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APPLICATION OF LOW-COST PARTICULATE MATTER SENSORS FOR MEASUREMENT OF POLLUTANTS GENERATED DURING 3D PRINTING

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Abstract. *This work presents measurement results of pollutants generated during 3D printing. The measure of pollutants is the concentration of particulate matter with a diameter of up to 2.5 µm (PM2.5). Materials acrylonitrile-butadiene-styrene (ABS), polyactide (PLA) for a 3D printer and low-cost particulate matter concentration sensors PMS3003, PMS7003 were used in the research. Research results show that low-cost sensors can be useful for monitoring pollution during 3D printing in offices, laboratories or private homes.*

Keywords: 3D printing, particulate matter, pollution measurement, low-cost sensor

WYKORZYSTANIE NISKOBUDŻETOWYCH CZUJNIKÓW STĘŻENIA CZĄSTECZEK W CELU POMIARU ZANIECZYSZCZEŃ POWSTAJĄCYCH W TRAKCIE PRACY DRUKAREK 3D

Streszczenie. *Praca prezentuje wyniki pomiarów zanieczyszczeń generowanych podczas druku 3D. Miarą zanieczyszczeń jest koncentracja cząstek stałych materii o wymiarach do 2,5 µm (PM2,5). W badaniach zostały wykorzystane materiały aktonitryl-budatien-styren (ABS), poliaktyd (PLA) dla drukarki 3D i niskobudżetowe czujniki koncentracji cząstek stałych materii PMS3003, PMS7003. Wyniki badań pokazują, że niskobudżetowe czujniki mogą być przydatne do monitorowania zanieczyszczeń podczas druku 3D w biurach, laboratoriach czy domach.*

Słowa kluczowe: druk 3D, pyły zawieszone, pomiar zanieczyszczeń, czujniki niskobudżetowe

Introduction

Air quality has a significant impact on health and quality of life. A number of scientific publications describe the negative impact of high concentrations of pollutants on human health [3, 4, 10]. For example, in Poland in 2018, the main producer of particulate matter - PM2.5, were households using coal and wood for heating purposes. It accounted for 40.80% of the total cumulative PM2.5 (particles with a diameter of up to 2.5 µm) emission in Poland [9]. This is a significant problem in zones with dense single-family housing. It is possible to avoid exposure to particulate matter by using appropriate air filters in domestic ventilation systems. The study attempts to characterize a less obvious source of pollution – 3D printers. The popularity of 3D printers is constantly increasing. Such devices are successfully used in offices, laboratories or private homes. The most common materials used in desktop 3D printers are acrylonitrile-butadiene-styrene (ABS) and polyactide (PLA) [7, 8]. The melting point of plastic filament in fused filament fabrication (FFF) technology is in the range of 180ºC -270ºC and depends on the type of material [12].

The literature review presents various ways to measure pollutants during 3D printing. There are two main types of measurements: in an insulated chamber [5, 13, 14] and in standard operating conditions [11, 13]. Measurement in an insulated chamber involves placing the entire printer inside a sealed chamber. The printing process is started and the emission of pollutants is monitored. In the second method, the 3D printer works under typical conditions, i.e. in an open space inside the building room. The sensors are placed near the print head or at a distance from the 3D printer.

Currently, particulate matter concentration sensors [1, 2, 6] can be successfully applied at home. Some of them have a direct interface for monitoring the concentration of particulate matter. However, such sensors typically come at a higher cost.

The aim of the work is to investigate the usefulness of low-cost PM2.5 particulate matter concentration sensors for monitoring pollution during 3D printing in the conditions of an office, laboratory or private home.

1. Methods

The experiment was divided into two stages. In the first stage, pollutants generated during the uniform extrusion of the material were examined under special conditions (an insulated chamber). In the second stage, the measurements were made under typical operation conditions of the printer. In both stages, the print head placed in the Creality Ender 3 desktop printer was used. To measure the concentration of particulate matter, PMS3003 and PMS7003 sensors were applied, their basic parameters are presented in table 1.

