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CONSIDERATIONS CONSIDERING THE EVOLUTION OF CO_2 EMMISION IN THE MSLA PRINTING PROCESS WITH ECO-FRIENDLY RESIN

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ABSTRACT: The purpose of this research tray is to show whether environmentally friendly resins produce any CO_2 emissions in the printed area during polymerization using mask stereolithography. For printing, the authors of this study used a masking stereolithography (MSLA) solution. One device and two separate sensors are used to measure CO_2 values. After the partial body is printed, it can be observed that the air quality of the printed bottom structure is good, and there is slight contamination of the mechanical area of the printed element. At the same time, it can be observed that the measured data between the device and the MG-811 sensor are not on the same level. Taking into account the sensor data sheet for the sensors and for the device, the value measured with the sensor is more accurate relative to the data obtained with the device.

KEYWORDS: 3D printing, MSLA printing, sensors, Arduino, CO_2

1. INTRODUCTION

The study is intended to be an indicative study that will allow us to determine the best way to assess emissions measured by air quality monitoring instruments or standalone sensors. Measurements can be used to determine the appropriateness of using a specific measurement system during 3D printing control.

In the literature, such studies have been carried out on thermoplastic materials [1-4], with an increasing number of cases for printing by photopolymerization [5-9].

2. MATERIALS AND METHODS

2.1 Materials and printer used

In the experimental program, a resin with ecological properties of ANYCUBIC type and a printer from the same supplier were used [10,11]. In Figure 1 you can see the 3D printer at the bottom of it and the measuring device used, respectively, the ARDUINO MEGA 256 module arranged inside a case printed by thermoplasty with a 2004 LCD screen to display the data measured by independent sensors. Their position in the printer's layout space is important because it is recommended that they be disposed as close as possible to where the environment is discharged from the enclosed printing space.

2.2 Sensors and device

The dedicated sensor type for measuring CO_2 emissions is the MG-811 (DM-118) [12,13]. The sensor uses the principle of nondestructive infrared (NDIR) to detect the presence of CO_2 in the air with a sensor range from 0 to 5,000ppm. When examining the graph specific to this sensor, it can be seen that there are two linear segments in the interval that can be used.

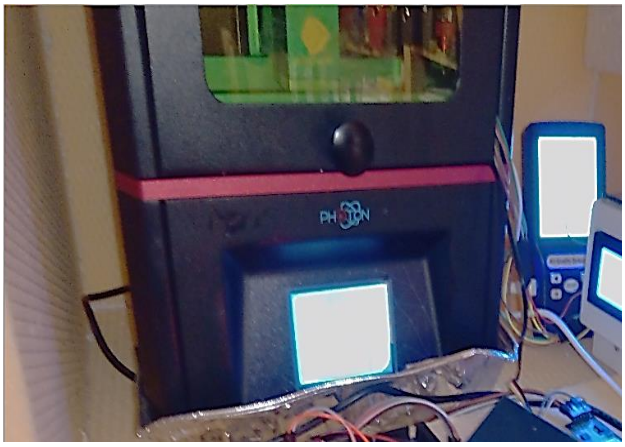


Figure 1. Printer inside the enclosure, device, and ARDUINO LCD with sensors for measuring

The first applies to emissions between 100 and 400 ppm, and the mathematical regression equation is linear (1). The second, between 400 ppm and 10,000 ppm, has a mathematical regression equation of power (2) with an R^2 factor of 97.61%.

$$ppm=-0.0011\times(Volt)+324.2 \quad (1)$$
$$ppm=587.7\times(Volt)^{(-0.9761)} \quad (2)$$

The second is model MQ135 [14,15], a sensor that can simultaneously determine multiple types of emissions, not just CO_2 emissions. The data sheet for MQ135 is 10 to 1,000 ppm. Use an EXCEL spreadsheet to determine the optimal mathematical regression equation, as shown in Figure 2. At the right place, the tree equation of the squared value R and the step line can be observed. The optimal mathematical regression equation is of linear type (3) with an R^2 of 99.87%.

$$ppm=-287.39\times(Rs/R_0) + 1977.9 \quad (3)$$

Y	X
8,815789474	6,82815534
95,26315789	6,526074896
159,2105263	6,333841886
246,8421053	6,031761442
306,0526316	5,853259362
355,7894737	5,619833564
396,0526316	5,537447989
426,8421053	5,413869626
458,8157895	5,317753121
483,6842105	5,207905687
506,1842105	5,098058252
529,8684211	5,043134535
589,0789474	4,809708738
655,3947368	4,57628294

