Future Cities and Environment

Experimental Investigation of a MopFan-Based Photocatalytic Air Purification Device

TECHNICAL ARTICLE

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ABSTRACT

Photocatalytic oxidation (PCO) is a potential approach for air cleaning, especially when utilising titanium dioxide (TiO2). A MopFan is similar to a roller brush but is made of flexible fibres coated with TiO2. Unlike conventional filter/mesh UV systems, a MopFan provides a wide UV-TiO2 interaction surface area and airflow passage. This revolutionary technique can be low cost, efficient, and potentially effective against viruses, making it suitable for cleaning indoor air. It is easy to use but technically advanced. The system may be mounted on walls, floors, or placed on desktops.

A photocatalytic air purification based on MopFan prototype was designed, constructed and tested. This study utilised copper wires (0.1 mm, 0.3 mm, 0.4 mm, and 0.5 mm), plastic fibres (0.5 mm and 1.1 mm), brass wire (0.4 mm), steel wire (0.38 mm), and organic "coco" fibres (0.4 mm). Copper wire (0.5 mm) and organic fibre (0.4 mm) were found to be effective against SARS-CoV-2, but brass (0.4 mm) and plastic (0.5 mm) fibres were found only partially effective. The purification performance was compared using MopFan with plastic (0.5 mm), brass (0.4 mm) and organic "coco" (0.4 mm) fibres but the other materials were rejected due to their poor qualities or difficulties in manufacturing. It was found that the system has a better effectiveness with organic fibres, around 21% of reduction consistently throughout the test. It was also found that by using the photocatalytic MopFan air cleaning system, the final concentration of pollutants in a room is determined by the rate and concentration of pollutant generation.

Highlights

1. Organic fibres do not require sanding prior to being coated with TiO2 solution.
2. Copper and organic fibres are effective SARS-CoV-2 inhibitors.
3. Organic fibres are the most efficient for air purification.
4. The performance of purification is related to the concentration of pollutants.

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1. INTRODUCTION

Globally, an estimated 3.8 million deaths were caused by indoor air pollution (IAP) in 2017. High concentrations of indoor air pollution increase the risk of heart disease, lung cancer, chronic obstructive pulmonary disease (COPD) and stroke. On average, the British population spends 90% of their lives indoors (Saini et al, 2020). As such, there is increasing focus on achieving clean breathable air. The Clean Air Bill is currently being discussed in UK parliament and its purpose is to qualify that having clean air to breathe is a human right. This is further demonstrated by the Environment Act, a 2030 target set by the UK Environment Agency (EA), to halt the decline of nature and specifically reduce ambient PM 2.5 concentrations, the most harmful pollutant to human health. Indoor air quality has been adversely affected by the continuous advancements in insulation and minimising waste heat. Buildings which have a high-grade Energy Performance Certificate (EPC), may also lack in adequate ventilation. By reducing heat loss through building design or retrofitting of insulation, natural ventilation can be blocked or disrupted. This can compromise adequate ventilation for the occupants and the building itself. Installing HVAC systems can be impractical and expensive depending the building's age, design and function. Mobile IAQ devices are more affordable and attainable when compared with HVAC systems and require no installation. This paper investigates a novel IAQ device, a prototype with unique characteristics and design, which demonstrates intensive photocatalytic oxidation (PCO) by combining a large TiO2 coated surface area with specific frequencies of UV light, in a highly reflective chamber. Furthermore, the paper documents the demand for improvement in IAQ, similar or known PCO purification systems, the material specification and assembly, as well as the results, conclusions and further implications of this research.

1.1. INDOOR AIR QUALITY

Indoor air quality (IAQ) can be measured by pollutant concentration, which includes gaseous pollutants and particle matter. Higher concentrations of particle matter, which are typically smaller than 0.1 µm, are often present in indoor environments. The demand for IAQ devices has risen due to the increased awareness of air quality. The COVID-19 pandemic has resulted in populations being required by law or societal parameters to remain indoors. This demand for clean breathable air can be addressed by using air quality devices. Within buildings, indoor air pollution (IAP) has a significant influence on the wellbeing, cognitive performance and health of the occupants. The aspects contributing to indoor air contamination are abundant, as sources of pollutions are vast and often unrecognised. The constant improvements in energy conservation and responses to climate change, have the capacity to further accentuate the challenge of achieving acceptable indoor air quality (Tham, 2016). 'The evaluation of indoor air quality in buildings is complex because IAQ involves a broad spectrum of substances and agents that vary over time and space.' (Wei et al., 2016) as such, indoor air is often influenced by:

- Building materials, including, furniture, fabrics and wall finishes which can either absorb or emit pollutants as a result of other environmental factors such as humidity, air delivery rate and temperature;
- occupants and occupant activities which may produce pollutants or further disperse pollutants already present;
- equipment or processes which can generate pollutants;
- bio-effluents which can cause respiratory contamination;
- air distribution, ventilation and cooling/heating processes which can generate turbulence, resulting in flow paths which can carry contaminants and facilitate exposure.

The following table outlines the major pollutants which affect IAQ, the common sources of their emission and relating medical health consequences.

In Cincinnati (USA), a study on HEPA purifier performance in reducing traffic related combustion particles (TRAP) was conducted. The study found that TRAP can increase the severity of asthma and other respiratory conditions. A reduction of TRAP by as much as 25% has a substantial influence on controlling asthma (Epstein et al., 2012). HEPA purifiers are evidenced to remove indoor air pollution (IAP) (Andersen et al., 2012), however, this study concentrated on the reduction of TRAP in indoor environments. The study found that HEPA purifiers were more efficient in removing diesel combustion particles as opposed to potassium chloride (KCl) particles which contradicted the study hypothesis. The clean air delivery rate (CADR) was higher in all six tests for removing TRAP as opposed to KCl particles. No correlation was found between noise levels and CADRs. This supports the application of air purifiers (APs) for use in urban environments with high concentration of TRAP (Peck et al., 2016).

1.2. ULTRA-VIOLET PHOTOCATALYTIC OXIDATION (UV-PCO)

The photocatalytic oxidation (PCO) process takes place when pollutants react with a semiconductor such as TiO2. This catalyst is illuminated by UV light. The wavelength can vary from 180 nm–400 nm. This produces hydroxyl radicals and oxide ions which will attract pollutants and oxidise them. The pollutants, in principle, are then broken down to water vapour and CO_2. Purifiers with PCO function have an advantage as the pollutant(s) begin to decompose during the PCO reaction into non-hazardous components, unlike HEPA filters where hazardous pollutants can still be present on the filter surface (Kolarik and Wargocki, 2010).

