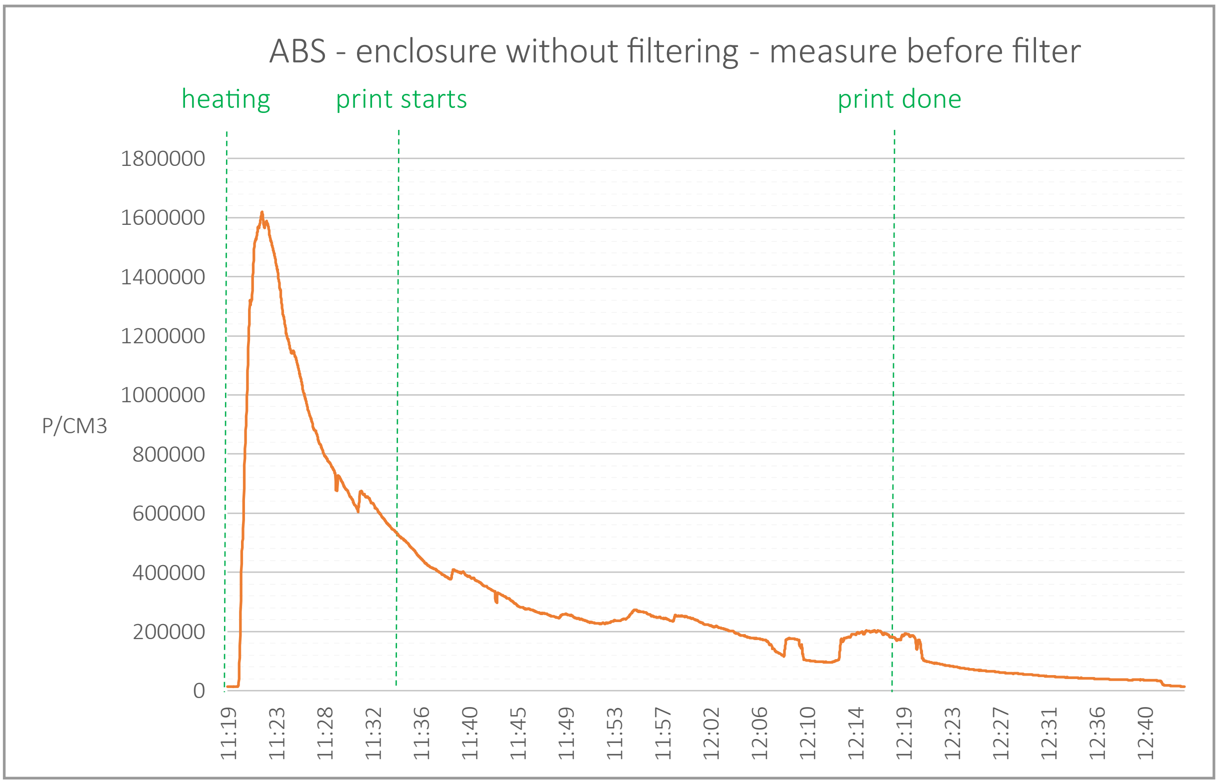
In the first sequence, the measurements were conducted according to a complete manufacturing cycle. For each plastic filament, the particles were measured in 3 distinct steps:

- Step 1: Measurement in the chamber without air ventilation.
- Step 2: Measurement in the box with air ventilation
- Step 3: Measurement after the filtration

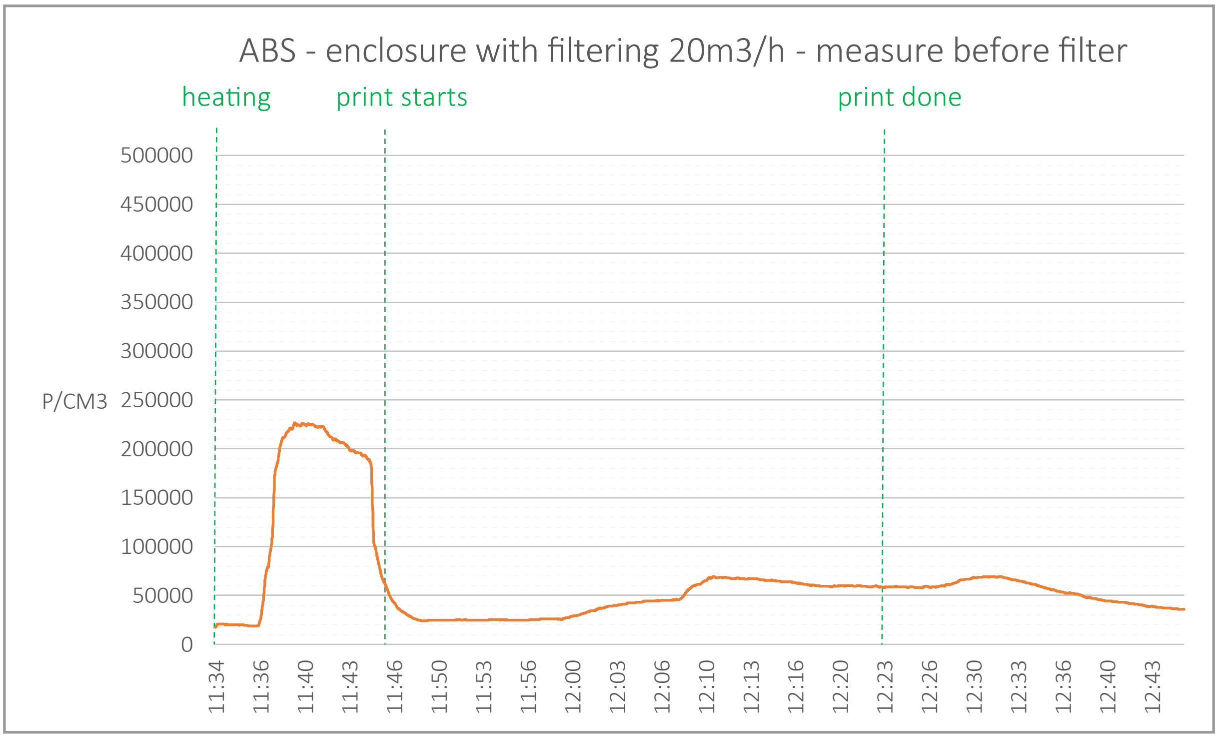
→ The first filament observed was ABS.