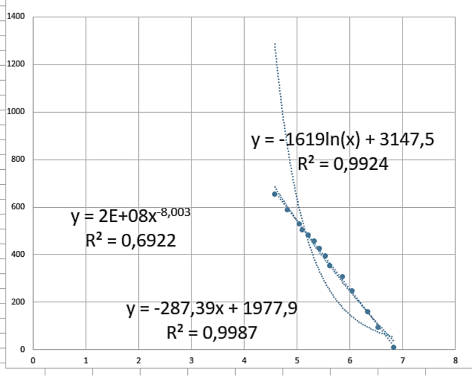


Figure 2. Mathematical equation MQ135 for the ppm value

The data of the individual sensors determined using this solution are set according to the values determined by the device. As can be seen from the introductory section, CO_2 is an important gas element that needs to be considered in the surrounding medium.

2.3 Considerations on the ARDUINO program

The ARDUINO program [15] envisages the use of three libraries that are related to the LCD display part [16], the one to record the SD-card data [17] and the one for the MQ135 sensor, respectively. These libraries are loaded into the common part of the program at the beginning of its Figure 3.

```
#include <SPI.h>
#include <SD.h>

//LCD-2004
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
LiquidCrystal_I2C lcd(0x3F,20,4);

//CO2-mare
#include <math.h>
#include "CO2Sensor.h" //senzor CO2

CO2Sensor co2Sensor(A9, 0.99, 100);

//SD
unsigned long delayTime;

File myFile;
File str;

int sensorValue;
//int pinCS = 53; // Pin 10 on Arduino Uno, 53 on Arduino Mega

long id=1;
int i;

//Include the library MQ
#include <MQUnifiedsensor.h>

//MQ135

#define Placa "Arduino MEGA"
#define Type13 "MQ-135" //MQ135
#define RatioMQ135CleanAir 3.6 //RS / R0 = 3.6 ppm
MQUnifiedsensor MQ135(Placa, 4.95, 10, A10, Type13);
```

Figure 3. The beginning common part of ARDUINO program

It can be seen that the two sensors used are connected to the analog ports A9 and A10, respectively, making the information read at these ports of a binary type.

In the second part, the settings define how the information is transmitted to the analog and digital ports to save information, but also to calibrate the MQ135 sensor.

The last part presented in Figure 4 is that in which the information measured by the sensors is loaded into the rigid memory and the duration of time that the information measured by the sensors is made is defined. It should be noted that both sensors are dependent on the humidity conditions of the environment in which the measurement process takes place, which is why a second module was used separately from the presented module that allows the control of temperature and humidity in the measurement area.

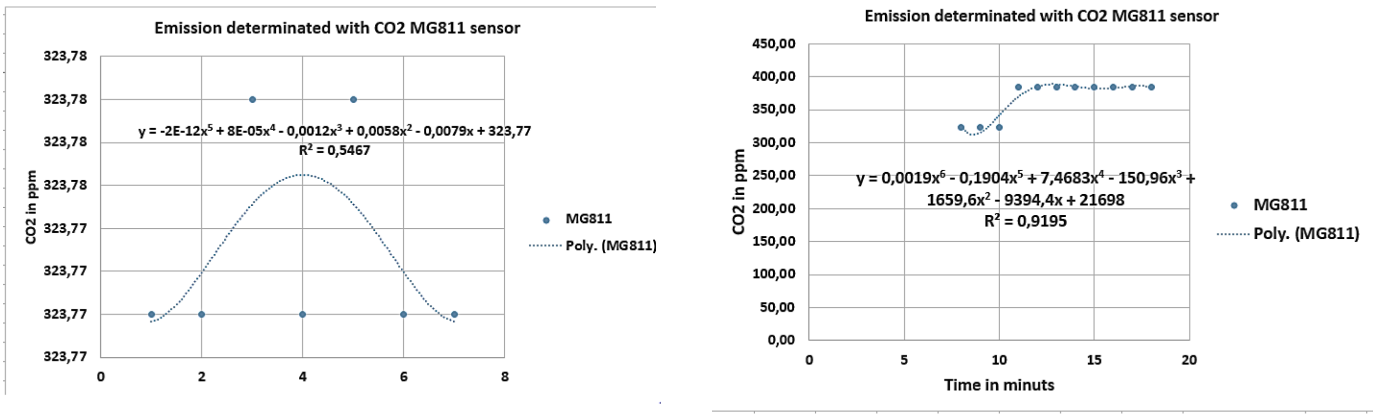
```
void loop() {

//CO2-mare
  int valCO2 = co2Sensor.read();
  Serial.print("CO2 value: mV");
  Serial.println(valCO2);
  float v = analogRead(A9);
  Serial.print("CO2 anal: ");
  Serial.println(v);

//MQ135
  MQ135.update();
  MQ135.setA(110.47); MQ135.setB(-2.862);
  float CO2 = MQ135.readSensor();
  Serial.print("   |   "); Serial.print(CO2 + 400);

 //SDCard
    i=id*5;

String linie_val=String(i)+", "+String(valCO2)+", "+String(v)+", "+String(CO2 + 400);

 Serial.println("Writing to test.txt.");
 myFile = SD.open("textFile.txt", FILE_WRITE);
if (myFile)
{
  myFile.println(linie_val);
  myFile.close();
}
else
{
  Serial.println("Nu am putut deschide fisierul");
}
    id++;

    lcd.clear();
    lcd.setCursor ( 0, 0 );
    lcd.print("CO2");
    lcd.print(valCO2);
    lcd.setCursor ( 9, 0 );
    lcd.print("V-PORT-CO2 ");
    lcd.print(v);
    lcd.setCursor ( 0, 1 );
    lcd.print("CO2-MQ135 ppm");
    lcd.print(CO2 + 400);

 delay(5000);
```

