Analysis of gaseous and particle number concentration from a binder jetting 3D printer during manufacturing of a mould

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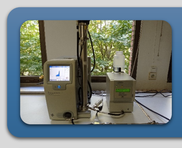
INTRODUCTION

Nowadays, the importance of indoor air quality (IAQ) is clear, since people spend more than 80 % of their time in indoor environments, like for example in office or laboratory environments. In last years, the use of laser printers or 3D printers has become widespread.

The IAQ in the printers laboratory may be deteriorated by the emission of particulate matter (PM) and volatile organic compounds (TVOCs), compromising the health of workers. In this context, inside the chambers of the binder jetting 3D printer, a continuous movement of dry powder occurs. Hence, this process can be a potential source of particles, from the powder, and VOCs, from the binder solution, as observed by Afshar-Mohajer *et al.* (2015).

The main aim of this study is to analyze the particle number concentration (PNC) during the processes of manufacturing 3D printing (3DP) mould, melting and pouring of aluminium. The concentrations of particles by sizes -modes (nucleation: <30 nm; Aitken: 30-100 nm; accumulation:100-310 nm) and gaseous (NO_2, SO_2, CO and TVOCs) have been analyzed.

MATERIAL AND METHODS



Scanning Mobility Particle Sizer spectrometer

(TSI-SMPS Model 3938)

Gray Wolf (WolfSense IQ-610)

- Temperature, relative humidity, CO, CO_2 and VOCs

Aeroqual series 500

- O_3, NO_2 and SO_2

EMISSION RATES

$$\overline{ER_p} = V \times \left[\frac{C - C_0}{\Delta t} + \overline{(\alpha + \kappa)}\,\bar{C} - \alpha C_0\right]$$

where ***C* and C_o** are the peak and initial particle concentrations, $\bar{C}$ is the mean concentration during printing, ***V*** is the volume, ***α*** is the average air exchange rate, $\overline{(\alpha + \kappa)}$ is the mean particle removal rate and ***Δt*** is the time difference between the initial and peak particle concentration. The particle removal rate $\overline{(\alpha + \kappa)}$ is the slope obtained by plotting $\ln(C/C_o)$ versus time (Alves *et al.*, 2013).

GROWTH PHASE FIT

$$C_t = \frac{(C_{max} - C_{min})}{\left(1 + e^{-\left(\frac{t - t_0}{b}\right)}\right)}$$

where ***t*** is time (s), C_t is the PNC in the time *t* (# cm^{-3}), **(C_{max} - C_{min})** is the interval of the upper asymptote minus lower asymptote; t_o is the inflection point, and ***b*** is the slope coefficient.

CASTING PROCESS USING BINDER JETTING TECHNOLOGY

1) Manufacturing 3DP mould: printing and post-processing

- 1.1) bed print
- 1.2) printing the mould
- 1.3) drying the mould
- 1.4) dust aspiration and extraction of the mould
- 1.5) cleaning the mould
- 1.6) heating in the oven at 240 °C for 60 min
- 1.7) maintenance at 240 °C for 90 min
- 1.8) cooling inside the oven

2) Melting and pouring

- 2.1) heating of aluminium to 750 °C
- 2.2) pouring and cooling
- 2.3) breaking mould
- 2.4) cooling