a) ABS filament

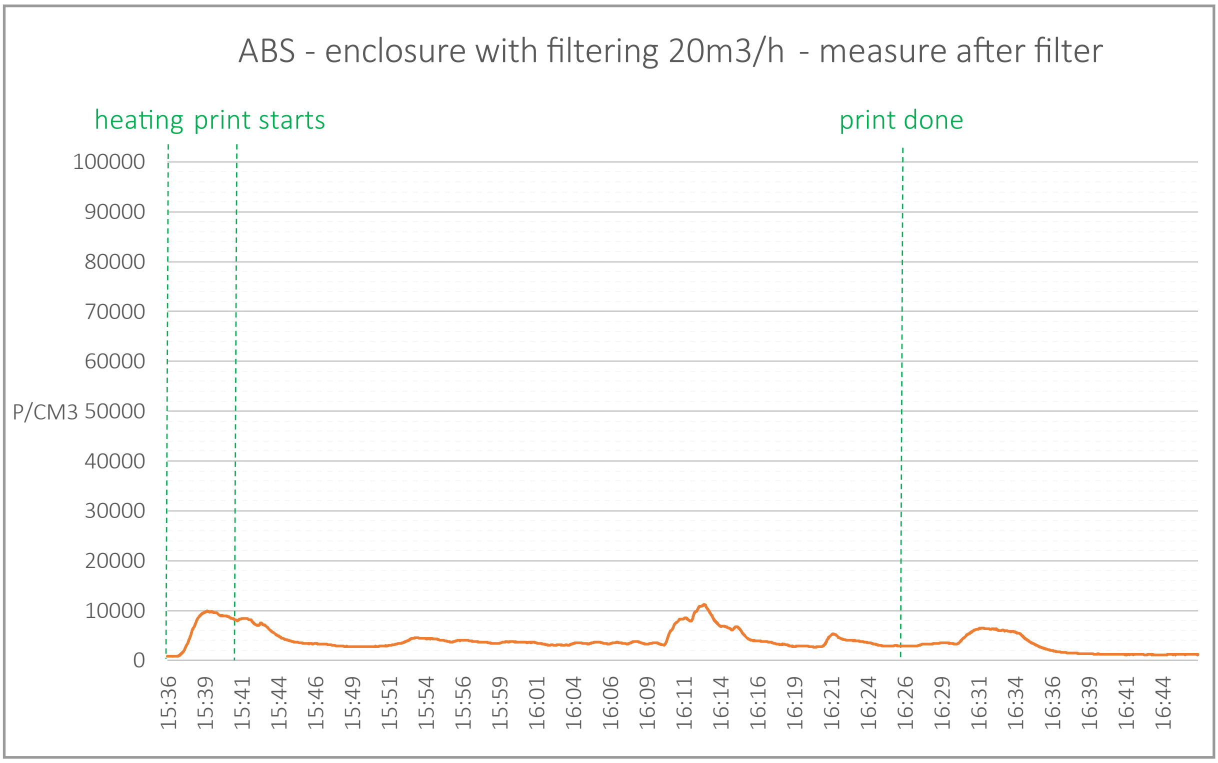
It is the most emissive one of our tests, this may be due to its chemical composition and/or its higher extraction temperature: 250°C.



This first measurement of particles generated by our 3D printer, in an unventilated chamber, reveals a high concentration of particles from the initial heating of the nozzle before any printing had even begun. We can see that the particle concentration remains high throughout the entire printing process, it was initially at 13,640 particles per cubic centimeter.



Regarding the second measurement, we can see that, throughout the entire printing process, the ventilation seems to limit the peaks and the average value of the particle concentration. We observe for the second time a high concentration of particles as soon as the extruder reaches its nominal temperature, before any printing had even begun.