Figure 4. The last part of ARDUINO program

3. RESULTS

In this study, the determination of CO_2 emission levels during 3D printing is considered at the environmental level where the printer is placed (connected). To better determine the presence of these emissions, an assembly is used that consists of a device that measures them, and a set of independent sensors connected to the ARDUINO EXCEL module. The emissions study is divided into three areas that are considered for other types of emission.

The first of these standalone sensors is the MG-811. In the printed area of the substrate, Figure 5a, the mean distribution has two levels, the minimum value is approximately 323.77 ppm, and the maximum value is approximately 323.78 ppm. As can be seen, from the perspective of the sensor sensitivity map with the measured values, we position ourselves in the first part of it, using equation (1) for the calculation.



(a) (b)

Figure 5. Evolution of CO_2 gas emission determinate with MG-811 sensor (**a**) bottom (**b**) support zone

A similar distribution is found around the second region in Figure 5b, as the calculated values are located in the first region (less than 400 mV). However, in this area, there is a minimum value at the beginning, and then the maximum value is passed in a slightly increasing trend. In the last region, Figure 6, it can be seen that in the gear generation region, the trend of gas emission decreases towards the cylindrical part generation region, and a minimum value is found to follow through the increase towards the last side of the printing process.

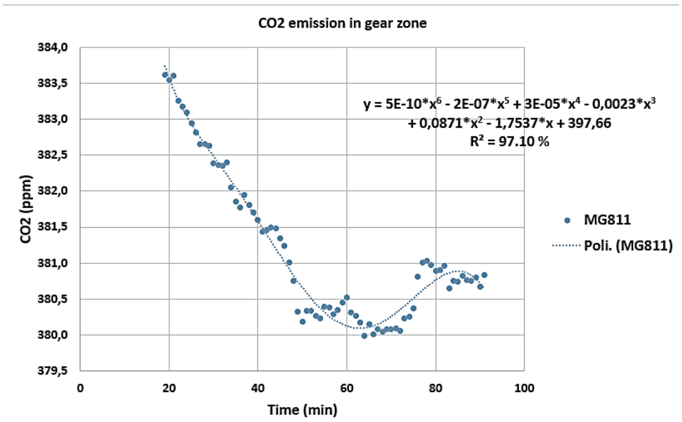


Figure 6. The evolution of CO_2 determined with the MG-811 sensor in the gear zone

In the area of the base plate used to measure MQ135 emissions, the distribution of the mean values trended downward, with a minimum value around 12 ppm, Figure 8a.

It should be noted that the gas equation provided by the program specified by the sensor manufacturer is used to determine the emissions. At the same time, this type of sensor cannot accurately determine the emission of a specific gas species but can indicate how the emission of several gases evolves within the sensor's sensitivity threshold.

In the second area, Figure 8b, the development of measured emissions shows a downward trend, with minimum and maximum fluctuations as the value of measured emissions.

In the gear footprint region on the last page of Figure 7, a larger range of readings is observed, especially due to the vertical motion of the bulk solid interacting with the liquid resin medium. Looking at the spread of measured values, they show a continuing upward trend.

