Construction and Analysis of 3D Printer Exhaust Gas Treatment Device

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Abstract: *With the rapid development of 3D printing technology, 3D printers have been applied in many fields. However, 3D printers with resin or plastic wires produce toxic exhaust (mainly VOCs), which may pose a great threat to the human body and the environment. In order to solve the problems above, this paper proposes a method of treating toxic exhaust gas by using heat-excited oxide semiconductors, and designs a device for treating toxic waste gas. From the aspects of force, heating performance and heat preservation performance, the feasibility of designing the device is verified through simulation analysis. On this basis, a physical device was built and a series of experiments were carried out. The experimental results show that after 10 minutes of treatment by the physical device, air quality from the exhaust outlet of the unit changed from heavily polluted to excellent, and the conclusion is drawn that the device can effectively deal with toxic waste gas. Briefly, the device can be applied to the waste gas treatment of 3D printers with resin or plastic wires, which has certain portability and can be used for the waste gas treatment of other equipment as well.*

Keywords: 3D Printing, Exhaust Gas, Oxide Semiconductor, Device Design

1. Introduction

As the main realization form of additive manufacturing, 3D printing technology has been developed to a certain extent in industrial manufacturing, aerospace and biomedical fields.3D printer utilizing resin or plastic as the printed wire at work, will produce toxic gases, whose main components are volatile organic compounds (VOCs). These toxic gases containing substances such as methanal and benzene; direct emissions into the atmosphere, which may remarkably stimulate a person's respiratory system, hinder the growth of plants and consume ozone at the same time which reduces the absorption of ultraviolet ray, will result in devastating consequences. Brent Stephens et al evaluated the particle emissions of desktop 3D printers, which fully illustrated the necessity to regulate the exhaust of 3D printers. Yonggang Yang summarized four methods of volatile organic compound terminal treatment, namely adsorption, absorption, condensation and membrane separation. Wenwei Yu unveiled an air filtration system for 3D printers that adsorbs impurities from exhaust gases but does not efficiently deal with volatile organic compounds. In this research, the thermal activated oxide semiconductor purification technology is used to design and build a device model and physical objects for the treatment of toxic waste gas generated by 3D printers, and the static stress analysis, heating performance analysis and thermal insulation performance analysis of the model, was carried out. The feasibility of device design is confirmed by simulation. Further, through the experimentation of the physical device, this research comes to the conclusion that the device can effectively deal with the exhaust gas generated by 3D printer.

2. Device structure

2.1. The whole device

Figure 1: Integral device

The device consists of a working box body, a processing unit, a heating unit and a heat preservation unit. It can be used for the collection, treatment and emission of waste gas generated by 3D printers made of resin or plastic. The device structure is shown in Figure 1.

2.2. Processing principle and filter unit

The device adopts thermal activated oxide semiconductors purification technology. The principle of the technology is that powder oxide semiconductors (TiO_2, Cr_2O_3, etc) have thermal activity, which under the condition of high temperature ($350 \sim 500°C$) will be heated to excite and lose electrons to produce a large number of electron holes. The waste gas produced by 3D printers made of resins or plastics is mainly VOCs. Electrons from covalent bonds of these volatile organic compounds will be captured by electron holes, while macromolecular chains lose their stability due to the absence of electrons causing them to break. As a result, low molecular weight monomer is formed and combusts with O_2 to generate CO_2 and H_2O, so as to realize the treatment of waste gas. A schematic diagram is shown in Figure 2.
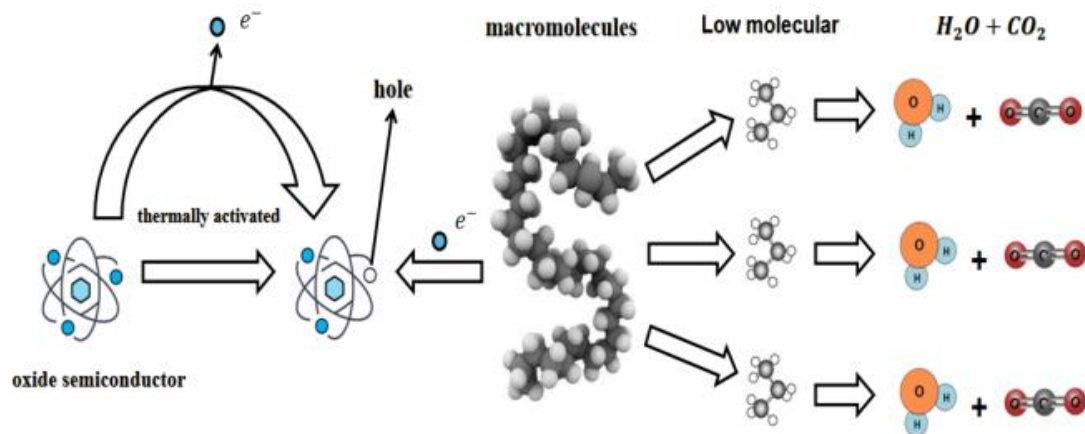