POLLUTANTS	MAJOR SOURCES OF EMISSION	ASSOCIATED MEDICAL HEALTH CONSEQUENCES
SO_2	Fossil fuel combustion such as oil, coal and natural gas, outdoor air	Acute exposure leads to bronchial activity.
CO	Tobacco smoke, stoves, boilers, kerosene or gas heaters, fuel burning	Low birth weight, Increase in perinatal deaths
CO_2	Combustion activities, metabolic activity and motor vehicle in garages	Headaches, sleepiness, Poor concentration, Loss of attention
Fungal Spores	Internal surfaces, foodstuffs, plants and soil	Asthma episodes, Allergic reactions, Eye, throat and nose irritation, Sinus and other respiratory problems
Radon	Soil Building concentration materials such as stone and concrete	Risk of lung cancer, Breathing problems
Asbestos	Insulation, fire retardant materials	Cancers such as mesothelioma, Pleural thickening, Pleural plaques and asbestosis
NO_2	Motor vehicles in garages, fuel burning and outdoor air	Exacerbation of asthma and wheezing, Reduced lung function in kids, Respiratory infections
Pollens and allergens	Outdoor air, plants, weeds, grass, trees, insects, domestic animals, and house dust	Trigger symptoms of allergy
Particles (small particles <10 μm; and <2.5 μm aerodynamic diameter)	Tobacco smoke, re-suspension, combustion products	Exacerbation of Asthma, Wheezing, Respiratory infections, Exacerbation of COPD, Chronic bronchitis and COPD
Ozone	Photochemical reactions	Airway irritation, Permanent lung damage, Pneumonia and bronchitis, Aggravate asthma
Lead	Paints, firearms, lead bullets, dust, soil, radiators, consumer products	Memory loss, Hearing loss, Damage to the nervous system in new-borns, High blood pressure, Kidney & heart disease, Reduced fertility, Hyperactivity or loss of consciousness
VOCs	Burning of gas, wood, and kerosene, cleaning agents, paints, hair spray, perfumes and tobacco smoke	Allergic skin reactions, Visual disorders and memory impairments, Damage to the central nervous system, kidney, and liver, Decline in serum, cholinesterase levels, SBS

Table 1 Major pollutants and their associated health consequences. (Saini *et al*, 2020).

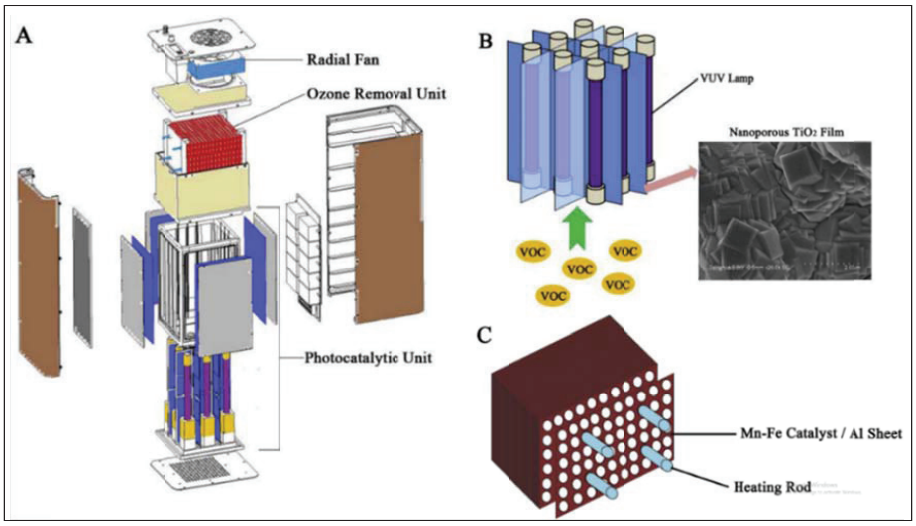

Figure 1 Diagram of the VUV-PCO air purifier (**A**), the photocatalytic unit (**B**) and the ozone removal unit (**C**). (Xu et al, 2018).

The use of UV-PCO technology has become increasingly popular during the last two decades. The use of this technology for indoor air purification has received extensive attention. There are potential by-products which can be generated by the PCO reaction and studies have been conducted to measure the concentration of these by-products (Zhong and Haghighat, 2018).

A study performed in China tested an innovative vacuum ultraviolet oxidation (VUV-PCO) air purifier (Figure 1). The purifier was equipped with a nanoporous TiO2 film, a radial fan and Mn-Fe catalyst. This purifier was evaluated in its removal of volatile organic compounds (VOCs) and O3. This testing was conducted in a sealed room. The results demonstrated that the purifier was highly efficient in reducing formaldehyde, nonanal, pentanal, benzene, toluene, octanal, ofm-xylene and ortho-xylene in values of up to 78.71%. The purifier was also equipped with a heated ozone remove unit which assisted in removing VOCs. This study demonstrates the potential for VUC-PCO air purifiers and the need for further research in more diverse environments.

A study conducted in France compared the efficiency of various commercially available photocatalytic air-purifiers (Costarramone et al., 2015). The study found that a critical element of a PCO air purifier is the design and assembly. When comparing the purifiers, despite operating at a reduced flow rate, some of the purifiers performed more efficiently than others due to the photocatalytic substance being better distributed to the source of irradiation and an optimised assembly of the lamp/photocatalyst and or fan (Costarramone et al., 2015). The arrangement of the PCO catalyst has also been examined in other studies where TiO2 coated fibres are used as opposed to a coated metal plate. A relating study found that the effects of a large surface area of TiO2 nanofibers increased the adsorption capability and visible light adsorption. The TiO2 nanofibers tested in this study are a viable option for integration in air quality devices offering an improved air purification efficiency with lower energy requirement (Wongaree et al., 2016).