Table 1. Basic parameters of the sensors used in the experiment

	PMS3003	PMS7003
Function in test	main measurment	background measurment
Price	89 PLN, 20 EUR	
Error	10% and ±10 $\mu g/m^3$	
Resolution	1 $\mu g/m^3$	
Counting efficiency	50% for 0.3 $\mu g/m^3$ 98% for ≥ 0.5 $\mu g/m^3$	
Communication	UART, baud rate 9600	
	24 byte frame	32 byte frame
Operating mode	passive or active, response time < 1s	
Software for data collection	e.g. LabVIEW	

The special conditions of experiment consisted in connecting the outlet of the print head nozzle with a tubular container with a diameter of 100 mm and a height of 125 mm. At the other end of the tubular container there is a tight shutter with a small hole to which the air inlet of the PMS3003 sensor is attached. In this way, all contaminants that could arise in the container would either have to settle on the wall of the container or would pass through the PMS3003 sensor, which is the main sensor. A second particulate matter concentration sensor – PMS7003 was placed outside the container for control purposes. Its task was to measure the background. The diagram of the first stage of the experiment is shown in figure 1A.

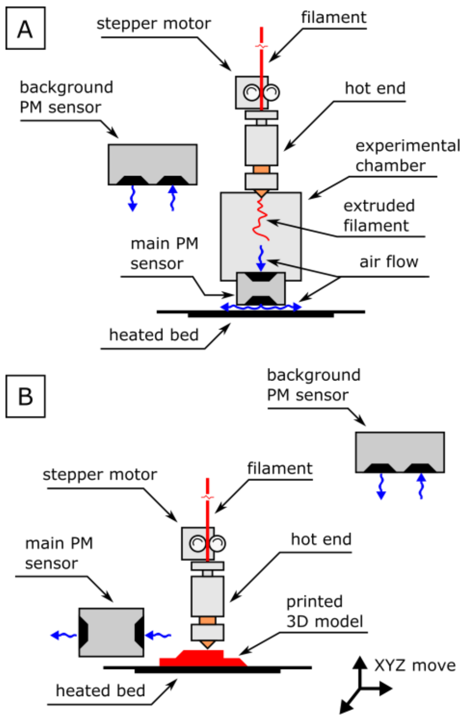

Fig. 1. Two stage of the experiment, measuring the concentration of particulate matter PM2.5, for the 3D printer: A – special working conditions, B – typical working conditions

After loading the material, the printer head was heated to the typical operating temperature of the material: PLA: 200ºC, ABS: 240ºC. Then, after stabilizing the temperature of the print head, the filament was extruded with the following lengths: 50 mm, 75 mm, 100 mm for ABS and 100 mm, 200 mm for PLA. After the airborne particulate matter concentration dropped to a level close to the background level as measured by PMS7003, repeated next extrusion. Five repetitions were performed for each material.

In the second stage, measurements were carried with the Creality Ender 3 printer with an open structure (without a housing) and the movement of the heated bed in the Y axis and the movement of the print head in the X axis. This is important from a measurement point of view because the print head is in motion and can therefore disperse airborne particulate. In addition, during the typical operation of the 3D printer, fans were used to lower the temperature of the print head cooling block and a fragment of the printed model (blowing of air on the print head nozzle). Therefore, the PMS3003 sensor is mounted in such a way that it is located at a constant, short distance from the print head. The diagram of the system during typical working conditions of the 3D printer is shown in figure 1B. At this stage measured particulate matter during the printing of a simple 3D model shown in figure 2. The total printing time was: 39 minutes. About 4 g of plastic were used (PLA: 1.41 m, ABS: 1.47 m of filament with a diameter of 1.75 mm). The concentration of PM2.5 particulate matter was measured for two types of materials: PLA and ABS, and for printing temperatures as in the first stage of the study. The heated working bed of the printer was set to the temperature 70ºC for ABS material and 50ºC for PLA. The measurements were carried out in a technical room with the dimensions 6.0 mm × 3.6 mm × 3.5 mm.