The CO_2 emissions in the study area can be measured simultaneously with the indoor gas emission measurement device. In the first area, Figure 10a, a slight increase in trend can be seen, followed by an alternating area with minimum and maximum points in the generating part of the support, Figure 10b.

In the gear imprint area, there may be an area where the readings increase, Figure 9, then decrease to a minimum, and finally the readings increase.

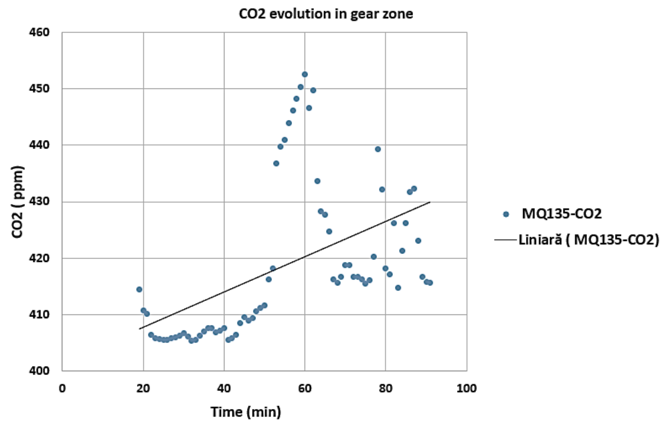
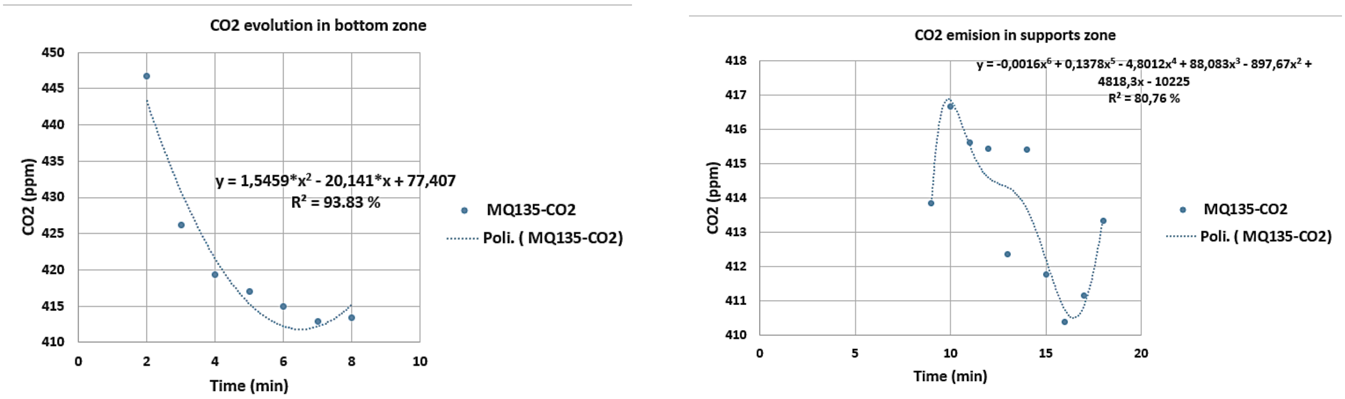


Figure 7. The evolution of CO_2 determined with the MQ135 sensor in the gear zone



(**a**) (**b**)

Figure 8. Evolution of CO_2 gas emission determined with the MQ135 sensor (**a**) bottom (**b**) support zone

4. DISCUSSIONS AND CONCLUSIONS

The CO_2 data were determined by the MG-811 and MQ135 sensors and with the device used for the experiments.

From a comparative analysis of CO_2 gas emissions detected by the MG-811 sensor, the highest percentage is in the support area of the printed structure. The minimum value is in the lower region of Figure 11. From a comparative analysis with the gas emissions determined by the MQ135 sensor in the pressure chamber, the largest proportion is in the printed transfer area structure. The minimum value is within the supported range shown in Figure 12.

