Design of an Intelligent Purification and Disinfection Apparatus for Air Conditioning Units

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Abstract. With the sudden outbreak and rapid spread of COVID-19, global economic development and social stability have been seriously affected. The virus mainly spreads infection among people on a large scale through the air. People are gradually focusing on how to use HVAC system, so that it can play a more efficient and positive role in epidemic prevention and control. Consequently, we designed an intelligent purification and disinfection apparatus for air-conditioning units. The apparatus integrates rapid virus detection and high-efficiency disinfection functions. It uses a modular design and different operating modes for different levels of epidemic periods. This apparatus is not only suitable for daily life, but also can meet the prevention and control requirements during the epidemic period, which takes the economy, energy saving, and environmental protection into account.

1. Introduction

At the beginning of 2020, COVID-19 suddenly broke out and spread rapidly around the world, seriously affecting global economic development and social stability. Because of the current Variation of Covid-19 and the unbalanced vaccine supply, people around the world are still facing a grim situation. At present, excellent epidemic prevention and control is an effective way to curb the spread of the epidemic and protect the health of people around the world. The virus mainly spreads through the air on a large scale among people. Except the individual epidemic prevention, it is also necessary to detect and sterilize in public places.

To solve the above problems, we designed an intelligent purification and disinfection apparatus for air conditioning units. The apparatus integrates virus detection and air purification functions, which utilize a modular design to adopt different epidemic periods. This apparatus is not only suitable for daily life, but also can meet the prevention and control requirements during the epidemic period, considering the economy, energy saving and environmental protection.

2. Design scheme

The apparatus is mainly composed of two parts:one part is a bacterial and virus detector,the other part is a purification and disinfection device.

2.1. A bacterial and virus detector

The bacterial and virus detector can quickly detect the airflow in the ventilation duct and transmit the acquired detection information to the main controller, so that it can control the purification and disinfection device to kill the virus and bacteria effectively in the airflow.

As shown in Figure1, the bacterial and virus detector includes a housing 1, an optical maser 2, a microfluidic chip 5, a sample collection element 6 and a Raman spectroscopy detection platform 7. The optical maser includes a laser source 3 and a mirror group 4.

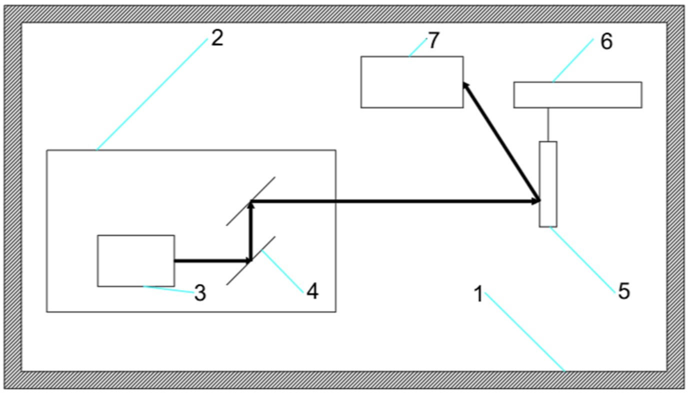


Figure1. Schematic diagram of a bacterial and virus detector

2.2. A purification and disinfection device

The purification and disinfection device controls different modules through the main controller to achieve filtration and sterilization, so as to achieve low energy consumption and high efficiency air purification effects.

As shown in Figure 2, it is composed of four modules A, B, C,and D. Module A is a first-level filter device composed of an adjustable baffle 4 and an activated carbon filter 5; module B is the secondary filtration and sterilization device consisted of 4 foldable UV-C ultraviolet germicidal lamps 10 and a liftable HEPA high-efficiency filter 6; module C is a three-stage filtration and sterilization device, which is composed of a high temperature resistant, high efficiency filter cotton 7, a metal aluminum mesh 8 and an insulating heating wire 9; module D is a four-stage one, which consists of 4 sets of foldable UV-C ultraviolet germicidal lamps 10 and a liftable TiO_2 photocatalytic filter[7].