Fig. 2. Printed 3D model with dimensions: 6.0 mm × 3.6 mm × 3.5 mm. LUT – Lublin University of Technology

Data from PMS3003 and PMS7003 sensors were sent via UART connection directly to the PC station. The measurement results were recorded with an LabVIEW application, at an interval of 800 ms.

2. Results

On the basis of figure 3, it can be observed that with the increase in the amount of extruded material – ABS – the concentration of particulate matter in the air inside the chamber increases. For the test in which 100 mm of ABS material was extruded (which corresponds to a mass of 0.25 g), the maximum concentration of PM2.5 particulate matter above the measuring range (based on the datasheet) of the PMS3003 sensor can be observed. During the extruding of PLA material, it turned out that the main measurement is similar to the background measurement. The concentration of PM2.5 particulate matter in single trials did not show any significant increase, as it was noticeable when extruding ABS plastic. Due to the low PM2.5 particulate emission, shorter sections of the material were not extruded. In the case of extruding PLA with a length of 200 mm, the time between individual extruding commands was twice as long (10 minutes per cycle) as for extruding a 100 mm long section (5 minutes per cycle). The result is shown in figures 3.

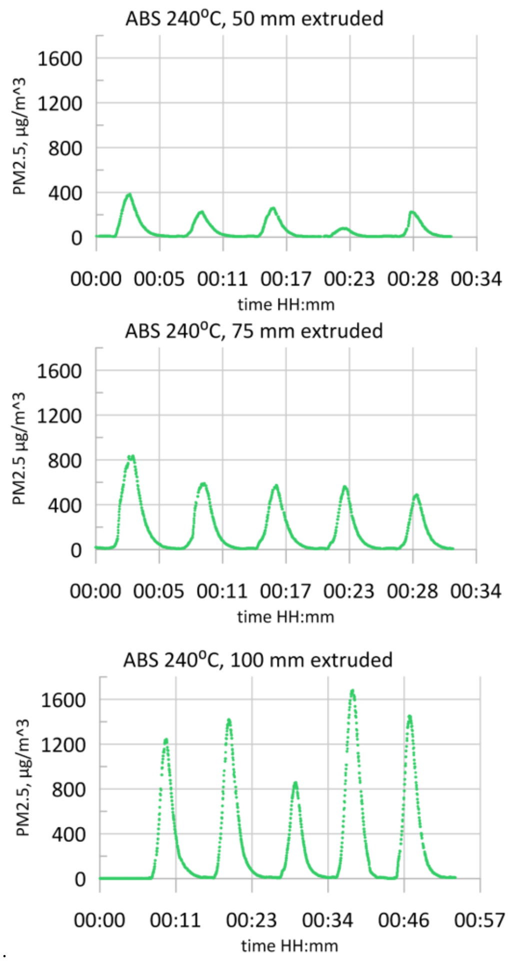

Fig. 3. Results for the special conditions (insulated chamber) in which the following lengths of ABS were extruded: 50 mm, 75 mm and 100 mm. The measurement background fluctuated in the range: (0-4) $\mu g/m^3$

Measurements of the concentration of PM2.5 under typical operating conditions of the 3D printer, for PLA and ABS, did not show any significant differences between the main measurement and the background measurement. In the case of printing with ABS, a peak was observed, it was related to the spraying of the preparation, which was to increase the level of adhesion of the heated working bed. This was required so that the printed 3D model did not detach from the surface during printing. In the case of PLA printing, the abovementioned preparation was not used. Figure 5 shows the measurement results of PM2.5 for the typical operation of the 3D printer.