The aim of this research is to test the air purification qualities of a photocatalysis-based system for enclosed domestic usage in an experimental setting. The "MopFan" comprises of a flexible fibre mop, similar in appearance to a chimney sweep brush yet is constructed of flexible fibres coated with TiO2. TiO2-fibres in a mop arrangement provide the essential extremely large UV-TiO2 interaction surface area and airflow passage, unlike current filter/mesh UV systems. This novel approach has significant advantages over current systems, will be low cost, efficient, and potentially effective against viruses, making it ideal as an indoor air cleaner. The system can be adapted to many forms, from thin wall mounted units, free standing floor units, and even small tabletop units. It is simple in operation yet technically highly advanced. No known competitor systems offer these advantages where the proven effectiveness of the PCO process of destroying/removal of pathogens, volatile organic compounds, bio-aerosols, and pollutants is ideal. A prototype was constructed, and various brush materials were tested.

2. MATERIALS AND METHODS.

2.1. BRUSHES

Copper wires (0.1 mm, 0.3 mm, 0.4 mm and 0.5 mm), plastic fibres (0.5 mm, and 1.1 mm), brass wire (0.4 mm), steel wire (0.38 mm) and organic "coco" fibres (0.4 mm) have been selected in this study. These fibres were bonded as strip brushes to be set in a cylindrical arrangement that when spinning will function as blades and push the air. The type of brushes is similar to the one shown in Figure 2a. The way to bond the fibres to a strip structure is similar the one shown in Figure 2b. It is a steel rib that holds the fibres by pressing them with a binding wire. To guarantee a large quantity of fibres, 1000 mm long brushes with 80 mm long fibres were used.

2.2. FIBRE PRE-TREATMENT

Because the fibre surface is very smooth, the coating is not easy to adhere to the fibre. Therefore, a pre-sanding process with sandpaper was first used in this study. The friction direction was across the curved surface.

This process was only used for samples to study the morphology and microstructure of the coated fibres. For the assembled brushes, sandblasting was selected to facilitate abrasing the bristles of the brush. A heavy-duty sand blasting cabinet was used, shown in Figure 3. The volume of the cabin used is 220 litres. A 4.5 mm ceramic nozzle was used with sand grade 0.5–1.25 mm and air at a pressure of 6 bar.

2.3. TIO2 SOLUTION PREPARATION

First, TiO2 powder (2% and 5%) was poured into 200 mL water and mixed this solution with a stirrer. Next sodium alginate (SA) powder (3%) was slowly added to the solution and mixed until it achieved a homogeneous consistency. Then, the solution was kept still for de-bubbling at indoor temperature for 8 hours.

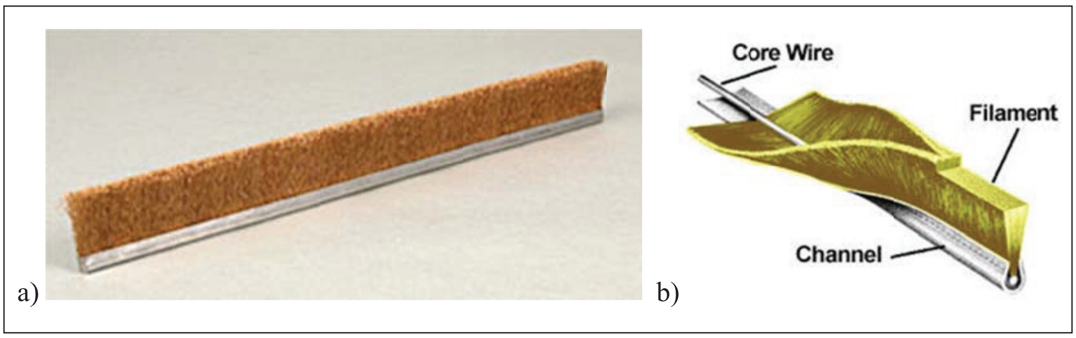

Figure 2 a) Strip metal brush. **b**) Brush construction.

2.4. COATING PROCESS

Every brush was coated with several layers of the TiO2 solution with a paint brush to ensure every bristle was coated and hence the entire brush was evenly covered. After coating, each brush was left to dry naturally in the open air. Once dry, the brushes were tested by rubbing them with a black cloth and checking that no white residue from the coating was removed from the fibres (Figure 4).

2.5. MORPHOLOGY AND MICROSTRUCTURE OF THE COATED FIBRES

The digital compound microscope KERN OBL 135C825 with an adapted camera ODC 825 (Figure 5) was used to study and photograph the internal structure of the materials.

Different fibers with coating are shown in Figure 6. It could be found that thin fibers were coated well. Using a black cloth to wipe the samples, it has been verified that

Figure 3 MAXBLAST Heavy duty sand blasting chamber 220 L.

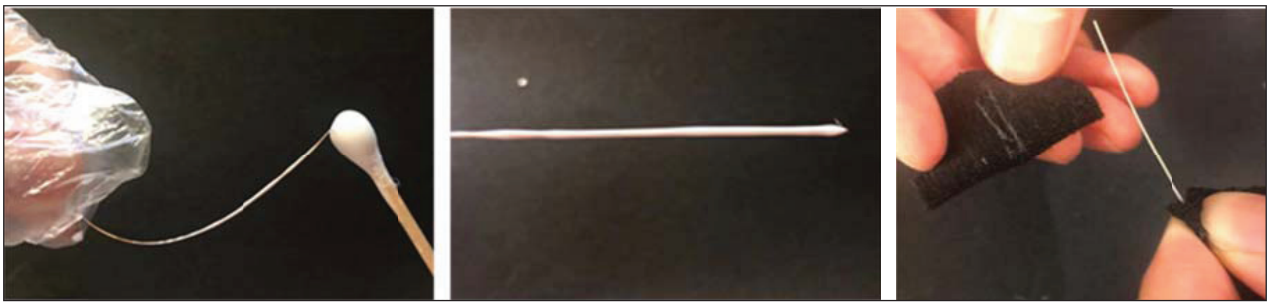

Figure 4 Coating process.

Figure 5 Image of the digital compound microscope.