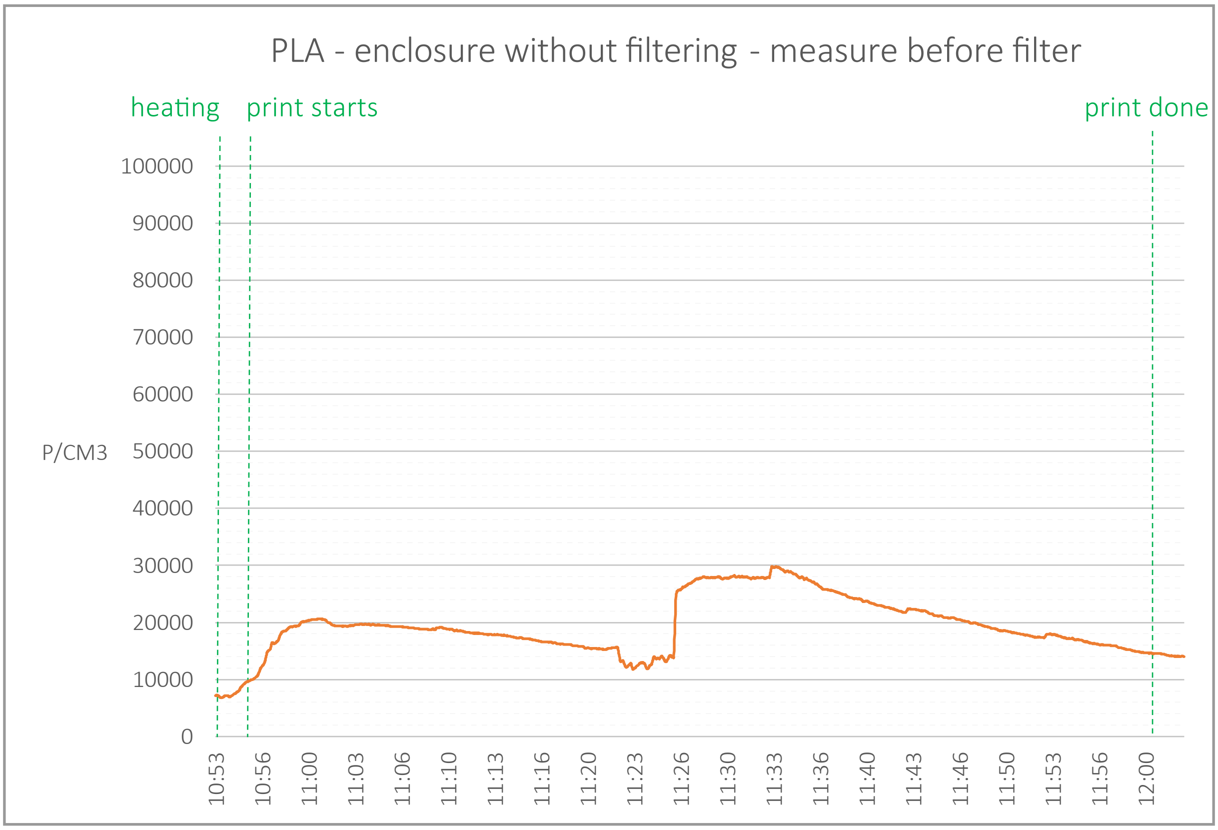


This third sequence of measurements reveals a significant reduction in the concentration of nanoparticles in the air after the filtration. However, it is still possible to find a production peak at the beginning of the process and some fluctuations during the manufacturing phase. Despite the fact that the ABS filament produces a lot of nanoparticles, the filter appears to be efficient. Even if it is the most emissive filament in our test, the amount of pollution naturally present in the air (13600 p/cm3), is not surpassed.

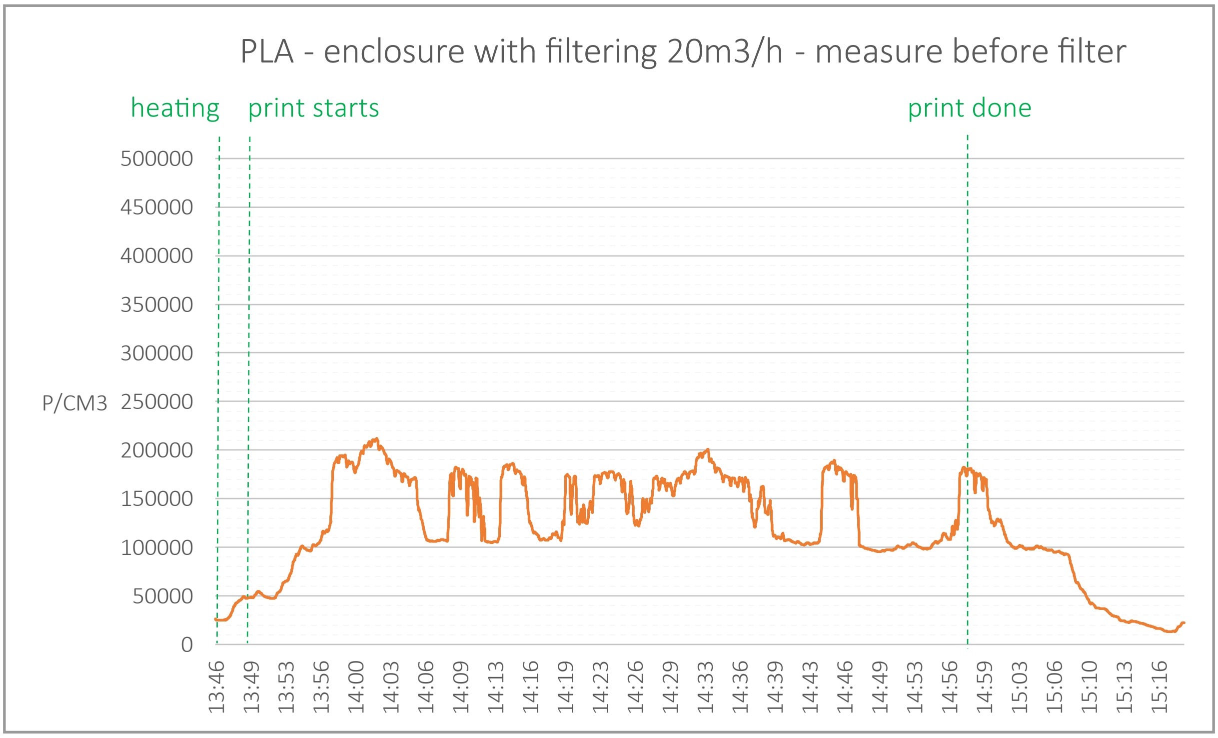
b) PLA filament

The PLA filament was the second filament tested. This organic filament prints at a lower temperature than ABS: 215°C.

We followed the same protocol starting with measuring the particle rate in the unventilated chamber.