RESULTS

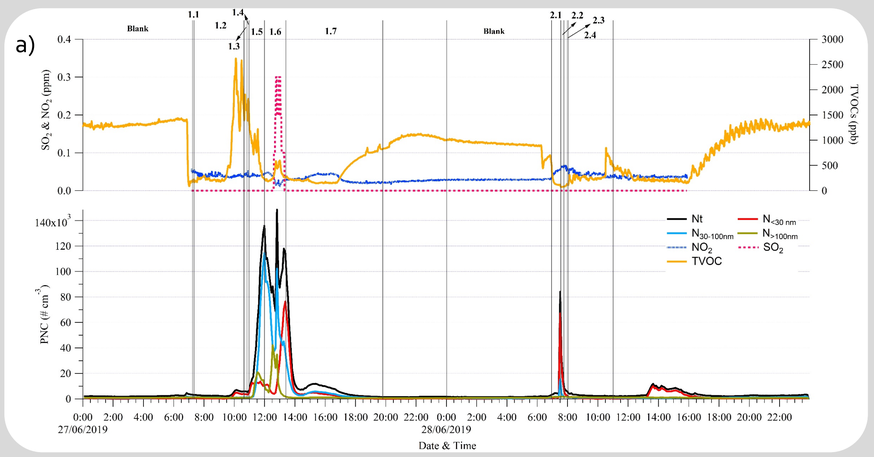


Figure 1. Evolution of: a) particle number concentration by modes, VOCs, NO_2 and SO_2 concentration along all processes; b) temperature, relative humidity, CO_2 and CO.

In Figure 1, it can be seen that:

- **SO_2**: this gas is only registered during the phase **1.7** (0.09 ppm), when keeping the mould in the oven at 240 ºC for 90 minutes. It was not registered along process 2.
- **TVOCs**: a continuous increase in volatile compounds between phases **1.1 and 1.5** (from 190 to 1672 ppb) is observed and there is a decrease in all phases related with heating (e.g. in the phases 1.6 and 1.7 from 1672 to 326 ppb).
- **CO** ranged between 1.58 ppm (phase **1.8**) and 4.30 ppm (phase **1.7**). A clear increase of CO concentration is registered during the use of oven at 240 ºC.

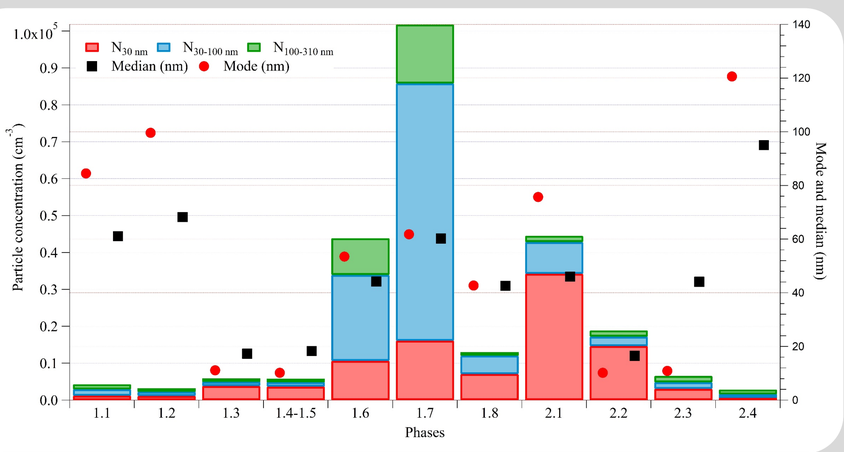


Figure 2. Particle number concentration by modes: nucleation (N_{nuc}), Aitken (N_{Ait}), and accumulation (N_{acc}), median and mode during the different phases.

- During the **process 1** (Figure 3), the phases **1.6** and **1.7** stand out as having a high concentration of particles in all size ranges.
- In phase **1.8**, a sharp decrease of particles above 40 nm is observed, returning to pre-heating conditions.
- During the **process 2**, no influence is observed for particle sizes larger than 75 nm as the data are practically identical throughout the four phases.
- The phases **2.1-2.4** presented the higher global particle rate emission ($3.07 \cdot 10^{11}$ particles min^{-1}) (Table 1).

Table 1. Summary of ventilation rates, PNC slope coefficients, time to reach maximum concentrations and global emission rates from the different phases.