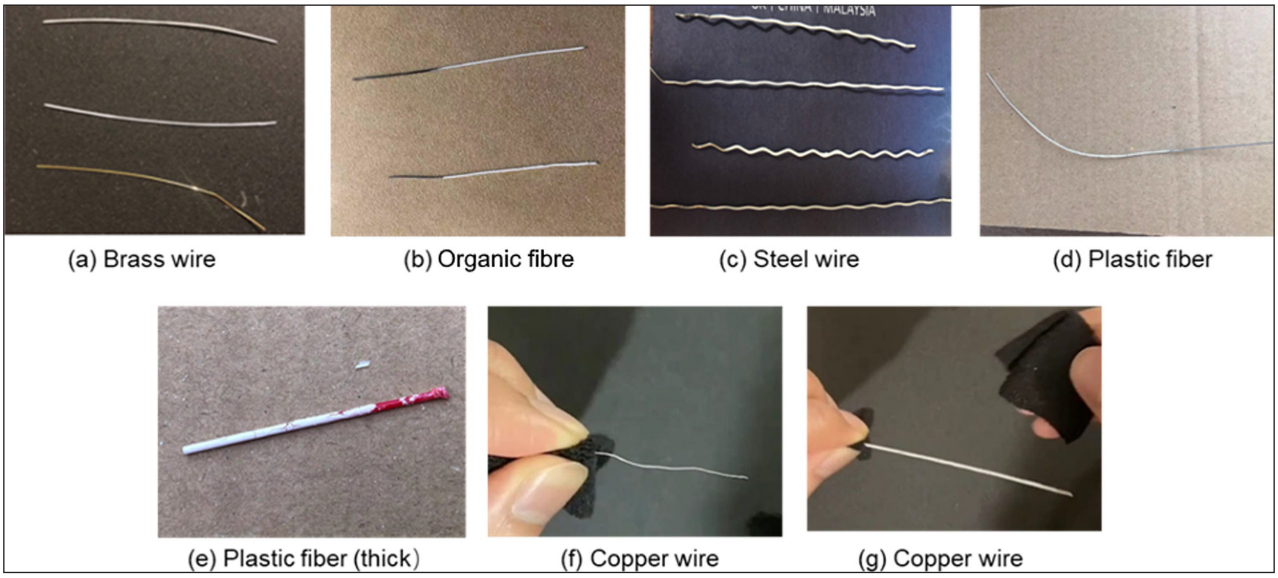

Figure 6 Image of different coated fiber samples.

the coating on the thin fibers adheres well. But for the thick plastic fiber (1.1 mm), the coating is easy to fall off after the drying process. As shown in Figure 6(e), there is a small crack appeared on the surface of the thick plastic fiber.

As presented in Figure 7 and Figure 8, there is a layer of coating covered on the surface of the different fibers when compared with the original fibers.

2.6. BIOLOGICAL TESTS OF THE FIBRE MATERIALS

In order to refine the selection of materials, biological tests have been carried out to examine the effectiveness of the coated fibres for removal of viruses. SARS-CoV-2 (CVR-GLA-1 variant) was obtained from the Centre for AIDS Reagents, NIBSC. Viral stocks were created by propagation of the original virus in Vero E6 cells and

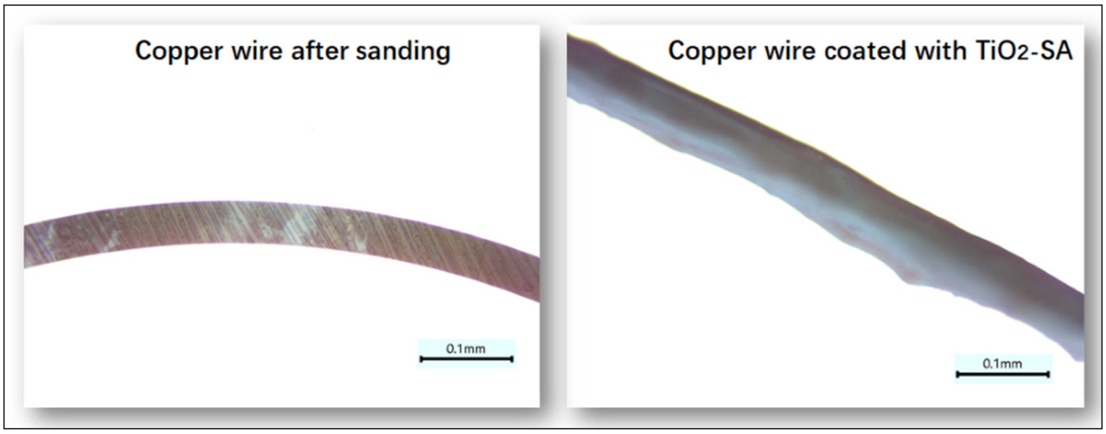

Figure 7 Microstructure of the copper wire with and without coating.