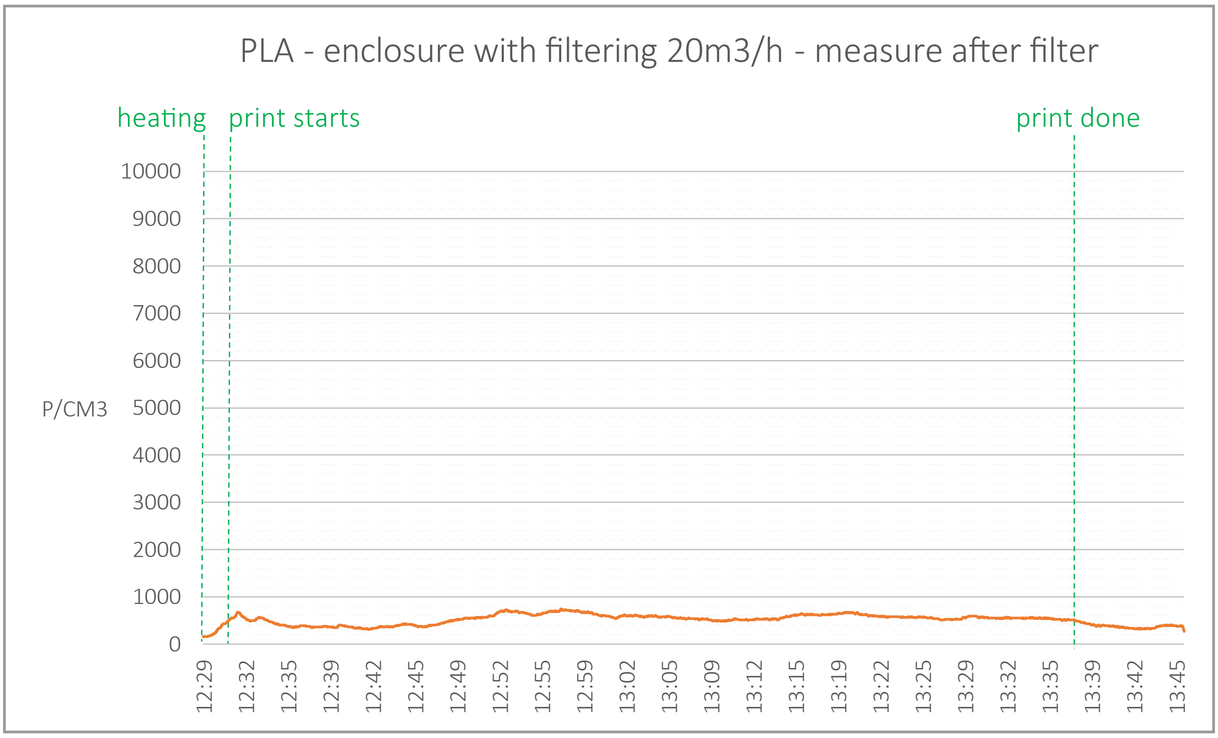


Our results indicate that PLA is a low-emission filament compared to ABS. In the most negative circumstances, air pollution with particles can be multiplied by three. We also observe that there is a rise in particle production during the filling of the printed object. These observations suggest a correlation between the beginning of filling and the increase in particle production.



Under the same conditions, activating the ventilation causes more particle pollution than in the previous measurement without ventilation.

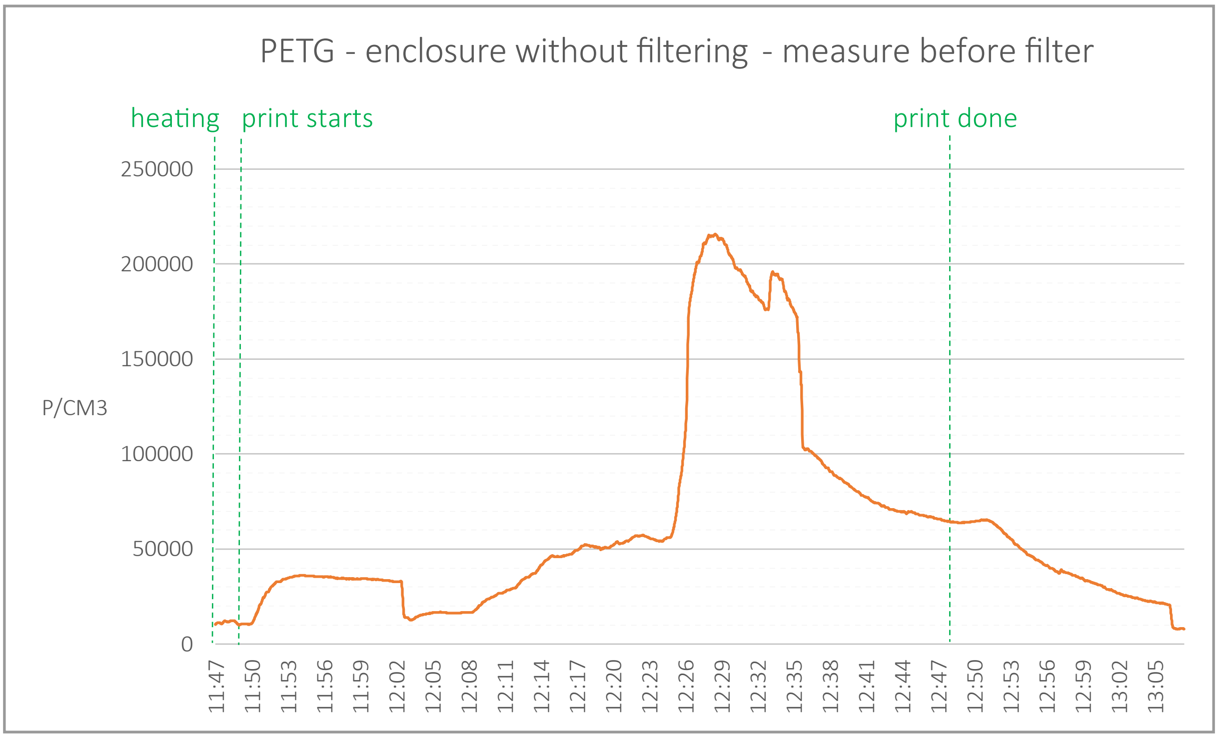
Our theory implies that air agitation generates variations in particle concentration in the volume of a 3D printer chamber.



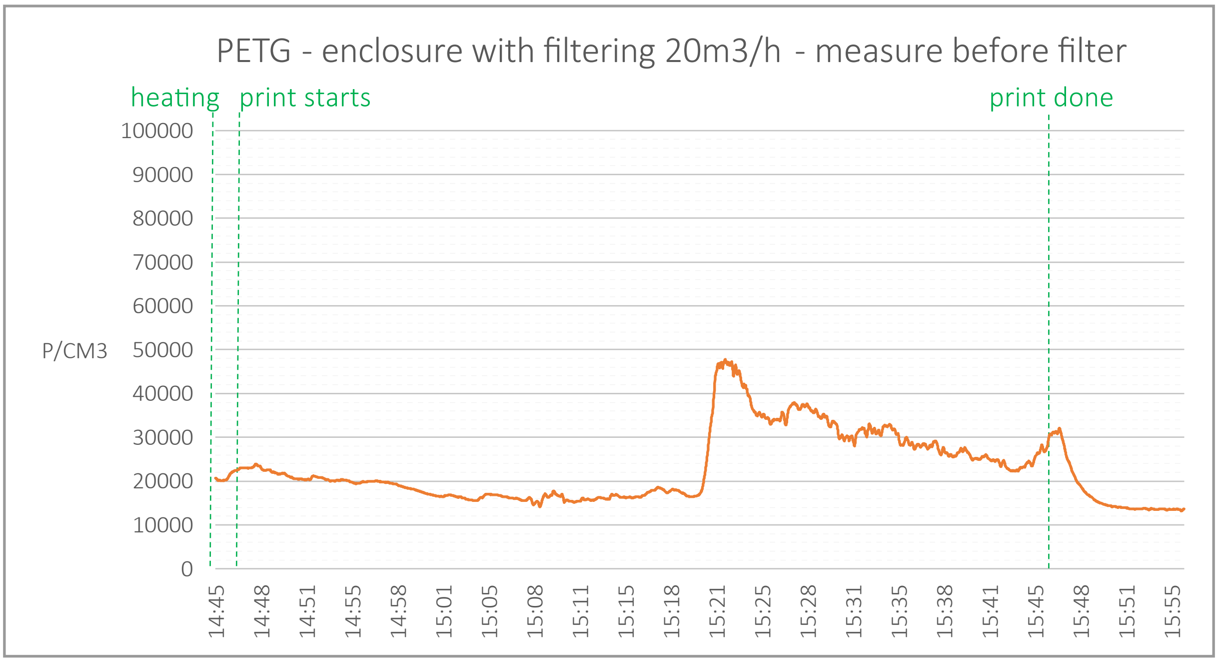
During the third measurement, after filtration, and throughout the entire PLA printing, we notice that the filtration is particularly effective when it comes to a concentration always below 1000 p/cm3.