Phases	1.1-1.5	1.6-1.8	2.1-2.4
Ventilation rate (h^{-1})	3.44	5.55	1.55
Slope coefficient (b)	0.1	15.9	41.4
Time to max PNC (min)	192	120	6
Emission rate particle number ($\overline{ER_p}$) (#·10^{11} min^{-1})	0.01	2.14	3.07

- During the **first 5 phases** a constant and slight increment was registered in N_{nuc}, while N_{Ait} and N_{acc} presented a constant and slight decrease.
- **1.6**: presented a mean N_{total} of 43,889±39,541 cm^{-3}. By modes, highlight the increment of N_{Ait} from 1216 cm^{-3} (phase **1.5**) to 23,268 cm^{-3} during phase **1.6**.
- **1.7**: this phase presented the highest concentration along all sampling 101,797±22,290 cm^{-3}.
- **2.1**: the increment of particles is caused by particles included in nucleation mode N_{nuc} (34,229 cm^{-3}).
- The size median values by phases (Figure 2) indicate that four phases (**1.3, 1.4-1.5 and 2.2**) showed values lower than 20 nm. The highest values of median and mode were registered in the phase **2.4** (95.0 and 120.6 nm, respectively).

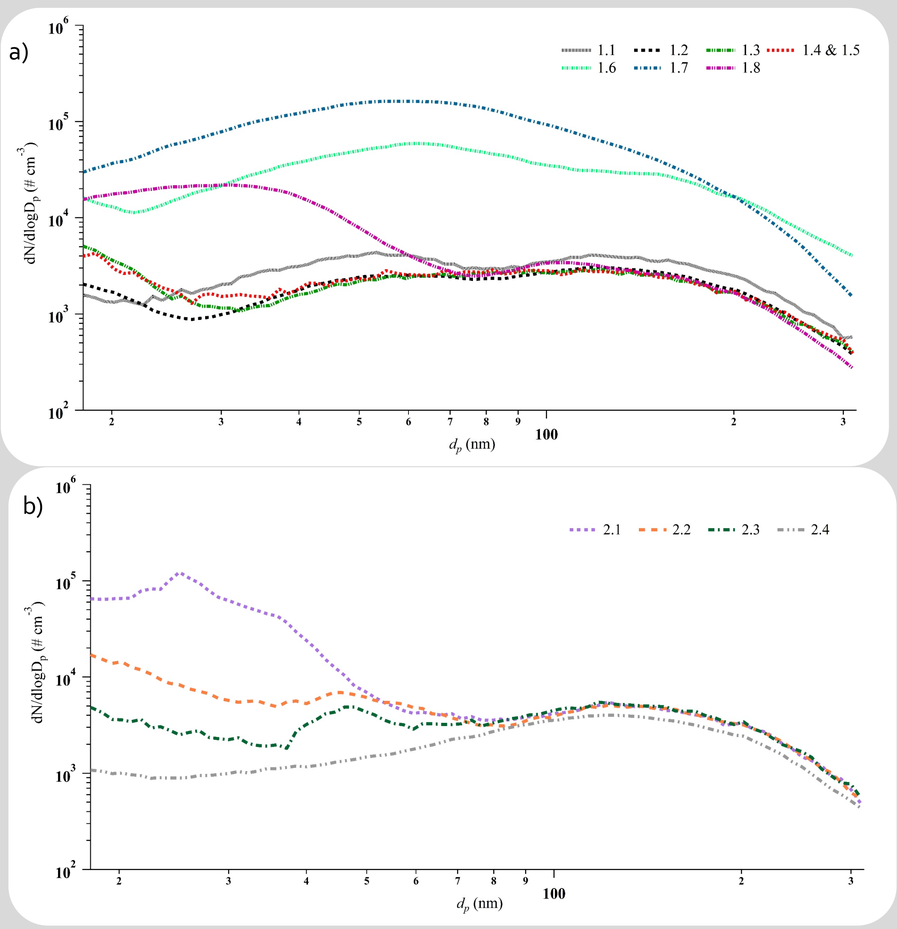


Figure 3. Mean aerosol particle size distribution during the different phases of: a) process 1: printing 3DP mould; b) process 2: melting and pouring.

CONCLUSION

The phases related with heating presented the higher concentrations, mainly with the heating of aluminium to 750 ºC, causing a great increase of nucleation mode particles. The gaseous emissions showed an increase in CO and SO_2 concentrations during heating phases. The study of the evolution of particle number size distribution and gaseous compounds during the processes of manufacturing 3DP mould, melting and pouring will allow to estimate the exposure of working individuals.

References

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