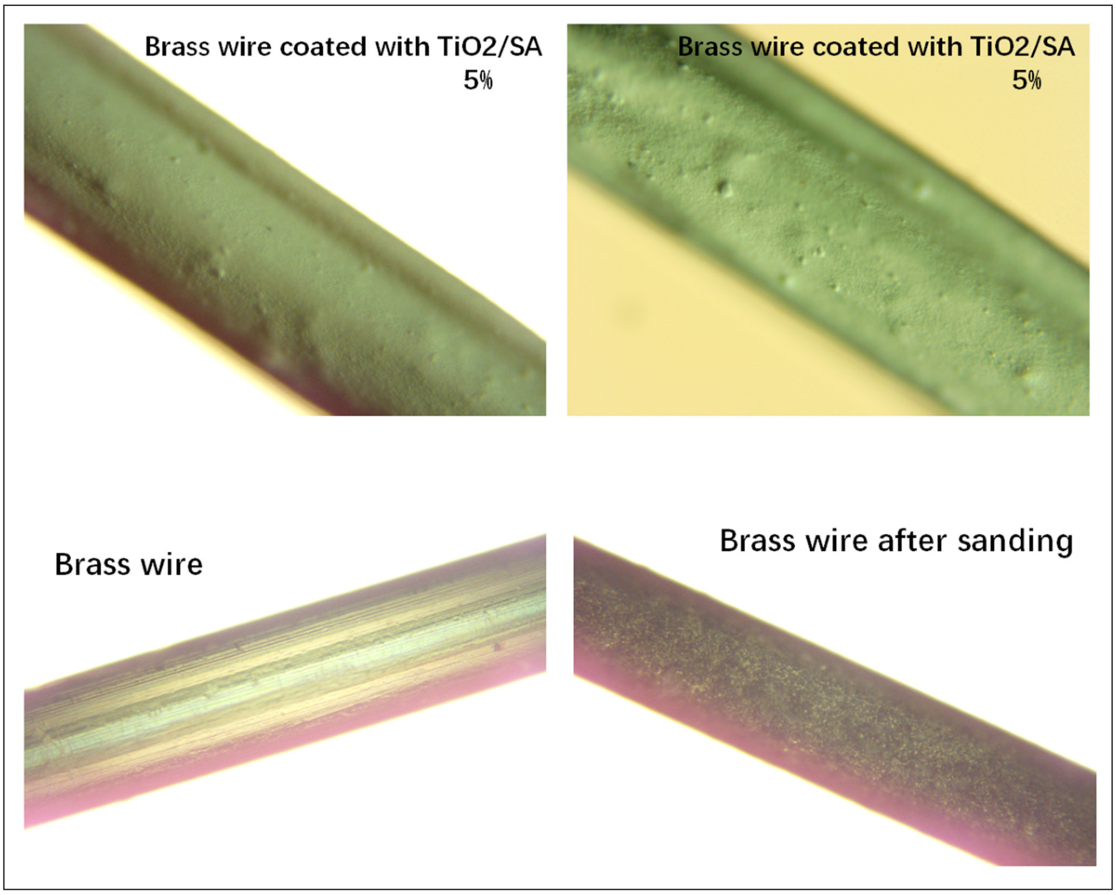

Figure 8 Microstructure of the brass wire with and without coating.

quantified using the median TCID50 method as previously described for other coronaviruses (Coleman and Frieman, 2015). All work with live SARS-CoV-2 was performed under containment level 3 (CL3) conditions at the University of Nottingham. Vero E6 cells (a kind gift from Prof Kin-Chow Chang, Department of Veterinary Medicine and Science, University of Nottingham) were maintained in minimal essential media supplemented with heat inactivated foetal calf serum, 2 mM L-glutamine and 1% penicillin/streptomycin (all from Sigma). Cells were maintained at 37 °C in 5% CO_2 in an incubator before and during experiments.

In these experiments: "ambient conditions" for experiments using live SARS-CoV-2 are defined as follows: all live SARS-CoV-2 experiments were performed in a CL3 laboratory under negative pressure. Virus was handled in a Class I/III microbial safety cabinet, with the normal airflow engaged. Samples were placed onto the surfaces within a 96- or 24-well plate and the lid was replaced for the duration of the exposure. The room is maintained at normal comfortable room temperature, ambient humidity and lighting.

The samples were tested for anti-virus performance. Under CL3 conditions, a 7.2×10^3 TCID50 of live SARS-CoV-2 was spotted onto each wire sample in 10 mL of normal cell growth media and left for 10 minutes. Then, the surface was washed briefly with 200 mL fresh cell media and the amount of recovered SARS-CoV-2 was quantified by TCID50 assay. A 'no wire' sample was used to assess natural degradation/loss of SARS-CoV-2 under these experimental conditions. The relative amount of SARS-CoV-2, compared to the 'no wire' control was calculated for each wire sample. A wire samples that caused a 10-fold drop in virus titre was considered a 'hit'. Example hits are: 0.5 mm copper wire and 0.4 mm organic fibre. Other samples were 'partial hits', in that the SARS-CoV-2 titre was lowered by between 3–5-fold, include brass wire and plastic wire. Further work will determine the degradation of virus over a longer time period and under different environmental conditions.

2.7. FIBRE SELECTION

Based on the antiviral activity and microstructure observations described above, the fibre materials were selected. The results of the biological tests discarded the steel fibres as they are not effective against viruses (section 3.1). After trying to cover the fibre samples, the use of thick plastic fibres (1.1 mm) was ruled out since the cracks that formed in the cover became suspended particles. Finally, although the copper wire (0.5 mm) was the most promising in all tests, it was not possible to manufacture brushes from this material due to its high cost. Therefore, only experiments with brass (0.4 mm), plastic (0.5 mm) and organic fibres (0.4 mm) were made.

2.8. HUB DESIGN

To cover the periphery of a cylinder, 20 brushes were mounted on a hub. The hub consists of three different pieces that together hold the 20 brushes forming a cylindrical figure with the fibres exposed. The upper part in addition to holding the brushes, has a spindle to facilitate an aligned rotation. The lower part has a coupling to the motor that will rotate the entire hub. The intermediate part only has a structural function and to keep the brushes straight while rotating. One key element of this design is it uses no adhesive. Adhesives could create VOCs and other pollutants which could negatively affect the system performance. The ribs of the brush strips are triangular to keep them in place. Each groove in the hub is designed to slide the brush strips into it. The groove becomes narrower towards the exterior surface to clamp the fibres/blades. In this way it is possible to exchange brushes to test different materials. Figure 9 shows the insertion process of the brush strips in the hub.

2.9. UV LIGHTS

In order to produce the photocatalytic reaction required to purify the air, the system requires UV light. Many related research papers were consulted and most of them converge in using UV light with wavelength range between 300 and 400 nm. For this prototype, it was used UV LED strips with a wavelength of 365 nm because it is relatively easy to find on the market. The LED strip is shown in Figure 10, it has a density of 60 LEDs per metre, operates with 12 V DC and consumes 4.8 W per metre, which means low extra power required. 6 meters of LED strip were placed around the cylindrical arrangement of brushes.

Finally, to maximise the UV light distribution, high efficiency reflection was achieved using a 1200 mm rigid extension for 350 mm sun tunnel, which is polished sheet metal tube also known as light pipe (Figure 11).