c) PETG filament

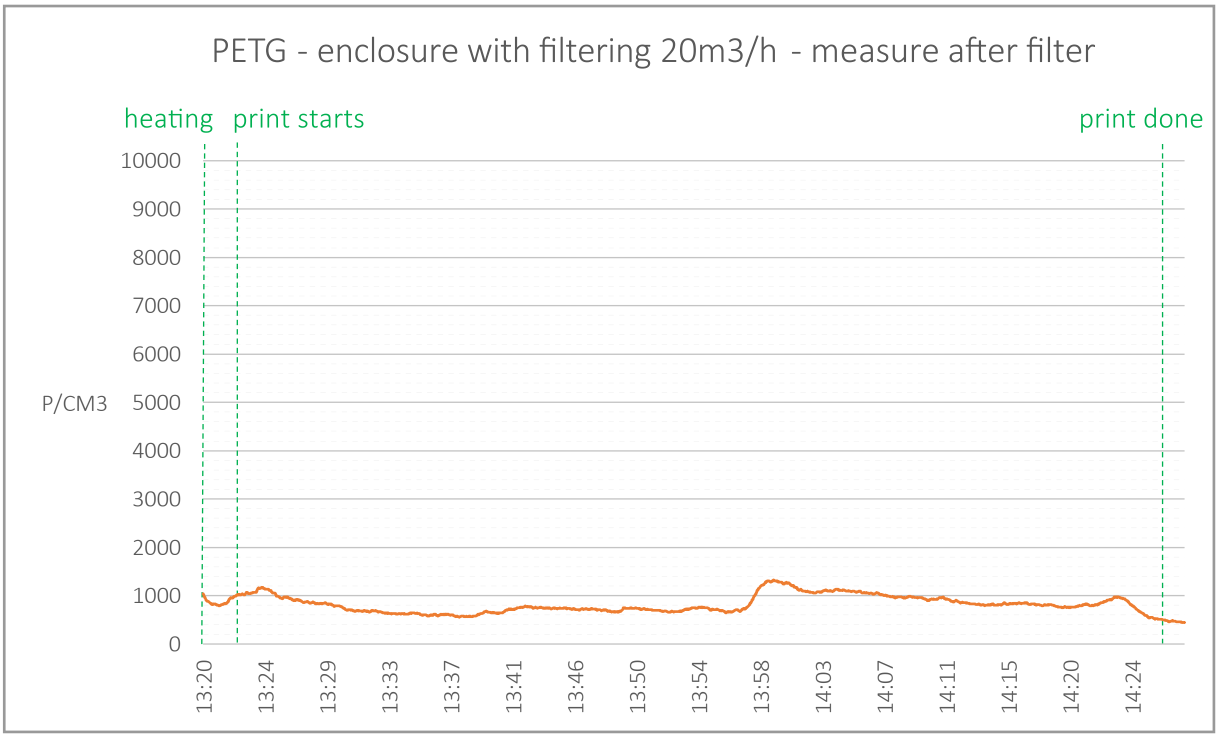
The last filament tested is PETG. It is a filament that we commonly use for the production of functional parts. Its printing temperature is 245°C.



The first measurement in the non-ventilated chamber is marked by a significant peak of particles. According to all the measurements, this filament is more emissive than PLA and ABS.



We also measure this concentration peak when the chamber is ventilated. But this time, the peak is less important, going from 200.000 p/cm3 to 48.000 p/cm3. Once more the proportion is respected, with a concentration of nanoparticles included between those of PLA and ABS.



Finally, post-filter measurements show that the filtration is highly efficient. The particle concentration after filtering is lower than the concentration of air pollution. However, it is important to point out that particle production peaks can still be detected when comparing the measurements before and after filtration.