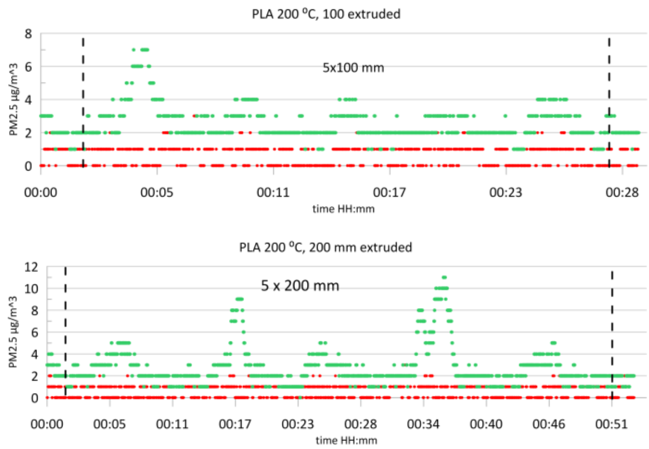

Fig. 4. Measurement results of PM2,5 concentration under special operating conditions (insulated chamber), for lengths of PLA material 100 mm and 200 mm. The results of the main measurement (PMS3003) are marked in green and background measurement (PMS700) in red

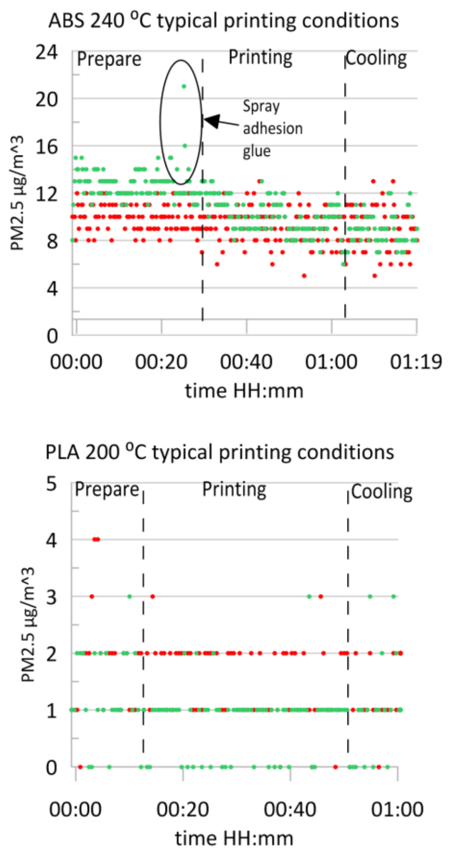

Fig. 5. Measurement results of particulate matter concentration during typical operation of the 3D printer, green colour – main measurement, red colour – background measurement

The statistics of data from measurements during printing with ABS and PLA plastics, for typical printer operating conditions are presented in table 2.

Table 2. Statistics of particulate matter concentration measurements for materials ABS and PLA (typical printer operating conditions)

Material	ABS		PLA	
Sensor role	Background	Main	Background	Main
Minimum	5.00 $\mu g/m^3$	7.00 $\mu g/m^3$	0.00 $\mu g/m^3$	0.00 $\mu g/m^3$
Maximum	14.00 $\mu g/m^3$	13.00 $\mu g/m^3$	3.00 $\mu g/m^3$	3.00 $\mu g/m^3$
Mean	9.48 $\mu g/m^3$	10.16 $\mu g/m^3$	0.90 $\mu g/m^3$	1.43 $\mu g/m^3$
Standard error	0.03 $\mu g/m^3$	0.03 $\mu g/m^3$	0.01 $\mu g/m^3$	0.01 $\mu g/m^3$

3. Conclusions

The measurements results show a significant difference in the level of the maximum concentration of PM2.5 particulate matter for ABS and PLA materials. In the case when a 100 mm long section was extruded at a uniform velocity, the average value of the five maximum values was 1329 $\mu g/m^3$ for ABS and 4.6 $\mu g/m^3$ for PLA. For ABS, the maximum concentration of particulate matter is almost 290 times higher than in the case of PLA extruding.

According to the data in table 2, under typical printer working conditions, the average value of the particulate matter concentration for ABS material is more than ten time higher compared to PLA material. It is worth mentioning, that the annual average limit value of particulate matter PM2.5 concentration should not exceed 25 $\mu g/m^3$[15].

The presented research confirm, in my opinion, the usefulness of low-cost sensors for monitoring pollution during 3D printing in offices, laboratories or private homes.

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