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Article

Analysis of hazardous waste in Additive Manufacturing

Análisis de residuos peligrosos en Manufactura Aditiva

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Abstract

This study examines the emission of volatile organic compounds (VOCs) during 3D printing closed printer configurations. Using BOZEAN TZ01 monitor, 40 tests evaluated the impact of ambient temperature. Results indicated that ABS produced higher emissions than PLA, especially in open printers, with a significant positive correlation with temperature (r = 0.8978). This analysis highlights the need for controlled environment and stricter regulations to mitigate exposures risks in industrial and educational settings (Stefaniak *et al*., 2017)

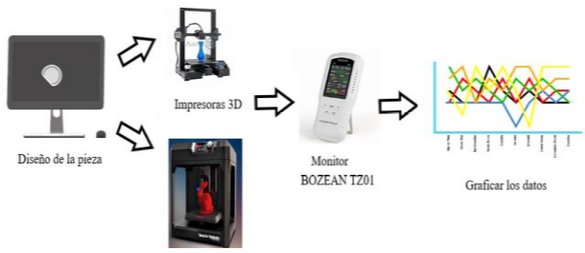
Detection of COVs emissions under different configurations in 3D printing

VOCs, 3D printing, PLA and ABS

Resumen

Este estudio analiza las emisiones de compuestos orgánicos volátiles (COVs) producidos en el proceso de impresión 3D utilizando filamentos de PLA y ABS bajo configuraciones de impresora abierta y cerrada. Se realizaron 40 pruebas con el monitor BOZEAN TZ01 evaluando el impacto de la temperatura ambiente. Los resultados mostraron que el ABS genera mayores emisiones que el PLA, particularmente en impresoras abiertas, donde se observó una correlación positiva significativa (r = 0.8978). Este trabajo resalta la necesidad de entornos controlados y normas más estrictas para reducir el riesgo de exposición en entornos industriales y educativos (Stefaniak *et at*., 2017).

Detección de emisiones de COVs bajo distintas configuraciones en la impresión 3D



COVs, Impresión 3D, PLA y ABS

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Introduction

In recent years, additive manufacturing or 3D printing has transformed sectors such as manufacturing, medicine and education, thanks to its advantages in customisation, cost efficiency and production times. However, the growth of this technology has also brought concerns about the impact on health and the environment due to the release of volatile organic compounds (VOCs) and fine particles in the printing process, especially in enclosed and poorly ventilated spaces.

Materials such as polylactic acid (PLA) and acrylonitrile butadiene styrene (ABS) are common in 3D printing, but their emissions have not been thoroughly regulated. This creates a need for studies that can quantify and characterise these hazardous wastes, to understand their implications for human health and their environmental impact. This article presents an investigation of VOC emissions generated by PLA and ABS under open and closed printer conditions, exploring also the influence of ambient temperature on the amount and type of emissions released.

Studies have shown that PLA emits mainly lactide, a compound considered less harmful than other VOCs Stefaniak *et al*., (2017).

The VOC emitted by ABS is styrene, which can cause adverse health effects, such as eye irritation, headaches and long-term effects on the central nervous system (Stefaniak *et al*., 2017).

Methodology

An experimental study will be conducted with a repeated measures design, considering different print sizes and two print conditions (open model and closed model). The independent variable will be the print size and the printing condition, while the dependent variable will be the amount of particulate emissions. In addition, VOC concentrations during the printing process will be measured. The sample will consist of 30 different tests, divided equally between the three print sizes (10 small, 10 medium, 10 large). Both open and closed model 3D printers will participate. The prints to be made will be models designed in SolidWorks.

Materials

Additive manufacturing uses a variety of materials to meet different needs and applications. Among these materials, thermoplastic polymers are the most widely used due to their flexibility, ease of use and suitable mechanical properties. The two most common polymers in 3D printing are poly lactic acid (PLA) and acrylonitrile butadiene styrene (ABS). Poly lactic acid (PLA) is a biodegradable polymer made from renewable resources such as corn starch, sugar cane and other bio-based materials, less prone to emit toxic VOCs.

Acrylonitrile butadiene styrene (ABS) is another thermoplastic widely used in 3D printing, known for its strength and durability. Although it is a petroleum-based material, emitting higher amounts of styrene, a toxic chemical compound, its durability makes it ideal for functional applications and mechanical parts. These two types of filament were used.

Printing conditions

To assess VOC emissions under different configurations, tests were carried out on both open and closed printers. This approach allows the effect of the environment on the release of compounds and their concentration to be compared. In total, 40 tests were carried out, divided into four groups:

1. PLA on open printer
2. PLA in closed printer
3. ABS in open printer
4. ABS in closed printer

Each material-configuration combination was replicated in 10 tests, and the results were averaged to ensure accuracy and consistency in the data.

Emissions measurement

To capture the concentration of emitted VOCs, the BOSEAN TZ01 monitor was used, which provides accurate mg/m³ measurement of VOCs. Measurements were taken at two time points: at the start of printing and at the end, thus recording the variation in emissions over time.

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Box 1

Figure 2
Experimental setup - Printer closed
Source: Own

Statistical analysis: Pearson correlation

In scientific research, great importance is attributed to statistics, as it allows for understanding and analysing the collected data as mentioned by Montgomery *et al*.

Pearson's correlation was calculated to explore the relationship between ambient temperature and VOC emissions. The formula used was:

$$r = \frac{\Sigma(X-\bar{X})(Y-\bar{Y})}{\sqrt{\Sigma(X-\bar{X})^2\Sigma(Y-\bar{Y})^2}} \ldots. \quad [1]$$

X and Y are the variables that are being correlated (in this case, X: the concentration of VOCs and another variable related to 3D printing, Y: which we will take as the ambient temperature at the time of printing are the means of the variables X and Y, respectively.