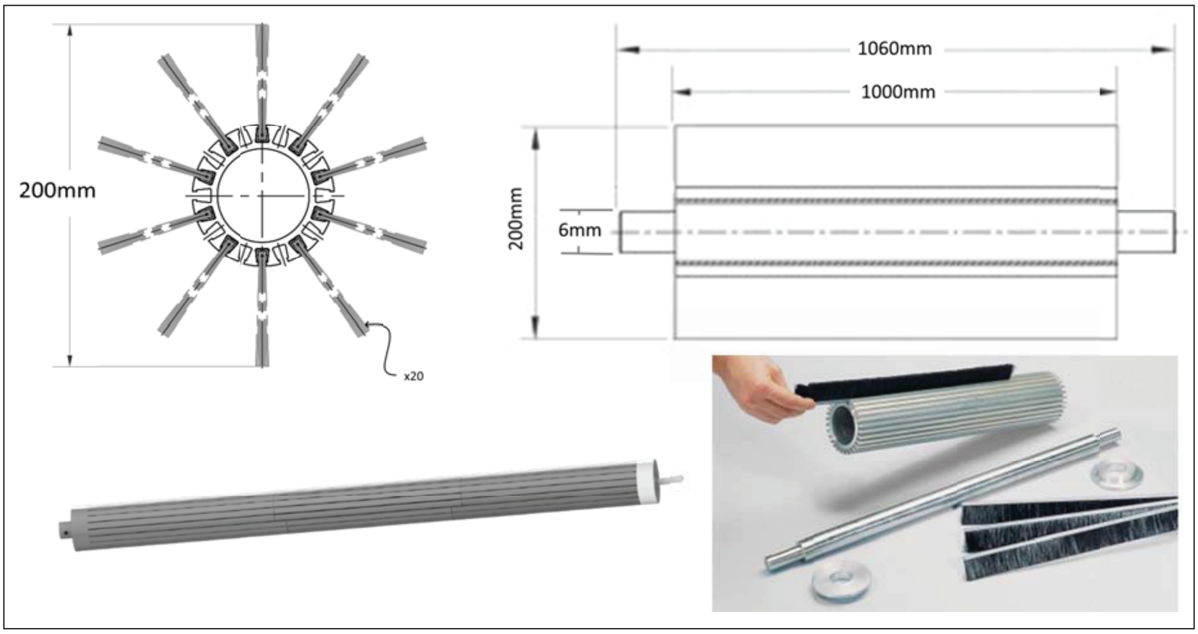

Figure 9 Dimensions and design of the hub.

Figure 10 365 nm UV-LED strip.

Figure 11 Velux ZTR 0K14 0124 Light pipe.

2.10. MOTOR

In the process of air purification by photocatalysis, in addition to light, a displacement of the purified air is required. To achieve this, the cylindrical brush will rotate using a motor conventionally used in tower fans.

For this prototype, an AC 220 V 50 W motor has been selected (Figure 12). With a maximum rotating speed of 1250 RPM which can be regulated with a variac.

2.11. PROTOTYPE CONSTRUCTION

With all the parts described above, the prototype in which the laboratory tests were carried out was assembled. The motor was fixed to a wooden base and the hub was attached to it. The brush strips were then placed in the hub as shown in Figure 13a. The complete roller has the capacity for 20 brushes (Figure 13b). The outer casing, which contains the UV lights, is placed from above (Figure 13c).

3. RESULTS AND DISCUSSION

3.1. BIOLOGICAL TESTING RESULTS

Following exposure to samples of each wire, the materials showed variable levels of reduction in SARS-Vo-2 titre, compared to a no material control (Figure 14). The samples made form copper (plate and 0.5 mm wire) and the "coco" fibre all showed a greater than 10-fold drop in titre, so are considered 'hits'. The brass, bronze and PB all showed a drop in SARS-CoV-2 titre compared to control, so were considered partial hits. None of the other materials tested showed any drop in SARS-CoV-2 titre compared to control. The thinner copper wires (0.1 mm and 0.3 mm) may have reduced surface contact with the SARS-CoV-2 and, therefore, were not as effective as the, relatively, thicker samples.

3.2. TESTING METHOD

To further asses the efficacy in practical applications, purification tests were conducted in a real room shown

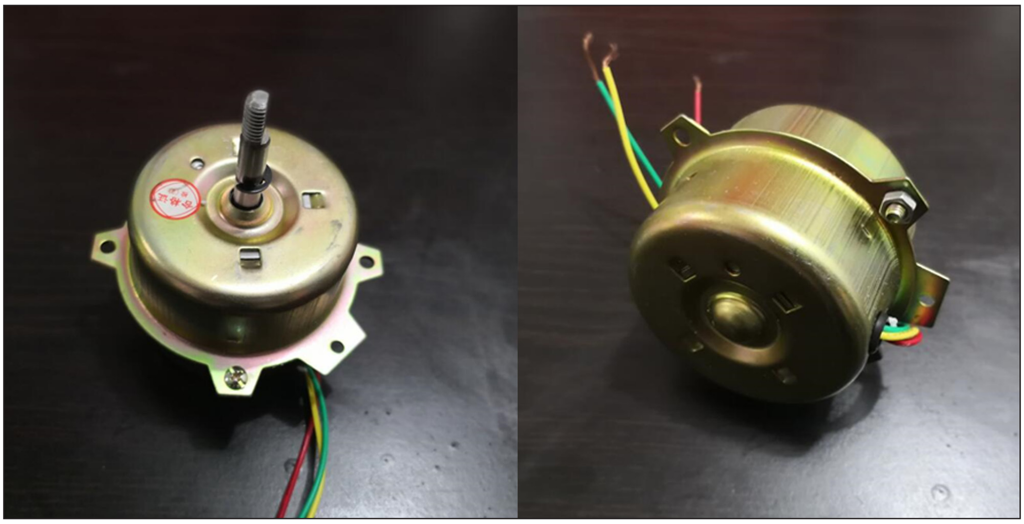

Figure 12 50 W AC motor.

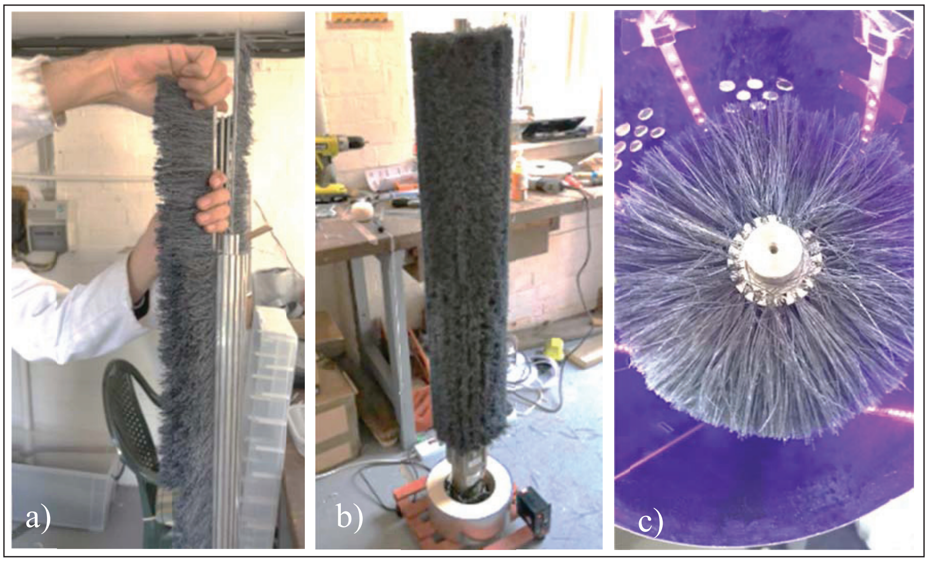

Figure 13 Prototype assembly.