Figure 2: Technical principle

2.3. Processing unit

The processing unit has a three-layer internal structure. The gas flows in from the top layer and out from the bottom layer after three layers of treatment. The interior is mainly loaded with oxide semiconductors honeycomb carrier, the porous structure of which can increase the contact area with the gas, ensuring the adequate treatment of the waste gas. The honeycomb carrier is arranged in multiple blocks to realize multi-level gradient processing, which effectively improves the processing efficiency. The structure of the processing unit is shown in Figure 3.
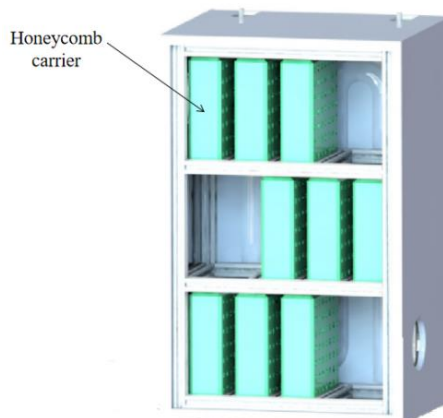

Figure 3: Processing unit

2.4. The heating unit

The waste gas treatment of the device needs to be carried out under high temperature conditions (350 ~ 500°C), so reasonable heating and insulation methods are required. The device adopts ceramic heating tube preheating and thermal radiation plate heating. The preheating of the ceramic tube can effectively ensure that the temperature of the gas entering the treatment chamber rises to the specified temperature. The large area heating of the heat radiation plate can guarantee the temperature of the honeycomb carrier in the treatment box at any time. Ceramic heating tube and the parameters of the thermal radiation plate as shown in Table 1. The heater is shown in Figure 4.

Table 1: Heater parameters1

	Temperature/°C	Principle	Hydrogen storage materials
Ceramic heating tube	300-500	220	3.5
Heat radiation plate	400-600	220	6

a.Ceramic heating tube   b.Thermal radiation plate
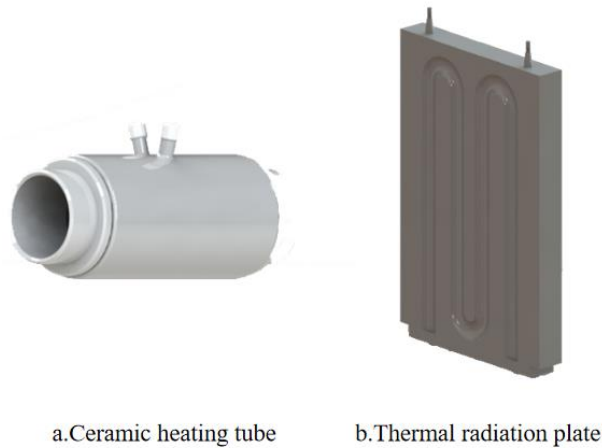
Figure 4: Heating Parts1