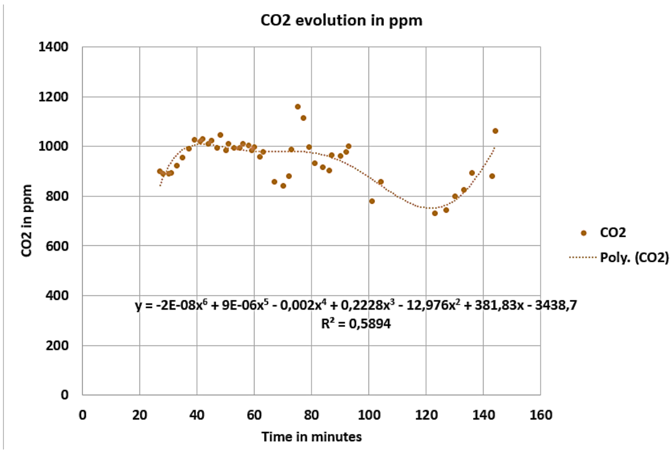
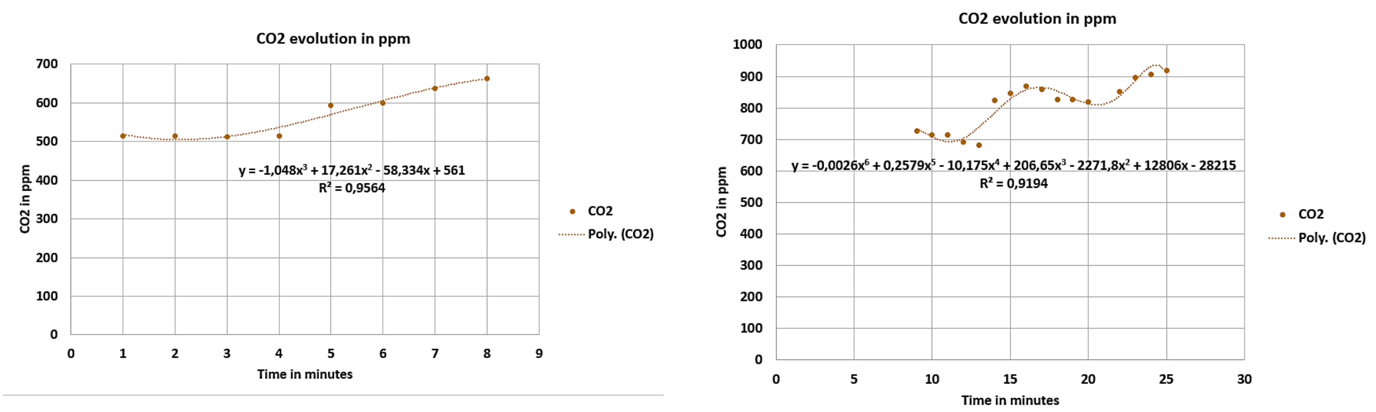


Figure 9. The evolution of CO_2 emission is determined with the device sensor in the gear zone



(**a**) (**b**)

Figure 10. The evolution of CO_2 emission is determined with the device (**a**) bottom (**b**) supports zone

Zone	MG-811			
	Min	Max	ΔCO2	%
Bottom	323,77	323,78	0,01	0,02%
Suport	323,76	384,20	60,44	94,32%
Gear	379,99	383,62	3,63	5,66%
Total			**64,08**	

Figure 11. Minimum and maximum CO_2 value for the MG-811

Zone	MQ135			
	Min	Max	ΔCO2	%
Bottom	412,84	446,80	33,95	38,83%
Suport	410,38	416,66	6,27	7,17%
Gear	405,35	452,56	47,21	53,99%
Total			**87,43**	

Figure 12. Minimum and maximum CO_2 value for the MQ135

From a comparative analysis of CO_2 gas emissions measured with this device, the largest percentage is in the gear zone of the printed structure. The minimum value is at the bottom of Figure 13.

Zone	Device			
	Min	Max	ΔCO2	%
Bottom	513,00	663,00	150,00	22,19%
Suport	683,00	870,00	187,00	27,66%
Gear	819,00	1158,00	339,00	50,15%
Total			676,00	

Figure 13. Minimum and maximum CO_2 value for the device

From the comparative study of the emission level in relation to the determined percentage values, the MG-811 sensor determines a maximum level in the range of the supports, while the MQ135 sensor, respectively, the measuring device identifies the maximum in the gear area.

A perfect air quality concordance can be observed for the first two printed areas and a difference between the values in the last zone. In view of the data obtained, it can be said that from the point of view of CO_2 emissions there are no problems with air quality in the printing space in the printing process Figure 14.

Zone	Device	CO2	Device	CO2
Bottom	513 to 663	323	Good	Excellent
Suport	683 to 870	323 to 384	Good	Excellent
Gear	819 to 1158	379 to 384	Slight Pollution	Excellent

Figure 14. AQI for CO_2 gas emission

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