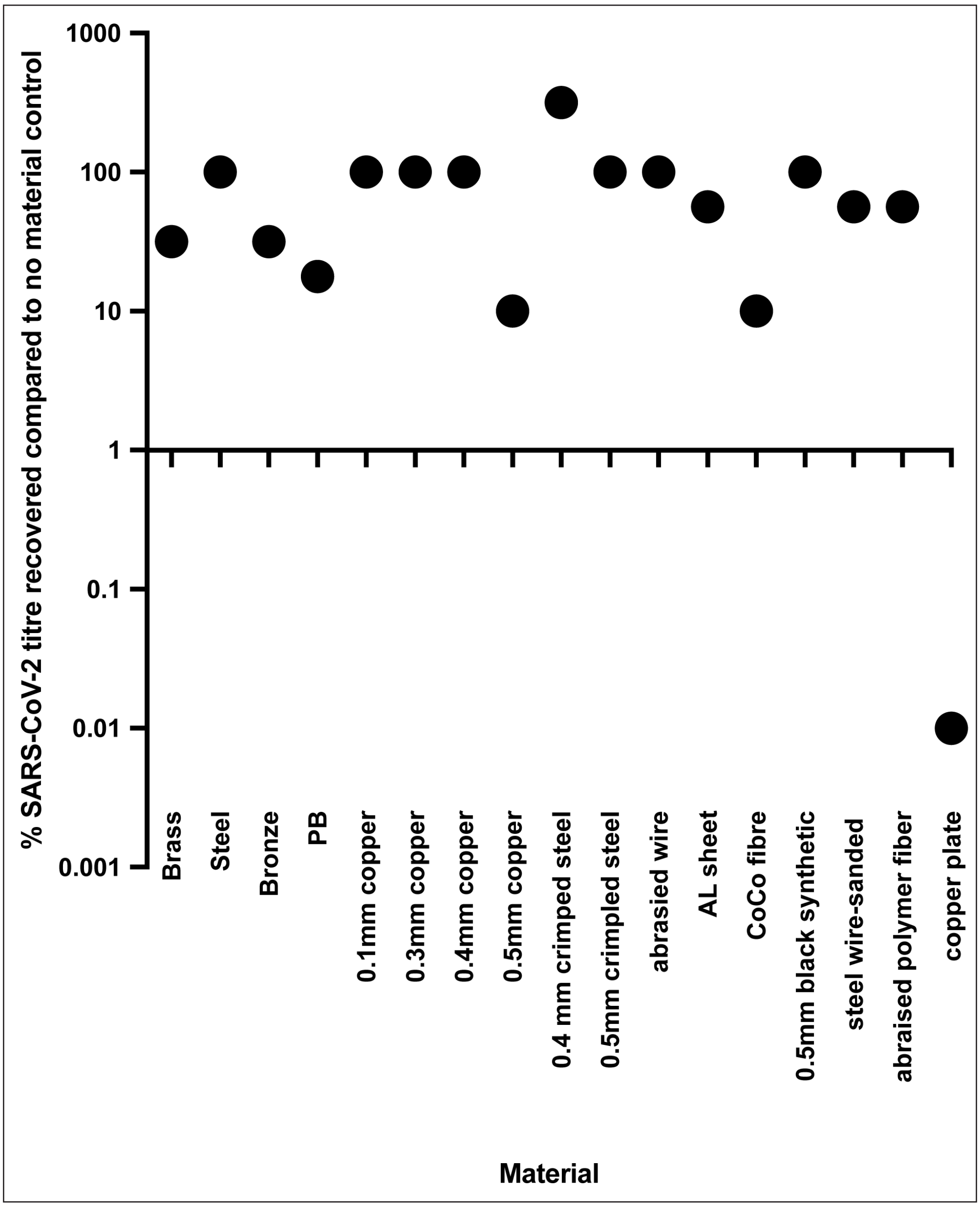

Figure 14 Biological test results.

Figure 15 Photo of real room experiment setup.

in Figure 15. The room used was approximately 45 m^2. 1.0 ml of methanol was evaporated an 80 °C hot plate situated one metre away from the prototype. The tests were made for the three selected materials. To simulate a contaminated environment, methanol was employed. For this test in real room, the methanol vapours were used as source of pollutants, and an air quality monitor (Temptop 1000s+) was used for VOCs and formaldehyde (HCHO) concentration detection. The amount of methanol utilised was adequate to avoid saturating the monitor sensors and bringing them to their maximum reading concentration without posing a health hazard. The prototype was put adjacent to the hot plate in order to cleanse the room›s air. The whole process was recorded in this test, which can be split into three stages: 1) the first stage during which the methanol is evaporating; 2) the stage during which the methanol concentration in the room reaches its maximum; and 3) the final stage when the pollution concentration declines.

3.3. COMPARISON OF VOCS REDUCTION

The VOC concentration was recorded following the procedure described above. Four different types of tests were conducted: with the device turned off, turned on with brass, plastic and organic fibres. The test run for two hours and data was logged every minute. The result of these experiments can be seen in Figure 16. As shown by the red line, the concentration of VOCs due to the evaporation of methanol rises sharply in the first five minutes, where it reaches the peak of maximum concentration, and then falls gradually, probably because the vapours are distributed throughout the room and they decant. However, even after two hours have passed, the VOC levels are still high. It is also possible to see that in all three cases where the device is on, there is a reduction in VOC, which suggests that photocatalysis is taking place. The similarity between the "device off" curve and the others implies that there is a direct relationship between the concentration of contaminants and the purification from the device. It can also be seen that around minute 70 the three types of fibres seem to reach a level very close to each other. During this time, the concentration of pollutants in the environment near the device is low, so that a smaller number of molecules can come into contact with the fibres to carry out the photocatalytic reaction.