2.5. Heat preservation unit

The heat preservation unit is a three-layer insulation structure, located in the outer layer of the treatment unit and heating unit. The innermost layer is 304 stainless steel, the middle is nano-aerogel felt, and the outermost is thermal insulation cotton. The three-layer insulation structure can ensure that the temperature in the treatment unit is stable within a certain range, and ensure the normal process of waste gas treatment. The multi-layer insulation structure is shown in Figure 5.
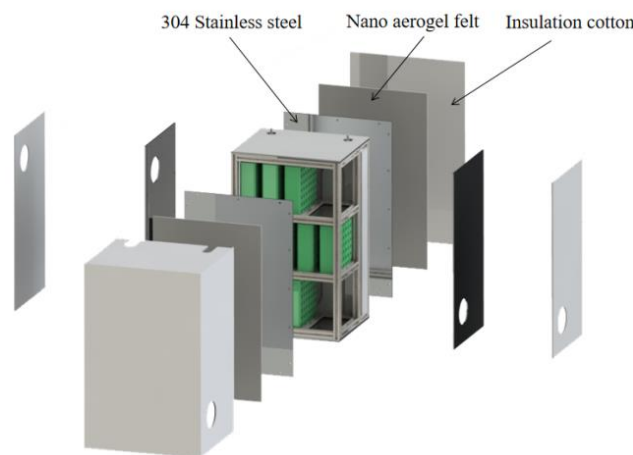

Figure 5: Multi-layer insulation structure2

3. Performance Analysis

3.1. Static stress analysis

The main bearing parts of the device are aluminum profile and bearing plates, aluminum profile as the main body of the outer frame, connected with the external insulation unit. The bearing plate is used to carry the honeycomb carrier. The mass of the honeycomb carriers used in the device are all 1kg. Finite element analysis was carried out for the main frame and bearing structure in this research. Through static stress analysis, the maximum stress of external aluminum profile is determined as $5.101 \times 10^5 \mathrm{N/m^2}$, which can be used. Its static stress analysis is shown in Figure 6.
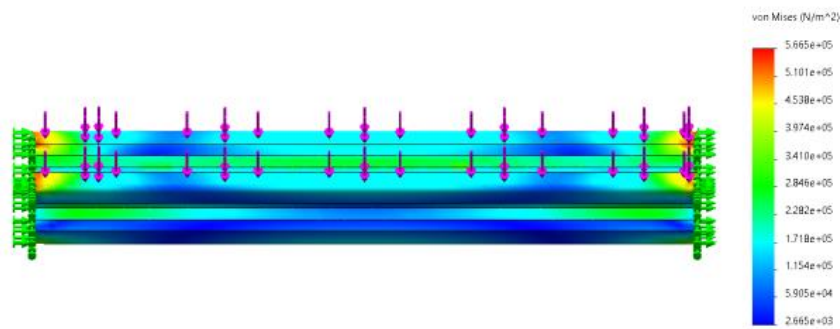

Figure 6: Static stress analysis of external aluminum profile

Through static stress analysis, the maximum stress of the internal aluminum profile is determined to be $7.256 \times 10^4 \mathrm{N/m^2}$, which can be used. Its static stress analysis is shown in Figure 7.3
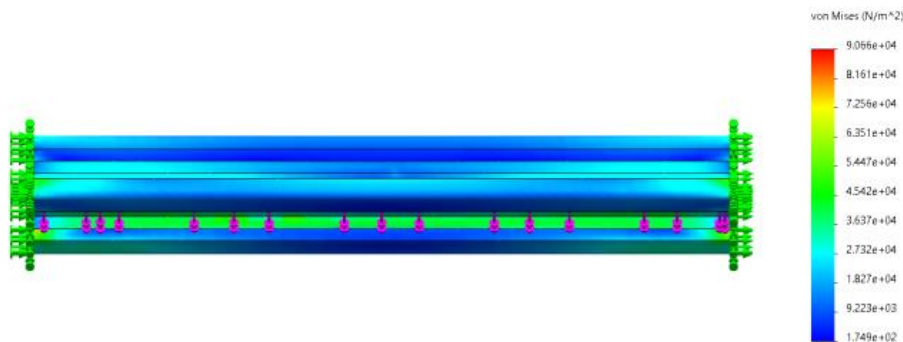