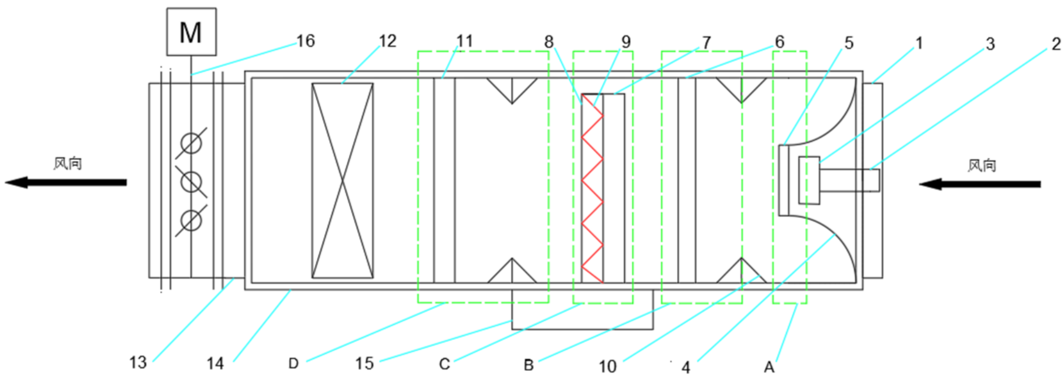


Figure2. Schematic diagram of intelligent purification and disinfection apparatus

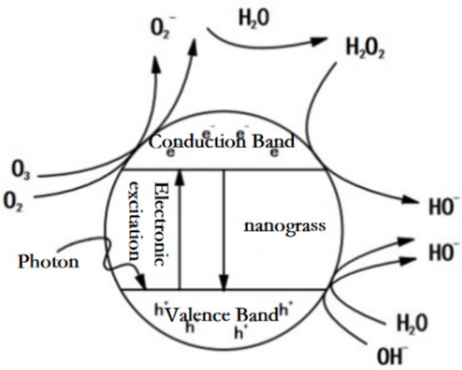
3. Working principle

3.1 Design principle

The apparatus has the function of detection and killing for bacterial and virus. The laser detection adopts Raman light data analysis to obtain microbial identification information, and then virus and bacteria elimination method involves ultraviolet sterilization, high temperature sterilization and TiO_2 photocatalytic sterilization.

The laser irradiates the area of bacterial and virus and then enters the detection platform by the surface scattering to form the corresponding and enhanced scattered light with the characteristic spectrum of bacterial and virus. After filtrating by Rayleigh filter, the corresponding refined spectral distribution is obtained by CCD detector through grating spectroscopy.[3] Processing algorithm module of machine learning obtains microbial identification according to the Raman spectrum database and refined spectral distribution .

The main wave band of UVC ultraviolet disinfection lamp is 253.7nm, which can destroy the genetic material DNA of organisms, resulting in the loss of survival and replication ability of the virus. High temperature is also an effective method of sterilization and disinfection, which can offset the lack of long delay time for ultraviolet sterilization. The principle is mainly based on two aspects. On the one hand, high temperature can make the proteins composed of living organisms irreversible variation, resulting in inactivation of enzymes and irreversible destruction of the cell structure of living organisms. On the other hand, DNA will decompose at high temperature, leading to the death of bacteria and viruses. TiO_2 photocatalytic sterilization has two different mechanisms. The direct reaction mechanism is that photogenerated electrons and photogenerated holes react with cell wall, cell membrane or cell components directly. As shown in Figure 3, the indirect reaction mechanism is photogenerated electrons or photogenerated holes reaction with water or dissolved oxygen in water, which forms strong oxidizing substances such as hydroxyl radical, superoxide ions and hydrogen peroxide. They have chain reactions with cell membranes and intracellular components, leading to cell death.



Figue 3 Schematic diagram of TiO_2 photocatalysis

This process can also be expressed by following mechanism equation:

$$TiO_2 + hv(> Eg) \rightarrow e^- + h^+ \tag{1}$$

$$h^+ + e^- \rightarrow heat \tag{2}$$

$$h^+ + OH^- \rightarrow \cdot OH \tag{3}$$

$$h^+ + H_2O \rightarrow \cdot OH + H^+ \tag{4}$$

$$e^- + O_2 \rightarrow \cdot O_2^- \tag{5}$$

$$O_2^- + H^+ \rightarrow HO_2 \cdot \tag{6}$$

$$2HO_2 \rightarrow O_2 + H_2O_2 \tag{7}$$

$$H_2O_2 + \cdot O_2^- \rightarrow HO \cdot + OH^- + O_2 \tag{8}$$

$$H_2O_2 + hv \rightarrow 2HO \cdot \tag{9}$$

3.2 Working mode

The light beam（532nm-785nm）emitted by the laser generator irradiates the bacterial and virus area. Then it enters the Roman spectrum detection platform after surface scattering, so as to obtain the microbial identification information and transmit it to main controller. The main controller realizes the information transmission and control with the Raman spectrum detection platform through the Internet of Things technology. If the microbial identification information meets the killing conditions, it will start the purification and disinfection device immediately. In addition, the main controller can realize the risk level according to the microbial identification information. The higher the risk level, the higher the level of module, and the number of the module will increase. The main controller is electrically connected with the fan 12，and the insulated electric heating wire controls them through cables for working in different periods. When the fan works, efficient filter cotton and metal aluminum mesh can effectively intercept bacteria and viruses in the air. When the fan stops working, the insulated electric heating wire heats the high efficiency filter cotton. At the same time, metal aluminum mesh（120℃-150℃）will kill the attached bacteria and viruses at high temperature. After the bacteria carried by the air flow are killed by the purification and disinfection device, the air flow enters the electric damper from the blower fan, which finally enters the room through the air outlet. The volume of the killing chamber is larger than that of the air outlet chamber, which can reduce air flow resistance in the pipeline.

4．Feasibility analysis

4.1 Analysis of detection and killing efficiency

The detector using Raman spectroscopy analysis has the characteristics of simplicity, rapidity and high accuracy, and its detection efficiency is as high as 100% under ideal conditions. Ultraviolet disinfection technology has a sterilization efficiency of 99%~99.9%, and the killing time of several common bacteria and viruses is usually kept within 1s. Traditional chemical disinfection methods using chlorine and ozone need 20min~60min to achieve the same sterilization effect. Four sets of UV-C ultraviolet lamps (253.7nm) are installed in the purification and disinfection device, which can ensure an efficient sterilization effect. Module D adopts photocatalytic sterilization technology, and the sterilization rate is as high as 99.99%. In summary, this apparatus can meet the requirements of accurate detection and efficient elimination of bacteria and viruses when the air quality of the environment is different.

4.2 Analysis of Energy-saving

The existing high-temperature air disinfection device, whether it is heating the air or heating the filter element during the aeration of the fan, the required power and energy consumption are relatively large. The apparatus uses the main controller 15 to control the blower fan 12 to ventilate and the insulated electric heating wire 9 to work in time intervals, so that the power consumed when killing the virus at high temperature is only the power of the insulated heating wire 9 for heating. The effect of heating exchange can greatly reduce energy consumption without air convection. Not only that, the multi-module intelligent control method can also achieve the effect of energy saving.

When the air flows through the module C, the airflow is instantly heated to the virus-killing temperature. Assuming that the mass flow of pipe air through module C is 0.048kg/s. If the traditional method of heating air is used for sterilization and disinfection and the air with a normal temperature of 20°C is heated to 150°C, the air temperature needs to be heated to the target temperature instantaneously as the airflow stays in the apparatus for a short time. When assuming the heating efficiency is 100%, the power required to heat the air instantaneously can be calculated as:

$$P = cq_m(t_2 - t_1) = 1\times10^3\, J/(kg\times{}^\circ C)\times 0.048\, kg/s\times 130{}^\circ C = 6.24kW$$

If insulated heating wires are wrapped around the metal aluminum mesh 8 along each layer of aluminum foil partitions, a total of 40 pieces insulated heating wires of 220mm is required. Let every 20 pieces wires be connected in series to form 2 insulated electric heating wires with a length of 4.4m. Pieces are connected in parallel, whose ends are electrically connected to the main controller 15, and the load voltage is 220V. If the resistance of insulated heating wire is 120Ω/m, then the total resistance of insulated heating wire can be calculated as R=264Ω. The heating power of the insulated heating wire can be calculated as:

$$P = \frac{U^2}{R} = \frac{220^2}{264}W = 183.3W$$

If the fan is set to ventilate for 50 minutes per hour and the high temperature kills for 10 minutes, the actual average power per hour is only one-sixth of the above power. Generally, in view of the actual size of the high-temperature-resistant and high-efficiency air filter element, it can be further optimized to obtain an optimal energy-saving solution for the resistance, length, and the serial and parallel modes of insulated heating wire.