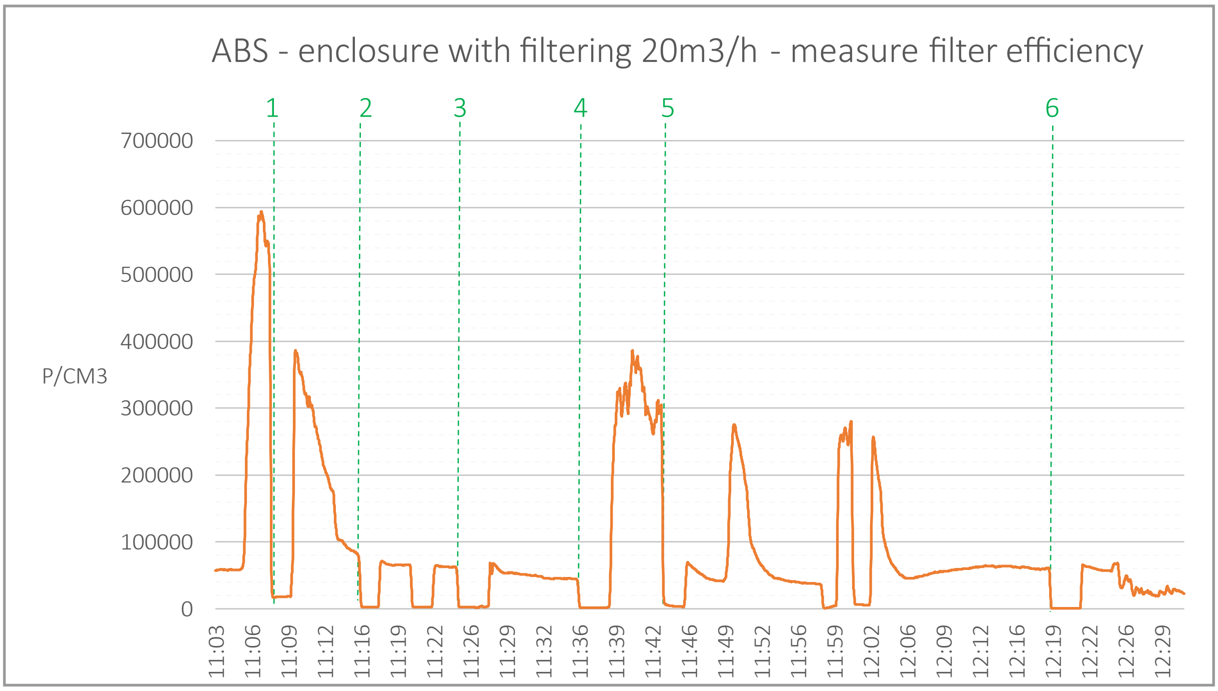
4. P3D filter efficiency

The filter efficiency was calculated by alternating between pre-filtration measurements in the housing and measurements at the filter output.

To avoid potential measurement errors caused by the reading time of the particle, we calculate an average efficiency rate over several measurements.

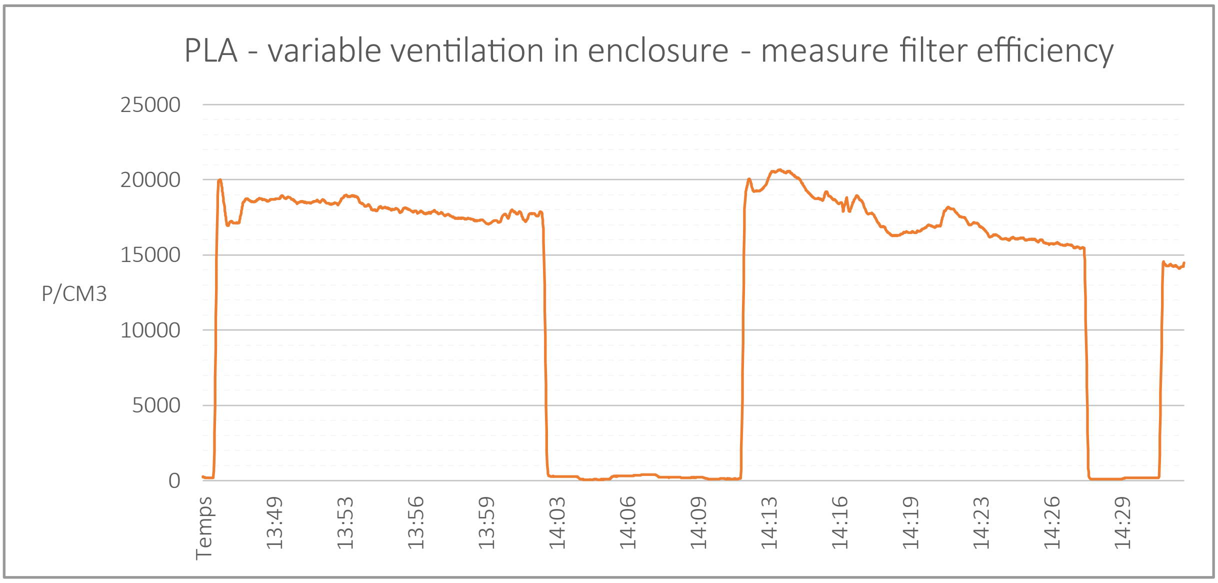
The particle concentration (p/cm3) is measured at different airflow rates. This airflow rate is proportional to the air velocity passing through the HEPA 13 filter media, which may cause variations in filtering efficiency.

a) ABS filament



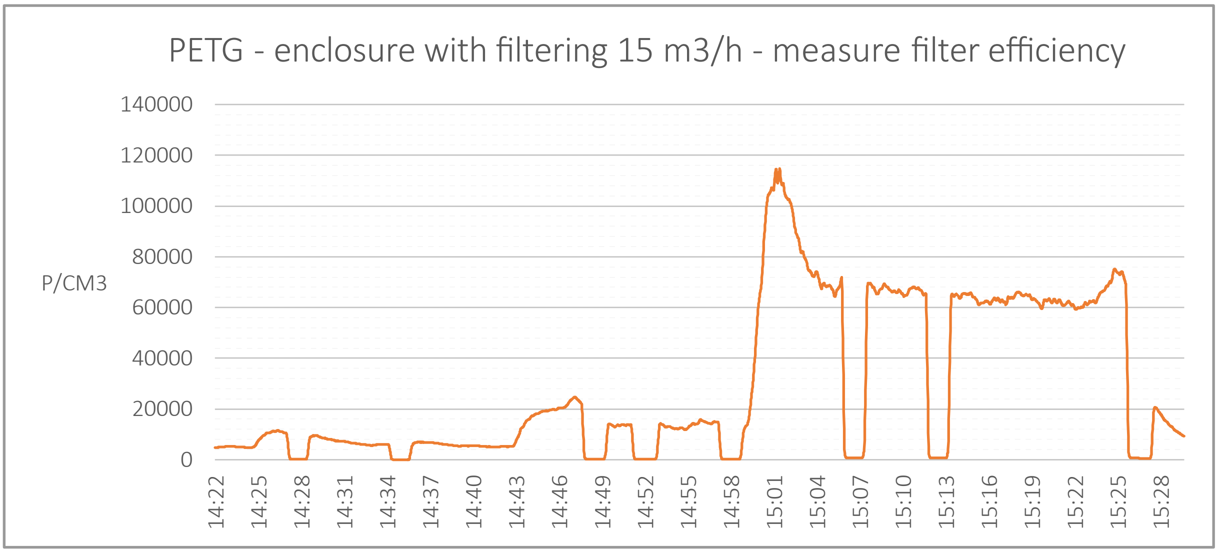
Following numerous measurements, we are able to estimate an ABS filament filtering effectiveness of nearly 97.36%.

b) PLA filament



Regarding PLA, the measurements allow us to estimate an average efficiency rate of approximately 98.69% for 20m3/h.

a) PETG filament



This time, for PETG, the measurements give us an average efficiency rate of 98.90% at 20m3/h.