Figure 7: Static stress analysis of internal aluminum profile

Through static stress analysis, the maximum stress of the bearing plate is determined to be $4.250 \times 10^4 \mathrm{N/m^2}$, which can be used. Its static stress analysis is shown in Figure 8.4
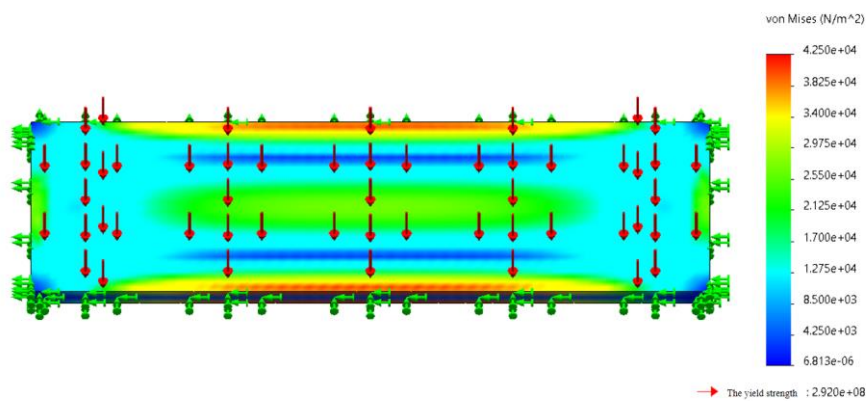

Figure 8: Static stress analysis of bearing plate

3.2. Analysis of heating performance

The device adopts ceramic heating tube preheating and thermal radiation plate heating, which can effectively make temperature reach the specified range. The simulation of this heating method is conducted in this research, and the temperature distribution cloud image is obtained. The ceramic heating tube can preheat the gas. The nearer the gas is to the ceramic surface of the inner ring, the hotter it is. The gas temperature is up to 800K, and the average temperature inside the processing unit is above 633K, which meets the requirement for high-temperature processing. The temperature distribution is shown in Figure 9.
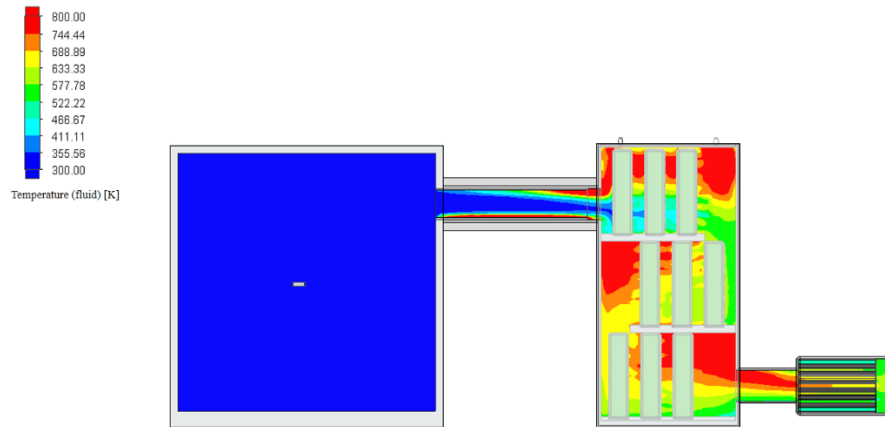

Figure 9: Temperature distribution

3.3. Thermal insulation performance analysis

The three-layer insulation structure adopted by the device is 304 stainless steel - nano aerogel felt - insulation cotton, which can effectively ensure the required temperature inside the processing unit. The parameters of the insulation material are shown in Table 2.

Table 2: Thermal insulation material parameters2

	Specific heat capacity J/(kg·K)	Thermal conductivity W/(m·K)
304 stainless steel	520	16.30
Nano aerogel felt	501	0.018
Insulation cotton	750	0.040

In this research, the treatment of waste gas is simulated, and the gas trajectory is obtained. The waste gas can be effectively dealt with, and the gas temperature can be kept within the specified range. The gas trajectory is shown in Figure 10.
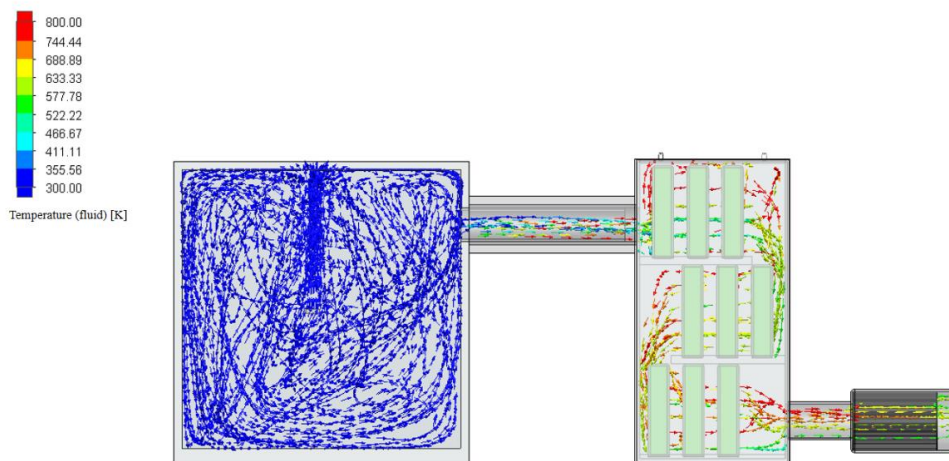