4.3 Environmental protection analysis

The apparatus adopts UV-C ultraviolet lamp for sterilization to avoid the environmental pollution brought about by chemical disinfectant sterilization, following the concept of environmental protection. In addition, the photosynthetic oxidation technology has low energy consumption due to mild reaction conditions, which can effectively reduce secondary environmental pollution. At the same time, it is possible to use sunlight as the reaction light source, which can effectively degrade almost all organic pollutants and finally generate inorganic small molecules and has no obvious selectivity for the reaction.[2] It can not only kill microbes but also remove toxins released in the process of microbial death in terms of microbial treatment, which has broad application prospects in the field of environmental protection[4][8].

4.4 Economic analysis

With the deterioration of living environment, environment pollution has become a common concern and an urgent problem to be solved. Microbial pollution in the air may lead to the outbreak of infectious diseases in a large area and cause serious harm to human health. Therefore, an intelligent purification and disinfection apparatus with high efficiency and low power consumption has broad market prospects. Traditional physical, chemical and biochemical methods of treating organic pollutants have problems such as incomplete reaction, high operating cost and secondary pollution during treatment. The apparatus proposes a solution. On the one hand, Module D uses titanium dioxide photocatalytic sterilization technology, which has great advantages for organic pollution control and lower cost. On the other hand, UVC ultraviolet sterilization lamp can not only replace the lamp normally, but also reduce the operation cost without maintenance, which has high cost performance.

5. Creative points

The purification and disinfection device consists of four modules. The filter of each module is designed as a lifting mode, which enhances the pertinence and efficiency of the single mode, and prolongs the lifespan of the device as a whole. At the same time, it is convenient for cleaning and exchange of the filter, which is efficient and convenient.Using the Internet of Things technology,intelligent purification and disinfection device can realize feedback and control functions. The main controller commands all devices in the apparatus as a terminal, which can effectively identify the information transmitted by the detector and feedback the data information timely.It judges the environmental hazard level and starts automatically the module to disinfect and purify the air.[6] In addition, it can also manually set. When the environment does not reach a high risk, it can still use multiple modules for heavy killing to achieve the role of prevention, or close the conversion mode to adapt to any emergency.

6. Conclusions

The apparatus realises the integration of detection and disinfection function against bacterial and virus.The bacterial and virus detector obtains microbial recognition information by Raman spectroscopy analysis, which is fast, simple and accurate. The purification and disinfection device can filters and kills the bacterial and viruses effectively in duct airflow through ultraviolet sterilization, high temperature sterilization, TiO_2 photosynthetic sterilization and HEPA high-efficiency filter.

The apparatus can be widely used in hospitals, factories, stations and other public places,which has broad promotion prospects.

References

[1] ZHOU Weiming, HOU Huiqin.Discussion on the HVAC design of combination of peace and epidemic in hospitaI buiIdings[J].Chinese Hospital Architecture and Equipment, 2021, 22(1): 54-55.(in Chinese)

[2] Wenquan GU, Wanjun Wang, Guiying Li, et al.Microwave-assisted synthesis of defective tungsten trioxide for photocatalytic bacterial inactivation: Role of the oxygen vacancy[J].Chinese Journal of Catalysis, 2020, 41(10): 1488-1497.(in Chinese)

[3] Wuhan Guanggu Aerospace Sanjiang Laser Industry Technology Research Institute Co., Ltd.Integrated device and method for rapid detection and killing of virus and bacteria by laser. CN202010921984. 2[P]. 2021-01-26.(in Chinese)

[4] LI Zhixiang, ZHANG Zhanzhao, YAN Xingyu, et al.Design of air purification and disinfection device[J].Peakdatasci, 2020, 9（8): 250-251.(in Chinese)

[5] LI Wenshuai, WU Guorui, ZHANG Qianjing, et al.Advances in bacterial detection based on Raman spectroscopy[J].Chemical Journal of Chinese Universities, 2020, 41(05): 872-883.(in Chinese)

[6] LI Jun, Gao Rui, HANG Xiao.Network security analysis and countermeasures of wireless technology in internet of things[J].Network Security Technology and Application, 2021(08): 84-85.(in Chinese)

[7] ZHANG Xiaoning, CAO Wenbin, LI Yanghong, et al.Preparation of N-doped TiO_2 photocatalytic paint and its sterilization performance under Visible-light irradiation[J]. Key Engineering Materials, 2007, 336/338(3): 1964-1967.

[8] CUI X, ISIAM M R, CHUA K J.Experimental study and energy saving potential analysis of a hybrid air treatment cooling system in tropical climates[J]. Energy, 2019, 172(Apr.1): 1016-1026.