It is observed that after 2 hours the three types of fibres manage to reduce the VOC concentration below 0.9 mg/m3, however their performance throughout the experiment is different, which means that in the organic fibres the reaction of photocatalysis is achieved more than in plastic or brass.

3.4. COMPARISON OF HCHO REDUCTION

Evaporated methanol, in addition to increasing VOC levels, also increases HCHO concentration so simultaneous VOC and HCHO readings were taken during each test. That is why the concentration curves shown in Figure 17 have a similar profile. It is interesting to note that the plastic fibres are not very effective in high concentrations, but after one hour they manage to reduce the concentration of contaminants to levels close to those of the other materials tested. In the case of brass, a more fluctuating behaviour is observed, presumably due to the characteristics of the material. At high concentration

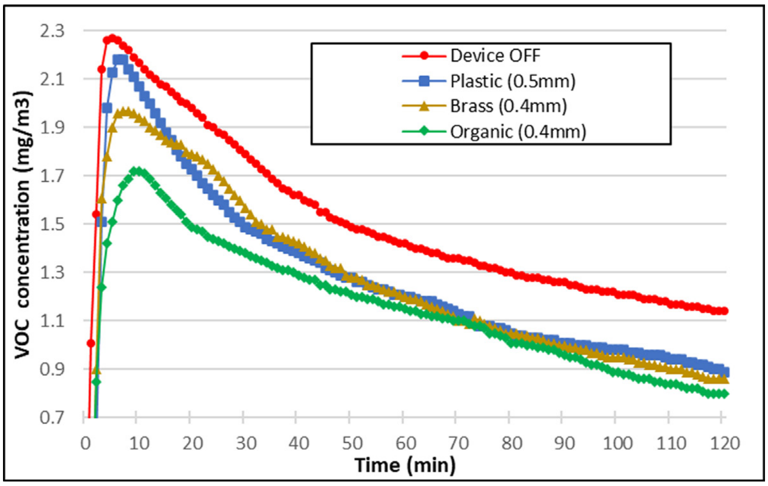

Figure 16 Monitoring results of VOC concentration.

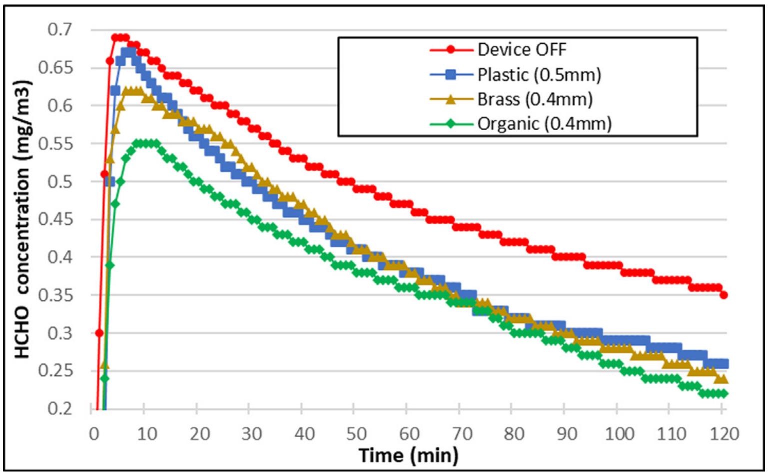

Figure 17 Monitoring results of HCHO concentration.

levels it works better than plastic fibres, but after the first twenty minutes, its operation is quite similar, although most of the time better. The reduction provided by the organic fibres was in both cases the greatest. And at all times the air purification system managed to reduce the concentration of pollutants. Even the highest peak, in which the HCHO concentration reached close to 0.7 mg/m3, the organic fibres reduced it to 0.55 mg/m3, which represents a reduction of 21%, which is maintained consistently throughout. of the entire test.

The above comparison shows that the prototype with the organic fibres has the best purification performance. This is because the TiO2 cover adheres better to this material than to the other two. In fact, it was noted that it does not need to be sanded, since the roughness and natural porosity of the "coco" fibres are sufficient for the cover to adhere properly.

CONCLUSIONS

A prototype of a MopFan-based device was successfully fabricated to test photocatalytic air purification utilising a variety of materials. A series of tests were conducted using plastic fibres (0.5 mm), brass wire (0.4 mm) and organic "coco" fibres (0.4 mm). Concentrations of VOCs and HCHO were measured in order to evaluate the anti-viral activity and air purification effectiveness in interior environments. Copper, brass and "coco" fibres were all shown to cause loss of SARS-CoV-2 and were used in subsequent experiments. According to the data obtained, all materials are capable of reducing VOC and HCHO when the UV light is turned on and the photocatalytic reaction occurs. Clear decreases in VOC and HCHO concentrations are seen, as the MopFan brush system maximises the TiO2 exposure area while also being capable of pushing the air to circulate it. Additionally, it was shown that MopFan's purifying capability is dependent on the quantity of pollutants. It was demonstrated that by using a super reflective material as part of the housing, eases the reaction. The device built was as compact as any commercially available fan or air purifier because the UV LED lights can be found in a very compact package that does not increase the demand for space inside.

Organic fibres turned out to be the most effective in terms of purification. They reduced VOCs and HCHO by

21% continuously. In addition, they do not need sanding pre-treatment prior to being coated with the TiO2 solution. They also showed promising antiviral properties, although more research in this regard is required. An additional advantage of the "coco" fibres is that being an organic material means that it is a biodegradable material and hence less detrimental to the environment. One disadvantage that organic fibres may present is that they are constructed of a less durable material than plastic or metal. In future examinations it would be beneficial to analyse the impact the use of this purification system has on the TiO2 cover in order to determine its degradation rate and anticipate its longevity.

In summary, the MopFan-based photocatalytic purification system shown a high potential for purification of chemical and biological pollutants commonly found in homes and workplaces.

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COMPETING INTERESTS

The authors have no competing interests to declare.

AUTHOR CONTRIBUTIONS

Emmanuel Tapia-Brito: Methodology, Data curation, Writing- original draft preparation. James Riffat: Methodology and Data curation. Yixin Wang: Methodology and Data curation. Amir M. Ghaemmaghami: Methodology and Data curation. Christopher M. Coleman: Methodology and Data curation. Saffa Riffat: Conceptualization, Review and editing, Project administration; Supervision. All authors have read and agreed to the published version of the manuscript.

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