The symbol indicates the sum of the values.

The correlation coefficient r varies between -1 and 1. A value of 1 indicates a perfect positive correlation, -1 indicates a perfect negative correlation and 0 indicates no correlation. The closer the value of r is to 1 or -1 the stronger the association between the variables.

Results

The results obtained provide a detailed analysis of how printing conditions affect the emission of VOCs in both materials.

1. VOC emissions by material type and printing condition

– **PLA**:

Open printer: Average emissions of 0.12 mg/m³, with stable emissions and no significant correlation with temperature.

Closed printer: Average emissions of 0.08 mg/m³, suggesting that the closed environment may slightly reduce emissions.

– **ABS**:

Printer open: Significantly higher emissions were recorded, with an average of 0.78 mg/m³ and a strong correlation with temperature (r = 0.8978).

Closed printer: Average emissions of 0.65 mg/m³, showing a reduction compared to the open printer, although a positive correlation with temperature remained.

Box 2

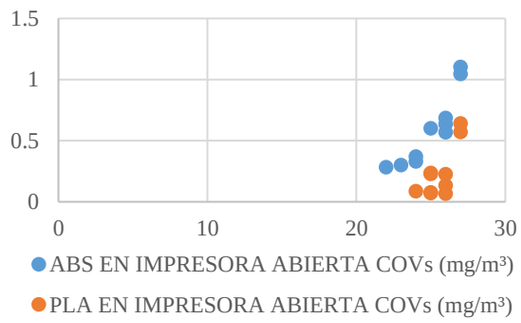

Figure 2
Scatter plot of VOCs in open printer with PLA and ABS material
Source: Own

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Box 3

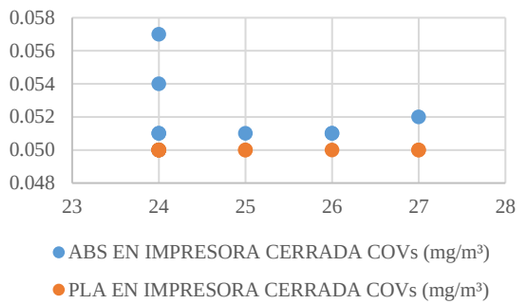

Figure 2

Scatter plot of VOCs in a closed printer with PLA and ABS material

Source: Own

2. Comparison between open and closed printers

The comparison of results suggests that the use of enclosed printers reduces VOC emissions in both materials, especially in the case of ABS. This indicates that a controlled environment helps to mitigate exposure risks.

3. Relationship between temperature and VOC emissions in ABS

The strong correlation between ambient temperature and VOC emissions for ABS in open printers reinforces the importance of controlling temperature in printing environments. This finding underlines that ABS is particularly sensitive to temperature increase, which may increase the risk of exposure to VOCs.

Discussion

The findings of this study indicate that both material type and printing conditions significantly influence VOC emissions during 3D printing. PLA shows lower emission levels than ABS, making it a safer choice in terms of emissions.

Ambient temperature plays a critical role in VOC emissions, especially in the case of ABS. This study suggests that temperature control is essential to reduce exposure risks, highlighting the need to use closed printers when printing materials such as ABS.

Conclusion

This study contributes to the understanding of VOC emissions in 3D printing, highlighting the differences between PLA and ABS under open and closed printing conditions. The findings underline the importance of proper ventilation and temperature control to reduce emissions in additive manufacturing processes. In addition, this study establishes an important basis for the development of more stringent regulations to regulate

Annexes

Box 4

Table 1

Results PLA tests on open printer

Ambient temperature (°C)	COVs (mg/m³)
25	0.237
27	0.572
27	0.641
25	0.078
26	0.226
25	0.230
26	0.068
24	0.089
25	0.072
26	0.136

Box 5

Table 2

Results PLA tests on closed printer

Ambient temperature (°C)	COVs (mg/m³)
27	0.050
24	0.050
25	0.050
24	0.050
26	0.050
24	0.050
24	0.050
24	0.050
27	0.050
25	0.050

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Box 6

Table 3
ABS test results on closed printer

Ambient temperature (°C)	COVs (mg/m³)
24	0.050
24	0.050
26	0.051
24	0.051
24	0.051
25	0.051
27	0.052
24	0.057
24	0.054
26	0.051

Box 7

Table 4
ABS test results on open printer

Ambient temperature (°C)	COVs (mg/m³)
27	1.105
26	0.686
23	0.302
22	0.284
26	0.569
24	0.332
25	0.603
26	0.636
27	1.048
24	0.370

Declarations

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Authors' contribution

Velázquez Hernández Stefany: I contribute with the idea of the project, carry out the measurements and statistical analysis.

Camarillo Villegas Alejandra: I contributed with the methodological and statistical development.

León Anaya Jorge: I contributed to the development of the state of the art of the project, and the computer-aided design.

Flores Quijada María de los Ángeles: I contribute with the operation and programming of the 3D printers.

Availability of data and materials

Indicate the availability of the data obtained in this research. can be requested from the following emails: acamarillo@upvm.edu.mx y jorge.leon@upvm.edu.mx

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Abbreviations

3D	Three-dimensional
ABS	Acrylonitrile Butadiene Styrene
VOCs	Volatile Organic Compounds
PLA	Polylactic Acid

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Background

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