Figure 10: Gas trajectory

4. Experimental Results

In this research, a physical model of the device is built and its gas treatment effect is tested. The mock-up is shown in Figure 11.

Figure 11: Mock-up

The exhaust gas treatment device of a 3D printer, ZP07-MP503-10VOC air quality detection module, a JG MAKER A3S desktop 3D printer and PLA wire materials were used in the experiment. The air quality detection module is placed at the rightmost exhaust port of the device. Its parameters are shown in Table 3. Port functions are shown in Table 4; output status is shown in Table 5.

Table 3: Sensor parameter3

Entry name	Parameter index
Voltage	5.0 + / - 0.2 V DC
Output status	Level 0-3 pollution signal
Output data type	TTL Level signal
Preheating time	The 180 s or less
Corresponding time	20 s or less
Recovery time	60 s or less

Table 4: Port functions4

Port	Function
GND	Negative pole of power supply
5V	Positive pole of power supply
A	Output signal A

Table 5: Output state5

Class of pollution	Output signal A (V)	Output signal B (V)	Pollution state
0	0	0	excellent
1	0	5	good
2	5	0	Slightly polluted
3	5	5	Heavily polluted

Test method: First, the JG MAKER A3S desktop 3D printer was started and PLA wire was used to print. After 10 minutes of work, the 3D printer stopped. Second, the exhaust gas treatment device of the 3D printer was started and it began to work properly after 5 minutes of preheating. The returned parameters of the air quality detection module at 2min, 4min, 6min and 10min were collected for three experiments. Experimental data are shown in Table 6; the data curve is shown in Figure 12.

Table 6: Experimental data6

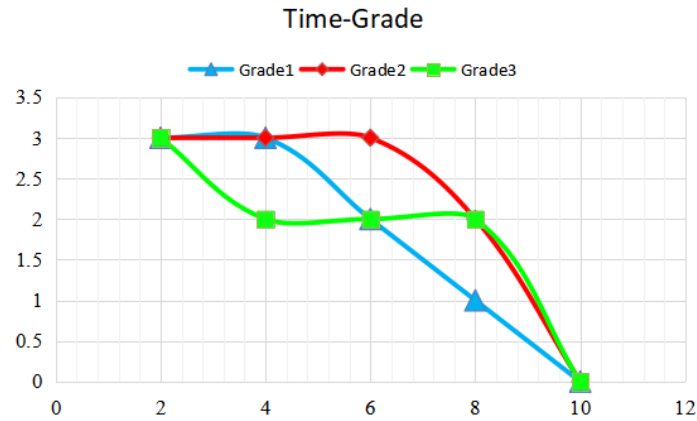| Time/min	Grade1	Grade2	Grade3
2	3	3	3
4	3	3	2
6	2	3	2
8	1	2	2
10	0	0	0

Figure 12: Data curve

Experiment Conclusion: A series of reliable experimental results show that after 10 minutes of operation, the quality of the exhaust gas is superior, and the treatment of the waste gas is effectively realized.

5. Conclusion

3D printers made of resin or plastic produce toxic waste gas when they work. This research designs an exhaust gas treatment device for such 3D printers, and uses a heat-excited oxide semiconductor to deal with toxic waste gas efficiently. At the same time, the device adopts ceramic heating tube preheating and thermal radiation plate heating to provide the required temperature for the treatment. The device adopts a multi-level gradient design to efficiently and fully treat the exhaust gas. In addition, the device designed in this research has high portability and can be used for the waste gas treatment of other equipment.

Acknowledgements

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