Now we are going to compare the filter efficiency based on the filament and the airflow.

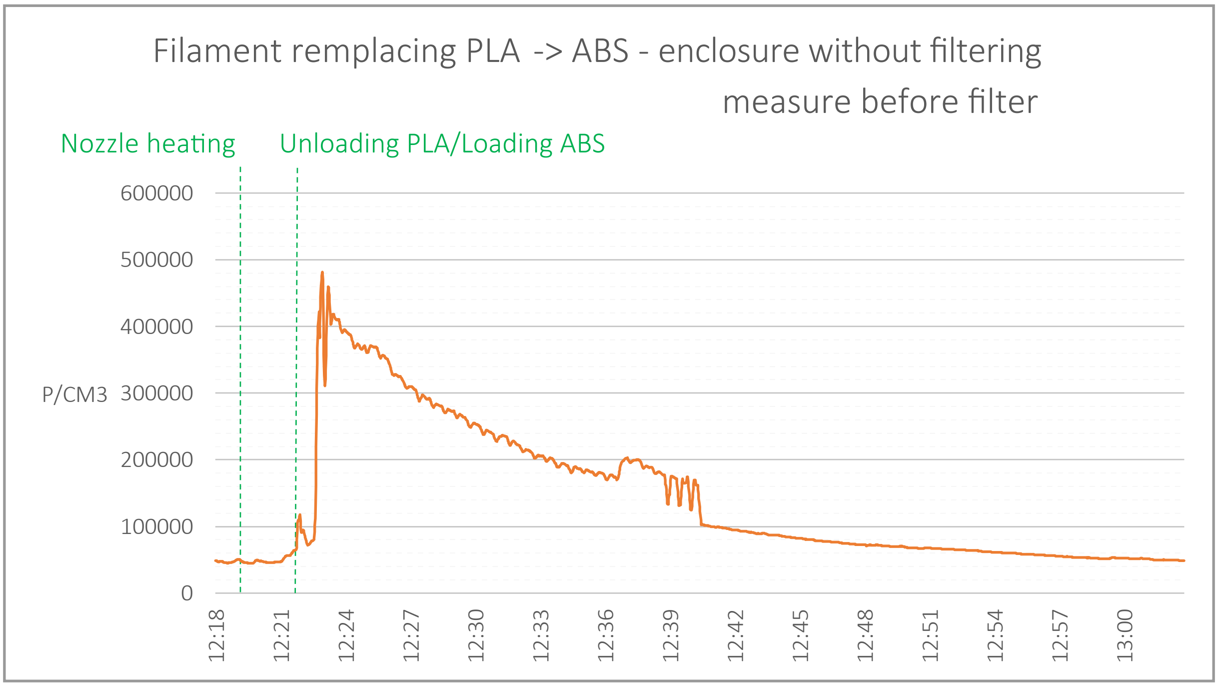
Regarding the efficiency depending on the filaments, we note that the nature of the filament has an impact on the filtration efficiency. We can explain this phenomenon by considering the size of the particles emitted during the printing process. ABS is printed at a higher temperature than PETG, which is itself printed at a higher temperature than PLA. We see the same hierarchy when it comes to the filtration efficiency, that seems to confirm that the high extrusion temperature generates smaller particles (less than 100 nm), which reduces the filtration efficiency. However, we cannot determine to what extent filament composition and extrusion temperature influence the size of the particles emitted. In this case, a granulometric analysis of the particles might be relevant.

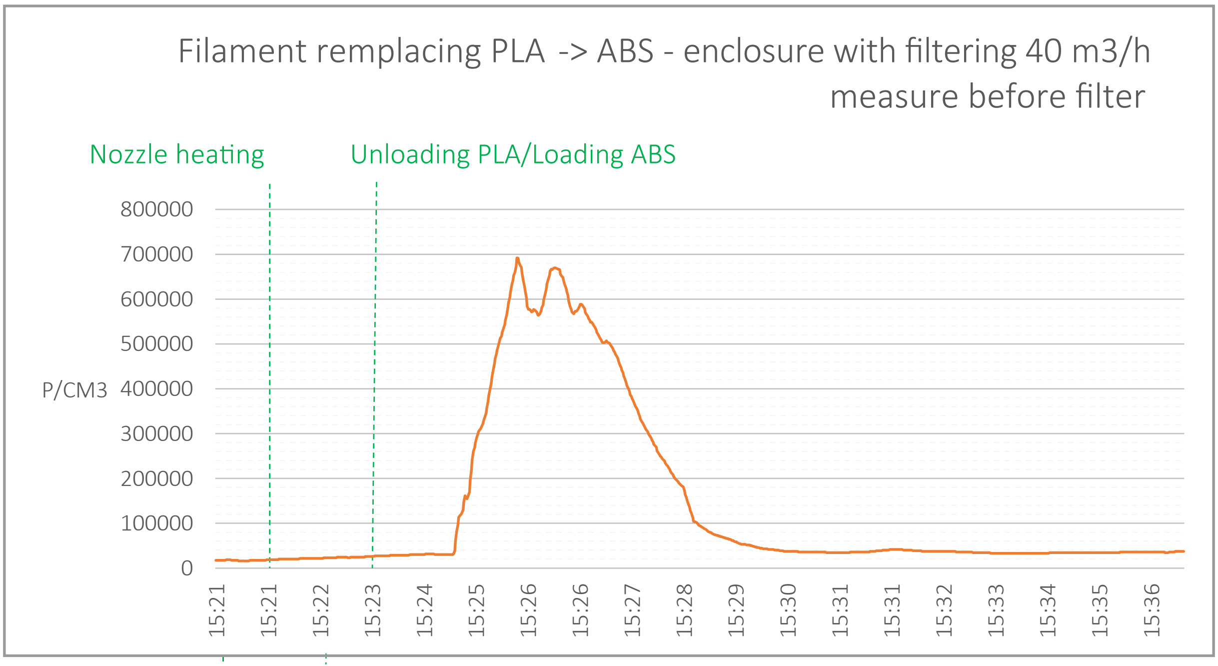
Regarding the efficiency of filtration depending on its airflow rate, we can observe an improvement when reducing the airflow. Therefore, with a lower air exchange rate, the concentration in the chamber will increase. This airflow can also have an impact on printing quality.

5. Filament change

Our first particle study revealed a significant particle production rate during filament-changing procedures.

To evaluate the benefit of the Alveo3D filtration system, we measured the particle concentration with and without ventilation.





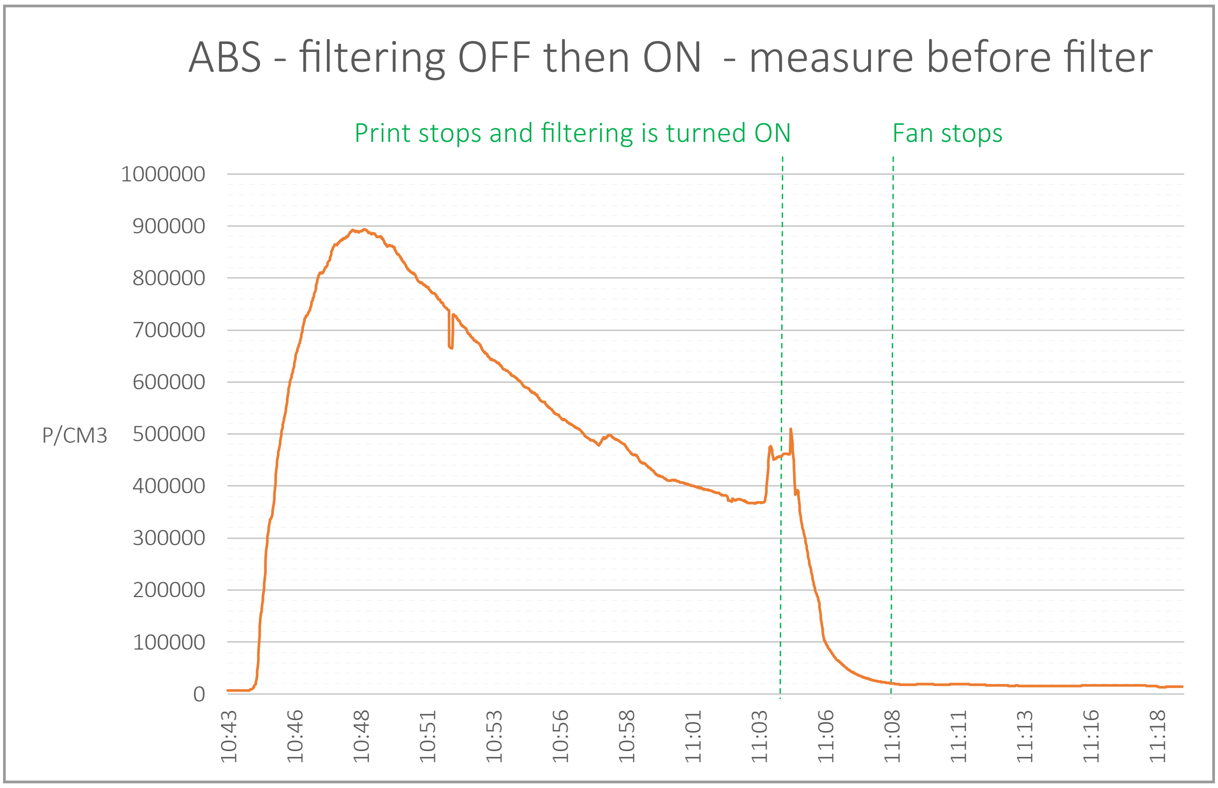
Based on our measurements, we notice several specific phenomena during filament change :

- The particle production is fast and important as soon as the extruder is heated.
- With ventilation, high particle concentration is significantly reduced in the chamber: now it only takes about 5 minutes, for more than 20 minutes without using it.
- The particle concentration peak occurs about 2 minutes after the filament change. This can be explained by the latency of the particle counter reading

To complete our measurements, we tested the effectiveness of fast ventilation.

In the following scenario, a printing defect occurs, necessitating an immediate stop of the production process, involving access to the printer.

We can see that by activating fast ventilation (100% of the ventilation power, i.e., 40 m³/h air flow), within 4 minutes, the concentration of particles goes down from 500 000 p/cm³ to less than 10 000 p/cm³.



6. Conclusion et recommandations

The implementation of our test bench, designed specifically for particle emission measurements in additive manufacturing, turned out to be offering a wealth of learning opportunities. These measurements not only allowed us to quantify the number of particles emitted during the printing process but also to ensure our P3D filter efficiency.

Efficiency measurements per complete cycle underline the higher harmfulness of ABS filaments compared to PLA and PETG. **We first recommend favoring these low-emission filaments to guarantee the safety of the operators**. Regardless of the filament selected during printing, **the continuous use of air filtration is also recommended** since air pollution levels are systematically surpassed.

Ventilation recommendations with V2 control card

- **ABS** requires 80% ventilation until printing begins. 30 to 40% throughout printing and **until the bet cools down**.
- **PETG and PLA** need 80% ventilation until printing starts. 50 to 70% during printing and **until the bed cools down**.
- At the beginning and end of the print cycle, you can also quickly drain your printer if you need immediate access to it.

The ventilation speed can have an impact on the print quality, especially for filaments that are sensitive to warping. It is therefore important to adapt this ventilation speed to the temperature conditions to which the 3D printer will be exposed.

With a minimum efficiency of 97.36%, and the need to access the machine depending on the production phase, **it is recommended that you use your 3D printers in ventilated rooms**.

We also recommend having the V2 board and printer interfaces accessible outside the enclosure so that they can be accessed during printing without having to be exposed to nanoparticle emissions.

Long-term exposure can lead to chronic toxicity, so **it is recommended that you reduce your exposure time**. Since very few studies prove the effects of nanoparticles in terms of toxicity on the human body, it is difficult to say at what level of particle concentration it may become toxic to one's health. Therefore, it is important to apply a precautionary principle by limiting exposure time, especially when accessing the printer (filament change and start and end of printing).

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Study conducted in february 2021 and report written in Mars 2021

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